Reprinted from

Forest Ecology and Management

Forest Ecology and Management 115 (1999) 231–242

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William J. Beese[a,*], Andrew A. Bryant[b]

[a] *MacMillan Bloedel Limited, 65 Front St., Nanaimo, B.C., V9R 5H9, Canada*
[b] *Andrew A. Bryant Services, 108 Fifth St., Nanaimo, B.C., V9R 1N2, Canada*

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Abstract

The montane alternative silvicultural systems (MASS) study was established to test the feasibility and ecological consequences of alternative silvicultural systems in montane old-growth forests of coastal British Columbia. The experiment includes replicated treatments representing a range of overstory removal (shelterwood, patch clearcut and green tree retention), adjacent old-growth and clearcut 'control' areas and pre- and post-harvest measurement of a variety of ecological attributes. In this paper, we report results from vegetation and bird studies. Forest trees and understory vegetation were sampled on a series of permanent plots. Forest birds were monitored using transect methods during winter and point-counts during the breeding season.

The cover, frequency and number of species of understory plants decreased after all harvesting treatments. Three years after harvest, cover increased in the harvested areas primarily due to herbaceous colonizers. The shelterwood, where understory vegetation was protected in undisturbed groups of leave trees, retained the greatest diversity of understory trees, shrubs and bryophytes compared to the other systems. Shelterwood species richness and abundance were greater 3 years after harvesting than before harvesting, but changes in species composition were quite variable. Presence of bryophytes and herbs that prefer moist, shaded habitats generally decreased after harvesting.

Pre-harvest breeding bird communities were dominated by a few abundant species. Of 26 species detected, 4 species accounted for 64% of all bird detections, and 10 species accounted for 96%. Different levels of canopy retention produced dramatic effects on breeding birds. Species richness and bird abundance were reduced 3 years after harvesting. Most common species (9 species) showed evidence of population decline, 2 species showed significant increase, and 3 species showed unchanged abundance. Few species were completely lost or added to the avifauna. Only 17 species were recorded during winter surveys, of which 2 species accounted for the majority (68%) of detections. The vast majority (85%) of winter resident birds were concentrated in the old growth and the unlogged portions of patch-cut blocks. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Silvicultural systems; Shelterwood; Forest birds; Forest vegetation; Old growth

1. Introduction

Conservation of biological diversity – the full variety of living things – has generated controversy in many countries, arising from the rapid pace of human

*Corresponding author. Tel:. +250 755 3422; fax: +250 755 3550; e-mail: WJ.Beese@mbltd.com

PII: S0378-1127(98)00402-2

development and the increasing scarcity of primary forest and associated wildlife. British Columbia (BC) contains large amounts of temperate old-growth rainforests; however, its forest industry is dependent on old growth harvesting to provide a major source of economic revenue. BC's strategy for biodiversity conservation includes its extensive system of parks and wilderness areas, which will comprise at least 12% of the total land base by 2000. In addition, recent legislation (Forest Practices Code of British Columbia Act, 1994) and policy initiatives (Province of B.C., 1995) include explicit provisions for protecting both stand and landscape-level biodiversity on public lands outside parks.

On the BC coast, much of the public concern about biodiversity is related to clearcutting. There are now site conditions and specific geographical areas (e.g. west coast Vancouver Island) where alternatives to clearcutting are mandated (Clayoquot Scientific Panel, 1995), yet we have practically no experience in using other silvicultural systems in the old growth forests of the Pacific coast. While experiences elsewhere in North America and Europe are relevant, they are not a model for prescriptions to meet multiple resource objectives in BC (Weetman, 1996). Much of the stand-level focus is on retention of habitat features that typify old-growth forests, such as diverse tree sizes and canopy structure, large dead standing trees, and abundant forest floor coarse woody debris. Information is particularly lacking for montane to subalpine forests (700–1400 m elevation) that represent a substantial portion of the future timber harvest. Aside from biodiversity concerns, foresters have observed growth inconsistencies and patchy regeneration on some high elevation clearcuts that suggest growth below expectations (Koppenaal and Mitchell, 1992). Foresters need to learn alternative silvicultural methods that are economical, practical, safe for forest workers and ensure consistent forest regeneration.

To address these concerns, the Montane Alternative Silviculture Systems (MASS) research partnership was formed in 1992 to test alternative silvicultural systems for BC coastal montane forests, document the costs and feasibility, and study the biological and silvicultural impacts[1].

[1] A World Wide Web site (www.pfc.cfs.nrcan.gc.ca/practices/mass/) describes the seventeen component studies of MASS (see also Arnott and Beese, 1997).

In this paper, we describe results from vegetation and forest bird studies. The specific objectives were to quantify changes in residual stand structure, seedfall and natural conifer regeneration; understory vegetation; and breeding and winter resident forest bird communities.

2. Methods

2.1. Study area

The study is located on MacMillan Bloedel's private land south of Campbell River on Vancouver Island (49°55′N, 125°25′E). It lies within the Montane Moist Maritime Coastal Western Hemlock biogeoclimatic variant (Green and Klinka, 1994). The site has a northerly aspect, a gentle slope of <20% and varies from 740 to 850 m in elevation. The original stand was an old-growth forest dominated by 40 m tall amabilis fir (*Abies amabilis*) and western hemlock (*Tsuga heterophylla*) with varying amounts of western redcedar (*Thuja plicata*) and yellow-cedar (*Chamaecyparis nootkatensis*). Overstory trees range in age from 200 to 800 years. Tree ages, stand structure and the presence of charcoal at the mineral soil surface, 10–40 cm under the forest floor, suggest that the stand has not had large-scale disturbance from fire or windthrow for at least 500 years.

The predominant 'HwBa-Pipecleaner moss' site association occurs on the well-to-moderately well drained slopes on which blueberry (*Vaccinium alaskaense* and *V. ovalifolium*) dominates the shrub cover (Green and Klinka, 1994). Moist-to-very moist 'BaCw-Salmonberry' sites occur in depressions. Soils are predominantly Orthic and Gleyed Ferro-Humic Podzols over 1 m deep, with some shallow areas over sandstone, shale or conglomerate bedrock. Well-drained to moderately well-drained soils occur on the middle to upper slopes and hummocks with moderately well-drained to imperfectly drained soils occurring on lower slopes and in depressions. Although the forest floor varies widely over short distances, the typical Mor humus is 10–20 cm thick with abundant decomposed wood.

2.2. Experimental design

The experiment includes three replicates for each of the three alternatives to clearcutting. Treatments were

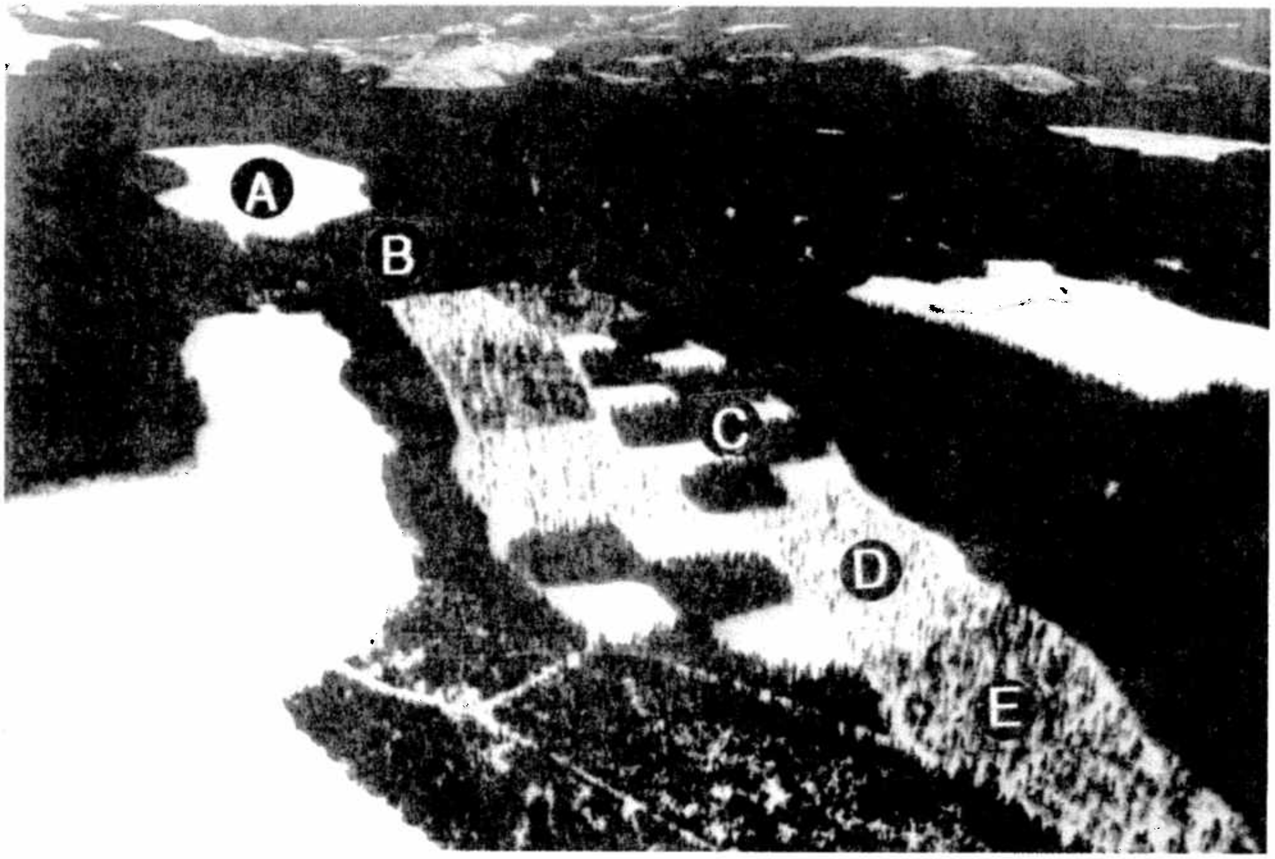

Fig. 1. Aerial view of study area looking west, 3 months after harvesting: (A) clearcut; (B) old growth; (C) patch cuts; (D) green tree retention; and (E) shelterwood.

randomly assigned to 8.6–11.5 ha blocks after dividing a 94 ha area into three east–west strata (Fig. 1). Adjacent to these treatments is a 69 ha clearcut and a 20 ha old growth monitoring reserve that serves as a 'control'. Since there are no untreated buffers between treatments, permanent monitoring plots were established within the centre of each replicate, buffered by three tree lengths of the same treatment. Plots were also established systematically within both the old growth and clearcut areas.

2.3. *Silvicultural systems and harvesting*

The silvicultural systems represent a gradient of microclimatic conditions and residual forest cover for regeneration protection and wildlife habitat. The *Shelterwood* retained trees representing the entire stand profile and 25% of the basal area (200 stems ha^{-1} >17.5 cm DBH) to provide protection for regeneration and enhance stand structural diversity. Reserve trees were selected for yarding feasibility, safety, wind-firmness and residual stand structure. Although the approach is considered a 'uniform' shelterwood, trees were left in small groups to facilitate harvesting and protect smaller trees. Leave trees will be recovered when regeneration is established, leaving 25 wildlife trees ha^{-1}, or may be left for the entire rotation, creating a multi-aged 'irregular' shelterwood. Regeneration on all treatments will be achieved primarily through natural seed-in, advanced stocking and supplemental planting.

Green tree retention, or clearcutting with reserves, retained 25 trees ha^{-1} to enhance structural diversity of future stands. It is comparable to a seed tree silvicultural system except that the reserves will be left for the entire rotation. Trees were selected for relatively even distribution, wind-firmness, safety and representation of the entire stand profile. Five snags per hectare will be created in future for cavity nesting bird habitat. *Patch cuts* were designed so that ≈50% of each treatment block was harvested in three small (1.5–2.0 ha) clearcuts. Cut and 'leave' areas were alternated so that regeneration is within two tree lengths of a forest edge, a practice that may ensure natural seedling establishment and mitigate the effects of snow, wind and temperature extremes. The remaining 50% of the stand will be harvested after regeneration is 10 m tall. The large *clearcut*, harvested over 2 years, provides an example of past clear-cutting practices.

Trees were felled manually in all treatments. Most of the clearcut was harvested in 1992; all other areas were harvested between May and November 1993. A hydraulic log loader was used to forward the logs from stump to roadside. In the shelterwood, trees were felled and yarded from 15-m wide access corridors before felling the remaining trees. Logs in the corridors were ground-skidded to roadside. The combined costs of falling and forwarding were 10% higher than the adjacent clearcut for the patch cut and green tree retention, and 38% higher for the shelterwood (Phillips, 1996).

2.4. Vegetation

Forest stand structure and understory vegetation conditions were measured before and after harvesting. A 3200 m^2 permanent sample plot was established in each treatment replicate to measure long-term forest growth. In addition, the entire study area was surveyed with variable radius forest inventory samples. Windthrown trees were tallied annually by canopy class and species within the green tree and shelterwood blocks as well as along the boundaries of the patch cut and clearcut blocks.

Eighteen sets of three nested sub-plots were established within each treatment to assess understory vegetation. Percent cover was estimated visually on a 500 m^2 plot by strata and life form; on a 10 m^2 plot by species for shrubs and trees; and on a 2 m^2 plot by species for herbs and bryophytes. Conifer regeneration was also counted in three classes: germinants; seedlings (<30 cm tall); and trees (30–130 cm tall). Height and diameter of six tagged natural trees were measured on each plot. All plots were assessed and photographed biennially. Seedfall was measured with three, 0.25-m^2 circular wire frame and screen mesh traps (Hughes et al., 1987) placed 1 m above the ground within each plot, and sampled in May, August and November. Differences in natural regeneration, seedfall and vegetation cover were examined using analysis of variance (ANOVA), followed by Tukey's pairwise comparison test to identify significant differences. All analyses were performed using SYSTAT (Wilkinson, 1990). Plant nomenclature follows Hitchcock and Cronquist (1973) and Schofield (1992).

2.5. Forest birds

Breeding birds were surveyed using fixed-radius point-count methods (Hutto et al., 1986; Verner, 1985). Observers recorded birds seen or heard within 75 m of a sampling station during a 12 min period. Surveys were conducted between 0430 and 0900 h, and were not conducted during periods of heavy rain or high wind. In 1992, each pre-harvest sampling station (n=60) was surveyed four times between May 9th and June 15th. In 1997, rainy weather in June combined with high spring snowpack forced a late start and compressed the sampling season for post-harvest monitoring. Each sampling station (n=46) was surveyed only three times between June 8th and July 3rd. The smaller number of sampling stations compared to pre-harvest surveys was necessary to avoid station placement near edges of treatment blocks.

Bird species nomenclature follows the American Ornithologists' Union (1983), American Ornithologists' Union (1995). Some bird detections were excluded from analysis because point-counts do not reflect actual abundance or breeding status (e.g. forest raptors; see Bryant et al., 1993). We also excluded detections that were not associated with the sampled habitat (i.e. birds flying overhead or outside the 75-m plot perimeter). Birds that landed in the plot during the count period were included. For each species, bird detections at each sampling location were averaged across repeated counts to provide a measure of relative abundance. Bird abundance per treatment type was expressed as $\bar{x}\pm$SE individuals/station. Between-treatment effects were tested using single-factor ANOVA for species richness and bird abundance, and for relative abundance of commonly detected species (i.e. those detected at >5% of sampling stations). Logged and unlogged portions of the patch-cut treatments were analysed separately. The 1992 pre-harvest sample was not included in between-treatment analysis.

Winter (December–March) bird surveys were conducted on four occasions during 1995–1996. Observers walked each stand and recorded all birds seen or heard (simple line transect method; Manuwal and Carey, 1991). Transects were not fixed, although the route travelled by observers was similar on different days. Data were recorded by time of observation, and were expressed as detections per hour of sampling effort. ANOVA was used to test for differences among bird abundance, species richness, and foraging flock size among treatments.

3. Results and discussion

3.1. Stand structure and regeneration

Pre- and post-harvest stand characteristics for the green tree retention and shelterwood blocks are summarized in Table 1. Species composition after harvesting remained similar to pre-harvest conditions for both treatments. The incidence of parasitic dwarf mistletoe on western hemlock was reduced from 18% in the original stand to 6% in the shelterwood and 3% in green tree through selection of leave trees (R. Nevill and C. Wood, pers. comm.). The proportion of net merchantable volume in the residual stand was also improved from 57 to 86% in the shelterwood through removal of decayed trees. All dead standing trees were removed to meet BC Worker's Compensation Board safety regulations.

The remaining trees are representative of the original stand profile; consequently, over half of the stems are in the intermediate crown class. Intermediates were left because many were amabilis fir with healthy crowns that should respond well to release. These same trees would contribute little value to harvest revenues, yet will provide protection for regeneration and a significant starting volume for the next rotation. Roughly one-quarter of the shelterwood leave trees and about one-third of the green tree retention trees were in the dominant and co-dominant crown classes.

After three seasons (i.e. by June 1996), the green tree treatment lost 25% of the leave-trees to windthrow (6 stems ha^{-1}), and the shelterwood lost 5% (11 stems ha^{-1}). The patch cut and clearcut treatments lost the equivalent of 4.3 and 5.8 stems ha^{-1}, respectively. A higher proportion (22%) of trees in the intermediate crown class in the green tree blocks were lost to windthrow than in the dominant (7%) and co-dominant (10%) classes, confirming that lower canopy trees are vulnerable when left at low density. Western redcedar appeared to be more wind-firm than either

Table 1
Pre- and post-harvest forest stand characteristics for green tree retention and shelterwood blocks

Stand characteristic	Green Tree				Shelterwood			
	Pre		Post		Pre		Post	
	Mean [a]	SE	Mean	SE	Mean	SE	Mean	SE
Species composition (%)								
Western hemlock	44	2.8	51	7.3	43	3.2	49	4.1
Amabilis fir	23	8.6	16	1.9	28	5.9	33	9.8
Western redcedar	28	8.1	28	7.5	25	6.0	17	6.3
Yellow cedar	5	2.4	5	3.2	4	3.3	1	1.2
Gross merchantable volume (m^3 ha^{-1})	1042	72	47	0.4	3978	24	172	42.7
Basal area (m^3 ha^{-1})	85	7.2	4	0.2	73	2.6	18	2.1
Stems per hectare (>17.5 cm DBH)	593	84.7	21	3.0	499	58.7	207	69.6
Average diameter (cm at 1.3 m)	41	7.4	40	2.5	45	1.8	31	4.9
Understory trees (stems ha^{-1}>1.3 m tall, and <17.5 cm DBH)	560	21.6	no data		580	75.7	311	136.6
Seedlings (<1.3 m tall, % cover)	8	1.0	1	0.4	10	2.4	3	1.5
Dead standing trees ha^{-1}	78	36.6	0		65	14.7	0	

[a] Data are means for three blocks per treatment.

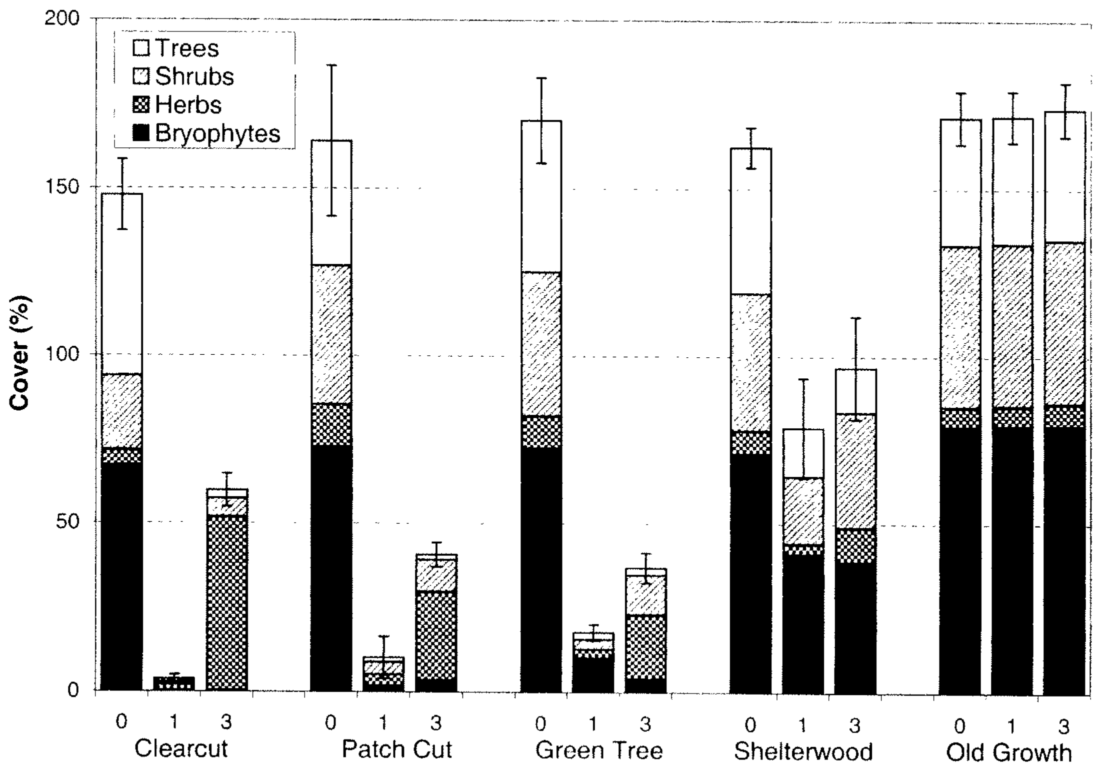

Fig. 2. Percent cover of understory vegetation pre-harvest (0), and post-harvest (Year 1 and 3). Note that cover exceeds 100% due to overlapping strata. Error bars are mean ±SE for total cover.

amabilis fir or western hemlock. Most of the windthrow occurred in the first 6 months from storms blowing from the southeast or northwest until a 25-year storm in October 1996 doubled the cumulative windthrow in the shelterwood, and increased windthrow in the green tree by 36%. There was virtually no windthrow along the patch cut and clearcut edges from this storm. Since it was not possible to remove windfall without damaging experiments, this material will add to coarse woody debris, which is already ca. 400 m^3 ha^{-1} in all treatments from pre-harvest forest floor materials and harvesting debris (Phillips, 1996).

Trends in the old growth revealed some insights about the relationship between seed production, germination and survival of understory trees. At plot establishment, western hemlock dominated regeneration with roughly one thousand small trees, 40–75 thousand seedlings and up to 1 million germinants ha^{-1} (Beese et al., 1995). Hemlock seedfall for the first season was estimated at 34 million seeds ha^{-1}; consequently, the ratio of seeds to established seedlings is extremely high, considering the multiple seed-years that established the present cover.

3.2. Understory vegetation

The cover of understory plants decreased after all harvesting treatments (Fig. 2). The shelterwood retained the greatest cover of understory trees, shrubs and bryophytes compared to the other systems because understory vegetation was protected from logging damage within the undisturbed clumps of leave trees. The shade provided by the shelterwood has allowed bryophytes to survive at over half of their original cover of 71%, in contrast to the three more open treatments where they were reduced to 10% cover or less. By the third growing season, cover increased in the harvested areas primarily due to herbaceous colonizers, such as fireweed (*Epilobium angustifolium*). The old growth showed only minor variations in species cover and frequency over the same period.

Tree, shrub, herb, and bryophyte cover have remained fairly stable in the old growth. Herb cover

Table 2
Comparison of pre- and post-harvest vegetation diversity measures by treatment

		Pre-harvest			Post-harvest (3 year)			P value [b]
		Mean [a] (total)	SE	CV (%)	Mean [a] (total)	SE	CV (%)	
Richness (species per replicate)	Clearcut	18.3(29)	4.1	38	20.7(30)	2.4	20	0.32
	Patch cut	33.3(52)	4.4	23	32.3(54)	1.5	8	0.78
	Green tree	28.3(42)	2.9	18	28.0(38)	2.0	12	0.87
	Shelterwood	30.7(47)	5.9	33	36.7(65)	6.1	29	0.01
	Old growth	27.7(43)	6.2	39	29.7(47)	6.3	37	0.07
Abundance (frequency per replicate)	Clearcut	61.0	9.8	28	62.3a	3.2	9	0.89
	Patch cut	88.3	7.5	15	81.0ab	1.5	3	0.37
	Green tree	77.7	3.7	8	75.7ab	8.0	18	0.80
	Shelterwood	79.0	4.4	10	93.0b	5.5	10	0.01
	Old growth	84.0	6.7	14	88.0ab	7.9	16	0.12
Diversity (Shannon H') $H'=-\mathrm{piLOG}_2(\mathrm{pi})$	Clearcut	2.726	0.15	0.10	2.159	0.21	0.17	0.01
	Patch cut	3.210	0.12	0.06	3.271	0.48	0.25	0.90
	Green tree	2.825	0.13	0.08	3.102	0.07	0.04	0.04
	Shelterwood	3.128	0.26	0.14	3.281	0.16	0.08	0.39
	Old growth	3.008	0.16	0.09	3.046	0.20	0.12	0.55
Evenness ($J'=H'/H'\mathrm{max}$) $H'\mathrm{max}=\mathrm{LOG}s$	Clearcut	0.666	0.03	0.07	0.495	0.03	0.11	0.07
	Patch cut	0.639	0.02	0.06	0.651	0.09	0.24	0.92
	Green tree	0.587	0.01	0.03	0.646	0.01	0.02	0.02
	Shelterwood	0.638	0.02	0.05	0.636	0.01	0.03	0.94
	Old growth	0.638	0.01	0.02	0.630	0.01	0.02	0.67

[a] Means within a column not blank nor followed by the same letter are different at $P<0.05$ using Tukey's HSD test. There were no significant pre-harvest differences among treatments for any of these measures. Total cumulative species for all replicates are given in parentheses. Diversity and Evenness indices are as described by Elliott, C.A. (pp. 297–300) in Hunter (1990).
[b] Pre- and post-harvest paired two-tailed t-test P values. H_0: pre-harvest=post-harvest.

increased significantly in the clearcut from one to three years after harvest, dominated by fireweed (25%). Fireweed cover was noticeably less in the shelterwood blocks (2%). The rate of increase in herb cover was inversely proportional to the level of tree retention.

Shrub cover is increasing more rapidly in the shelterwood than any of the other treatments. Species composition is also noticeably different in the alternative treatments than in the clearcut. Five-leaved bramble (*Rubus pedatus*) is the predominant shrub species in the clearcut, while Alaskan blueberry (*Vaccinium alaskaense*) is increasing more rapidly in the shelterwood. Bryophyte cover – primarily mosses – remained very low (<4%) in the clearcut and patch cuts, and declined slightly in the green tree retention blocks. Moss remained fairly stable in the shelterwood at ca. 40% cover.

Species abundance and richness were both significantly greater ($P<0.01$) after harvesting in the shelterwood than before harvesting (Table 2). Species abundance in the shelterwood was greater than the clearcut ($P<0.05$), but did not differ from the old growth or other harvesting treatments. The shelterwood retained the greatest number of pre-harvest species in relatively undisturbed patches, particularly bryophytes, while adding those species that colonize after disturbance. Species diversity and evenness indices (Shannon H′, J′) increased after harvesting ($P<0.05$) for the green tree blocks, and diversity decreased ($P<0.01$) in the clearcut. None of the treatments showed statistically significant differences before harvesting; however, the clearcut appeared to have fewer species before harvesting than any of the other areas. Unlike herb *cover*, frequency and number of species of herbs generally increased with increasing levels of retention. Only bryophytes had higher frequency in the old growth than the shelterwood.

Changes in species composition varied considerably among treatment replicates. Overall, species increases only slightly exceeded losses on permanent plots. Twenty-six species, representing 2 trees, 7 shrubs, 13 herbs and 4 bryophytes, consistently increased after harvesting disturbance. These included: 3 *Rubus* spp., *Ribes lacustre*, 3 *Epilobium* spp., *Hieracium albiflorum*, *Hypocharis radicata*, *Linnaea borealis*, *Lactuca muralis* and *Polytrichum juniperinum*. Some species were present before harvesting and responded to increased light and moisture (e.g. *Rubus spectabilis*); others colonized with wind-blown seed from surrounding clearcuts (e.g. *Epilobium angustifolium*). Seven species showed both losses and gains on different harvesting blocks. Of the 21 species 'losses', most were herbs (10) and bryophytes (8) and only five occurred on more than a single treatment. Herbs whose presence decreased with disturbance were mostly Orchidaceae (*Platanthera dilatata*, *Listera caurina*) and Pyrolaceae (*Moneses uniflora*, *Orthilia secunda*, *Chimaphila menziesii*) that prefer moist, shaded habitats. Bryophytes that decreased with disturbance included *Hookeria lucens*, *Pellia neesiana*, *Plagiochila porelloides*, *Rhizomnium glabrescens* and *Plagiomnium insigne*. Several of the species changes were incidental losses of plants generally tolerant of disturbance (e.g. *Mahonia nervosa*, *Lysichiton americanum*). Losses on plots are an indication of compositional change, but they should not be interpreted as extirpation from the entire treatment area.

3.3. Breeding birds

A total of 26 species were recorded during pre-harvest breeding bird surveys in 1992. Three species (Marbled Murrelet, *Brachyramphus marmoratus*; Northern Pygmy Owl, *Glaucidium gnoma*; and Saw-whet Owl, *Aegolius acadicus*) were excluded from analysis because survey methods were inappropriate to assess their relative abundance. Four species (Chestnut-backed Chickadee, Winter Wren, Varied Thrush and Red-breasted Sapsucker) were abundant (>0.5 individuals per sampling station) and accounted for 64% of all bird detections. An additional 6 species (Red-breasted Nuthatch, Golden-crowned Kinglet, Pacific Slope Flycatcher, Pine Siskin, Brown Creeper and Dark-eyed Junco were common (0.1–0.5 individuals per station). Overall, the 10 abundant and common species accounted for 96% of all bird detections.

Post-harvest surveys showed considerable changes. Only 19 forest bird species were detected in 1997. Six species were apparently 'lost' from the study area (Rufous Hummingbird, Pileated Woodpecker (*Dryocopus pileatus*), Western Wood Pewee, Hammond's Flycatcher, Common Raven, McGillivray's Warbler). Two species were 'added' (Olive-sided Flycatcher and Song Sparrow). Most of the 'deletions' represent migrants that were probably detected in 1992 because of the earlier survey start date (Blue Grouse, Western Wood Pewee, Hammond's Flycatcher, Common Raven and MacGillivray's Warbler were detected only on the initial survey). Only the Pileated Woodpecker appeared to be a genuinely rare resident species that was consistently detected in 1992 and not in 1997. Both the Olive-sided Flycatcher and Song Sparrow appear to represent actual additions to the MASS avifauna as they were detected only in treatment types consistent with their known habitat preferences.

Species richness and bird abundance were reduced in all partial harvest treatments (Fig. 3). Most individual species showed greatly altered abundance, and there were substantial changes in patterns of dominance and rarity among treatment types (Table 3). Overall, 9 species showed significantly reduced abundance, 2 species showed significant increase, and 6 were stable. All other species were essentially rare species (<0.25 birds/sampling station) for which detection rates were inadequate to assess true population status. Only three relatively common species (Winter Wren, Pacific Slope Flycatcher and Brown Creeper) showed no change in abundance. In general, ground-dwelling species have done relatively well (especially Dark-eyed Junco), while cavity nesters have done relatively poorly (woodpeckers, nuthatches and chickadees).

The contiguous unlogged old-growth area (~20 ha) contained significantly more species, and more birds, than any of the other treatment types. The small (~4.5 ha) unlogged portions of the patch cut treatments ('leave' areas) resembled the unlogged old-growth community, but showed significant reductions in both richness and abundance. The shelterwood and

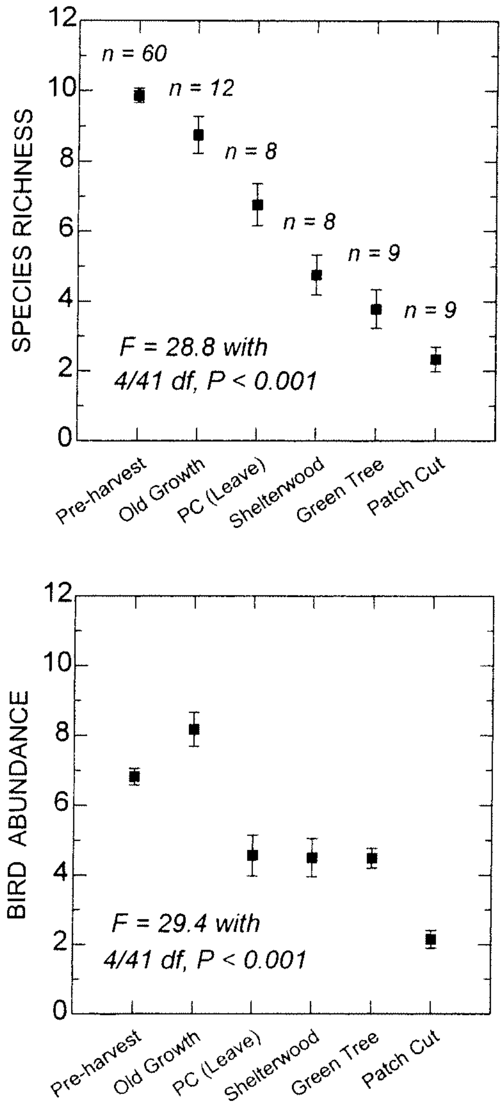

Fig. 3. Between-treatment effects on breeding bird richness and abundance. Data are mean±SE values/sampling station. Numbers of sampling stations for each treatment type are shown. Richness and abundance differed among treatment types. Note that the 1992 pre-harvest data were excluded from analysis, but are included here for comparison. PC=Patch Cut.

green tree retention treatments were quite similar in richness and abundance, while the harvested portions of the patch cuts contained the lowest numbers of birds and species.

3.4. Winter resident birds

Bird diversity and abundance in winter were considerably reduced from summer conditions. Only 11 species were consistently recorded (Table 4). Pine Siskins and Chestnut-backed Chickadees accounted for the majority (68%) of detections, although caution is warranted in interpreting relative abundance of individual species. For example, Pine Siskins were highly vocal and commonly observed flying overhead in large flocks. Repeated counts of the same birds were difficult to avoid, and their abundance was almost certainly overestimated. In contrast, Red-breasted Sapsuckers were usually detected by hearing their subtle tapping on tree trunks at extremely close range, and were probably underestimated. Despite such problems, strong differences were apparent among treatment types.

The old-growth control area and unlogged portions of the patch cuts contained the highest species richness and bird abundance, and accounted for >70% of all detections. These habitats generally contained twice as many birds as the shelterwood, and four times as many as the green tree retention class. Sizes of foraging flocks showed no difference. Most commonly-detected species showed considerable variation in distribution and abundance among treatments. Red-breasted Sapsuckers and Brown Creepers were more abundant in the old-growth and unlogged portions of the patch cuts. Chestnut-backed Chickadees and Pine Siskins were more flexible in their choice of habitats and were also found in the shelterwood. Only the Winter Wren approached uniform abundance in all treatments, but this result was principally due to large numbers observed in the green tree blocks on a single survey (March 21), when spring migrants could have confused the issue.

4. Conclusions

The shelterwood retained more stand structure and pre-harvest plant species from the original old-growth forest than other systems, with the exception of the unlogged portion of the patch cuts. The variety of habitat conditions in the shelterwood increased overall vegetation diversity, yet some plant species may still decline in abundance or be locally eliminated. These early results suggest that bryophytes and certain herbaceous plants are the most vulnerable to losses from harvesting; therefore, we plan to focus future effort on these taxa and expand sampling to include lichens. Windthrow remains a key concern for

Table 3
Breeding bird relative abundance by treatment type

Species		Old growth		Patch cut (leave)		Shelterwood		Green tree		Patch cut		*P* value
		Mean [a]	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	
Dark-eyed Junco	*Junco hyemalis*	0.17	0.11	0.55	0.18	1.6	0.23	2.37	0.27	1.26	0.26	<0.001
Winter Wren	*Troglodytes troglodytes*	0.86	0.16	0.69	0.19	1.33	0.13	1.18	0.22	0.63	0.14	0.008
Chestnut-backed Chickadee	*Parus rufescens*	1.69	0.17	0.76	0.18	0.56	0.16	0.30	0.15	0.11	0.08	<0.001
Varied Thrush	*Ixorius naevius*	1.33	0.21	0.40	0.13	0.22	0.08	—		—		<0.001
Pacific Slope Flycatcher	*Empidonax difficilis*	1.08	0.19	0.45	0.16	—		—		0.04	0.04	<0.001
Brown Creeper	*Certhia americana*	1.03	0.13	0.38	0.16	0.04	0.04	0.07	0.05	—		<0.001
Red-breasted Nuthatch	*Sitta canadensis*	0.58	0.11	0.40	0.18	0.15	0.16	0.07	0.00	—		<0.001
Red-breasted Sapsucker	*Sphyrapicus ruber*	0.44	0.12	0.55	0.13	0.15	0.09	—		—		<0.001
American Robin	*Turdus migratorius*	0.06	0.04	0.14	0.06	0.30	0.16	0.22	0.08	0.04	0.04	<0.001
Golden-crowned Kinglet	*Regulus satrapa*	0.19	0.05	0.31	0.17	—		—		0.04	0.04	<0.001
Gray Jay	*Perisoreus canadensis*	0.22	0.07	0.10	0.06	0.04	0.04	—		—		0.088
Pine Siskin	*Carduelis pinus*	0.17	0.12	0.10	0.09	—		0.04	0.04	—		0.016
Red Crossbill	*Loxia curvirostra*	0.14	0.10	—		—		—		—		0.132
Hermit Thrush	*Catharus guttatus*	0.11	0.06	—		—		—		—		—
Hairy Woodpecker	*Picoides villosus*	0.06	0.04	—		0.04	0.04	—		—		—
Olive-sided Flycatcher	*Contopus borealis*	—		—		0.04	0.04	0.04	0.04	—		—
Blue Grouse	*Dendragapus obscurus*	—		0.05	0.05	—		—		—		—
Steller's Jay	*Cyanocitta stelleri*	0.03	0.03	—		—		—		—		—
Song Sparrow	*Melospiza melodia*	—		—		—		—		0.04	0.04	—
Total birds/station of		8.17		4.88		4.44		4.30		2.15		
species detected		16		13		11		8		7		
N of sampling stations		12		8		9		9		8		

[a] Data are mean numbers of detections per sampling station calculated across repeated counts.

Table 4
Winter resident bird abundance, richness and flock size by treatment type

Variable		Old growth		Patch cut (leave)		Shelterwood		Green tree		*P* value
		Mean [a]	SE	Mean	SE	Mean	SE	Mean	SE	
Bird abundance/hour		13.37	0.35	12.01	1.66	6.85	1.15	3.27	1.71	0.035
Species richness/hour		3.32	0.35	2.29	0.29	2.11	0.14	0.73	0.31	0.005
Flock size		2.18	0.29	2.13	0.34	2.20	0.45	1.33	0.76	0.770
Individual species										
Brown Creeper	*Certhia americana*	2.43	0.62	1.95	0.74	0.13	0.09	—		
Red-breasted Sapsucker	*Sphyrapicus ruber*	1.31	0.39	1.00	0.26	0.12	0.09	0.09	0.07	
Chestnut-backed Chickadee	*Parus rufescens*	3.95	1.69	4.91	0.47	3.16	0.73	0.12	0.08	
Pine Siskin	*Carduelis pinus*	1.18	0.34	2.86	1.84	1.04	0.64	1.89	1.39	
Winter Wren	*Troglodytes troglodytes*	1.13	0.44	0.84	0.37	1.22	0.79	0.96	0.43	
Varied Thrush	*Ixorius naevius*	1.46	1.00	0.13	0.09	—		0.12	0.08	
Red Crossbill	*Loxia curvirostra*	0.84	0.57	—		—		—		
Hairy Woodpecker	*Picoides villosus*	0.46	0.23	0.22	0.15	—		—		
Red-breasted Nuthatch	*Sitta canadensis*	0.40	0.10	0.10	0.07	0.74	0.20	—		
Common Raven	*Corvus corax*	0.12	0.08	—		0.45	0.19	0.09	0.07	
Golden-crowned Kinglet	*Regulus satrapa*	0.09	0.06	—		—		—		
N of species detected		11		8		7		6		
N of hours		8.55		8.08		7.75		7.37		

[a] Data are hourly abundances calculated across counts. No detections were obtained in the logged portions of the patch-cut treatments.

retaining various levels of forest canopy in coastal BC. The MASS site was not considered a high risk site for windthrow, yet losses were substantial after 3 years. Windthrow was lower than anticipated along the edges of the patch cuts.

Alternative harvest practices produced dramatic changes in breeding bird communities, although few species were lost or added to the avifauna. Average species richness and bird abundance were reduced after harvest, and most individual species showed post-harvest declines. Removal of >70% of the tree basal area from a montane forest reduced its attractiveness to insectivorous, foliage-gleaning, bark-gleaning or cavity nesting species, such as flycatchers, woodpeckers, nuthatches and chickadees. Conversely, partial cutting systems made habitats more suitable for three ground-foraging species.

The small 'leave' areas in the patch-cut treatments were interesting from two standpoints. These small areas contain significantly reduced bird densities (richness and abundance/station) yet maintained their original species complement and between-species relative abundance patterns. In contrast, the partially harvested treatments and the small patch cuts showed evidence of fundamental change in community structure, including reduced bird density and richness, changes in the relative importance of individual species, and altered species composition.

Winter bird results were striking. Most (70%) detections were made in the old-growth control area and the unlogged portions of the patch cuts (30% of the sampled habitat). That winter birds congregate in old-growth forest is not surprising; such sites presumably offer maximum food resources and shelter from harsh winter nights (Walsberg, 1985). For small bird species at north temperate latitudes, stored fat reserves are often sufficient to provide energy for only one winter night and a portion of the following day (King, 1972).

MASS provided a unique opportunity to examine changes in bird communities using an empirical pre-harvest : post-harvest experimental approach, rather than the more common but imperfect technique that involves simultaneous examination of communities in forests of various age and harvest history (e.g. Wetmore et al., 1985; Carey et al., 1991; Bryant et al., 1993). The advantage of classical experimental methods removes bias imposed by the forced assumption that different sites are equivilent on the basis of vegetation similarity prior to logging. Concurrent studies of canopy arthropods (L. Humble and N. Winchester, pers. comm.) at MASS will further enhance our knowledge of species in these forests.

Setting stand-level goals for maintaining biodiversity values must be done in the context of landscape-level objectives. No single silvicultural system will meet all objectives; consequently, results from MASS are not meant to select a single 'best' practice, but to improve our ability to predict the consequences of alternatives so that systems can be chosen to meet specific goals. Retention of relatively intact old-growth forest patches appears to be a more useful strategy for conservation of some plant and bird species and structural elements than uniform distribution of leave-trees. This approach also appears to have cost, wind-firmness and safety advantages. Nevertheless, each silvicultural system will likely benefit some groups of species. Challenges to those designing silvicultural systems include: ensuring that regeneration and product objectives are met; minimizing windthrow and protecting regeneration during multiple entries; meeting wildlife needs without compromising worker safety and forest health; and thinking beyond traditional silvicultural systems to create innovative approaches.

Acknowledgements

Research partners for the MASS project included MacMillan Bloedel Limited, Canadian Forest Service, Forest Engineering Research Institute of Canada (FERIC), University of Victoria, University of British Columbia and the BC Ministry of Forests. Financial support was provided by the Canada-BC Forest Resource Development Agreement, Forest Renewal BC and the sponsoring agencies. We thank Jeff Sandford and many others for assistance with field measurements and analyses; Jim Loftus for operational support; and Dave Aldcroft, Jason Lewis, Karen McDonald, Steve Mooney and Nancy Prockiw for assistance with bird surveys. Special thanks go to the staff and crew of MacMillan Bloedel, Menzies Bay Division for taking up the challenge of the harvesting and making it successful.

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