THE ECOLOGY OF TERRESTRIAL GASTROPODS AND THEIR RESPONSE TO CONIFER RELEASE TREATMENTS IN NORTHWESTERN ONTARIO

BY

JOHN WILLIAM HAWKINS ©

A THESIS
PRESENTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE

DEPARTMENT OF BIOLOGY
LAKEHEAD UNIVERSITY
THUNDER BAY, ONTARIO

APRIL, 1995

National Library of Canada
Acquisitions and Bibliographic Services Branch
395 Wellington Street
Ottawa, Ontario
K1A 0N4

Bibliothèque nationale du Canada
Direction des acquisitions et des services bibliographiques
395, rue Wellington
Ottawa (Ontario)
K1A 0N4

Your file Votre référence

Our file Notre référence

ISBN 0-612-09210-0

ABSTRACT

The primary objective of this study was to document any changes in terrestrial gastropod species richness and density associated with alternative methods of managing competing vegetation on regenerating conifer plantations. Pre-treatment data were collected in 1993 and post-treatment data in 1994, following application of four conifer release treatments including, two chemical herbicides (Vision® and Release®), removal of vegetation by mechanical means (Silvana Selective/Ford Versatile), and manual cutting with brushsaws. Gastropod densities were estimated using cardboard sheets. A total of 47,595 gastropods was collected over the two years, comprising 21 species. No change in gastropod richness or density was detected between the four conifer release areas and the control in 1994, despite changes in vegetation cover following treatments. This was attributed to rapid re-establishment of the herbaceous layer following treatments which probably continued to provide favourable conditions for snails and slugs.

Species richness and density of gastropods in a 9-year-old regenerating conifer plantation and an adjacent 70-year-old mixedwood forest were compared. Gastropod density was higher on the regenerating plantation (15.5±1.3 m^{-2}) than in the mature forest (9.4±0.6 m^{-2}) and species richness was also slightly greater (20 spp. *vs.* 18 spp., respectively). These differences were attributed to the more abundant near-ground vegetation and the greater amount of deciduous litter characterizing the regenerating plantation.

Near ground temperature was measured on the four conifer release areas and the control using thermocouples. Temperature was measured 2 cm above cardboard sheets, directly beneath the sheets, and 2 cm deep in the humus layer. Results suggest that temperatures were not affected by the release treatments. Temperatures above and beneath the sheets were similar and greater than those in the humus layer throughout the early part of the summer. In August, temperature above and beneath the sheets cooled to below that in the humus layer. Gastropod collections were greatest when the temperature beneath the cardboard sheets was approximately 15°C.

Possible limitations associated with the cardboard sheet sampling method were investigated. Gastropod collections from sheets enclosed with a barrier were compared to unenclosed sheets to determine the extent of horizontal movement. The mean density recovered beneath enclosed sheets (2.1 ± 0.2 m^{-2}) was less than that from unenclosed sheets (3.1 ± 0.4 m^{-2}) suggesting horizontal movement to the sheets does occur. However, whether gastropods are actually attracted to the sheets remains unknown. Gastropod collections from weathered sheets were contrasted with those from new sheets. Overall, total mean densities of gastropods from weathered sheets (27.3 ± 4.1 m^{-2}) and new sheets (16.2 ± 2.6 m^{-2}) did not differ, but four species were collected in greater numbers on the weathered sheets suggesting differential use of cardboard sheets by particular species.

ACKNOWLEDGEMENTS

I would like to express my sincere thanks to my supervisor Dr. Murray Lankester for his guidance, support, and patience. He inspired me to strive for perfection and to seek a better understanding of the natural world.

My thanks to Drs. D.A. Boag, A.U. Mallik, K.M. Brown, and W.T. Momot for their comments on this work and suggestions which enhanced the quality of the thesis.

This project would not have been possible without the generous funding provided through the Vegetation Management Alternatives Program of the Ontario Forest Research Institute.

Thanks go out to all the intrepid people who spent long hours helping me in the field, in spite of the early mornings and often wet days. A special thanks to Andrew, Jackie, Cam, Karen, Heather, and Kelly.

To all my friends in Thunder Bay and Toronto, who provided me with many hours of engaging conversation, debates, and just a few nights on the town, I thank you for keeping me sane.

I also thank my parents and brother for their moral and financial support through all my years of education. Without their enthusiasm toward my endeavours and their constant reassurance, I may not be where I am now.

Finally, I would like to express my love and gratitude to Karen, without whom the past two years would have seemed much longer and more difficult. Thanks for the "re-structuring" sessions, picking me up when I was down, keeping me calm when things where crazy, and all the good times we've shared.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Competition from undesirable vegetation is a common problem in young conifer plantations. Competing hardwoods, shrubs, and herbs limit the resources available to conifer seedlings, leading to a potential reduction in yield and a possible increase in rotation time between harvests (Sutton 1969; Radosevich and Osteryoung 1987; Freedman *et al.* 1993). To ameliorate the effects of undesirable vegetation, a variety of conifer release methods are practiced that reduce the density of competing vegetation, allowing young conifers to become established.

The main method of conifer release in re-forested areas is the aerial application of chemical herbicides (Campbell 1990; Lautenschlager 1993). Although herbicides have proven effective and economical in the past (Campbell 1984), recent public concern over their environmental effects (Environics Research Group 1989; Campbell 1990; Freedman 1991; Burt Perrin Associates 1993) has prompted the search for alternative methods to control competing vegetation (Campbell 1991; Wagner 1993). Two alternatives to chemicals are mechanical and manual release. Mechanical release is accomplished by the use of a brush-cutting blade attached to a hydraulic boom and mounted on a tractor (Hunt 1993; Lautenschlager and Bell 1994). Manual release involves the use of hand-held power brushsaws. Both methods have the disadvantage of promoting rapid regrowth through sprouting of freshly cut hardwoods and shrubs (Campbell 1984; Wagner 1993).

Any deleterious effects of mechanical and manual methods of conifer release on forest ecosystems must be evaluated before wider use of these practices is recommended (Wagner 1993). In addition, comparisons between these alternative methods and the favoured chemical herbicides currently used in forestry are necessary (Campbell 1991). Impact studies of this nature must take into consideration all components of the ecosystem. It is particularly useful to document the effects of alternative conifer release methods on potential indicator species. Terrestrial gastropods have previously been used as biomonitors to measure heavy metal contamination (Greville and Morgan 1989; Berger and Dallinger 1993).

Snails and slugs are relatively immobile and, consequently, cannot escape areas that are subjected to disturbance (Strayer *et al.* 1986). Changes in density and diversity of terrestrial gastropods should, therefore, reflect the immediate impact of a natural or experimental disturbance on their habitat. Studies of the ability of snails and slugs to re-colonize a disturbed area have yielded conflicting results. Reinink (1979) found a positive correlation between species richness of gastropods and the age of forest plantations in the Netherlands. In addition, Cameron *et al.* (1980) found more species of gastropods in British hedgerow habitat established prior to the 20th century than in more recent hedgerows. However, Strayer *et al.* (1986), in a study of 16 forested sites disturbed by a variety of events, including small-scale clear-cutting, found no correlation between species diversity of gastropods and time elapsed since disturbance.

Terrestrial gastropod distributions are positively correlated with percent cover of vegetation (Boag and Wishart 1982), with the greatest abundances occurring in habitats dominated by deciduous tree and shrub growth (Gleich and Gilbert 1976; Beyer and

Saari 1977; Kralka 1986). As well, snails and slugs apparently are dependent on the nature of the litter layer (Baker 1942; Burch 1956; Karlin 1961) and on the amount of litter present in an area (Locasciulli and Boag 1987). Whether the litter layer is deciduous or coniferous in origin will affect the density and species composition of gastropods. It is possible that alterations to the near-ground vegetation cover, and the reduced accumulation of deciduous leaf litter associated with the removal of competing hardwood vegetation, will affect the density and diversity of gastropods inhabiting an area.

Terrestrial snails and slugs are dependent upon near-ground microclimatic temperature and relative humidity conditions to ensure their optimal growth, reproduction, and mobility (Boycott 1934; Dainton 1943; Cowie 1984; Prior 1985; South 1992). They are most active under moderate near-ground temperatures and moist conditions (Boag 1985). Ground and near-ground vegetation cover have been shown to influence the forest floor temperature and humidity conditions favoured by snails and slugs (Burch 1956; Hunter 1964; Beyer and Saari 1977).

Terrestrial gastropods play an important role in the ecology of the forest floor. They provide food for a variety of soil arthropods (Newell 1971; Brandmayr and Brandmayr 1986; Digweed 1993), ground foraging birds (South 1980), and small mammals (Hamilton 1941; Whitaker 1966; Rudge 1968; Whitaker and Mumford 1972; Churchfield 1984). As well, they are important intermediate hosts for a number of helminth parasites affecting vertebrate wildlife (Lankester and Anderson 1968; Gleich *et al.* 1977; Rowley *et al.* 1987; Raskevitz *et al.* 1991). Snails and slugs also play a role in litter decomposition and the nutrient cycle of the forest floor (Mason 1970; Richter 1979).

The primary objective of this study was to document any changes in the richness and density of terrestrial gastropods following various alternative methods of managing competing vegetation on regenerating conifer plantations. Differences in gastropod species richness and abundance between a 9-year-old conifer plantation and a mature 70-year-old forest were also examined. Possible limitations of the sampling technique (cardboard sheets) were investigated, including the influence of near-ground temperature on terrestrial gastropod activity, the extent of horizontal movement of gastropods to the sheets, and the attractiveness to gastropods of weathered versus un-weathered cardboard sheets.

MATERIALS AND METHODS

Study area

The study area was located in Fraleigh Township (48°08'N, 89°47'W), about 60 km southwest of Thunder Bay, Ontario, within the Great Lakes-St. Lawrence Forest Region (Rowe 1972). Within each of four replicate blocks, four experimental treatments and a control were assigned in a Randomized Complete Block Design (RCBD). The blocks, ranging in size from 25.4 to 45.4 hectares (ha), were surveyed and a 60X60 m grid pattern staked out in an alpha-numeric coordinate system (Lautenschlager and Bell 1994).

Each block had been harvested and replanted prior to the initiation of the study (Table 1). Block 1 was situated on a south facing slope and had shallow, sandy loam soils. The pre-harvest stand was a mixed hardwood-conifer forest consisting of trembling aspen (*Populus tremuloides*), white spruce (*Picea glauca*), balsam fir (*Abies balsamea*), black spruce (*Picea mariana*), white birch (*Betula papyrifera*), and ash (*Fraxinus* spp.) (Lautenschlager and Bell 1994). Block 2, the smallest in area, had clay loam soils and was located on a south-east facing slope. The pre-harvest forest consisted of trembling aspen, balsam fir, white birch, and white spruce. Block 3, the largest in area, originally was a pure trembling aspen stand, with an understory of black spruce and balsam fir, prior to harvest. The block was positioned on a slope with a southern aspect and deep, silty soils. Block 4 was on a south facing slope consisting of deep soils with a large gravel component. The pre-harvest stand was comprised of trembling aspen and

TABLE 1. Cutover size, dates of harvest, site preparation techniques, planting dates, and replanted stock types of the four experimental blocks

Block	Area (ha)	Harvested	Site preparation	Planted	Stock type
1	37.7	1986, 1988	Power disc trencher	1991	black spruce
2	25.4	1987	Young's teeth	1990	white spruce
3	45.4	1985	na*	1987	white spruce, black spruce
4	25.9	1987	Young's teeth	1989	white spruce

* information not available

balsam fir. The four blocks were harvested between 1985 and 1988 and were planted with black spruce and white spruce (Lautenschlager and Bell 1994; Wagner *et al.* 1994).

The conifer release treatments included two chemical herbicides (glyphosate [Vision®] and triclopyr [Release®]) applied aerially by helicopter, cutting the vegetation by mechanical means (the Silvana Selective/Ford Versatile), and manual cutting with brushsaws (Stihl FS420 and Husquavarna Professional). Each block also included a control area. Vision® and Release® were applied at 1.5 kg[a.i.]ha^{-1} and 1.9 kg[a.i.]ha^{-1}, respectively, on August 16, 1993. The brushsaw treatment was applied between October 12 and 22, 1993, and the Silvana Selective/Ford Versatile treatment between October 19 and November 5, 1993.

Gastropod collection

The 1993 field season was devoted to collecting baseline data on terrestrial gastropod populations before the treatments were applied. Post-treatment gastropod collections were made in 1994. In early June 1993, ten cardboard sheets, each 0.85 m^2, were placed in a systematic-random fashion on the forest floor, approximately 10-30 m apart, along each of three transects in the treatment areas (30 sheets per treatment area X 5 treatment areas X 4 blocks = 600 sheets total). New cardboard sheets were used for post-treatment sampling beginning in May 1994.

Each block was sampled, over a period of 1-3 days, four times during the snow-free season in both 1993 and 1994. Gastropods located beneath and on top of each cardboard sheet were identified to species, counted, and removed. The sheets were then replaced 1 m from the previously sampled location and left in position for approximately 14 days before sampling again.

Gastropods were identified using Pilsbry (1939-1948), Oughton (1948), Burch (1962), and Clarke (1981). Those species unknown to the collector or too small to be identified in the field were preserved in glycerin alcohol and identified later under a dissection microscope at 16X. Voucher specimens were sent to the Royal Ontario Museum, Toronto, where identifications were confirmed.

Regenerating plantation *vs.* mature forest

To determine if terrestrial gastropod species composition and abundance varied between a regenerating experimental block and a mature forest typical of the area, a fifth sampling site (three transects, each with 10 cardboard sheets) was established in 1994 in a 70-year-old forest adjacent to block 3. The site had a tree layer dominated by white spruce and trembling aspen forming a closed canopy. The shrub layer was sparse and the herb layer dominated by large-leaf aster (*Aster macrophyllus*) and bunchberry (*Cornus canadensis*).

Gastropod species composition and abundance from the mature forest were compared with those of the untreated control area on block 3. Both areas were sampled for gastropods five separate times (May 20, June 29, July 12, July 25, August 28, 1994), within 2 to 3 days of each other. The two areas were separated by approximately 1 km.

Vegetation response

To determine how the treatments affected vegetation composition, 24 vegetation sample plots (2.26 m diameter = 4 m^2) were randomly placed in each of the treatment areas on the four experimental blocks (120 plots per block, 480 total plots) (Lautenschlager and Bell 1994). On each plot, total percent cover was visually assessed for each species and categorized into six vegetation groups (coniferous trees, deciduous trees, shrubs, herbs, ferns, and grasses/sedges). Percent cover data were collected once for each of the four blocks, during late July and early August, in both 1993 and 1994. Relationships between these data and gastropod distribution and abundance on the corresponding treatment areas were examined.

Microclimatic effects

The effect of conifer release treatments on near-ground temperature and gastropod activity was studied in 1994. A thermocouple station was established at six cardboard sheets, chosen randomly, in each treatment area on block 3 (total of 30 stations). Each station included three type-T copper-constantan thermocouple leads, one placed 2 cm above the cardboard sheet, one on the forest floor directly beneath the sheet, and one 2 cm deep in the humus beneath the sheet. Each of the 30 sheets was sampled for gastropods five times throughout the summer of 1994 between 0700 hrs. and 1100 hrs. Immediately prior to sampling a sheet, thermocouple temperatures were measured using a Cole-Parmer digital thermometer (Model 08500-41). The time and percent cloud cover at sampling was also recorded.

In addition to microclimate data, mean daily air temperatures and total monthly precipitation were obtained for April through September in 1993 and 1994. These data were provided by the Thunder Bay station of the Atmospheric Environment Service, Environment Canada (approximately 50 km northeast of the study area).

Barrier-enclosed sheets

An experiment was designed to determine whether cardboard sheets sample only gastropods residing beneath them or if collections also include gastropods immigrating from the surrounding area. Ten pairs of cardboard sheets were randomly placed at approximately 10 m intervals on the ground vegetation in the control area of block 3 on July 20, 1994. One cardboard sheet of each pair was tightly encircled by a strip of sheet metal (22 gauge, 12 cm high) penetrating 7 cm into the soil and protruding 5 cm above the soil surface. The buried portion of the sheet metal barrier was intended to prevent the lateral movement of gastropods through the soil layer and into the area beneath the cardboard sheet. The corresponding control sheet *(i.e.* without a barrier) was placed approximately 4 m from the enclosed sheet.

The above-ground surface of the sheet metal was coated with automotive bearing grease and covered with a mixture of coarse grain, black pepper and cayenne pepper (2:1) to inhibit gastropod movement over the barrier. In addition, any overhanging ground vegetation, which could have allowed gastropods to cross the barrier, was removed. Pairs of cardboard sheets were sampled simultaneously for gastropods, between 0800 hrs. and

1000 hrs., every 2-3 days until August 18, 1994, for a total of 11 sampling days. Gastropods were removed and each sheet returned to its original position.

Weathered sheets

An experiment was designed to determine if weathered cardboard sheets produce larger samples of gastropods than new sheets. In early June, 1993, ten cardboard sheets were randomly placed on the ground vegetation in the control area of block 3. These sheets were sampled five times over the 1993 field season and were left in position on block 3 over the winter. On May 2, 1994, 10 new cardboard sheets were positioned in the control area of block 3, each approximately 4 m from a sheet used the previous season. At the same time, the weathered sheets were moved approximately 1 m from their over-winter position and any gastropods adhering to the sheets were removed. Each of the 10 new sheets was sampled, simultaneously with its corresponding weathered sheet, four times during the 1994 field season (May 20, June 29, July 12, and July 25, 1994).

Statistical analysis

Tests for differences between terrestrial gastropod densities, within different data sets, were done using only those species with numbers exceeding 2% of the total collected. All differences were considered significant at $p<0.05$.

To examine the response of individual terrestrial gastropod populations to the conifer release treatments, a repeated measures analysis of variance (ANOVA) (Appendix A, Table A1 and Table A2) was performed to determine if gastropod densities varied between treatments (Meredith and Stehman 1991; Norusis 1992a; Gumpertz and Brownie 1993) followed by a least significant difference (LSD) multiple comparison procedure (Steel and Torrie 1980). Tests for differences in densities between the four sampling periods through the summer and any treatment X time interactions were also done using this procedure. Data were first normalized using a logarithmic transformation ($\log_{10}$).

The response of the terrestrial gastropod community to the different treatments was analyzed by means of a canonical variates analysis (CVA) (Pimentel 1979; Williams 1983; Morrison *et al.* 1992). To remove any multicollinearity due to time, numbers of each species of gastropod were summed over all four experimental blocks and a separate analysis was performed for each of the four sampling periods in 1993 and 1994. Ordination diagrams, based on the first and second canonical vectors, were produced and 95% confidence circles plotted around the treatment centroids (Pimentel 1979).

Population densities in the mature forest and in the control area of block 3 were calculated. To test the null hypothesis of no difference between a mature forest and a regenerating conifer plantation, these densities were compared using a Wilcoxon Rank Sum test (Bradley 1968; Norusis 1992b).

Changes in percent vegetation cover in treatment areas between the pre-treatment (1993) and post-treatment (1994) years were evaluated using canonical variates analysis. Two analyses, one for 1993 and one for 1994, were performed on the percent cover data of all species observed, combined over the four experimental blocks.

The first and second canonical vectors were used to construct ordination diagrams for each year, and 95% confidence circles were plotted around each treatment centroid.

To detect differences in near-ground temperature among treatment areas and between the different thermocouple positions, a repeated measures ANOVA (Appendix A, Table A3 and Table A4) was performed. The dependent variable was normalized, for this analysis, using a square root transformation.

The null hypothesis of no difference between enclosed cardboard sheets and control sheets was tested using the Wilcoxon Rank Sum test. To test for differences in gastropod densities between the 11 sample periods, a Kruskal-Wallis ANOVA was performed (Bradley 1968). The Wilcoxon Rank Sum test was also used to test the null hypothesis of no difference in the use of new and weathered cardboard sheets by gastropods.

RESULTS

Population response

Totals of 27,396 and 20,199 terrestrial gastropods were collected from the four experimental blocks, over the four sample periods, in the summers of 1993 and 1994, respectively (Table 2; Appendix B, Table B1-B5). Twenty-one species, including 19 snails and two slugs (*Deroceras laeve* and *Pallifera dorsalis*), were collected from each block in each of the two years, with the exception of the snail, *Pupisoma minus*, which was absent on block 2 in 1993 and was not found on any block in 1994.

The total number of terrestrial gastropods collected varied between blocks within each of the two years (Table 2). Block 3 had the greatest abundance of snails and slugs in 1993 and 1994, while block 4 had the lowest in each year. Total numbers of gastropods collected also varied between years for each block, with greater numbers of snails and slugs collected from each block in 1993 than in 1994.

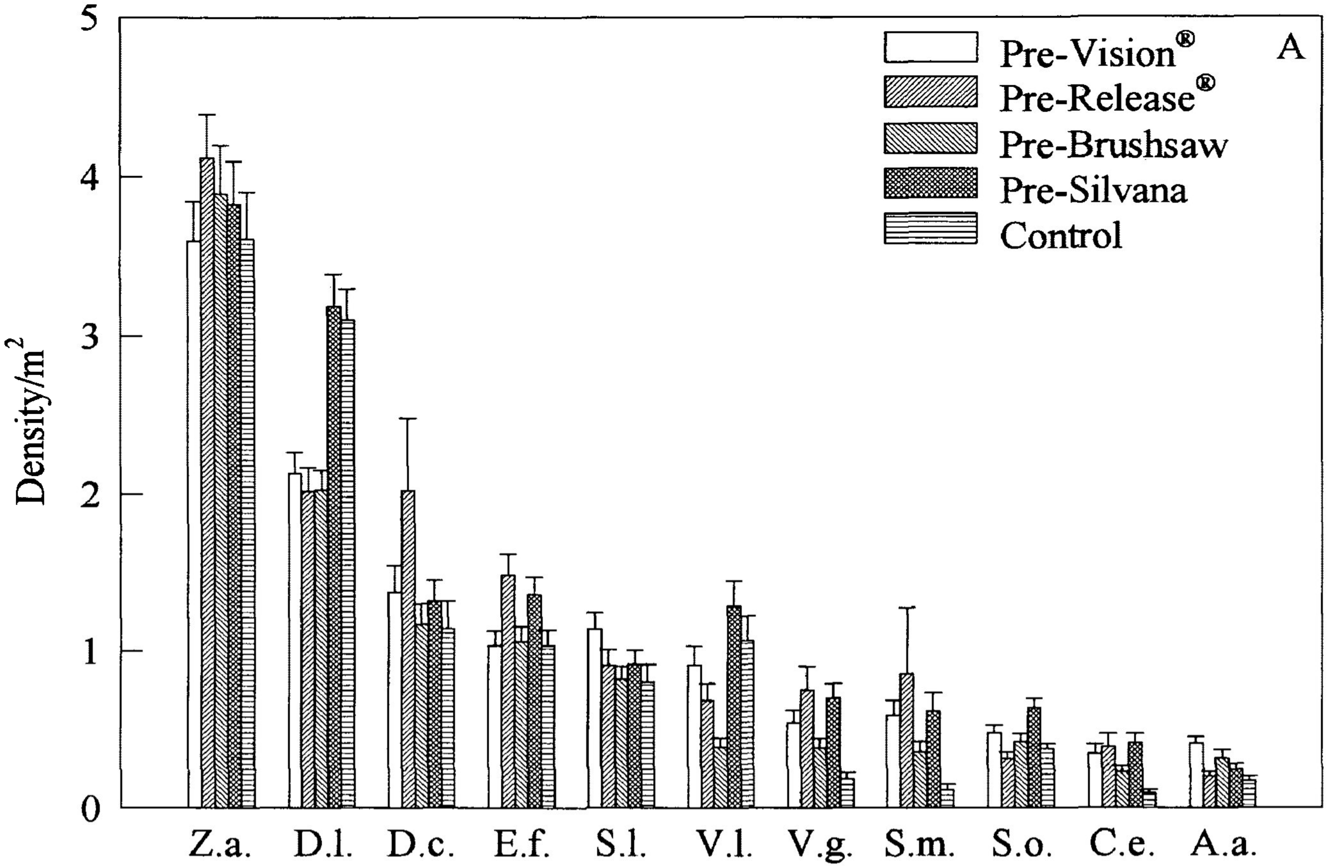
Mean overall gastropod density, and the individual densities of the 11 most common gastropods, did not vary between treatment areas within blocks either before (1993) or after treatments were applied (1994) (Figure 1, Table 3). In 1993, mean gastropod density (Figure 2A) and the densities of six species (*Euconulus fulvus*, *Strobilops labyrinthica*, *Vertigo gouldi*, *Striatura milium*, *Columella edentula*, and *Anguispira alternata*) increased over the four sample periods during the summer (Figures 3-5; Table 3). In 1994, only *S. milium* increased in density over the summer (Figure 4C; Table 3). No treatment by time interaction effects were evident in either the

TABLE 2. Total numbers of terrestrial gastropods collected from each of the four experimental blocks in the summers of 1993 (pre-treatment) and 1994 (post-treatment)

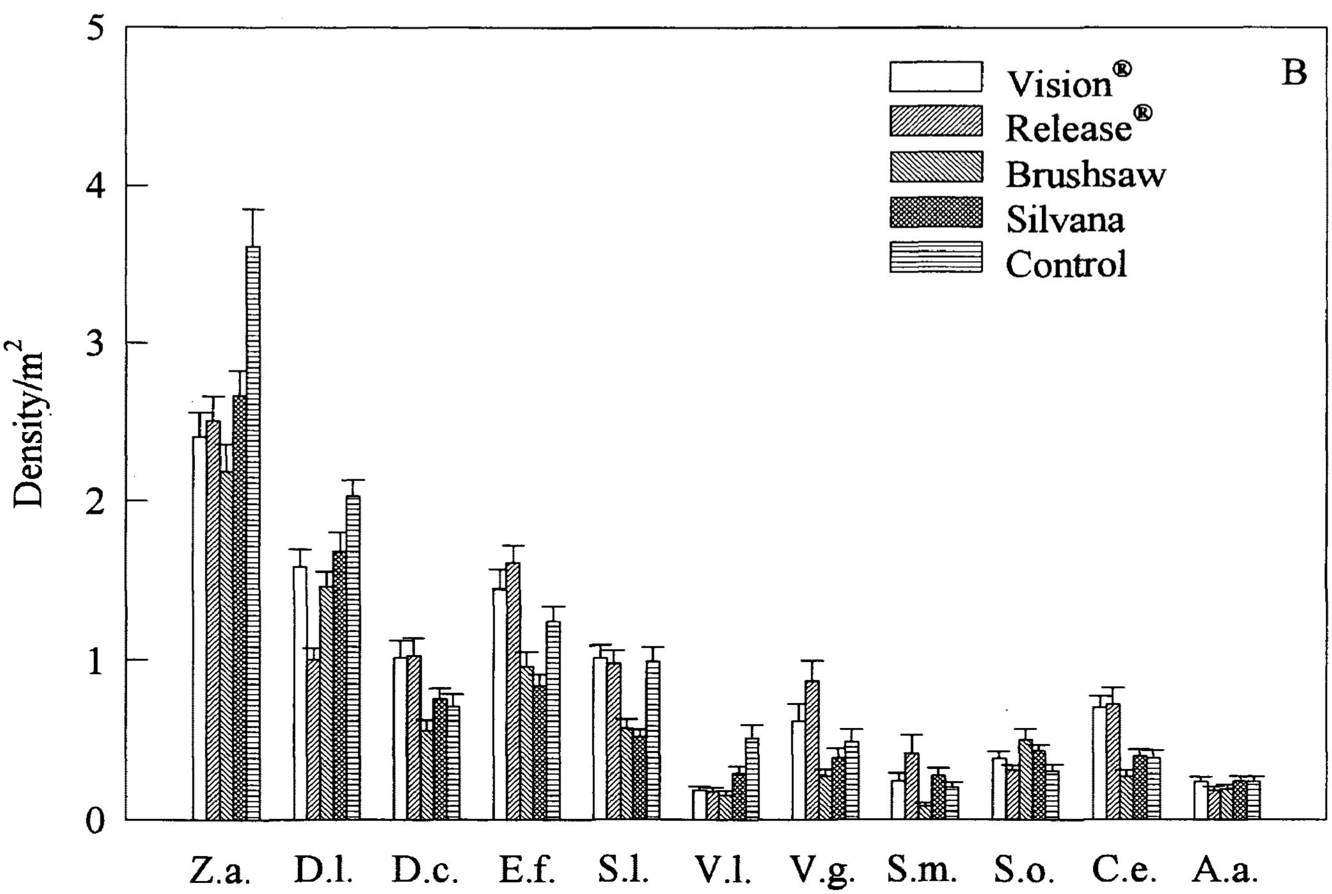
	1993					1994				
	Block					Block				
	1	2	3	4	Total	1	2	3	4	Total
Zonitoides arboreus	3933	1688	1759	447	7827	2124	1050	1802	516	5492
Deroceras laeve	607	1302	2257	951	5117	322	914	1284	672	3192
Discus cronkhitei	1502	868	180	337	2887	800	420	326	119	1665
Euconulus fulvus	643	507	1027	275	2452	354	906	963	284	2507
Strobilops labyrinthica	304	265	791	523	1883	367	427	568	306	1668
Vitrina limpida	253	263	1110	155	1781	62	135	291	45	533
Vertigo gouldi	152	197	363	346	1058	218	214	396	252	1080
Striatura milium	68	75	419	478	1040	77	81	85	251	494
Succinea ovalis	62	155	345	355	917	67	136	370	214	787
Columella edentula	89	127	217	174	607	347	301	219	144	1011
Anguispira alternata	27	57	317	151	552	9	40	217	177	443
Cochlicopa lubrica	84	18	173	17	292	73	36	171	9	289
Pallifera dorsalis	20	19	121	46	206	5	15	41	17	78
Zöogenetes harpa	13	16	91	78	198	9	36	46	37	128
Vertigo ovata	38	40	59	61	198	39	47	70	85	241
Striatura exigua	27	21	45	48	141	28	38	45	17	128
Gastrocopta tappaniana	11	12	34	19	76	32	110	76	37	255
Vertigo modesta	15	18	23	9	65	8	23	30	31	92
Carychium exile canadense	2	10	13	34	59	23	5	51	15	94
Punctum minutissimum	2	2	4	21	29	6	2	5	9	22
*Pupisoma minus**	2	0	1	8	11	0	0	0	0	0
Total	7854	5660	9349	4533	27396	4970	4936	7056	3237	20199

* tentative identification by the Royal Ontario Museum, Toronto

FIG. 1. Mean densities (±S.E.) of each of the 11 most common species of terrestrial gastropod in the four conifer release treatment areas and the control area in 1993 (A) and 1994 (B). [Z.a.=*Zonitoides arboreus*; D.l.=*Deroceras laeve*; D.c.=*Discus cronkhitei*; E.f.=*Euconulus fulvus*; S.l.=*Strobilops labyrinthica*; V.l.=*Vitrina limpida*; V.g.=*Vertigo gouldi*; S.m.=*Striatura milium*; S.o.=*Succinea ovalis*; C.e.=*Columella edentula*; A.a.=*Anguispira alternata*]



A
Pre-Vision®
Pre-Release®
Pre-Brushsaw
Pre-Silvana
Control
Density/m²
0
1
2
3
4
5
Z.a.
D.l.
D.c.
E.f.
S.l.
V.l.
V.g.
S.m.
S.o.
C.e.
A.a.



B
Vision®
Release®
Brushsaw
Silvana
Control
Density/m²
0
1
2
3
4
5
Z.a.
D.l.
D.c.
E.f.
S.l.
V.l.
V.g.
S.m.
S.o.
C.e.
A.a.

TABLE 3. F-statistics and *p*-values of main treatment and interaction effects, calculated from repeated measures ANOVA, for the total number of gastropods and each of the 11 most common terrestrial gastropod species in 1993 (pre-treatment) and 1994 (post-treatment)

	1993 (Pre-Treatment)			1994 (Post-Treatment)		
	Treatment	Time	TreatmentXTime	Treatment	Time	TreatmentXTime
Total	$F^{\dagger}=0.52$, $p>0.05$	$F^{\ddagger}=6.52$, $p<0.05$*	$F^{\S}=1.64$, $p>0.05$	F=1.16, $p>0.05$	F=0.26, $p>0.05$	F=0.71, $p>0.05$
Zonitoides arboreus	F=0.46, $p>0.05$	F=3.21, $p>0.05$	F=0.44, $p>0.05$	F=0.87, $p>0.05$	F=2.32, $p>0.05$	F=0.69, $p>0.05$
Deroceras laeve	F=1.35, $p>0.05$	F=2.38, $p>0.05$	F=1.54, $p>0.05$	F=2.43, $p>0.05$	F=2.03, $p>0.05$	F=0.67, $p>0.05$
Discus cronkhitei	F=0.59, $p>0.05$	F=3.62, $p>0.05$	F=0.84, $p>0.05$	F=0.55, $p>0.05$	F=0.87, $p>0.05$	F=0.80, $p>0.05$
Euconulus fulvus	F=0.76, $p>0.05$	F=7.72, $p<0.05$*	F=1.33, $p>0.05$	F=1.92, $p>0.05$	F=0.19, $p>0.05$	F=1.18, $p>0.05$
Strobilops labyrinthica	F=0.29, $p>0.05$	F=11.67, $p<0.05$*	F=1.08, $p>0.05$	F=0.79, $p>0.05$	F=1.77, $p>0.05$	F=0.67, $p>0.05$
Vitrina limpida	F=1.02, $p>0.05$	F=1.04, $p>0.05$	F=1.00, $p>0.05$	F=1.00, $p>0.05$	F=0.34, $p>0.05$	F=1.00, $p>0.05$
Vertigo gouldi	F=1.29, $p>0.05$	F=36.93, $p<0.05$*	F=1.46, $p>0.05$	F=1.77, $p>0.05$	F=1.68, $p>0.05$	F=0.80, $p>0.05$
Striatura milium	F=0.81, $p>0.05$	F=9.86, $p<0.05$*	F=0.71, $p>0.05$	F=0.71, $p>0.05$	F=5.13, $p<0.05$*	F=2.00, $p>0.05$
Succinea ovalis	F=2.33, $p>0.05$	F=1.87, $p>0.05$	F=1.00, $p>0.05$	F=0.80, $p>0.05$	F=2.12, $p>0.05$	F=1.50, $p>0.05$
Columella edentula	F=1.46, $p>0.05$	F=58.75, $p<0.05$*	F=2.00, $p>0.05$	F=2.11, $p>0.05$	F=3.09, $p>0.05$	F=1.29, $p>0.05$
Anguispira alternata	F=0.94, $p>0.05$	F=4.08, $p<0.05$*	F=1.33, $p>0.05$	F=0.20, $p>0.05$	F=3.00, $p>0.05$	F=1.00, $p>0.05$

* significant at $p<0.05$

†F distribution with 4 and 12 degrees of freedom

‡F distribution with 3 and 9 degrees of freedom

§F distribution with 12 and 36 degrees of freedom

FIG. 2. Mean densities (±S.E.) of terrestrial gastropods, in each of the four conifer release treatment areas and the control areas, through the summer of 1993 and 1994. Months with the same letter are not significantly different, with respect to mean density, at $p<0.05$. Total (A), *Zonitoides arboreus* (B), and *Deroceras laeve* (C).

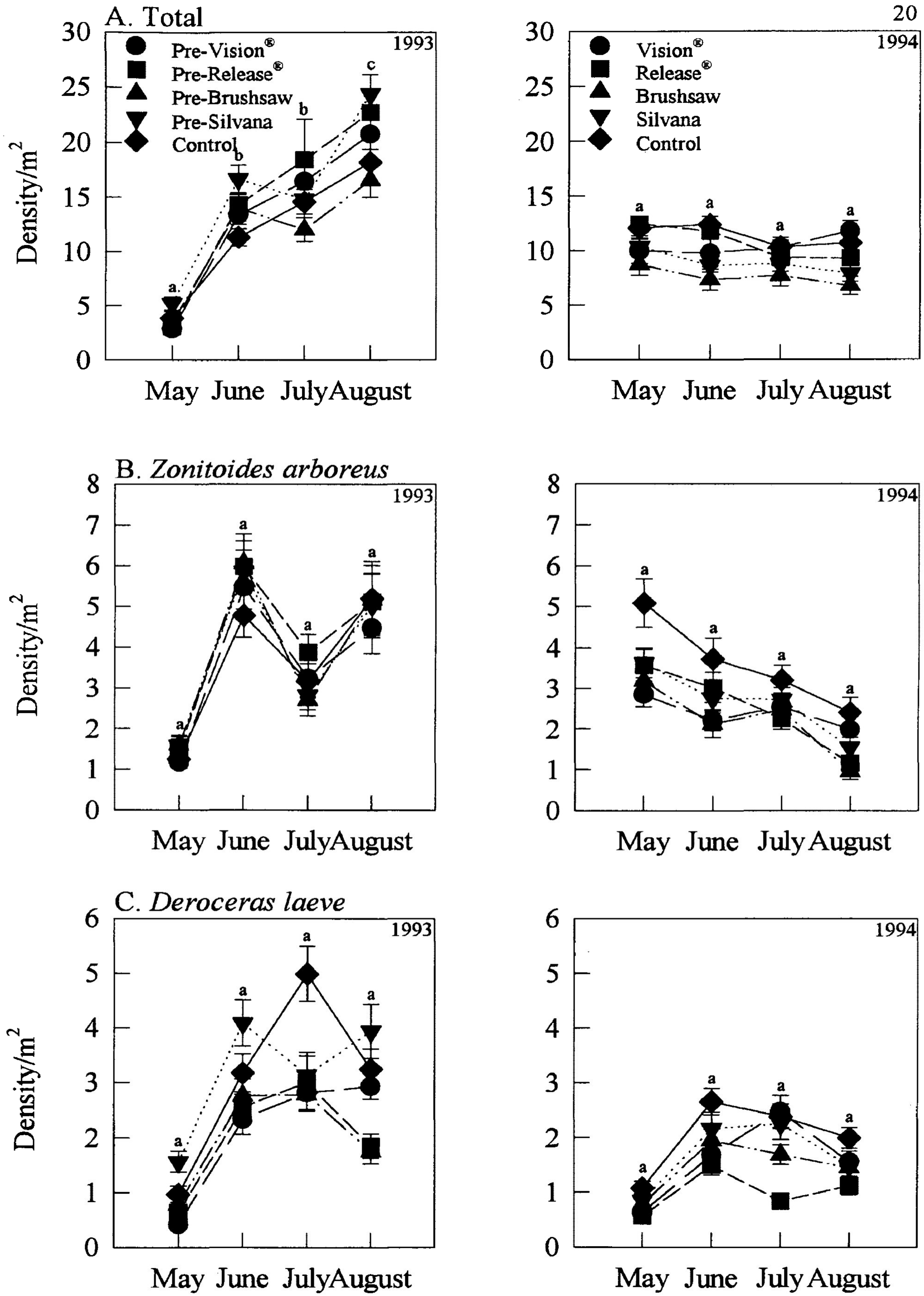

A. Total
1993
Pre-Vision®
Pre-Release®
Pre-Brushsaw
Pre-Silvana
Control
Density/m²
May June July August
1994
Vision®
Release®
Brushsaw
Silvana
Control
B. Zonitoides arboreus
C. Deroceras laeve

FIG. 3. Mean densities (±S.E.) of terrestrial gastropods, in each of the four conifer release treatment areas and the control areas, through the summer of 1993 and 1994. Months with the same letter are not significantly different, with respect to mean density, at $p<0.05$. *Discus cronkhitei* (A), *Euconulus fulvus* (B), and *Strobilops labyrinthica* (C).

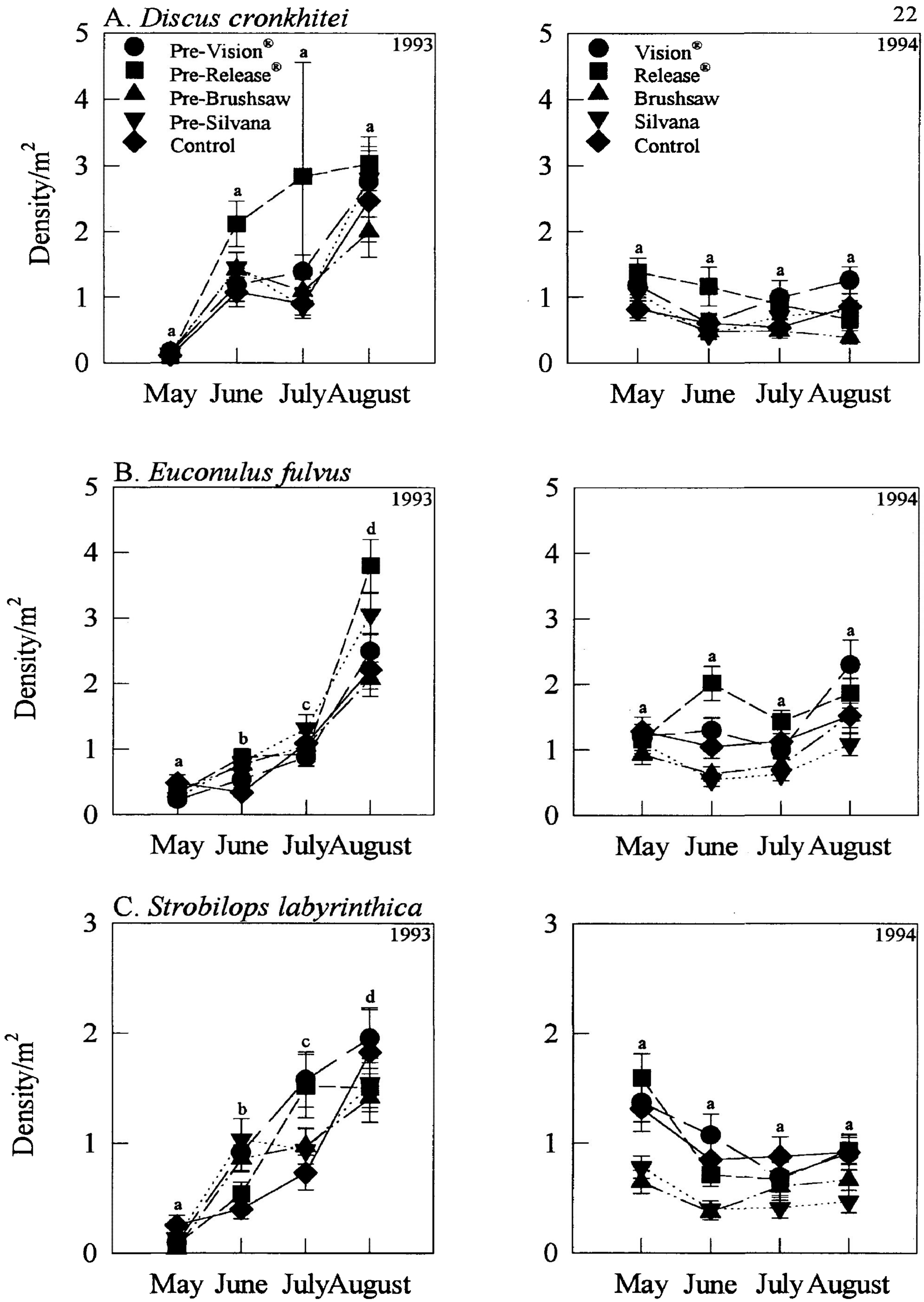

A. Discus cronkhitei
1993
1994
Pre-Vision®
Pre-Release®
Pre-Brushsaw
Pre-Silvana
Control
Vision®
Release®
Brushsaw
Silvana
Control
B. Euconulus fulvus
C. Strobilops labyrinthica
Density/m2
May June July August
0 1 2 3 4 5
a b c d

FIG. 4. Mean densities (±S.E.) of terrestrial gastropods, in each of the four conifer release treatment areas and the control areas, through the summer of 1993 and 1994. Months with the same letter are not significantly different, with respect to mean density, at $p<0.05$. *Vitrina limpida* (A), *Vertigo gouldi* (B), and *Striatura milium* (C).

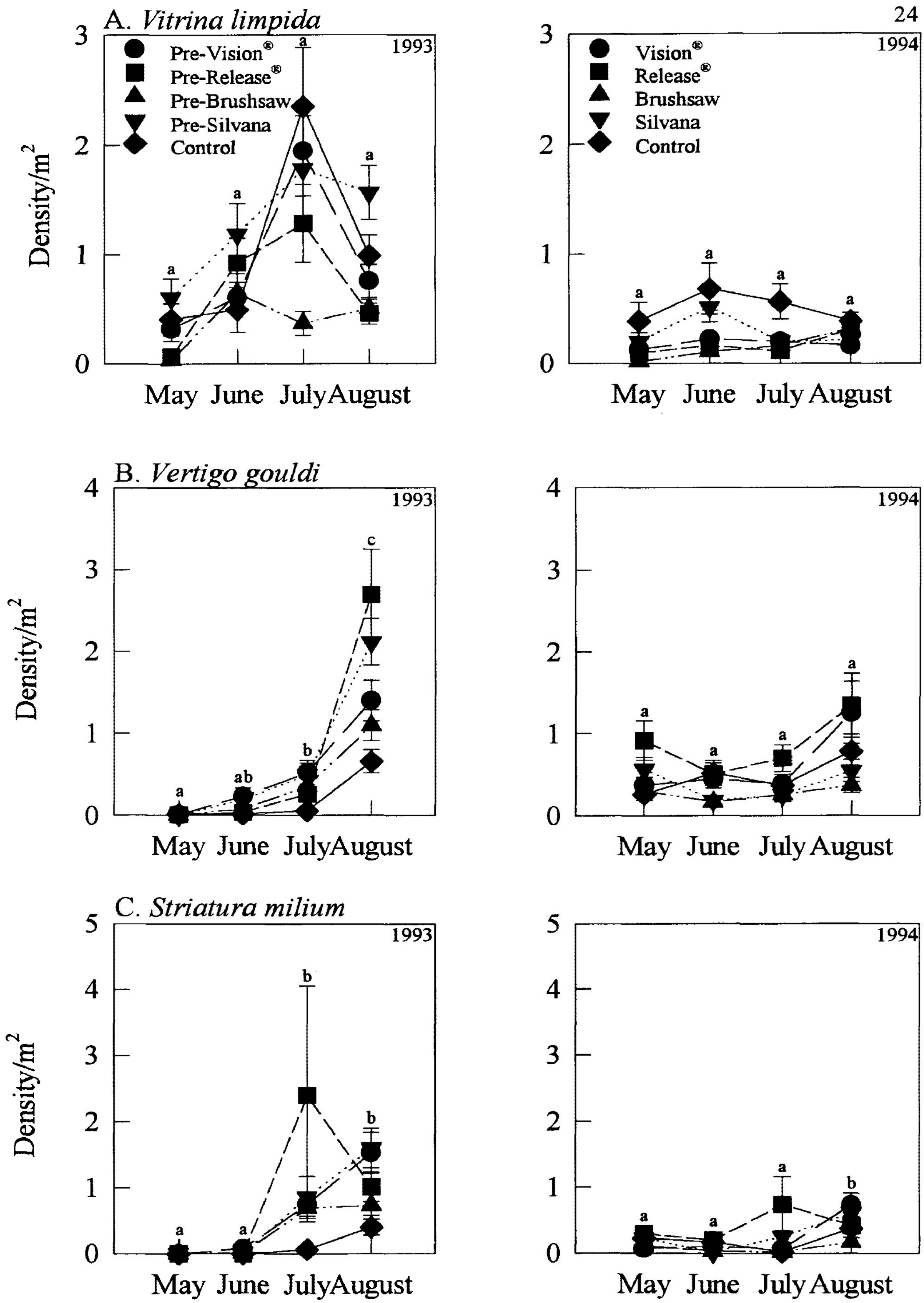
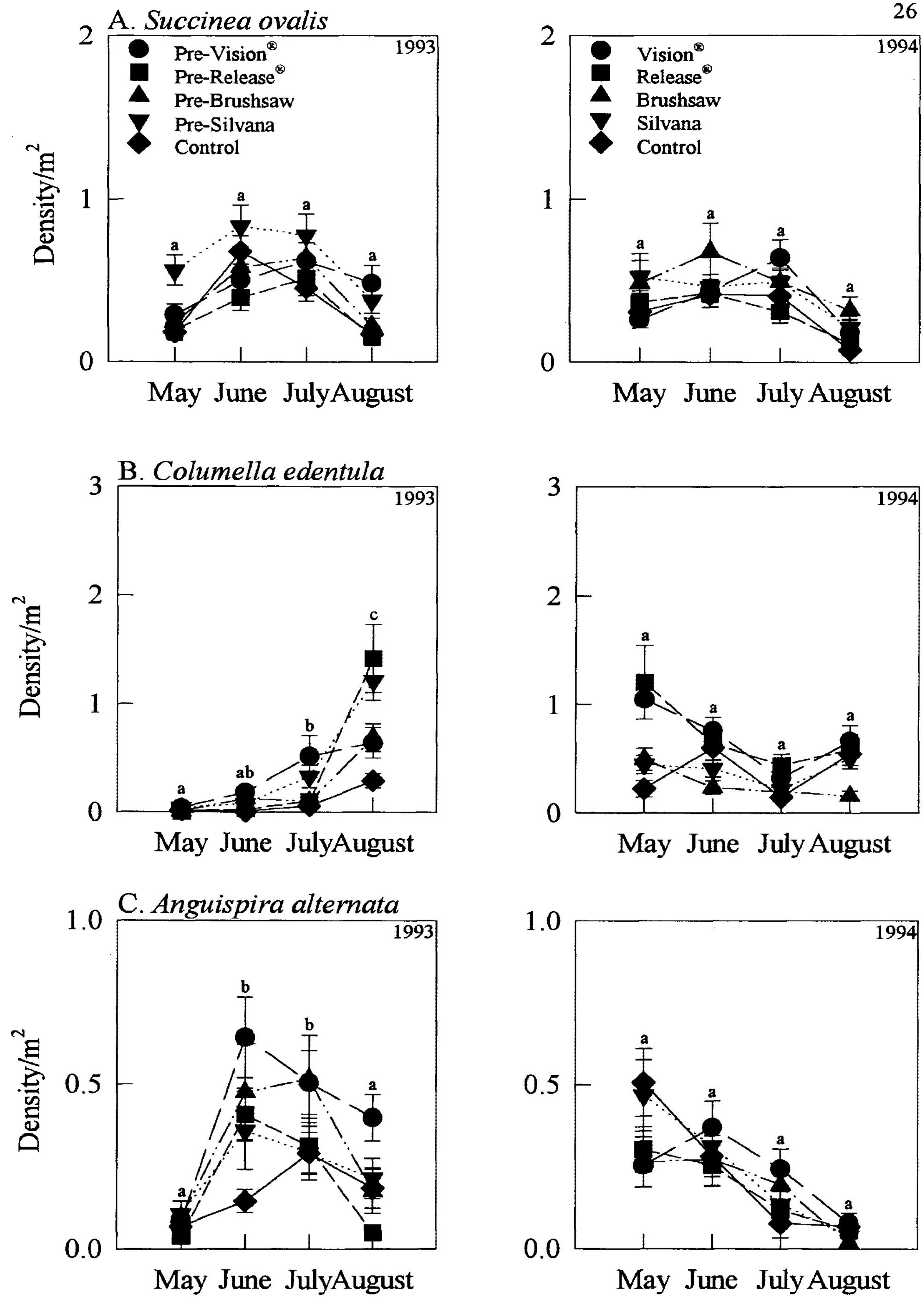

A. Vitrina limpida
1993
Pre-Vision®
Pre-Release®
Pre-Brushsaw
Pre-Silvana
Control
1994
Vision®
Release®
Brushsaw
Silvana
Control
Density/m2
May June July August
B. Vertigo gouldi
1993
1994
C. Striatura milium
1993
1994

FIG. 5. Mean densities (±S.E.) of terrestrial gastropods, in each of the four conifer release treatment areas and the control areas, through the summer of 1993 and 1994. Months with the same letter are not significantly different, with respect to mean density, at $p<0.05$. *Succinea ovalis* (A), *Columella edentula* (B), and *Anguispira alternata* (C).


A. Succinea ovalis
1993
Pre-Vision®
Pre-Release®
Pre-Brushsaw
Pre-Silvana
Control
1994
Vision®
Release®
Brushsaw
Silvana
Control
B. Columella edentula
C. Anguispira alternata
Density/m²
May June July August
0
1
2
3
0.0
0.5
1.0
a
ab
b
c

mean overall gastropod density or any of the 11 most common species of gastropod during the summers of 1993 and 1994 (Table 3).

Community response

Canonical variates analyses produced ordination diagrams with overlapping treatment centroids indicating that gastropod community composition and relative abundance were similar in each of the five treatment areas, across the four experimental blocks, for each of the four sample periods in both the pre- and post-treatment years (Figure 6). The eigenvalues, and associated variances, of each of the axes of the ordination diagrams are presented in Table 4.

Regenerating plantation *vs.* mature forest

The species composition of gastropods in the regenerating and mature forests were similar (20 spp. *vs.* 18 spp., respectively) (Table 5). Overall, mean gastropod density (±S.E.) was higher in the regenerating forest (15.5±1.3 m^{-2}) than in the mature forest (9.4±0.6 m^{-2}) (p=0.008). This difference was due primarily to greater numbers of *Zonitoides arboreus* (p=0.014), *E. fulvus* (p=0.01), *D. laeve* (p<0.0001), *V. gouldi* (p=0.002), and *S. milium* (p=0.041) in the regenerating forest. *Vertigo modesta* and *Punctum minutissimum* were not found in the mature forest. One species, *Discus cronkhitei*, had a higher density in the mature forest (p<0.0001).

FIG. 6. Ordination diagrams, produced from canonical variates analyses, of the terrestrial gastropod community in each of the four conifer release treatment areas and the control areas through the summer before (1993) and after (1994) treatments were applied. [V=Vision®; R=Release®; B=Brushsaw; S=Silvana Selective; C=Control].

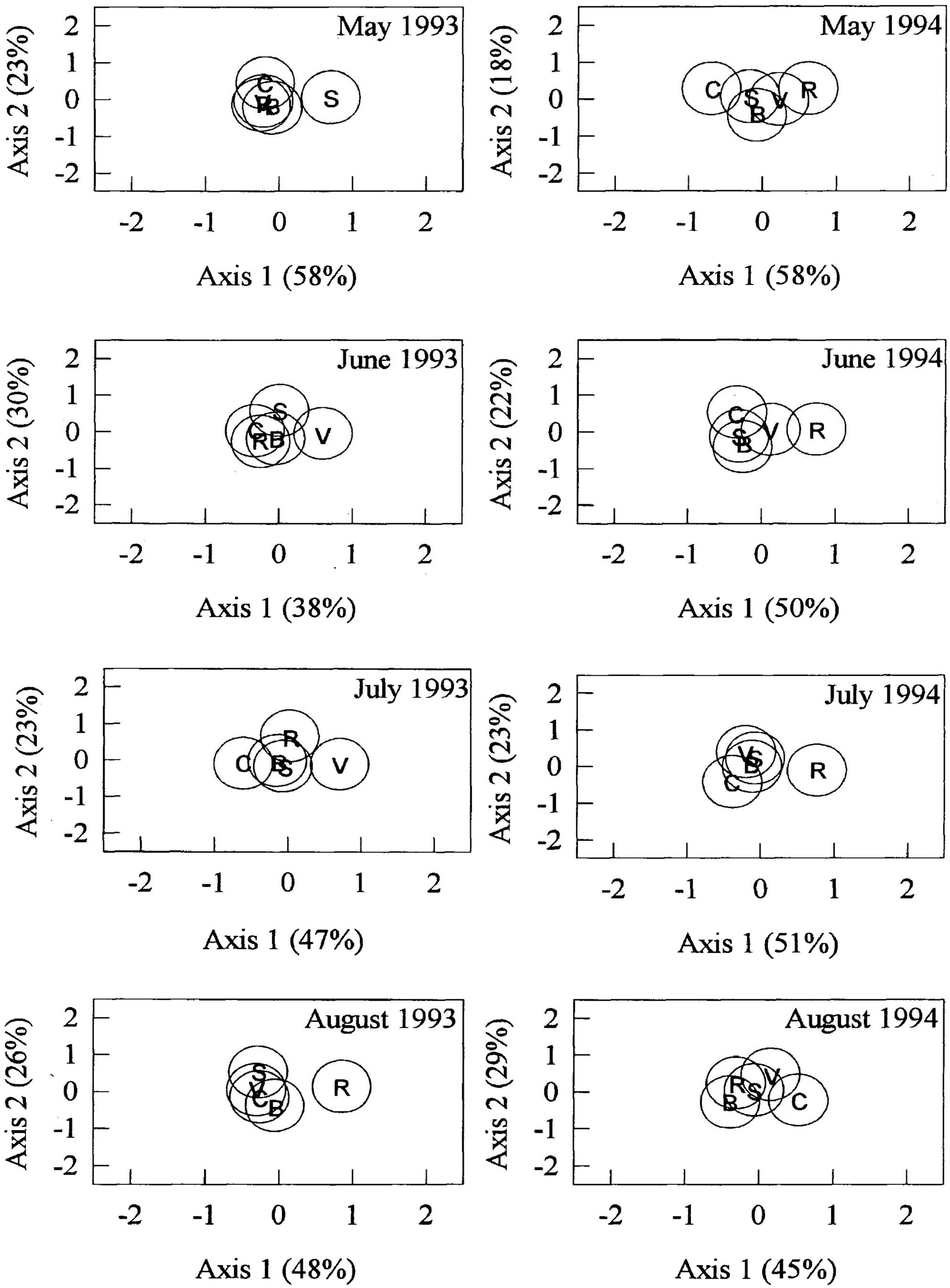

May 1993
Axis 2 (23%)
Axis 1 (58%)
May 1994
Axis 2 (18%)
Axis 1 (58%)
June 1993
Axis 2 (30%)
Axis 1 (38%)
June 1994
Axis 2 (22%)
Axis 1 (50%)
July 1993
Axis 2 (23%)
Axis 1 (47%)
July 1994
Axis 2 (23%)
Axis 1 (51%)
August 1993
Axis 2 (26%)
Axis 1 (48%)
August 1994
Axis 2 (29%)
Axis 1 (45%)

TABLE 4. Eigenvalues and associated percent variances, calculated from the canonical variates analyses, for the first two axes of the ordination diagrams of terrestrial gastropod communities over the four sample periods in 1993 (pre-treatment) and 1994 (post-treatment)

	1993 (Pre-Treatment)				1994 (Post-Treatment)			
	Axis 1		Axis 2		Axis 1		Axis 2	
	Eigenvalue	% Variance	Eigenvalue	% Variance	Eigenvalue	% Variance	Eigenvalue	% Variance
May	0.128	57	0.051	23	0.186	58	0.059	18
June	0.106	38	0.085	30	0.169	50	0.073	22
July	0.179	47	0.088	23	0.164	51	0.075	23
August	0.191	48	0.105	26	0.115	45	0.075	29

TABLE 5. Mean densities (±S.E.) of terrestrial gastropods in the regenerating plantation and the mature forest

	Regenerating plantation	Mature forest	p-value*
Zonitoides arboreus	4.14±0.44	2.28±0.21	p=0.014
Euconulus fulvus	2.17±0.23	1.17±0.12	p=0.010
Strobilops labyrinthica	1.79±0.24	1.36±0.16	p=0.489
Deroceras laeve	2.20±0.20	0.72±0.09	p<0.001
Vitrina limpida	1.14±0.24	0.65±0.10	p=0.257
Discus cronkhitei	0.41±0.08	1.28±0.15	p<0.001
Cochlicopa lubrica	0.49±0.12	0.51±0.08	p=0.059
Vertigo gouldi	0.77±0.16	0.16±0.05	p=0.002
Columella edentula	0.49±0.09	0.34±0.07	p=0.276
Succinea ovata	0.47±0.10	0.23±0.05	p=0.143
Anguispira alternata	0.19±0.05	0.28±0.07	p=0.315
Striatura milium	0.34±0.09	0.10±0.03	p=0.041
Striatura exigua	0.23±0.05	0.09±0.03	p=0.027
Gastrocopta tappaniana	0.19±0.09	0.04±0.02	p=0.063
Vertigo ovata	0.09±0.03	0.06±0.04	p=0.082
Zöogenetes harpa	0.05±0.02	0.09±0.03	p=0.570
Pallifera dorsalis	0.07±0.03	0.05±0.02	p=0.990
Vertigo modesta	0.12±0.04	0	p=0.002
Carychium exile canadense	0.09±0.05	0.01±0.01	p=0.056
Punctum minutissimum	0.02±0.02	0	p=0.157
Total	15.48±1.31	9.43±0.57	p=0.008

* p-values based on a Wilcoxon Rank Sum Test

Vegetation response

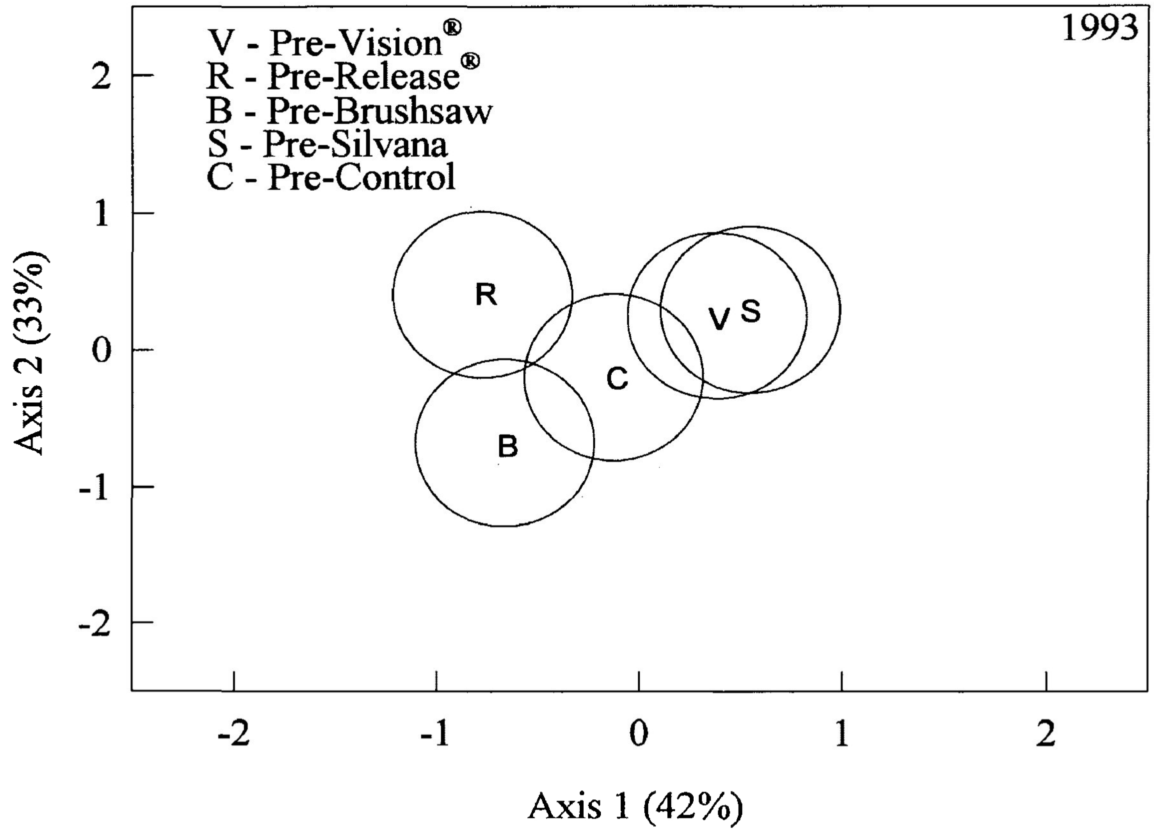
In the pre-treatment year, the vegetation communities on the designated treatment areas were similar and the treatment centroids were not separated on the ordination diagram (Figure 7A). In 1994, after application of the conifer release treatments, four structurally distinct vegetation communities became evident: two associated with the chemical herbicide treatments (Vision® and Release®), one with the Silvana Selective/Ford Versatile and brushsaw treatments, and one with the control area (Figure 7B).

The herbicide Vision® reduced the percent cover of deciduous trees and shrubs, and increased the herb community on the treated areas (Figure 8). Release® reduced the deciduous tree and shrub layer to a lesser extent than Vision®, and increased the establishment of grasses/sedges. The Silvana Selective/Ford Versatile and brushsaw treatments reduced the percent cover of deciduous trees in the post-treatment year. The percent cover of each of the different vegetation types remained the same on the control areas over the two years of the study. The species of vegetation identified on the experimental blocks, and their associated percent cover, are listed in Appendix C, Table C1.

The first canonical axis of the pre-treatment ordination diagram had an eigenvalue of 0.212, accounting for 42% of the variation within the CVA. The second axis had an eigenvalue of 0.168, accounting for 33% of the variation. The first axis on the post-treatment ordination diagram separated the four treatments and the control and had

FIG. 7. Ordination diagrams, produced from canonical variates analyses, of the vegetation community in each of the four conifer release treatment areas and the control areas, across the four experimental blocks, in 1993 (A) and 1994 (B). Circles represent 95% confidence regions for each treatment centroid.

A


V - Pre-Vision®
R - Pre-Release®
B - Pre-Brushsaw
S - Pre-Silvana
C - Pre-Control
1993
R
V S
C
B
Axis 2 (33%)
Axis 1 (42%)
2
1
0
-1
-2

B

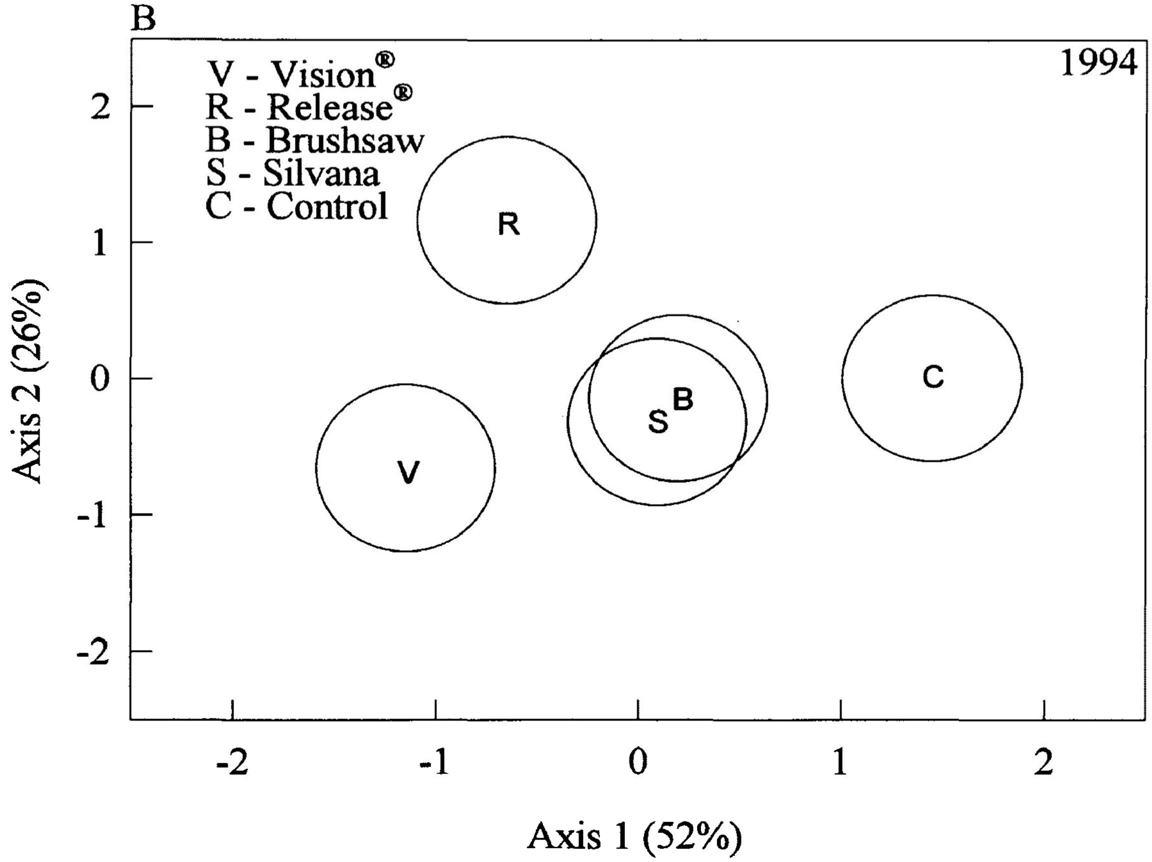
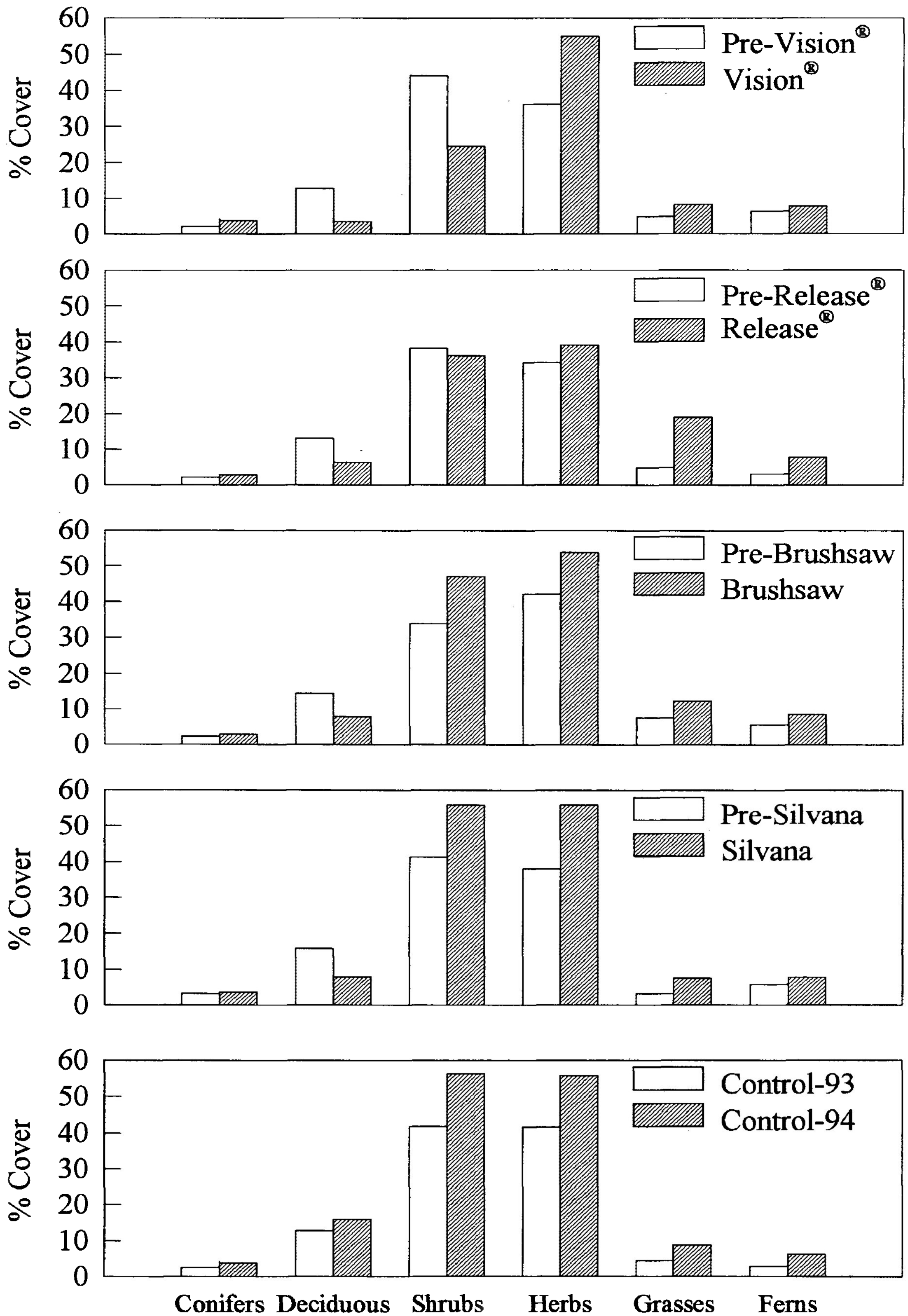

V - Vision®
R - Release®
B - Brushsaw
S - Silvana
C - Control
1994
R
S B
C
V
Axis 2 (26%)
Axis 1 (52%)
2
1
0
-1
-2

FIG. 8. Percent cover of coniferous trees, deciduous trees, shrubs, herbs, grasses/sedges, and ferns in the four conifer release treatment areas and the control area in 1993 (pre-treatment) and 1994 (post-treatment).


Pre-Vision®
Vision®
Pre-Release®
Release®
Pre-Brushsaw
Brushsaw
Pre-Silvana
Silvana
Control-93
Control-94
% Cover
0
10
20
30
40
50
60
Conifers
Deciduous
Shrubs
Herbs
Grasses
Ferns

an eigenvalue of 0.786, accounting for 52% of the variation present within the data. The second axis, with an eigenvalue of 0.386, accounted for 26% of the variation.

Microclimatic effects

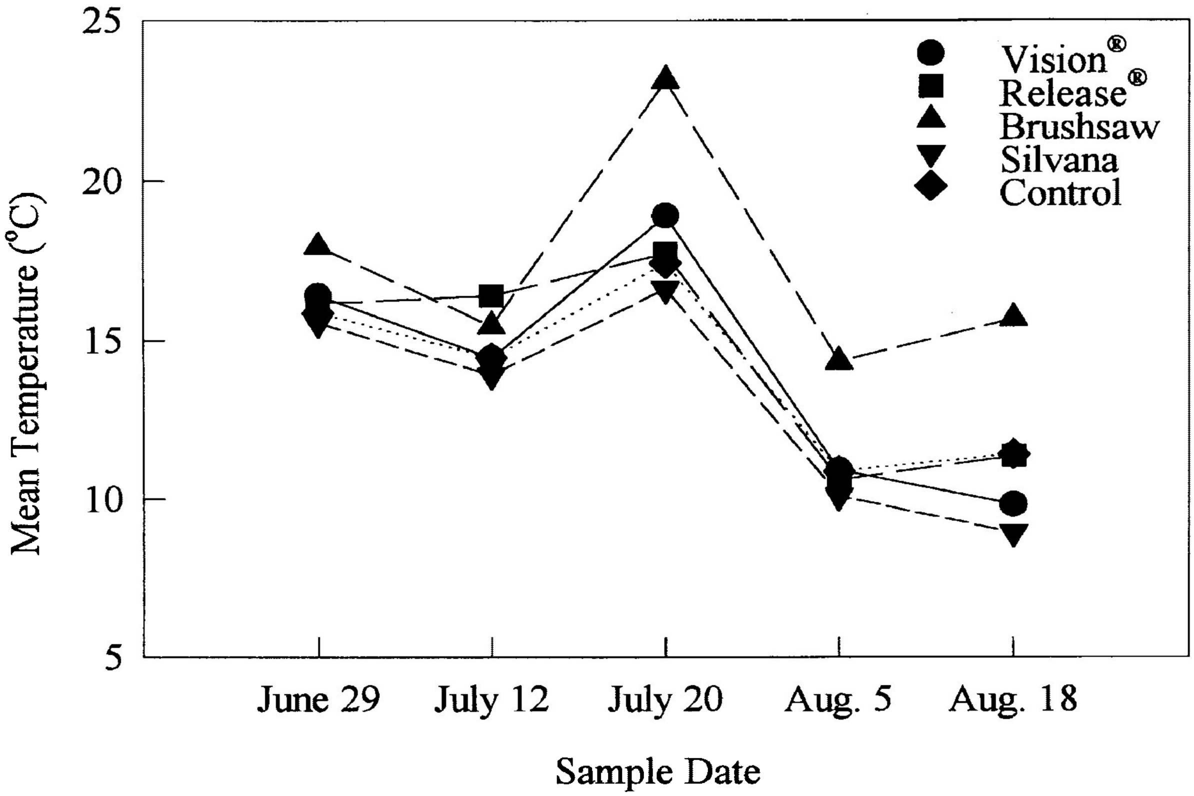
Near-ground temperature was greater in the brushsaw treated area than in the other conifer release treatment areas and the control (Figure 9). However, there was significant interaction in near-ground temperature between the treatment areas over the course of the summer ($F=3.17$; $p<0.05$). Near-ground temperature on the Release® treated area increased through early July while temperatures on the other areas declined.

Interaction in near-ground temperature between the three thermocouple positions was also observed over the summer ($F=11.75$; $p<0.05$). The temperatures 2 cm above and directly beneath (0 cm) cardboard sheets were greater than those measured 2 cm deep in the humus layer through July (Figure 10). In August, higher temperatures were measured 2 cm deep in the humus layer than those above or beneath the sheets.

Gastropod collections reached a peak when the temperature beneath the cardboard sheets was approximately 15°C and decreased at lower and higher temperatures (Figure 11). Temperature was more variable on clear days, ranging from 4°C to 30°C ($\bar{X}=13.5\pm0.56$), than on overcast days, which ranged from 11°C to 22°C ($\bar{X}=15.8\pm0.33$). Mean daily temperatures were similar in 1993 and 1994 (Figure 12A) but spring and summer rainfall was greater in 1993 than in 1994 (Figure 12B).

FIG. 9. Mean near-ground temperature on the four conifer release treatment areas and the control area of block 3 during the summer of 1994.

FIG. 10. Mean near-ground temperature, 2 cm above cardboard sheets, directly beneath sheets (0 cm), and 2 cm deep in the humus layer beneath sheets, on block 3 during the summer of 1994.


Vision®
Release®
Brushsaw
Silvana
Control
25
20
15
10
5
Mean Temperature (°C)
June 29
July 12
July 20
Aug. 5
Aug. 18
Sample Date

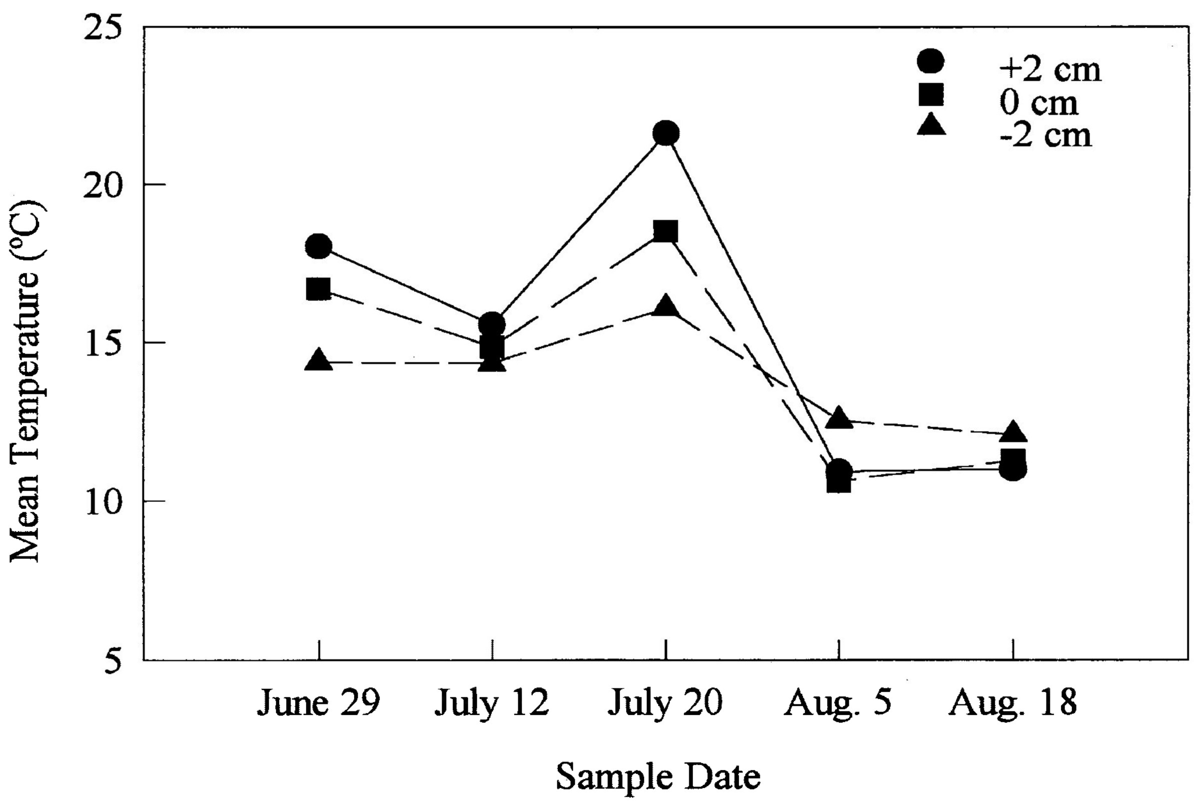
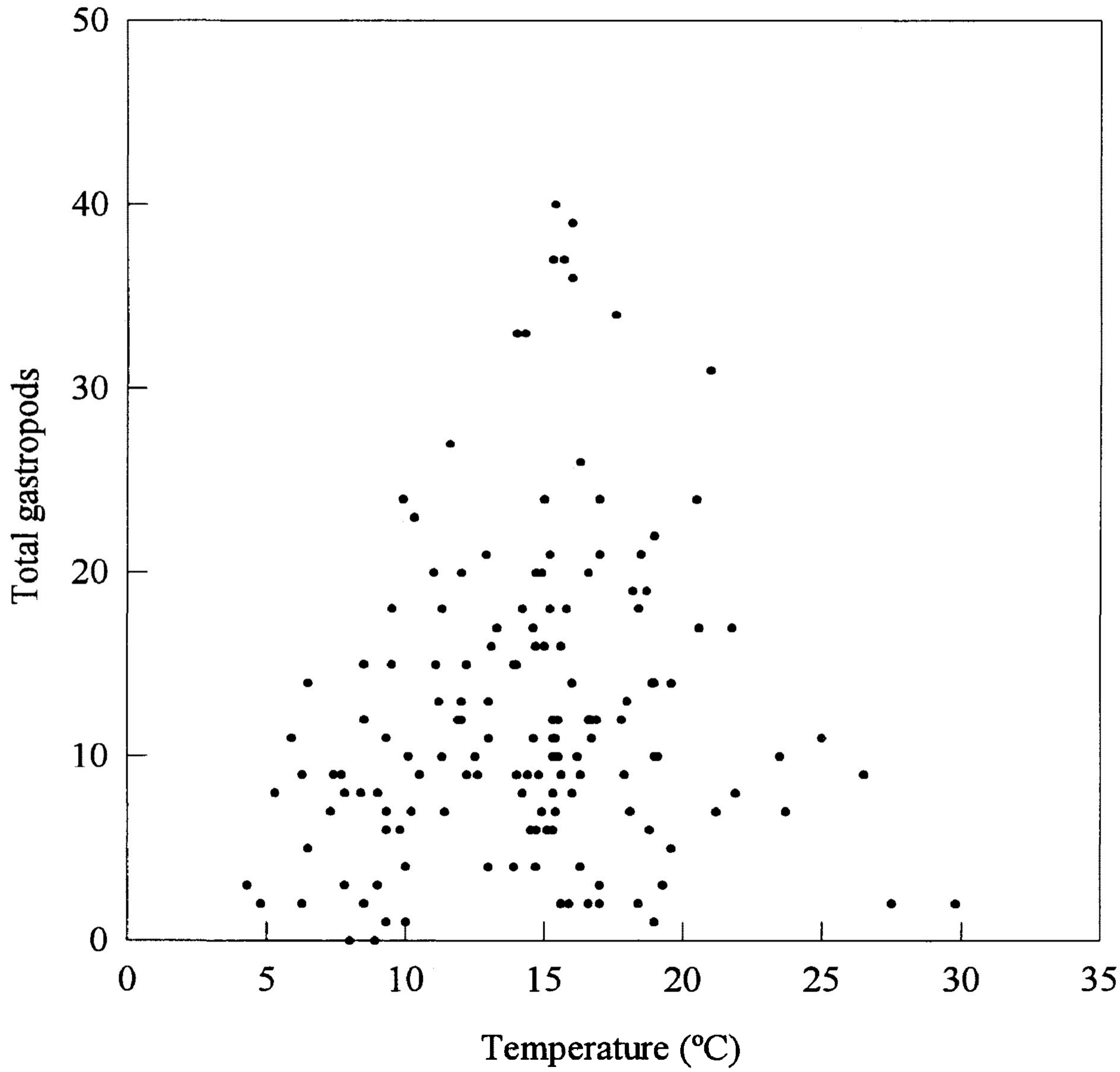
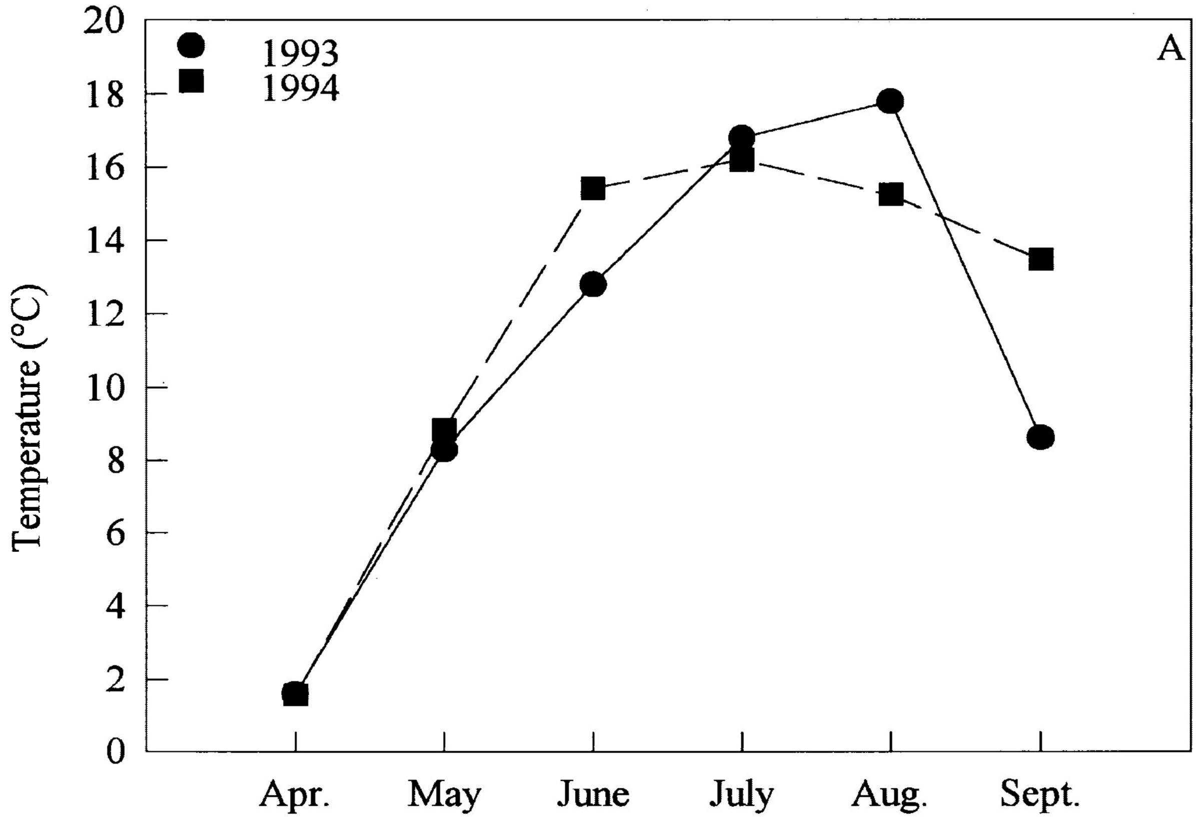

+2 cm
0 cm
-2 cm
25
20
15
10
5
Mean Temperature (°C)
June 29
July 12
July 20
Aug. 5
Aug. 18
Sample Date

FIG. 11. Scattergram of the total number of terrestrial gastropods collected beneath cardboard sheets and the temperature directly beneath the sheets.

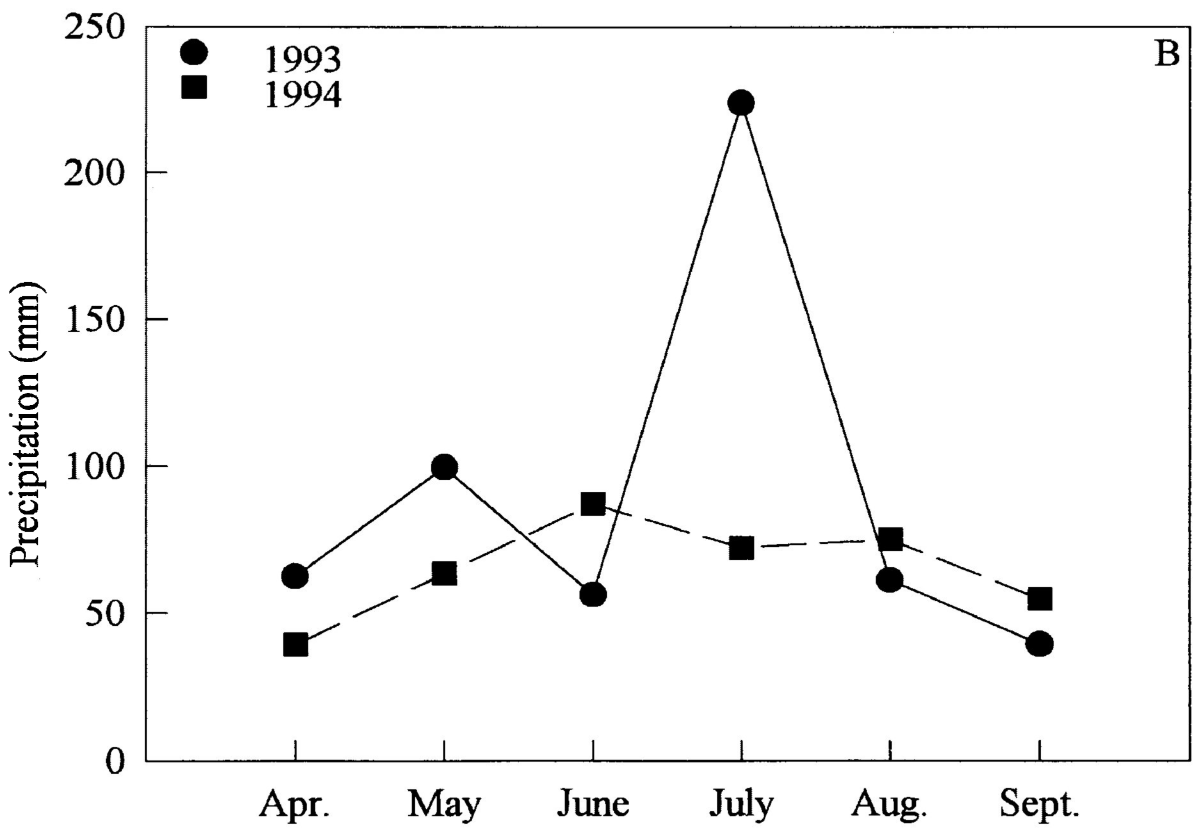


50
40
30
20
10
0
Total gastropods
0
5
10
15
20
25
30
35
Temperature (ºC)

FIG. 12. Mean daily temperature (A) and total monthly precipitation (B), between the months of April and September, in 1993 and 1994.



A
1993
1994
Temperature (°C)
0
2
4
6
8
10
12
14
16
18
20
Apr.
May
June
July
Aug.
Sept.



B
1993
1994
Precipitation (mm)
0
50
100
150
200
250
Apr.
May
June
July
Aug.
Sept.

Barrier-enclosed sheets

Total mean gastropod density (±S.E.) was greater on unenclosed cardboard sheets (3.1±0.4 m^{-2}) than on sheets encircled with a barrier (2.1±0.2 m^{-2}) (p=0.038), although no differences were detected between individual gastropod species (Table 6). Cumulative totals of 287 and 195 gastropods were collected from unenclosed and enclosed cardboard sheets, respectively, over the course of the experiment. Sixteen species of terrestrial gastropod were collected from the enclosed and unenclosed cardboard sheets. Two of these species, *P. dorsalis* and *Gastrocopta tappaniana*, were not collected from the sheets enclosed with a barrier. *Zöogenetes harpa*, *Vertigo ovata*, and *Anguispira alternata* were not collected from the unenclosed sheets. The total density of snails and slugs, from both enclosed and unenclosed cardboard sheets, showed significant variation over the 11 sample periods (p<0.0001) (Figure 13). Over the first five collection days, mean gastropod density (±S.E.) was lower under enclosed sheets (2.0±0.21) than unenclosed (3.9±0.26) (p=0.0029). The mean density of snails and slugs under both enclosed and unenclosed sheets increased sharply following rains on August 3rd and 7th totalling 35.2 mm and another on August 16 of 3.8 mm (Figure 13; Table 7).

Weathered sheets

Total mean gastropod densities on new (16.2±2.6 m^{-2}) and weathered (27.3±4.1 m^{-2}) cardboard sheets were not significantly different (p=0.09). However, of the twenty species of terrestrial gastropod collected (Table 8), four of the 12 most common [*E. fulvus* (p=0.001), *V. gouldi* (p=0.018), *Carychium exile* *canadense* (p=0.0003), and *S. milium* (p=0.008)], were present in greater densities on the weathered sheets than on the new sheets.

TABLE 6. Mean densities (±S.E.) of terrestrial gastropods collected from cardboard sheets enclosed with a sheet metal barrier and sheets without a barrier

	Barrier-Free Sheets	Barrier Enclosed Sheets	*p*-value*
Deroceras laeve	1.90±0.280	1.18±0.152	p=0.097
Euconulus fulvus	0.20±0.058	0.23±0.060	p=0.472
Columella edentula	0.27±0.076	0.12±0.034	p=0.328
Zonitoides arboreus	0.23±0.056	0.14±0.047	p=0.077
Striatura milium	0.04±0.026	0.12±0.062	p=0.462
Succinea ovalis	0.09±0.036	0.06±0.025	p=0.974
Vitrina limpida	0.10±0.034	0.03±0.018	p=0.121
Vertigo gouldi	0.09±0.033	0.02±0.015	p=0.088
Strobilops labyrinthica	0.02±0.015	0.04±0.021	p=0.409
Cochlicopa lubrica	0.04±0.021	0.02±0.015	p=0.409
Discus cronkhitei	0.02±0.015	0.03±0.018	p=0.652
Pallifera dorsalis	0.04±0.034	0	p=0.156
Zöogenetes harpa	0	0.04±0.026	p=0.082
Vertigo ovata	0	0.02±0.015	p=0.156
Anguispira alternata	0	0.01±0.011	p=0.317
Gastrocopta tappaniana	0.01±0.011	0	p=0.317
Total	3.05±0.349	2.07±0.228	p=0.038

* *p*-values based on a Wilcoxon Rank Sum Test

FIG. 13. Mean densities (±S.E.) of slugs (A) and snails (B) from beneath cardboard sheets enclosed with a sheet metal barrier and sheets without a barrier, over 11 sample periods, July 22 to August 18, 1994. [R=rain greater than 3 mm]

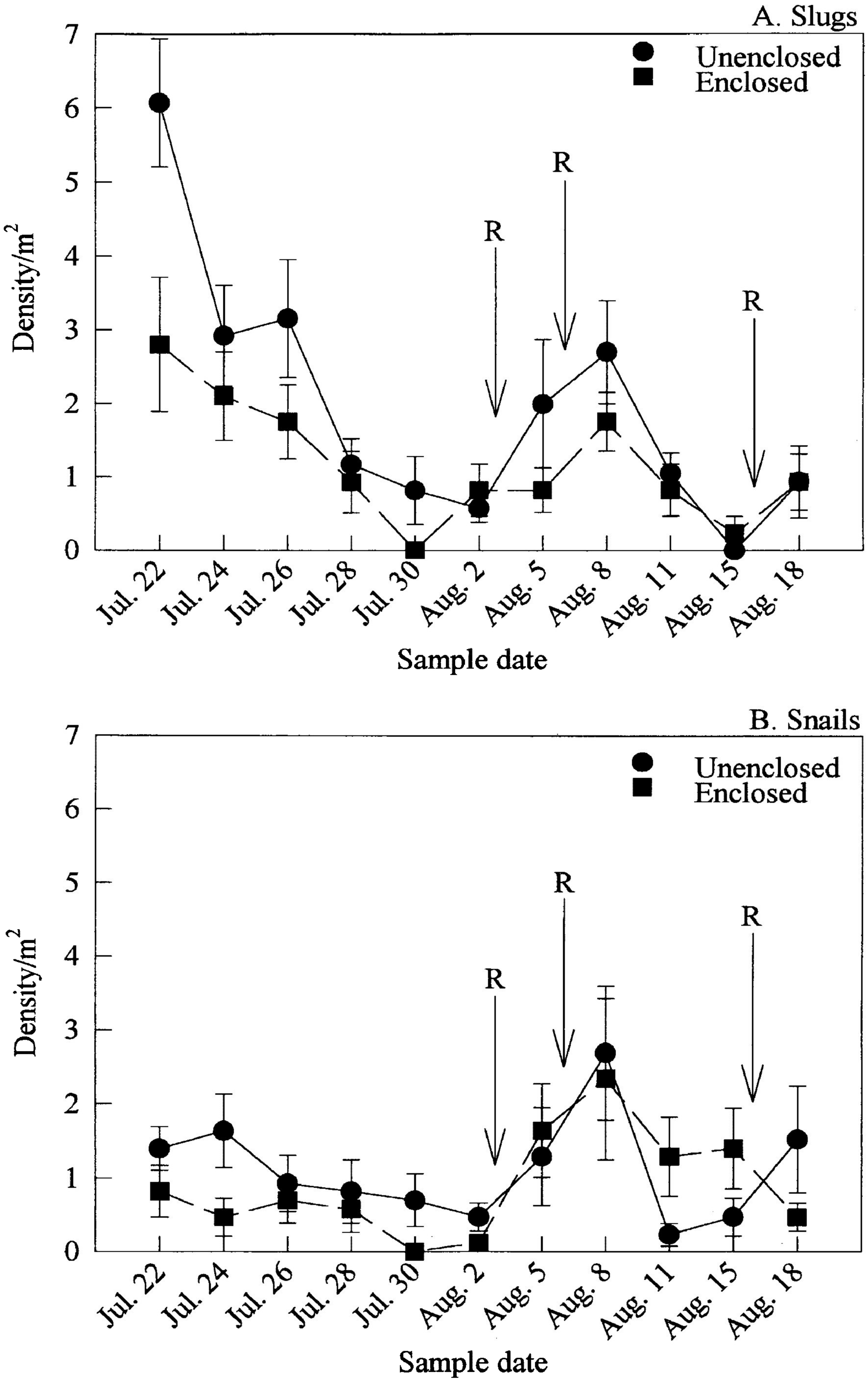

A. Slugs
Unenclosed
Enclosed
Density/m2
R
R
R
Sample date
Jul. 22
Jul. 24
Jul. 26
Jul. 28
Jul. 30
Aug. 2
Aug. 5
Aug. 8
Aug. 11
Aug. 15
Aug. 18
B. Snails
Unenclosed
Enclosed
Density/m2
R
R
R
Sample date

TABLE 7. Daily precipitation during the period of terrestrial gastropod collection from barrier enclosed and unenclosed cardboard sheets

Date		Precipitation (mm)	Date		Precipitation (mm)
July	20	3.2	August	4	0
	21	0		5*	0
	22*	0		6	2.4
	23	0.4		7	21.6
	24*	0.8		8*	0
	25	1.3		9	0
	26*	0.9		10	0
	27	0		11*	0
	28*	0		12	0.4
	29	0		13	0.3
	30*	0		14	1.2
	31	0		15*	0
August	1	0		16	3.8
	2*	0		17	0
	3	13.6		18*	0

* dates when barrier enclosed cardboard sheets and unenclosed sheets were sampled for terrestrial gastropods

TABLE 8. Mean densities (±S.E.) of terrestrial gastropods collected from new and weathered cardboard sheets

	New Sheets	Weathered Sheets	*p*-value*
Zonitoides arboreus	5.12±1.03	6.53±1.04	p=0.187
Strobilops labyrinthica	1.85±0.46	4.51±1.08	p=0.072
Euconulus fulvus	1.71±0.42	4.51±0.85	p=0.001
Deroceras laeve	2.72±0.49	2.23±0.35	p=0.712
Vitrina limpida	1.30±0.49	1.10±0.45	p=0.889
Discus cronkhitei	0.40±0.14	1.30±0.38	p=0.110
Vertigo gouldi	0.35±0.18	1.10±0.36	p=0.018
Carychium exile canadense	0.09±0.09	1.24±0.38	p<0.001
Striatura milium	0.20±0.15	1.07±0.35	p=0.008
Succinea ovalis	0.75±0.28	0.52±0.12	p=0.665
Columella edentula	0.46±0.19	0.78±0.32	p=0.703
Anguispira alternata	0.29±0.12	0.69±0.29	p=0.631
Striatura exigua	0.23±0.12	0.64±0.24	p=0.278
Cochlicopa lubrica	0.23±0.08	0.52±0.30	p=0.863
Gastrocopta tappaniana	0.06±0.04	0.20±0.07	p=0.079
Vertigo ovata	0.14±0.08	0.12±0.09	p=0.655
Vertigo modesta	0.14±0.10	0.06±0.04	p=0.960
Zöogenetes harpa	0.06±0.04	0.06±0.04	p=1.000
Punctum minutissimum	0.06±0.06	0.06±0.06	p=1.000
Pallifera dorsalis	0.03±0.03	0.03±0.03	p=1.000
Total	16.19±2.61	27.25±4.13	p=0.086

* *p*-values based on a Wilcoxon Rank Sum Test

DISCUSSION

All 21 species of terrestrial gastropod identified on the four experimental blocks were indigenous to North America (Pilsbry 1939-1948; Chichester and Getz 1969) and have previously been documented in Northwestern Ontario (Oughton 1948). However, a greater number of species is reported here than in previous studies of similar northern habitats. Kearney and Gilbert (1978) identified 16 species of terrestrial gastropod, including two introduced species of slug, from the Himsworth Game Preserve south of North Bay, Ontario. Van Es and Boag (1981), Kralka (1986), and Locasciulli and Boag (1987) collected 18, 13, and 11 species of gastropod, respectively, from a variety of coniferous, deciduous, and mixedwood stands in the boreal forest region of Alberta. In addition, Boag and Wishart (1982) identified a total of 15 species from nine different habitat types in southwestern Alberta. The greater number of gastropod species collected in the current study may be a result of more abundant near-ground vegetation typical of early, rather than late, stages of forest succession (Gratowski 1967; Kimmins 1987). Live vegetation is not considered essential as a source of food for snails and slugs, rather, they feed on decomposing organic material, soil algae, and fungal hyphae (Boycott 1934; Chatfield 1974). However, vegetation is important in providing the near-ground temperature and moisture conditions favoured by gastropods (Hunter 1964).

Total mean density of gastropods was 12 m^{-2} and ranged from 6 m^{-2} to 18 m^{-2} on the experimental blocks. Using sampling techniques similar to those used in this study, Lankester and Peterson (1995) found gastropod densities of 2 m^{-2} and 4 m^{-2} in two different habitats in northeastern Minnesota. As well, Boag and Wishart (1982) and Kearney and Gilbert (1978) reported total numbers of terrestrial gastropods from which mean densities on the surface of the forest floor were calculated to be 2 m^{-2} and 38 m^{-2}, respectively. However, Kralka (1986) examined 5 cm deep soil cores and estimated a total mean density of 80 m^{-2}, with maximum densities of *Discus cronkhitei* and *Vertigo gouldi* reaching 340 m^{-2} and 460 m^{-2}, respectively, suggesting that large numbers of gastropods inhabit the superficial soil layer. Nelson (1994), working in the same area as the present study, compared the cardboard sheet and soil core sampling methods. Density estimates of 28 m^{-2} were obtained using cardboard sheets while a mean density of 1610 m^{-2} of the same gastropod species was estimated to be in the 10 cm depth of soil beneath the sheets. Clearly, many more gastropods are present within the litter and underlying soil than are active on the surface. Although cardboard sheets provide a time-efficient method of sampling (Nelson 1994), numbers collected beneath them are likely to be influenced by surface microclimatic factors important for gastropod mobility.

Greater numbers of terrestrial gastropods were collected beneath cardboard sheets in 1993 than in 1994. Mean gastropod densities increased steadily over the summer of 1993 to 21 m^{-2}, but remained fairly stable throughout the summer of 1994 at 10 m^{-2}. This difference between years was not related to the conifer release treatments since gastropod densities on both treated and control areas were lower in 1994. Rather, the greater amount of spring and summer precipitation in 1993 probably increased soil moisture on the blocks and may have improved the reproductive success of gastropods (Walton 1963;

Berry 1966) causing populations to grow over the summer. In addition, periods of rain and increased soil moisture in 1993 may have caused gastropods to move toward the surface (Locascuilli and Boag 1987) where they were more likely to be sampled beneath cardboard sheets.

Blocks 1 and 3 had the greatest densities of snails and slugs in both years of the study. Differences between the four experimental blocks were probably related to soil moisture. Although soil moisture was not measured directly, blocks 1 and 3 were low lying with poor drainage and were visibly wetter than blocks 2 and 4. Block 2 was situated on a steep slope and was more thoroughly drained. The substrate on block 4 was characterized by a large gravel component which would have led to greater percolation of soil water from the upper layers of the soil to deeper soil strata (Foth and Turk 1972). Positive correlations between soil moisture and the distribution of both snails and slugs have previously been demonstrated (Prior 1985).

Canonical variates analysis of percent cover indicated that structural differences in vegetation had developed between treated and control areas by mid-summer 1994. Deciduous trees and shrubs were greatly reduced by all conifer release methods. However, herbs and grasses became widespread on the chemical herbicide treated areas while they remained at pre-treatment percent cover on the mechanical and manually released areas and on the control areas. Freedman *et al.* (1993) observed similar post-herbicide succession in a New Brunswick mixedwood forest. After releasing conifers with Vision®, mean vegetation cover was reduced from 95% to 64% the following year but herbs and grasses increased (Freedman *et al.* 1993).

Despite marked changes in vegetation structure on the conifer released sites, no differences were evident in species richness and density of gastropods following treatments. Removal of vegetation from an area may cause near-ground temperatures to be more extreme and relative humidity to decrease (Geiger 1957; Coates *et al.* 1991; McInnis and Roberts 1995). Terrestrial gastropods may respond to such conditions by moving deeper into the soil. However, once near-ground vegetation has regenerated and if soil temperature and moisture conditions are restored, resident snails and slugs may again become abundant at or near the surface. Although tree and shrub cover was reduced following treatments in this study, the abundance of near-ground vegetation remained the same or increased the following year. Microenvironmental conditions experienced by snails and slugs were probably changed little and continued to provide favourable habitat. Maze and Johnstone (1986) observed the greatest number of gastropod species and highest densities of snails and slugs in areas with dense near-ground vegetation. They attributed this to the shelter and protection provided by the abundant herbaceous vegetation. As well, Andersen and Halvorsen (1984) found the greatest numbers of two particular species, *Cochlicopa lubrica* and *Vertigo modesta*, in areas rich with ground vegetation.

Strayer *et al.* (1986) studied the effects of three types of forest disturbance (agricultural cropping, burning, and clear-cutting) on terrestrial gastropods and concluded that any relationship between disturbance and short-term changes in gastropod numbers was unclear. Species richness and density appeared to decline following disturbance, but declines seemed short lived; sites disturbed 5 years earlier had already returned to pre-disturbance levels. They also suggested that disturbed sites were recolonized as a result of gastropods moving in from surrounding, undisturbed habitat. However, rapid dispersal into large disturbed areas seems doubtful since terrestrial gastropods are assumed to be relatively immobile. Considering findings reported here and by Kralka (1986) and Nelson (1994), a more likely explanation is that the large reservoir of gastropods in the soil is the source of colonizers and vertical movement may quickly restore the detectable community on the surface, provided that suitable microclimate is re-established for all of the original species.

The density of terrestrial gastropods was greater on the regenerating control area of block 3 (16 m^{-2}) than in the adjacent mature forest (9 m^{-2}). Beach (1992) similarly found greater numbers of gastropods on 5-10 year old regenerating clearcuts than in mature forests. In my study, the regenerating area was characterized by a greater variety of deciduous species and an abundance of herbaceous ground vegetation. The mature forest, on the other hand, had a closed canopy dominated by white spruce and trembling aspen. The understory was sparse and the litter had a noticeably greater coniferous component.

Gastropod densities typically are greater in deciduous rather than coniferous forests (Boycott 1934; Karlin 1961). For example, Boag and Wishart (1982) observed gastropod densities of 3.2 m^{-2} and 0.5 m^{-2} in mature deciduous and coniferous forests, respectively. Similarly, Gleich and Gilbert (1976) reported gastropod densities of 5 m^{-2} in a deciduous forest and 3 m^{-2} in a coniferous forest in central Maine. This difference has generally been attributed to the relative contributions of deciduous and coniferous species to the litter. However, Locascuilli and Boag (1987) found a strong positive correlation between gastropod abundance and the amount of litter, regardless of its composition.

Species richness was somewhat greater on the regenerating control area than in the mature forest; *V. modesta* and *Punctum minutissimum* were not collected in the latter. Kralka (1986) also reported more gastropod species in deciduous forests (13 species) than in coniferous dominated stands (8 species). However, Locasciulli and Boag (1987) found the same nine species of gastropod in both a deciduous and a coniferous forest.

The regenerating blocks appear more favourable to snails and slugs than the mature, original forest examined. Being in an early successional stage and having a greater variety and abundance of near-ground vegetation and deciduous litter, they may provide a wider range of suitable microsites for snails and slugs to inhabit. Although light intensity and near-ground temperatures are greater on conifer plantations than in mature forests (Margolis and Brand 1990; Spittlehouse and Stathers 1990), soil moisture remains high because of less transpiring vegetation (Klinka *et al.* 1985). Relative humidity at ground level beneath a dense layer of herbaceous vegetation can approach 100%, while the relative humidity immediately above it may be only 50% (Geiger 1957; Oke 1978; Begon *et al.* 1990). As well, pH values and available Ca^{2+} are higher in soils overlain by deciduous leaf litter (Burch 1955; Millar 1974; Swift *et al.* 1979), and the distribution of snails and slugs has been correlated with these conditions (Cameron 1973; Walden 1981; Gärdenfors 1992). Gastropods require abundant sources of available calcium for shell precipitation and egg development during growth and reproduction (Wilbur 1964; Fournié and Chétail 1984).

The objective of conifer release is to suppress competing vegetation, allowing young conifers to become established and promoting more rapid succession of a conifer dominated stand (Freedman *et al.* 1993). Because much of the literature suggests that gastropods prefer forests with a strong deciduous component, tended conifer plantations would be expected, eventually, to become less suitable for them. However, over the medium and short term, habitat alteration appears to have other effects. Results reported here suggest that within 5-8 years of a disturbance such as logging, regenerating areas can be expected to have markedly greater density and somewhat greater richness of gastropod species than occurred in the original mature forests that they replace. The indication of increased richness is possibly due to previously rare species becoming numerous enough, as the area regenerates, to be detected by the cardboard sheet method. In the short term, immediately following management of competing vegetation on a regenerating plantation, no changes in gastropod populations could be detected, at least within one year of chemical, mechanical and manual release treatments.

The cardboard sheet sampling technique has been employed in a number of field studies (Lankester and Anderson 1968; Gleich and Gilbert 1976; Boag 1982; Strayer *et al.* 1986). It is clearly a convenient method of collecting large numbers of terrestrial gastropods but several poorly understood factors must be considered when using the technique to estimate their relative densities. For example, does this method sample only those gastropods living directly beneath a sheet, or does it also include individuals that have immigrated from the surrounding area? An experiment designed to detect horizontal movement involved counting and removing gastropods from paired cardboard sheets every 2-3 days for a period of 28 days. One sheet of each pair was enclosed with a barrier intended to prevent gastropod movement in or out of the area beneath the sheet; the control was unenclosed. With repeated sampling and removal, the mean number of gastropods collected beneath both sheets would be expected to decline. However, if individuals were continually immigrating from the surrounding area, the mean density of individuals found beneath the enclosed sheets should fall to a lower level than that under control sheets. In fact, this was observed over the first 5 collection days (9 day period). The mean density recovered beneath enclosed sheets (2.0±0.21 m^{-2}) was half that from unenclosed sheets (3.9±0.26 m^{-2}) suggesting that horizontal movement does occur. A more direct demonstration of this behaviour was provided by Boag (1990) who marked individual snails and found up to 5% of *D. cronkhitei* and 12% of *E. fulvus* collected beneath cardboard sheets had immigrated from the surrounding area.

An additional observation made during the experiment using enclosed cardboard sheets confounded conclusions regarding horizontal movement but nonetheless revealed another response of gastropods that undoubtedly influences the numbers of animals sampled. On the seventh day, after several days of declining numbers, the mean density of gastropods collected from beneath both enclosed and unenclosed sheets increased markedly. A second increase occurred beneath unenclosed sheets on the eleventh sampling day. These increases followed rains of 35 and 4 mm, respectively. Although the increase on both occasions was greatest beneath the unenclosed sheets, indicating that some increase in horizontal movement had probably occurred, an increase beneath the enclosed sheets suggests that individuals moved vertically in response to the wetter conditions, even beneath sheets where the ground was protected from direct rainfall.

The extent to which gastropods might actually be attracted to cardboard sheets has not been determined, yet there is some empirical evidence that they accumulate beneath more permanent sampling structures (Boag 1990). These animals can be observed moving openly across the surface of the litter at night and on overcast and rainy days until moisture, temperature, and/or light conditions become unfavourable (Boag 1985). Under natural circumstances, their most direct route to refuge would be downward into the litter and soil. Conditions that discourage gastropod movement on the surface may be delayed in onset and be less severe beneath a cardboard sheet and gastropods near the perimeter likely would sense this. However, sheets seldom remain suitable refuge for long. They dry readily in the sun and the vegetation beneath them dies back if left covered for more than 2-3 weeks. In some circumstances, the litter beneath a cardboard sheet may be drier than its surroundings, for example if a sheet has been put in place before a light rain or heavy dew occurs. Horizontal movement of gastropods clearly occurs and the extent to which this affects population estimates probably will vary with microclimatic conditions and the relative mobility of different species. Similarly, the movement of gastropods up and down in the litter layer will also affect estimates. This expected variability can best be minimized by placing already dampened sheets in a new location during or immediately after a rainy period and by checking the sheets only in the early hours of the morning.

Vegetation is thought to influence terrestrial gastropods indirectly by moderating near-ground temperature and moisture conditions (Burch 1956; Hunter 1964; Beyer and Saari 1977). In this study, near-ground temperature was highest in the brushsaw released area in late July and August. The remaining released areas and the control had similar near-ground temperatures throughout the summer. The higher mean temperature recorded on the brushsaw area was probably an artifact of the sampling design on three particular days. Based on random draw, higher temperatures recorded at three of the six thermocouple stations on the brushsaw area were taken late in the morning on three days in late July and August, all of which were clear sunny days. If the higher temperatures on the brushsaw treated area were a consequence of the sampling design, results would suggest that near-ground temperature was not greatly affected by any of the conifer release treatments.

The mean temperature immediately beneath the cardboard sheets was always similar to the air temperature 2 cm above them. Both were slightly higher than the mean temperature 2 cm deep in the humus layer throughout the early part of the summer but in August they cooled to below that in the humus layer. This probably occurred in response to lower early morning temperatures in August and soil heat retention later in the summer. The thermal conductivity of soil is a function of its moisture content (Foth and Turk 1972). Block 3, where near-ground temperature was measured, had imperfect drainage (Lautenschlager and Bell 1994). Wetter soils take longer to warm early in the summer and cool more slowly later in the season (Foth and Turk 1972). This usually results in maximum seasonal soil temperatures being reached after surface temperatures have begun to cool (Kimmins 1987).

The temperature beneath cardboard sheets appears to influence the number of gastropods that can be collected using this method. Collections were greatest when the temperature beneath the sheets was approximately 15°C. Boag (1990) reported the greatest number of gastropods beneath masonite boards at ambient air temperatures between 7.5°C and 17.5°C and direct observation of snails in terraria indicated greater activity on the surface of the litter at temperatures ranging from 6°C to 15°C (Boag 1985). Snails and slugs most likely take refuge deeper in the litter and underlying soil when temperatures reach lower or higher extremes. Temperatures beneath the sheets varied less on overcast mornings (11°C-22°C, $\bar{X}$=15.8±0.33°C) than on clear mornings (4°C 30°C, $\bar{X}$=13.5±0.56°C). The time of day and amount of cloud cover will clearly play a role in moderating the temperature beneath the sheets. On sunny, hot days, favourable temperatures beneath the sheets will only prevail for a limited period of time early in the morning. On overcast days, however, daytime temperatures will remain cooler and larger numbers of gastropods are likely to be found beneath cardboard sheets later into the day. The apparent relationship between temperature beneath the sheets and the number of gastropods collected should be considered when using this technique in field studies of terrestrial gastropods.

Although temperature appears to influence the number of gastropods found beneath cardboard sheets, other environmental conditions may also play a role. Light intensity will influence near-ground temperature (Geiger 1957) and is an important consideration when examining animal distributions and activity (Begon *et al.* 1990). Boag (1985) studied the effects of light on snails in terraria under ambient field conditions. There was no difference in the number of snails visible between dark and light periods but more snails were active in darkness. Generally he believed that light had little effect on the microdistribution of snails. In addition to near-ground temperature, soil moisture and near-ground relative humidity play an important role in determining the distribution and activity of terrestrial gastropods (Cowie 1984; Arad 1993). It is likely that near-ground relative humidity beneath cardboard sheets is at times, greater than that experienced on the surrounding forest floor. When this occurs, it may account for some of the horizontal movement of gastropods to the sheets which appears to be occurring.

Using masonite boards, Boag (1990) found greater numbers of gastropods beneath them in the latter half of the summer. This result could be interpreted several ways. Gastropods may be moving to the surface from deeper regions of the litter layer and underlying soil in response to improving near-ground microclimatic conditions over the summer (Boag 1985; Locasciulli and Boag 1987). Another possibility is that populations of gastropods may be increasing over the course of the sampling season with the maturation of individuals hatched in the spring and early summer (Gleich and Gilbert 1976). Alternatively, as the cardboard sheets weather over the sampling season, they may become increasingly attractive to gastropods. The latter possibility was investigated here.

Overall, the mean densities of gastropods collected from weathered and unweathered cardboard sheets were similar but greater densities of four species

(*Euconulus fulvus*, *V. gouldi*, *Carychium exile canadense*, and *Striatura milium*) were collected from beneath the weathered sheets. Weathered sheets appeared to absorb more moisture and retain it longer following a rain. A similar increase in use of weathered boards was seen by Boag and Wishart (1982) and Boag (1990). It was suggested that boards exposed for long periods to the elements may become more attractive as a result of having dissipated any possible repellant chemicals, or acquiring fungal hyphae and slime trails on their lower surface. Boag (1990) also suggested that various gastropod species may use sampling boards differentially. This factor may also explain, in part, the greater collections of particular species from weathered sheets here and underscores another limitation to using cardboard sheets to estimate terrestrial gastropod densities.

The different life histories of gastropod species can also be expected to cause seasonal fluctuations in collections from beneath cardboard sheets. For example, *Vitrina limpida* has a one year life cycle (Comfort 1957; Uminski and Focht 1979). Eggs over-winter and hatch in the spring. Individuals reach maturity by late fall, lay eggs and die. On the other hand, species such as *E. fulvus* and *C. lubrica*, lay eggs in the spring and early summer (Livshits 1983). Eggs hatch in late summer or early autumn and the young overwinter, reaching reproductive maturity the following year. The possible effects of differential seasonal recruitment on the sampling estimates obtained using cardboard sheets should be investigated in the future.

LITERATURE CITED

Andersen, J., and Halvorsen, O. 1984. Species composition, abundance, habitat requirements and regional distribution of terrestrial gastropods in Arctic Norway. Polar Biol. **3:** 45-53.

Arad, Z. 1993. Effect of desiccation on the water economy of terrestrial gastropods of different phylogenetic origins: a Prosobranch (*Pomatias glaucus*) and two Pulmonates (*Sphincterochila cariosa* and *Helix engaddensis*). Israel J. Zool. **39:** 95-104.

Baker, F.C. 1942. Land and freshwater mollusca of New Hampshire. Am. Midl. Nat. **27:** 74-85.

Beach, T.D. 1992. Transmission of meningeal worm: an analysis of sympatric use of habitat by white-tailed deer, moose and gastropods. M.Sc. thesis, University of New Brunswick, Fredericton, N.B.

Begon, M., Harper, J.L., and Townsend, C.R. 1990. Ecology-individuals, populations and communities. Blackwell Scientific Publications. Boston.

Berger, B., and Dallinger, R. 1993. Terrestrial snails as quantitative indicators of environmental metal pollution. Environ. Monit. Assess. **25:** 65-84.

Berry, A.J. 1966. Population structure and fluctuations in the snail fauna of a Malayan limestone hill. J. Zool. **150:** 11-27.

Beyer, W.N., and Saari, D.M. 1977. Effect of tree species on the distribution of slugs. J. Anim. Ecol. **46:** 697-702.

Boag, D.A. 1982. Overcoming sampling bias in studies of terrestrial gastropods. Can. J. Zool. **60:** 1289-1292.

Boag, D.A. 1985. Microdistribution of three genera of small terrestrial snails (Stylommatophora: Pulmonata). Can. J. Zool. **63:** 1089-1095.

Boag, D.A. 1990. On the effectiveness of artificial shelters in the study of population attributes of small terrestrial gastropods. Can. J. Zool. **68:** 254-262.

Boag, D.A., and Wishart, W.D. 1982. Distribution and abundance of terrestrial gastropods on a winter range of bighorn sheep in southwestern Alberta. Can. J. Zool. **60:** 2633-2640.

Boycott, A.E. 1934. The habits of land Mollusca in Britain. J. Ecol. **22:** 1-38.

Bradley, J.V. 1968. Distribution-free statistical tests. Prentice-Hall Inc., Englewood Cliffs, NJ.

Brandmayr, P., and Brandmayr, T.Z. 1986. Food and feeding behaviour of some *Licinus* species (Coleoptera Carabidae Licinini). Monitore Zool. Ital. **20:** 171-181.

Burch, J.B. 1955. Some ecological factors of the soil affecting the distribution and abundance of land snails in eastern Virginia. Nautilus **69**(2): 62-69.

Burch, J.B. 1956. Distribution of land snails in plant associations in eastern Virginia. Nautilus **70**(2): 60-64.

Burch, J.B. 1962. How to know the eastern land snails. William C. Brown Co., Dubuque, IA.

Burt Perrin Associates. 1993. Public attitudes towards herbicides and their implications for a public involvement strategy for the Vegetation Management Alternatives Program. VMAP Technical Report 93-04. Burt Perrin Associates, Toronto, Ont.

Cameron, R.A.D. 1973. Some woodland mollusc faunas from southern England. Malacologia **14:** 355-370.

Cameron, R.A.D., Down, K., and Pannett, D.J. 1980. Historical and environmental influences on hedgerow snail faunas. Biol. J. Linn. Soc. **13:** 75-87.

Campbell, R.A. 1984. The value of herbicides in forest management. Can. For. Indust. **104**(31): 41-44.

Campbell, R.A. 1990. Herbicide use for forest management in Canada: where we are and where we are going. For. Chron. **66**(4): 355-360.

Campbell, R.A. 1991. Silvicultural herbicides in Canada: registration status and research trends. For. Chron. **67**(5): 520-527.

Chatfield, J.E. 1974. A summary of studies on food and feeding in some European land snails. Malacol. Rev. **8:** 123-125.

Chichester, L.F., and Getz, L.L. 1969. The and ecology zoogeography of Arionid and Limacid slugs introduced into northeastern North America. Malacologia. **7**(2-3): 313-346.

Churchfield, S. 1984. Dietary separation in three species of shrew inhabiting water-cress beds. J. Zool. **204:** 211-228.

Clarke, A.H. 1981. The freshwater molluscs of Canada. National Museum of Natural Sciences, Ottawa, Ont.

Coates, K.D., Emmingham, W.H., and Radosevich, S.R. 1991. Conifer-seedling success and microclimate at different levels of herb and shrub cover in a *Rhododendron-Vaccinium-Menziesia* community of south central British Columbia. Can J. For. Res. **21:** 858-866.

Comfort, A. 1957. The duration of life in molluscs. Proc. Malac. Soc. London. **32:** 219-241.

Cowie, R.H. 1984. The life-cycle and productivity of the land snail *Theba pisana* (Mollusca: Helicidae). J. Anim. Ecol. **53:** 311-325.

Dainton, B.H. 1943. Effects of air currents, light, humidity and temperature on slugs. Nature **151:** 25.

Digweed, S.C. 1993. Selection of terrestrial gastropod prey by Cychrine and Pterostichine ground beetles (Coleoptera: Carabidae). Can. Entomol. **125:** 463-472.

Environics Research Group. 1989. 1989 National survey of Canadian public opinion on forestry issues. Final report. Environics Research Group Ltd. Toronto, Ont.

Foth, H.D., and Turk, L.M. 1972. Fundamentals of soil science. John Wiley and Sons Inc., Toronto, Ont.

Fournié, J., and Chétail, M. 1984. Calcium dynamics in land gastropods. Amer. Zool. **24:** 857-870.

Freedman, B. 1991. Controversy over the use of herbicides in forestry, with particular reference to glyphosate usage. J. Environ. Sci. Health. **C8:** 277-286.

Freedman, B., Morash, R., and MacKinnon, D. 1993. Short-term changes in vegetation after the silvicultural spraying of glyphosate herbicide onto regenerating clearcuts in Nova Scotia, Canada. Can. J. For. Res. **23:** 2300-2311.

Gärdenfors, U. 1992. Effects of artificial liming on land snail populations. J. Appl. Ecol. **29:** 50-54.

Geiger, R. 1957. The climate near the ground. Das klima der bodennahen. *Translated from* 2nd German ed. *by* M.N. Stewart et al. Harvard University Press, Cambridge.

Gleich, J.G., and Gilbert, F.F. 1976. A survey of terrestrial gastropods from central Maine. Can. J. Zool. **54:** 620-627.

Gleich, J.G., Gilbert, F.F., and Kutscha, N.P. 1977. Nematodes in terrestrial gastropods from central Maine. J. Wildl. Dis. **13:** 43-46.

Gratowski, H. 1967. Ecological considerations in brush control. *In* Herbicide and vegetation management in forest, range, and noncrop lands. Oregon State University, Corvallis. pp. 124-140.

Greville, R.W., and Morgan, A.J. 1989. Concentrations of metals (Cu, Pb, Cd, Zn, Ca) in six species of British terrestrial gastropods near a disused lead and zinc mine. J. Moll. Stud. **55:** 31-36.

Gumpertz, M.L., and Brownie, C. 1993. Repeated measures in randomized block and split-plot experiments. Can. J. For. Res. **23:** 625-639.

Hamilton, W.J. 1941. The food of small forest mammals in eastern United States. J. Mamm. **22:** 250-263.

Hunt, J.A. 1993. Introduction of the Silvana Selective/Ford Versatile cleaning machine to Alberta. Forest Engineering Research Institute of Canada, Vancouver, B.C. Field Note No. Silviculture-52.

Hunter, R.W. 1964. Physiological aspects of ecology in nonmarine mollusca. *In* Physiology of Mollusca. *Edited by* K.M. Wilbur and C.M. Young. Academic Press, New York. pp. 83-126.

Karlin, E.J. 1961. Ecological relationships between vegetation and the distribution of land snails in Montana, Colorado and New Mexico. Am. Midl. Nat. **65**(1): 60-66.

Kearney, S.R., and Gilbert, F.F. 1978. Terrestrial gastropods from the Himsworth Game Preserve, Ontario, and their significance in *Parelaphostrongylus tenuis* transmission. Can. J. Zool. **56:** 688-694.

Kimmins, J.P. 1987. Forest ecology. Macmillian Publishing Company, New York, NY.

Klinka, K., Scagel, A.M., and Courtin, P.J. 1985. Vegetation relationships among some seral ecosystems in southwestern British Columbia. Can. J. For. Res. **15:** 561-569.

Kralka, R.A. 1986. Population characteristics of terrestrial gastropods in boreal forest habitats. Am. Midl. Nat. **115**(1): 156-164.

Lankester, M.W., and Anderson, R.C. 1968. Gastropods as intermediate hosts of *Pneumostrongylus tenuis* Dougherty of white-tailed deer. Can. J. Zool. **46:** 373-383.

Lankester, M.W., and Peterson, W.J. 1995. The possible importance of wintering yards in the transmission of *Parelaphostrongylus tenuis* to white-tailed deer and moose. J. Wildl. Dis. (in press).

Lautenschlager, R.A. 1993. Effects of conifer release with herbicides on wildlife (A review with an emphasis on Ontario's forests). Ontario Ministry of Natural Resources, Ontario Forest Research Institute, Sault Ste. Marie, Ont., Forest Research Information Paper No. 111.

Lautenschlager, R.A., and Bell, F.W. 1994. The Fallingsnow Ecosystem Project - Establishment report and pre-treatment data. Ontario Ministry of Natural Resources, Ontario Forest Research Institute, Sault Ste. Marie, Ont., Vegetation Management Alternatives Program.

Livshits, G.M. 1983. Ecology of the terrestrial snail (*Brephulopsis bidens*): age composition, population density and spatial distribution of individuals. J. Zool. **199:** 433-446.

Locasciulli, O., and Boag, D.A. 1987. Microdistibution of terrestrial snails (Stylommatophora) in forest litter. Can. Field-Nat. **101**(1): 76-81.

Margolis, H.A., and Brand, D.G. 1990. An ecophysiological basis for understanding plantation establishment. Can. J. For. Res. **20:** 375-390.

Mason, C.F. 1970. Snail populations, beech litter production, and the role of snails in litter decomposition. Oecologia. **5:** 215-239.

Maze, R.J., and Johnstone, C. 1986. Gastropod intermediate hosts of the meningeal worm *Parelaphostrongylus tenuis* in Pensylvania: observations on their ecology. Can. J. Zool. **64:** 185-188.

McInnis, B.G., and Roberts, M.R. 1995. Seedling microenvironment in full-tree and tree-length logging slash. Can. J. For. Res. **25:** 128-136.

Meredith, M.P., and Stehman, S.V. 1991. Repeated measures experiments in forestry: focus on analysis of response curves. Can. J. For. Res. **21:** 957-965.

Millar, C.S. 1974. Decomposition of coniferous leaf litter. *In* Biology of Plant Litter Decomposition. *Edited by* C.H. Dickinson and G.J.H. Pugh. Academic Press, New York. pp. 105-128.

Morrison, M.L., Marcot, B.G., and Mannan, R.W. 1992. Wildlife-habitat relationships. The University of Wisconsin Press, Madison, WI.

Nelson, R.R.A. 1994. Acomparison of two terrestrial gastropod sampling methods: soil cores vs. cardboard sheets. H.B.Sc. thesis, Lakehead University, Thunder Bay, Ont.

Newell, P.F. 1971. Mollusca. *In* Methods of study in quantitative soil ecology: population, production and energy flow. *Edited by* J. Phillipson. Blackwell Scientific Publications, Oxford. pp. 128-149.

Norusis, M.J. 1992a. SPSS/PC+ Advanced Statistics Version 5.0. SPSS Inc., Chicago, IL.

Norusis, M.J. 1992b. SPSS/PC+ Base System User's Guide Version 5.0. SPSS Inc., Chicago, IL.

Oke, T.R. 1978. Boundary layer climates. Methuen and Co. Ltd., London.

Oughton, J. 1948. A zoogeographical study of the land snails of Ontario. University of Toronto, Biological Series No. 57.

Pilsbry, H.A. 1939-1948. Land mollusca of North America (North of Mexico). Acad. Nat. Sci. Philadelphia Monogr. No. 3. Vols 1 and 2.

Pimentel, R.A. 1979. Morphometrics - the multivariate analysis of biological data. Kendall/Hunt Publishing Co., Dubuque, IW.

Prior, D.J. 1985. Water-regulatory behaviour in terrestrial gastropods. Biol. Res. **60:** 403-424.

Radosevich, S.R., and Osteryoung, K. 1987. Principals governing plant-environment interactions. *In* Forest vegetation management for conifer production. *Edited by* J.D. Walstad and P.J. Kuch. John Wiley and Sons Inc., New York. pp. 105-156.

Raskevitz, R.F., Kocan, A.A., and Shaw, J.H. 1991. Gastropod availability and habitat utilization by wapiti and white-tailed deer sympatric on range enzootic for meningeal worm. J. Wildl. Dis. **27**(1): 92-101.

Reinink, K. 1979. Observations on the distribution of land snails in the woods of the Ijsselmeer polders. Basteria. **43:** 33-45.

Richter, K.O. 1979. Aspects of nutrient cycling by *Ariolimax columbianus* (Mollusca: Arionidae) in Pacific Northwest coniferous forests. Pedobiologia. **19:** 60-74.

Rowe, J.S. 1972. Forest regions of Canada. Publication No. 1300, Department of the Environment, Canadian Forestry Service, Ottawa.

Rowley, M.A., Loker, E.S., Pagels, J.F., and Montali, R.J. 1987. Terrestrial gastropod hosts of *Parelaphostrongylus tenuis* at the National Zoological Park's Conservation and Research Center, Virginia. J. Parasit. **73**(6): 1084-1089.

Rudge, M.R. 1968. The food of the common shrew *Sorex araneus* L. (Insectivora: Soricidae) in Britain. J. Anim. Ecol. **37:** 565-581.

South, A. 1980. A technique for the assessment of predation by birds and mammals on the slug *Deroceras reticulatum* (Muller) (Pulmonata: Limacidae). J. Conchol. **30:** 229-234.

South, A. 1992. Terrestrial slugs - biology, ecology and control. Chapman and Hall, New York.

Spittlehouse, D.L., and Stathers, R.J. 1990. Seedling microclimate. British Columbia Ministry of Forests, Victoria. Land Manage. Rep. No. 65.

Steel, R.G.D., and Torrie, J.H. 1980. Principals and procedures of statistics - a biometrical approach. McGraw-Hill Publishing Co., Toronto.

Strayer, D., Pletscher, D.H., Hamburg, S.P., and Nodvin, S.C. 1986. The effects of forest disturbance on land gastropod communities in northern New England. Can. J. Zool. **64:** 2094-2098.

Sutton, R.F. 1969. Chemical control of competition in plantations. For. Chron. **45**(4): 252-256.

Swift, M.J., Heal, O.W., and Anderson, J.M. 1979. Decomposition in terrestrial ecosystems. University of California Press, Berkeley, CA.

Uminski, T., and Focht, U. 1979. Population dynamics of some land gastropods in a forest habitat in Poland. Malacologia. **18:** 181-184.

Van Es, J., and Boag, D.A. 1981. Terrestrial molluscs of central Alberta. Can. Field-Nat. **95**(1): 75-79.

Wagner, R.G. 1993. Research directions to advance forest vegetation management in North America. Can. J. For. Res. **23:** 2317-2327.

Wagner, R.G., Buse, L.J., Lautenschlager, R.A., Bell, F.W., Strobl, S., Morneault, A., Hollstedt, C., Pickering, S., and Ter-Mikaelian, M.T. 1994. Vegetation Management Alternatives Program Annual Report 1993-1994. Ontario Ministry of Natural Resources, Ontario Forest Research Institute, Sault Ste. Marie, Ont.

Waldén, H.W. 1981. Communities and diversity of land molluscs in Scandinavian woodlands. I. High diversity communities in taluses and boulder slopes in SW Sweden. J. Conch. **30:** 351-372.

Walton, M.L. 1963. Length of life in west American land snails. Nautilus 76(4): 127-131.

Whitaker, J.O. 1966. Food of *Mus musculus*, *Peromyscus maniculatus bairdi* and *Peromyscus leucopus* in Vigo County, Indiana. J. Mamm. **47**(3): 473-486.

Whitaker, J.O., and Mumford, R.E. 1972. Food and ectoparasites of Indiana shrews. J. Mamm. **53**(2): 329-335.

Wilbur, K.M. 1964. Shell formation and regeneration. *In* Physiology of Mollusca. *Edited by* K.M. Wilbur and C.M. Young. Academic Press, New York. pp. 243-282.

Williams, B.K. 1983. Some observations on the use of discriminant analysis in ecology. Ecology. **64**(5): 1283-1291.

APPENDIX A

TABLE A1. Model equation used in the repeated measures analysis of variance to test conifer release treatment effects and the description of model parameters

Model	$Y_{ijklmnp}=\mu+B_i+\gamma_{(i)j}+T_k+BT_{ik}+\delta_{(ijk)l}+t_m+Bt_{im}+Tt_{km}+BTt_{ikm}+\varepsilon_{(ijklm)n}+\rho_{(ijklmn)p}$

Parameter	Definition
$Y_{ijklmnp}$	=the gastropod density
μ	=the overall mean
B_i	=the random effect of the i^{th} block (i=4)
$\gamma_{(i)j}$	=the restriction error due to blocking
T_k	=the fixed effect of the k^{th} treatment (k=5)
BT_{ik}	=the interaction effect of the i^{th} block and the k^{th} treatment
$\delta_{(ijk)l}$	=the experimental error due to treatment (random)
t_m	=the fixed effect of the m^{th} time (l=4)
Bt_{im}	=the interaction effect of the i^{th} block and the m^{th} time
Tt_{km}	=the interaction effect of the k^{th} treatment and the m^{th} time
BTt_{ikm}	=the interaction effect of the i^{th} block with the k^{th} treatment and the m^{th} time
$\varepsilon_{(ijklm)n}$	=the experimental error due to time (random)
$\rho_{(ijklmn)p}$	=the sampling error (random)

TABLE A2. Expected mean squares and associated degrees of freedom used in parameter estimation in the repeated measures analysis of variance to test conifer release treatment effects

Parameter	Expected Mean Squares	df*
B_i	$\sigma^2_\rho+30\sigma^2_\varepsilon+120\sigma^2_\delta+600\sigma^2_\gamma+600\sigma^2_B$	3
$\gamma_{(i)j}$	$\sigma^2_\rho+30\sigma^2_\varepsilon+120\sigma^2_\delta+600\sigma^2_\gamma$	0
T_k	$\sigma^2_\rho+30\sigma^2_\varepsilon+120\sigma^2_\delta+120\sigma^2_{BT}+480\emptyset(T)$	4
BT_{ik}	$\sigma^2_\rho+30\sigma^2_\varepsilon+120\sigma^2_\delta+120\sigma^2_{BT}$	12
$\delta_{(ijk)l}$	$\sigma^2_\rho+30\sigma^2_\varepsilon+120\sigma^2_\delta$	0
t_m	$\sigma^2_\rho+30\sigma^2_\varepsilon+150\sigma^2_{Bt}+600\emptyset(t)$	3
Bt_{im}	$\sigma^2_\rho+30\sigma^2_\varepsilon+150\sigma^2_{Bt}$	9
Tt_{km}	$\sigma^2_\rho+30\sigma^2_\varepsilon+30\sigma^2_{BTt}+120\emptyset(Tt)$	12
BTt_{ikm}	$\sigma^2_\rho+30\sigma^2_\varepsilon+30\sigma^2_{BTt}$	36
$\varepsilon_{(ijklm)n}$	$\sigma^2_\rho+30\sigma^2_\varepsilon$	0
$\rho_{(ijklmn)p}$	σ^2_ρ	2320

* degrees of freedom

TABLE A3. Model equation used in the repeated measures analysis of variance of near-ground temperature and the description of model parameters

Model	$Y_{ijklmn}=\mu+T_i+S_j+TS_{ij}+\delta_{(ij)k}+t_l+Tt_{il}+St_{jl}+TSt_{ijl}+\varepsilon_{(ijkl)m}+\rho_{(ijklm)n}$

Parameter	Definition
Y_{ijklmn}	=the near-ground temperature
μ	=the overall mean
T_i	=the fixed effect of the i^{th} treatment (i=5)
S_j	=the fixed effect of the j^{th} distance from the ground (j=3)
TS_{ij}	=the interaction effect of the i^{th} treatment and the j^{th} distance from the ground
$\delta_{(ij)k}$	=the experimental error due to treatments (random)
t_l	=the fixed effect of the l^{th} time (l=5)
Tt_{il}	=the interaction effect of the i^{th} treatment and the l^{th} time
St_{jl}	=the interaction effect of the j^{th} distance from the ground and the l^{th} time
TSt_{ijl}	=the interaction effect of the i^{th} treatment with the j^{th} distance from the ground and the l^{th} time
$\varepsilon_{(ijkl)m}$	=the experimental error due to time (random)
$\rho_{(ijklm)n}$	=the sampling error (random)

TABLE A4. Expected mean squares and associated degrees of freedom used in parameter estimation in the repeated measures analysis of variance of near-ground temperature

Parameter	Expected Mean Squares	df*
T_i	$\sigma^2_\rho+6\sigma^2_\varepsilon+30\sigma^2_\delta+90\emptyset(T)$	4
S_j	$\sigma^2_\rho+6\sigma^2_\varepsilon+30\sigma^2_\delta+30\emptyset(TS)+150\emptyset(S)$	2
TS_{ij}	$\sigma^2_\rho+6\sigma^2_\varepsilon+30\sigma^2_\delta+30\emptyset(TS)$	8
$\delta_{(ij)k}$	$\sigma^2_\rho+6\sigma^2_\varepsilon+30\sigma^2_\delta$	0
t_l	$\sigma^2_\rho+6\sigma^2_\varepsilon+90\emptyset(t)$	4
Tt_{il}	$\sigma^2_\rho+6\sigma^2_\varepsilon+18\emptyset(Tt)$	16
St_{jl}	$\sigma^2_\rho+6\sigma^2_\varepsilon+30\emptyset(St)$	8
TSt_{ijl}	$\sigma^2_\rho+6\sigma^2_\varepsilon+6\emptyset(TSt)$	32
$\varepsilon_{(ijkl)m}$	$\sigma^2_\rho+6\sigma^2_\varepsilon$	0
$\rho_{(ijklm)n}$	σ^2_ρ	375

* degrees of freedom

APPENDIX B

TABLE B1. Total numbers of terrestrial gastropods collected from Pre-Vision® and Vision® treated areas on the four experimental blocks over the four sample periods in 1993 and 1994

	Pre-Vision® (1993)				Vision® (1994)			
Species	May	June	July	Aug.	May	June	July	Aug.
Zonitoides arboreus	120	563	334	461	293	228	262	205
Deroceras laeve	43	240	290	302	65	173	254	160
Discus cronkhitei	18	122	143	283	122	63	102	129
Euconulus fulvus	23	55	90	257	124	133	102	236
Strobilops labyrinthica	10	94	162	201	141	110	71	93
Vitrina limpida	33	63	200	78	13	23	21	17
Vertigo gouldi	1	24	54	144	38	46	40	129
Striatura milium	0	8	77	157	7	10	7	75
Succinea ovalis	30	52	64	50	27	45	66	19
Columella edentula	4	19	53	66	108	78	33	68
Anguispira alternata	9	66	52	41	26	38	25	8
Cochlicopa lubrica	4	23	20	13	12	13	20	11
Pallifera dorsalis	0	17	71	7	5	2	9	4
Zöogenetes harpa	0	8	30	12	7	5	3	7
Vertigo ovata	0	7	19	24	1	9	10	16
Striatura exigua	0	3	16	18	5	3	1	19
Gastrocopta tappaniana	1	2	5	3	15	17	17	7
Vertigo modesta	1	4	2	4	15	6	3	2
Carychium exile canadense	0	0	4	4	2	2	9	6
Punctum minutissimum	0	0	1	8	2	0	4	1
*Pupisoma minus**	0	0	0	0	0	0	0	0
Total	297	1370	1687	2133	836	928	1241	1672

* tentative identification by the Royal Ontario Museum

TABLE B2. Total numbers of terrestrial gastropods collected from Pre-Release® and Release® treated areas on the four experimental blocks over the four sample periods in 1993 and 1994

Species	Pre-Release® (1993)				Release® (1994)			
	May	June	July	Aug.	May	June	July	Aug.
Zonitoides arboreus	153	615	399	526	367	311	231	119
Deroceras laeve	66	263	309	190	58	153	86	115
Discus cronkhitei	11	217	291	311	142	120	91	68
Euconulus fulvus	33	90	95	391	119	207	146	191
Strobilops labyrinthica	8	55	156	155	164	73	69	96
Vitrina limpida	7	95	132	47	10	17	12	32
Vertigo gouldi	1	4	27	277	94	52	72	138
Striatura milium	0	0	246	104	30	20	76	43
Succinea ovalis	20	41	53	16	38	44	32	12
Columella edentula	1	3	10	146	124	66	45	60
Anguispira alternata	4	42	32	5	31	26	12	6
Cochlicopa lubrica	7	23	13	28	22	21	16	13
Pallifera dorsalis	0	5	15	2	1	12	3	2
Zöogenetes harpa	0	10	35	9	13	12	7	10
Vertigo ovata	0	1	14	37	18	26	22	17
Striatura exigua	0	0	29	19	5	4	6	11
Gastrocopta tappaniana	1	0	18	11	21	24	29	14
Vertigo modesta	2	2	0	15	13	3	4	4
Carychium exile canadense	2	0	3	39	9	22	5	0
Punctum minutissimum	0	0	5	5	0	1	0	5
Pupisoma minus	0	0	8	0	0	0	0	0
Total	316	1466	1890	2333	836	710	880	1281

TABLE B3. Total numbers of terrestrial gastropods collected from Pre-Brushsaw and Brushsaw treated areas on the four experimental blocks over the four sample periods in 1993 and 1994

	Pre-Brushsaw (1993)				Brushsaw (1994)			
Species	May	June	July	Aug.	May	June	July	Aug.
Zonitoides arboreus	165	623	279	532	327	218	254	98
Deroceras laeve	80	284	287	180	80	200	173	149
Discus cronkhitei	17	146	112	205	89	50	50	40
Euconulus fulvus	36	78	108	213	95	65	78	156
Strobilops labyrinthica	4	88	100	145	66	38	62	68
Vitrina limpida	4	67	38	52	2	11	17	33
Vertigo gouldi	1	8	37	113	31	17	26	38
Striatura milium	0	1	71	75	11	3	2	17
Succinea ovalis	25	60	66	23	50	70	51	33
Columella edentula	1	13	10	71	51	24	20	16
Anguispira alternata	10	49	53	18	27	28	20	2
Cochlicopa lubrica	7	13	16	4	11	6	16	7
Pallifera dorsalis	0	1	12	10	1	0	3	3
Zöogenetes harpa	1	3	8	22	1	6	2	8
Vertigo ovata	0	0	18	19	15	6	11	13
Striatura exigua	0	0	5	13	5	0	0	9
Gastrocopta tappaniana	1	1	7	2	13	8	4	4
Vertigo modesta	1	1	2	1	17	1	1	0
Carychium exile canadense	0	0	1	0	6	2	1	0
Punctum minutissimum	0	0	0	0	1	0	0	1
Pupisoma minus	0	0	0	0	0	0	0	0
Total	353	1436	1230	1698	1627	637	1032	914

TABLE B4. Total numbers of terrestrial gastropods collected from Pre-Silvana and Silvana Selective treated areas on the four experimental blocks over the four sample periods in 1993 and 1994

	Pre-Silvana Selective (1993)				Silvana Selective (1994)			
Species	May	June	July	Aug.	May	June	July	Aug.
Zonitoides arboreus	163	602	291	518	373	283	280	159
Deroceras laeve	161	420	323	405	87	222	231	152
Discus cronkhitei	15	149	89	289	110	45	73	81
Euconulus fulvus	26	82	135	315	113	56	64	111
Strobilops labyrinthica	14	106	96	159	80	41	42	48
Vitrina limpida	62	122	183	161	21	53	21	22
Vertigo gouldi	0	20	51	218	58	19	26	56
Striatura milium	0	1	88	164	23	1	26	62
Succinea ovalis	58	86	80	39	54	48	51	22
Columella edentula	4	8	34	125	46	42	22	52
Anguispira alternata	11	37	30	22	48	32	14	4
Cochlicopa lubrica	11	30	27	13	13	7	6	8
Pallifera dorsalis	0	22	20	11	2	11	4	2
Zöogenetes harpa	4	9	24	7	7	10	11	7
Vertigo ovata	1	7	14	25	12	6	13	14
Striatura exigua	0	0	8	18	6	2	1	3
Gastrocopta tappaniana	2	4	9	7	8	7	16	7
Vertigo modesta	4	2	10	2	4	2	0	0
Carychium exile canadense	2	2	0	0	0	3	0	1
Punctum minutissimum	0	0	0	8	1	0	0	0
Pupisoma minus	0	0	1	1	0	0	0	0
Total	538	1709	1513	2507	1304	1033	494	859

TABLE B5. Total numbers of terrestrial gastropods collected from control areas on the four experimental blocks over the four sample periods in 1993 and 1994

Species	Control (1993)				Control (1994)			
	May	June	July	Aug.	May	June	July	Aug.
Zonitoides arboreus	129	492	327	535	523	383	330	248
Deroceras laeve	100	327	513	334	111	273	245	205
Discus cronkhitei	12	111	93	253	84	63	55	88
Euconulus fulvus	50	35	112	228	132	108	115	156
Strobilops labyrinthica	26	41	75	188	135	87	90	94
Vitrina limpida	42	51	242	102	40	70	58	40
Vertigo gouldi	2	2	6	68	27	53	38	82
Striatura milium	0	0	7	41	23	17	2	39
Succinea ovalis	19	70	47	18	32	43	42	8
Columella edentula	2	1	6	30	23	62	15	56
Anguispira alternata	7	15	30	19	52	29	8	7
Cochlicopa lubrica	5	7	18	10	13	27	29	18
Pallifera dorsalis	1	5	6	1	4	3	4	3
Zöogenetes harpa	0	1	6	9	3	5	0	4
Vertigo ovata	1	0	1	10	6	15	1	10
Striatura exigua	0	2	2	8	16	10	2	20
Gastrocopta tappaniana	0	0	0	2	2	21	18	3
Vertigo modesta	2	0	2	8	8	4	0	5
Carychium exile canadense	0	0	0	2	2	1	10	13
Punctum minutissimum	0	0	0	2	5	0	0	1
Pupisoma minus	0	0	0	1	0	0	0	0
Total	398	1160	1493	1869	1870	1029	661	355

APPENDIX C

TABLE C1. Species of vegetation and associated percent cover, in each of the four conifer release treatment areas and the control area, averaged over the four experimental blocks, in 1993 (pre-treatment) and 1994 (post-treatment), according to vegetation category*

		Percent cover									
		1993					1994				
		Pre-Treatment†					Treatment				
Group	Species	1	2	3	4	5	1	2	3	4	5
Coniferous trees	*Abies balsamea*	0.5	0.4	0.4	0.7	0.3	0.7	0.5	0.5	1.2	0.7
	Picea glauca	1.3	1.2	1.5	1.3	1.4	2.4	1.9	1.7	1.8	1.5
	Picea mariana	0.5	0.5	0.2	0.6	0.3	0.5	0.4	0.5	2.4	0.8
	Pinus banksiana	0.08	0.05	0.2	0	0.5	0.2	0.2	0.3	0	0.9
	Pinus strobus	0	0	0	0.03	0	0	0	0	0	0
Deciduous trees	*Betula papyrifera*	1.4	1.6	0.9	1.0	1.8	0.7	0.4	1.3	0.9	2.5
	Populus balsamea	0.5	1.0	0.2	0.6	0.4	0.2	1.0	0.2	0.4	0.5
	Populus tremuloides	10.8	10.5	13.3	14.2	10.6	2.5	4.9	6.5	6.5	12.9
Shrubs	*Acer rubrum*	0	0	0	0.03	0	0	0	0	0.05	0
	Acer spicatum	4.2	3.6	3.2	4.8	2.8	1.9	2.5	3.5	5.1	4.2
	Alnus crispa	0.5	0.2	0	1.2	1.6	0.4	0.2	0.05	0.5	2.5

TABLE C1. (continued)

Group	Species	Percent cover 1993 Pre-Treatment 1	2	3	4	5	1994 Treatment 1	2	3	4	5
Shrubs	*Alnus rugosa*	0.9	1.5	0.6	0.7	0.1	0.03	0.7	0.6	0.5	0.2
	Amelanchier spp.	0.4	0	0.5	1.6	0.7	0.05	0.03	0.5	0.7	0.8
	Apocynum androsaemifolium	2.0	0.3	0.7	0.7	1.8	0.2	0.4	1.0	4.0	1.4
	Cornus alternifolia	0	0	0.03	0	0.03	0	0	0.03	0	0
	Cornus stolonifera	2.1	2.1	2.1	1.9	1.7	1.3	0.6	3.0	2.6	2.3
	Corylus cornuta	7.9	5.1	5.0	7.8	5.4	1.8	3.0	4.7	5.6	7.6
	Diervilla lonicera	4.4	1.8	2.2	4.9	2.7	1.3	3.4	2.8	5.6	4.6
	Lonicera canadensis	0.08	0.1	0.2	0.05	0.05	0.2	0.2	0.5	0.4	0.5
	Lonicera hirsuta	0.6	0.8	0.1	0.05	0.2	0.1	0.2	0.1	0.4	0.3
	Prunus pensylvanica	0.4	0.8	0.2	0.1	0.4	0.05	0.2	0.3	0.1	0.4
	Prunus virginiana	0.2	0.1	0.3	0	0.2	0.3	0.2	0.5	0.08	0.2
	Ribes glandulosum	0.08	0.1	0.4	0.1	0.2	0.2	0.2	0.4	0.1	0.3
	Ribes hirtellum	0.05	0.2	0	0	0	0	0.1	0	0	0.05

TABLE C1. (continued)

		Percent cover									
		1993					1994				
		Pre-Treatment					Treatment				
Group	Species	1	2	3	4	5	1	2	3	4	5
Shrubs	*Ribes oxycanthoides*	0	0.05	0	0	0	0	0.03	0.03	0.05	0
	Ribes triste	0.2	0.5	0.3	0.2	0.3	0.2	0.6	0.5	0.3	0.7
	Rosa acicularis	0.8	0.4	0.7	0.6	1.0	0.8	0.8	1.0	4.0	1.6
	Rubus idaeus	10.3	11.1	10.2	7.9	8.7	10.8	7.8	16.1	16.2	14.0
	Rubus parviflorus	7.7	7.5	5.3	7.8	10.1	13.3	12.5	8.4	10.3	10.4
	Salix spp.	3.2	5.0	2.3	0.7	2.9	1.5	2.5	2.3	1.2	2.3
	Sambucus pubens	0.08	0.2	0	0.03	0.08	0.05	0.2	0.05	0.03	0.1
	Shepherdia canadensis	0	0	0.4	0	0	0	0	0.2	0	0
	Sorbus americana	0	0.1	0.08	0	0.2	0	0.05	0.08	0.08	0.4
	Sorbus decora	0	0	0	0	0	0	0	0.05	0	0
Herbs	All herbs grouped	36.2	34.2	42.2	38.1	41.6	55.0	39.2	53.9	56.0	55.8

TABLE C1. (continued)

		Percent cover									
		1993					1994				
		Pre-Treatment					Treatment				
Group	Species	1	2	3	4	5	1	2	3	4	5
Ferns	All ferns grouped	6.4	3.1	5.6	5.7	2.8	4.8	7.8	8.5	7.8	6.3
Grasses	All grasses grouped	4.3	3.1	6.5	2.5	3.9	6.7	15.9	10.3	5.6	7.9
Sedges	All sedges grouped	0.6	1.9	1.2	0.8	0.5	1.5	3.2	2.0	2.0	0.8

* data provided by Mr. F.W. Bell, Vegetation Management Alternatives Program, Ontario Forest Research Institute, Sault Ste. Marie, Ontario.

† treatment 1=Vision®; 2=Release®; 3=Brushsaw; 4=Silvana Selective; 5=Control.