EFFECTS OF ALTERNATIVE CONIFER RELEASE TREATMENTS ON TERRESTRIAL GASTROPODS OF REGENERATING SPRUCE PLANTATIONS

BY

JOHN R. PREZIO

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, 1997

0-612-33431-7

TABLE OF CONTENTS

ABSTRACT

This study examined changes in terrestrial gastropod densities and species richness associated with alternative methods of managing competing vegetation on regenerating spruce plantations. Data were collected monthly from June to September in 1995 and 1996, the second and third years following use of four conifer release treatments (herbicides, Vision® and Release®; manual clearing, brushsaw and mechanical clearing, Silvana Selective/Ford Versatile) on each of four replicate blocks. A total of 15,083 terrestrial gastropods, comprising 21 species, was collected from litter surface sampling sites (beneath cardboard sheets) over the two years. In 1995, recorded gastropod densities were low ($4.2 \pm 0.2 m^{-2}$)(Mean ± S.E.) during an unusually dry summer and were similar among all treated and control areas. With wetter conditions in 1996, these numbers increased on all areas ($6.9 \pm 0.3\ m^{-2}$), but were significantly lower on areas treated with herbicides (Vision®, $3.7 \pm 0.4\ m^{-2}$; Release®, $3.2 \pm 0.3\ m^{-2}$). This may be attributable to variability in near ground temperature and relativity humidity. As well, the decreased accumulation of broadleaf litter in these sites may have provided inadequate habitat conditions during dry periods. Despite this difference in surface active gastropods suggested by cardboard sheet collections, no difference in numbers was apparent in a limited number of soil core samples taken from untreated and Vision® treated sites (258 ± 145 and $377 \pm 221\ m^{-2}$, respectively).

Overall gastropod densities were highest where soil moisture, pH and calcium concentraion were highest. Gastropod densities measured by surface sampling cardboard

sheets were greater on a regenerating plantation than on an unharvested forest and on a complete removal plot (CRV), where vegetation was removed annually using Vision® (9.4 ± 0.5, 6.7 ± 0.4 and 6.4 ± 0.5 m^{-2}, respectively). These differences may be attributable to the more abundant near ground vegetation and larger broadleaf component of the litter layer in the regenerating plantation. Species richness was similar among these sites, but several species were not collected on all CRV plots.

ACKNOWLEDGEMENTS

I would like to express my gratitude to my supervisor Dr. Murray Lankester for his support and patience during these last two years. His assistance and dedication proved to be an integral part in the completion of my thesis.

My thanks to Drs. D.A. Boag, A.U. Mallik and W.L. Meyer for their time and input in developing this thesis.

I would also like to thank the Vegetation Management Alternatives Program of the Ontario Forest Research Institute for providing the necessary funding for this project and support in other ways too numerous to mention. Input from the many cooperators of the Fallingsnow Ecosystem Project was also greatly appreciated; they always provided thought provoking conversation and suggestions to further my research. A special thanks to Dr. Phillip Reynolds and Wayne Bell who provided additional data used in this thesis.

A special thanks goes out to all of the diligent research assistants who helped collect data in spite of long hours and more importantly, Mother nature. Thanks to Alec, Hao, Robyn, Jackie and Heather.

To my family and friends who provided support, encouragement and often a much needed diversion, I am indebted. It was often the day to day assistance provided by these people that allowed me to persevere.

I would like to convey my appreciation to the Departments of Biology and Forestry for their assistance. Their commitment to education and research was evident in their willingness to supply advice, equipment and often lab space.

Finally, I would like to thank John Hawkins for his continued support throughout my research. His knowledge and assistance in the laboratory and in the field was an important part of my success.

LIST OF FIGURES

LIST OF TABLES

Page

LIST OF APPENDICES

INTRODUCTION

Conifer release treatments have been employed to reduce the effects of competition from undesirable vegetation in young conifer plantations for several decades (Stewart *et al.* 1984; Campbell 1990). Potential reduction in yield and a possible increase in rotation time results from the loss of nutrients to competition (Sutton 1969; Radosevich and Osteryoung 1987; Freedman *et al.* 1993). A variety of conifer release methods have been practiced, but the use of herbicides is the most popular.

By 1991, Ontario had the largest aerial herbicide program in Canada (Campbell 1990). In an eight year period (1983-1990), 430,000ha of forest were sprayed with herbicide (Ghebremichael 1993). Despite the high treatment efficacy and cost effectiveness of chemical application (Campbell 1984; Bell *et al.* 1997a), recent public concern over the environmental effects of herbicides (Environics Research Group 1992; Campbell 1990; Freedman 1991; Burt Perrin Associates 1993) has prompted the search for alternative methods to control competing vegetation (Campbell 1991; Wagner 1993). Two such alternatives employ mechanical and manual cleaning methods. Mechanical cleaning involves the use of a brush-cutting blade attached to a hydraulic boom and mounted on a tractor (Bell *et al.* 1997a). Manual cleaning involves the use of hand-held power brushsaws.

The effects of manual and mechanical methods of conifer release on forest ecosystems have not been widely studied (Wagner 1993; Lautenschlager 1993), as they are not common operational procedures. Yet, comparisons between these alternative methods and the favoured herbicide application currently used in forestry are necessary (Campbell 1991) since non-chemical release has the disadvantage of promoting rapid regrowth through sprouting of freshly cut broadleaf trees and shrubs (Campbell 1984; Wagner 1993). The effects of this and other potential responses can be examined using indicator species which in turn may reflect larger ecosystem changes.

The potential value of terrestrial gastropods as possible indicators of ecosystem change is worth investigating for several reasons. Ecologically, they are an important component of boreal ecosystems (Mason 1970; South 1980; Churchfield 1984; Digweed 1993; Lankester and Peterson 1996), and are unique in being relatively immobile and therefore slow to vacate or recolonize disturbed sites (Strayer *et al.* 1986). Thus, changes in density and/or richness of resident gastropod populations may reflect the immediate impact of natural or human induced disturbances. Reinink (1979) and Cameron *et al.* (1980) found decreased species richness in recently disturbed sites. However, Hawkins *et al.* (1997) reported no difference in gastropod density or richness one year after conifer release treatments, despite significant changes in vegetation.

Distribution of terrestrial gastropods has been positively correlated with percent cover of near ground vegetation (Boag and Wishart 1982). Near ground vegetation and the structure of the litter layer can influence near ground temperature and relative humidity (Hunter 1964), by creating a microclimate that differs from ambient conditions. Gastropods are most active under moderate near-ground temperatures and moist conditions (Boag 1985) that ensure optimal growth, reproduction and mobility (Boycott 1934; Prior 1985; South 1992). Therefore, changes in microclimate and soil characteristics due to alterations in near-ground vegetation may affect the richness and abundance of gastropods.

As well as being influenced by vegetation, terrestrial gastropod distribution is also influenced by soil chemistry (Locasciulli and Boag 1987; Gärdenfors 1992). For example, calcium (Ca) is important to gastropods, and its availability in soil is affected either directly or indirectly by pH. The cation exchange capacity (CEC) of a soil (organic and mineral) is determined by the total negative electrical charge associated mainly with colloidal organic matter and clay particles. The CEC refers to the ability of soil to adsorb available cations (Foth 1990; Krause 1991). Acid soil, generally having a lower cation exchange capacity, limits the availability of calcium. Failure of hydrogen ions to dissociate from soil particles in acid soils, especially in organic layers, limits the sites available for Ca to bond, resulting in the loss of these cations from the immediate habitat (Krause 1991).

Calcium availability in soil is an important component in the survival, reproduction and mobility of terrestrial gastropods (Baker 1958; Fournié and Chétail 1984). Distribution of gastropods is often influenced by soil pH that may limit the availability of Ca (Cameron 1973; Walden 1981; Gärdenfors 1992). The Ca necessary for shell, egg, slime and epiphragm production is acquired from the soil and vegetation of the immediate habitat. Calcium can be absorbed through the epithelium of the foot or ingested as a component of vegetation (Fournié and Chétail 1984). Therefore, by affecting available Ca, changes in vegetation and soil resulting from the application of conifer release treatments, may in turn affect gastropod populations.

The Fallingsnow Ecosystem Project was initiated in 1993 to study alternatives to spraying herbicides as a method of releasing conifer seedlings. This large scale project was established as a Randomized Complete Block Design to compare effects of two herbicides (Vision® and Release®) and two non-herbicide (brushsaw and Silvana

Selective) methods with a control area (10 year old regenerating conifer plantation). Hawkins *et al.* (1997) measured the density and richness of terrestrial gastropod populations one year before and after competing vegetation had been treated and found no apparent adverse effects. The present study continues to compare terrestrial gastropod populations two and three years post-treatment and examines associated soil and microclimatic conditions. In addition, gastropod populations in plots sprayed annually with Vision® herbicide and in plots within an unharvested forest (100 years old) were compared with those in the regenerating conifer plantation.

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 27.8 to 52.4 ha, were surveyed and a 60 x 60 m grid pattern staked out in an alpha-numeric coordinate system, oriented north-south and east-west (Bell *et al.* 1997a).

Each block had been harvested and replanted prior to the initiation of the study (Table 1). Prior to harvesting, Blocks 1 and 4 were primarily coniferous and Blocks 2 and 3 broadleaf. All blocks were planted with either *Picea mariana* (Mill)B.S.P. and/or *Picea glauca* (Moench) (black/white spruce).

Block 1 was situated on a south facing slope and had shallow, sandy loam soils with highly variable drainage. Block 2 was situated on a south-east facing slope, had well drained clay loam soils and was 170 m higher in altitude than the lowest block (Block 3) (380 *vs.* 550 m above sea level). Block 3 was situated on a south facing slope and had relatively deep silty soils with imperfect drainage. Block 4 was also situated on a south-facing slope and had relatively deep clay soils with moderate to poor drainage (Bell *et al.* 1997a).

The conifer release treatments included one of two chemical herbicides (glyphosate [Vision®] or triclopyr [Release®]) applied aerially by a Bell 206 helicopter. Vegetation was cut by mechanical means using either the Silvana Selective/Ford

Table 1. Harvesting and silvicultural history of the four experimental blocks of the Fallingsnow Study Area.*

Block	Previous stand composition†	Study area (ha)	Year of harvest	Stand age at harvest (yr)	Year and method of site preparation	Year and species planted
1	$Po_3Sw_2Bf_2Sb_1$ Bw_1A_1	37.9	1986/1988	77-79	1990-Power disc trencher	1991-black spruce
2	$Po_6Bf_2Bw_1Sw_1$	27.8	1987	100	1989-Young's teeth	1990-white spruce
3	Po_{10}	52.4	1985	74	1986-Trencher	1987-white & black spruce
4	$Pj_8Po_1Bf_1$	29.3	1987	84	1988-Young's teeth	1989-white spruce

* after Bell *et al.* 1997a
† Po_3 = 30% trembling aspen
Sw_2 = 20% white spruce
Bf_2 = 20% balsam fir
Sb_1 = 10% black spruce
Bw_1 = 10% white birch
A_1 = 10% ash
Pj_8 = 80% jack pine

Versatile or motor-manual cutting with brushsaws (Stihl FS420 and Husquavarna Professional). Vision® and Release® were applied at 1.5 kg [a.e.] ha^{-1} and 1.9 kg [a.e.] ha^{-1}, respectively, on August 16, 1993. The brushsaw treatment was done between October 12 and 22, 1993, and the Silvana Selective/Ford Versatile treatment between October 19 and November 5, 1993.

In addition, a complete removal Vision® plot (CRV plots≈30 m x 30 m) was located within the Vision® treatment area on each of the four experimental blocks. All broadleaf plants were removed annually by the herbicide treatment in late summer - early autumn after the conifers had hardened off. This was accomplished by two applications of Vision® at 2.0 kg [a.e.] ha^{-1} using a Solo backpack sprayer (W. Bell, unpublished data, Ontario Forest Research Institute).

Gastropod collection

Gastropods were collected during the second and third summers (1995 and 1996) following treatments. A total of 20 unwaxed cardboard sheets, each measuring 0.85 m^2, were placed in a systematic-random fashion, 10 - 30 m apart, along three transects (chosen randomly by Hawkins *et al.* 1996) in each treatment area (7 + 6 + 7 sheets x 5 treatment areas x 4 blocks = 400 sheets total).

All four blocks were sampled each month from June-September. Monthly sampling was conducted, as much as possible, only during or following a rainy period. In 1995, samples were collected within a 4-9 day period on June 20-23, July 5-10, July 26-August 1 and August 30-September 7 and in 1996, within 4-16 days on June 24-27, July 9-15, July 31-August 15 and September 3-11. Sampling of a block began at dawn and was completed by 1300 hrs. Gastropods beneath each cardboard sheet (as well as any on top) were identified, counted and removed. Sheets were then repositioned 1m from the previous location, weighed down with rocks or logs and sampled again the following month.

To study the effect of repeated removal of the herbaceous layer on gastropod populations ten cardboard sheets were placed in a systematic-random fashion (10 - 20 m apart) in each CRV plot and sampled the same day as the entire block (only in August and September of 1995, but in each of the four sampling periods of 1996).

The gastropod species compostion and abundance on each regenerating experimental block were compared with those on an adjacent unharvested forest site. Typically, each unharvested forest site had a closed canopy and tree species similar to those thought to have been present prior to harvesting in the mid 1980's. Twenty cardboard sheets were placed on two transects (10 + 10) on the sites adjacent to blocks 2 and 3, and on three transects (7 + 6 + 7) on the sites adjacent to blocks 1 and 4. Unharvested forest sites were sampled on the same day as experimental blocks.

In addition to using cardboard sheets, an independant estimate of gastropod density was obtained in 1996 using a soil core sampling method. Nine soil cores were extracted from a 1 m^2 quadrat in each of four areas (untreated contol, Vision®, CRV and unharvested forest on block 3) using a metal coring device measuring 8 x 7 x 10 cm (Hawkins *et al.* 1996). The samples were placed in polyethylene bags and stored in an environmental chamber at 20 °C until later examination (1 - 14 days). A soil sample was taken from each quadrat and analyzed within three days to determine moisture and pH. Temperature and relative humidity was measured every three hours using continuous data loggers at 2 m (ambient), 0.25 m (near ground) and -0.05 m (duff) above the forest floor at each sampling quadrat. Mean, maximum and minimum values were recorded for each time interval. Data were recorded in the CRV plots using temperature and relative humidity Stowaways (Onset Computer Corp.,) and in the Vision, unharvested forest and untreated control as described in Reynolds (1996).

Extraction of terrestrial gastropods from soil cores was accomplished in two steps. Individual samples were placed in a large container and sprayed with a jet of water to break apart the soil core. After settling, floating organic matter was removed from the surface. A preliminary study determined that finely divided floating material contained no live gastropods.

The remaining mineral soil was washed through 4 seives of decreasing screen size (12.5, 2.0, 1.4, 1.0 mm) and examined systematically 3-5 times for live gastropods using an illuminated magnifying lens. Shells were removed from the screens and examined using a dissecting microscope at 16x to detect living tissue or movement. The number of empty gastropod shells found in the sediment and those removed with the floating material were noted but not included in density estimates.

Gastropods were identified using Pilsbry (1939-1948), Oughton (1948), and Burch (1962). Those species too small to be identified in the field were preserved in glycerin-alcohol (10% glycerin in 70% ethanol) and identified later under a dissecting microscope at 16x. Voucher specimens were sent to the Royal Ontario Museum, Toronto, where identifications were confirmed.

Soil analysis

Soil samples (15 x 15 x 15 cm deep) were collected during each gastropod sampling period within 2 m of every other cardboard sheet on all control areas and CRV plots. Four samples were collected from each of the three transects and 5 from each CRV plot (17 total x 4 blocks). A soil sample was also collected at the ends of each transect in the unharvested forest (4 or 6 total). Organic samples typically consisted of L / F / H layers, however, mineral soil was highly variable among locations. The organic and mineral layers were separated in polyethylene bags, labelled and refrigerated 1 to 3 days until processing.

Gravitational water was measured by weighing field moist samples before and after oven drying at 105 °C for 48 hours. Percent moisture was calculated by expressing weight loss of the sample as a percentage of the oven dry weight. The remainder of the sample was air dried (48 hours), sieved through a 2 mm screen and the soil acidity (pH) measured by suspending a 10 g sample in a 0.01M $CaCl_2$ solution (soil-to-solution ratio of 1:2 for mineral soils; 1:4 for organic soils). Available cations were measured using inductively coupled plasma (ICP) analysis of ammonium acetate extractions (1995 samples only) (Kalra and Maynard 1991).

Statistical analysis

In all tests, the maximum probability of a Type -I error was set at $p < 0.05$ (unless otherwise stated). Individual species analysis were performed only on those that exceeded 2% of the total collected.

Gastropod densities (numbers m^{-2}) recorded from the four blocks were analysed using a repeated measures analysis of variance to test for differences between treatments throughout the 4 sampling periods in 1995 and 1996 (Norusis 1992a; Gumpertz and Brownie 1993). Interval means were used in a 1-way ANOVA followed by a Bonferroni multiple comparison to identify overall treatment differences in 1995 and 1996. Individual 1-way ANOVA's were performed as a multiple comparison (with a Bonferonni correction) to identify treatment differences among blocks in 1996 (Howell 1997). Data were first normalized using a $\log_{10}(x + 1)$ transformation in 1995 and 1996.

Overall gastropod densities from each block were tested using a 1-way ANOVA for each separate sampling period followed by Tukey's HSD test in 1995 and 1996 (Zar 1984). A Wilcoxon Rank Sum test was used to measure differences in gastropod densities between untreated control (UC) and complete removal Vision® plots (CRV) in 1995. The same analysis was used in 1996 to compare gastropod densities among UC, CRV and unharvested forest sites (UF). Differences in soil core gastropod densities between Vision®, CRV, UF and UC sites were tested using a Kruskal-Wallis 1-Way ANOVA in 1996 (Bradley 1968; Norusis 1992b) since the data did not meet the requirements for ANOVA.

Soil moisture, pH and Ca were tested among blocks and treatments using a 1-way ANOVA (Zar 1984). Data were normalized using either a square root, $\log_{10}$ or $\log_{10}(x + 1)$ transformation to meet the assumptions of normality and homogeneity of variance. Raw data on pH were first converted to concentration of hydrogen ions and then transformed using a -1(ln) transformation. A linear regression was performed to test gastropod density *vs.* available Ca concentration in organic and mineral soil (Zar 1984; Howell 1997).

RESULTS

Totals of 5,825 and 9,258 terrestrial gastropods were collected from the 4 blocks over the 4 monthly sampling periods during the summers of 1995 and 1996, respectively (Appendix 1-5). Twenty species were represented in total, including 18 species of snails and 2 species of slugs (Table 2) comprising 79.3% and 21.7% of the total gastropods collected in 1995 and 76% and 24% in 1996, respectively (Table 3). Some species were not recorded on all blocks *(Carychium exile canadense*, *Striatura exigua*, *Vertigo ovata*, and *Punctum minutissimum)*. Mean gastropod densities estimated, using the cardboard sheet sampling method, varied among years and blocks (Figure 1) from 2.5 ± 0.9 m^{-2} on Block 4, to 6.1± 1.8 m^{-2} on Block 3 in 1995 and 4.4 ± 0.3 m^{-2} on Block 4, to 10.3 ± 0.5 m^{-2} on Block 3 in 1996.

Total summer precipitation varied between years being much less in 1995 than in 1996 (270 and 343 mm, respectively; Appendix 6)(P. Reynolds unpublished data, Canadian Forest Service). Precipitation also varied throughout both summers (Appendix 1). June was the driest (11.75 and 68 mm total) and July was the wettest (117.5 and 133.5 mm total) in 1995 and 1996 (Figure 2A). However, rainfall accumulation was greater and more frequent in 1996, with a large amount in early July (Figure 2B).

Overall gastropod totals and densities (mean of all four blocks) varied among the 4 monthly sampling periods in both 1995 and 1996, being lowest in June (0.8 ± 0.1 m^{-2} and 0.3 ± 0.04 m^{-2}, respectively), and increasing rapidly in July (6.1 ± 0.3 m^{-2} and 6.6 ± 0.3 m^{-2}, respectively)(Table 4). In 1995, densities declined in August (4.5 ± 0.3 m^{-2}) and increased again in September (5.7 ± 0.3 m^{-2}) but in 1996, densities continued to increase

Table 2. Total numbers of terrestrial gastropods collected using cardboard sheets from each of the four experimental blocks at the Fallingsnow Study Area in the summers of 1995 and 1996.

	1995					1996				
	Block					Block				
	1	2	3	4	Total	1	2	3	4	Total
Zonitoides arboreus	450	499	590	232	1771	227	223	391	132	973
Deroceras laeve	233	429	368	179	1209	765	547	783	279	2374
Succinea ovalis	22	163	229	166	580	88	200	358	225	871
Euconulus fulvus	60	249	235	33	577	260	368	203	169	1000
Strobilops labyrinthica	83	123	106	85	397	53	69	55	54	231
Discus cronkhitei	94	84	75	24	277	112	140	162	55	469
Vitrina limpida	13	97	95	5	210	383	322	1105	91	1901
Anguispira alternata	8	45	101	51	205	73	132	130	172	507
Cochlicopa lubrica	18	17	63	7	105	26	9	110	16	161
Striatura milium	1	37	57	25	120	8	7	31	112	158
Vertigo gouldi	10	33	33	8	84	36	16	15	30	97
Zoogenetes harpa	2	30	28	22	82	46	66	47	59	218
Pallifera dorsalis	11	8	30	12	61	16	29	27	39	111
Vertigo modesta	10	19	17	2	48	10	12	41	27	90
Columella edentula	19	17	6	2	44	18	11	6	21	56
Vertigo ovata	0	3	19	0	22	0	2	0	1	3
Gastrocopta tappaniana	1	2	11	7	21	3	7	3	0	13
Striatura exigua	0	2	4	1	7	8	1	0	3	12
Punctum minutissimum	0	0	3	0	3	0	0	0	0	0
Carychium exile canadense	0	0	2	0	2	1	0	0	0	1
Pupisoma minus	0	0	0	0	0	5	1	1	5	12
Total	1035	1857	2072	861	5825	2138	2162	3468	1490	9258

Table 3. Frequency (% of total) of terrestrial gastropod species in 1995 and 1996 from the experimental blocks and complete removal Vision® plots (CRV) on all four experimental blocks at the Fallingsnow Study Area.

	Experimental block		Complete removal Vision®	
Species	1995	1996	1995	1996
Zonitoides arboreus	30	10.5	14.8	19.3
Deroceras laeve	21	25.6	22.6	13.5
Succinea ovalis	10	9.4	7.1	5.1
Euconulus fulvus	10	10.8	4.5	15.1
Strobilops labyrinthica	7	2.5	15.5	25.5
Discus cronkhitei	5	5.1	11.6	5.1
Vitrina limpida	4	20.5	1.3	1.3
Anguispira alternata	4	5.5	3.2	3.6
Cochlicopa lubrica	1.8	1.7	0	1.3
Striatura milium	2	1.7	2.6	2.4
Vertigo gouldi	1	1	6.5	1.4
Zöogenetes harpa	1	2.4	0	0.9
Pallifera dorsalis	0.7	1.2	1.3	1.6
Vertigo modesta	0.8	1	3.2	0.2
Columella edentula	0.7	0.6	0.6	1.5
Vertigo ovata	0.3	0.03	0	0
Gastrocopta tappaniana	0.3	0.1	6.5	1.3
Striatura exigua	0.1	0.1	0.6	0.7
Punctum minutissimum	0.05	0	0	0
Carychium exile canadense	0.03	0.01	0	0.1
Pupisoma minus	0	0.1	0	0.1
Total	100	100	100	100

Figure 1. Mean (± S.E.) annual summer densities of terrestrial gastropods from 1993 to 1996 on the Fallingsnow Study Area (data for 1993 and 1994 from Hawkins *et al.* 1997)

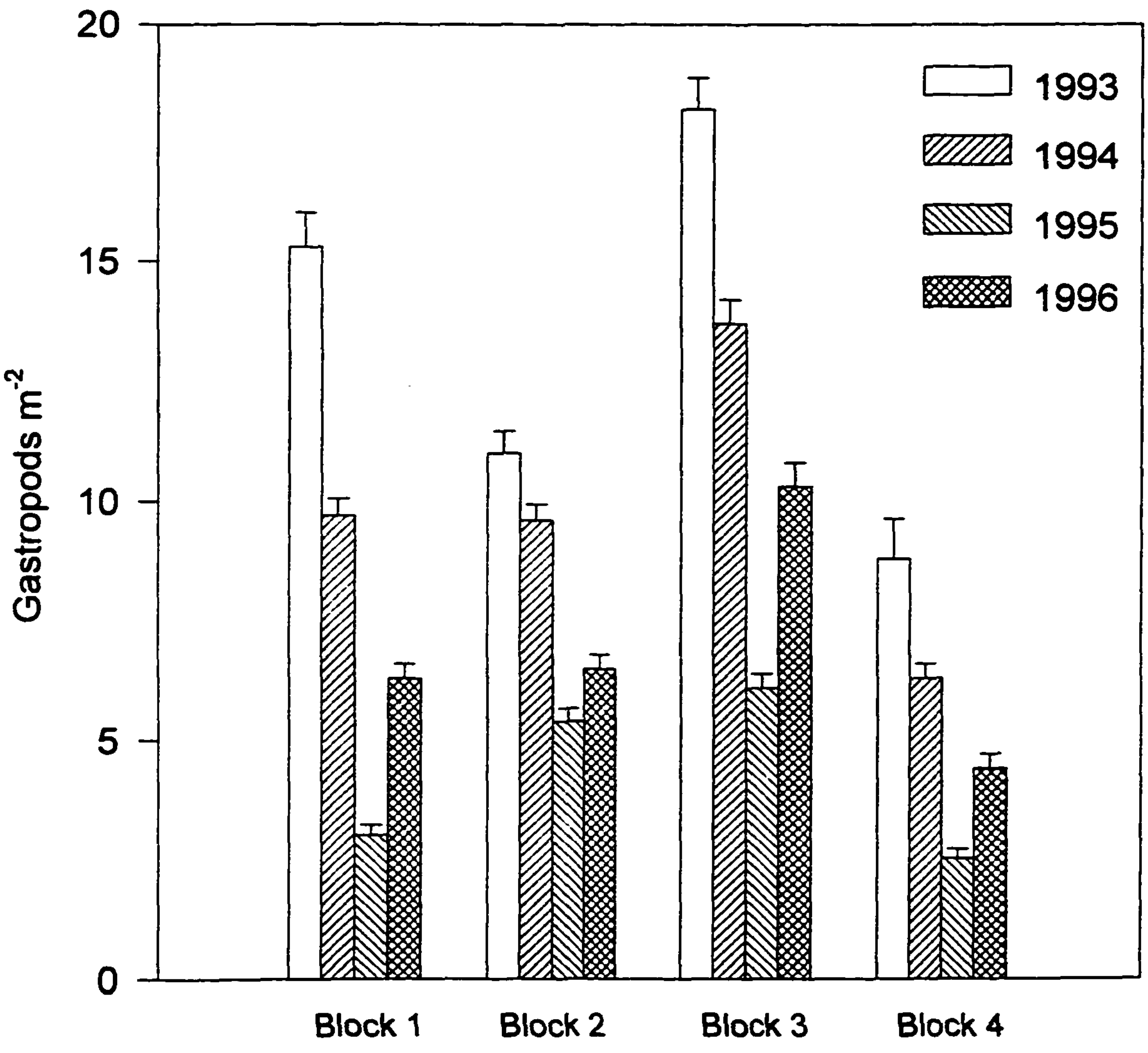
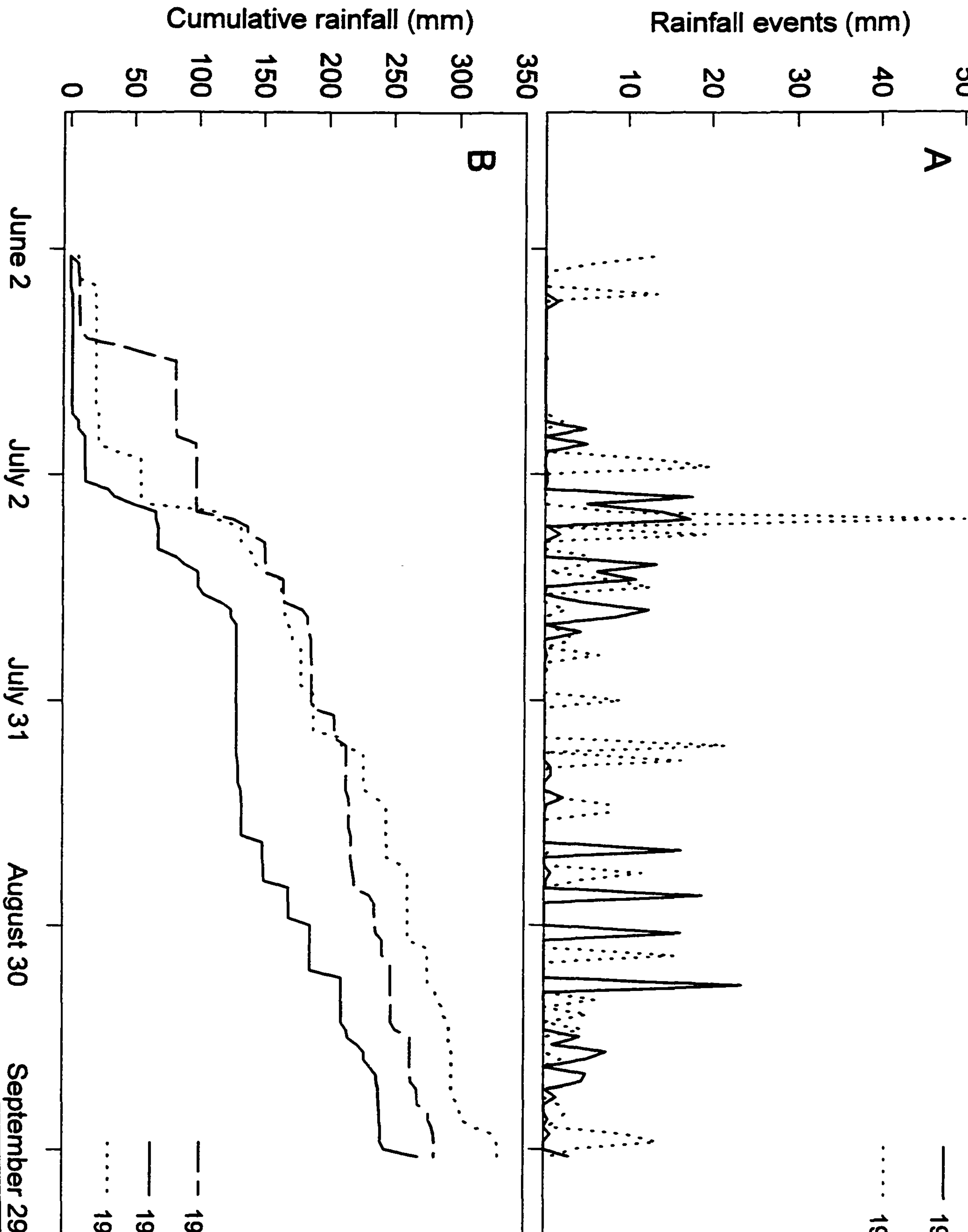

20
15
10
5
0
Gastropods m-2
1993
1994
1995
1996
Block 1
Block 2
Block 3
Block 4

Figure 2. Summer rainfall events from 1995 and 1996 (A) and cumulative summer rainfall from 1994-1996 on Block 3 of the Fallingsnow Study Area (B) (after Reynolds 1996).


Rainfall events (mm)
A
1995
1996
Cumulative rainfall (mm)
B
1994
1995
1996
June 2
July 2
July 31
August 30
September 29

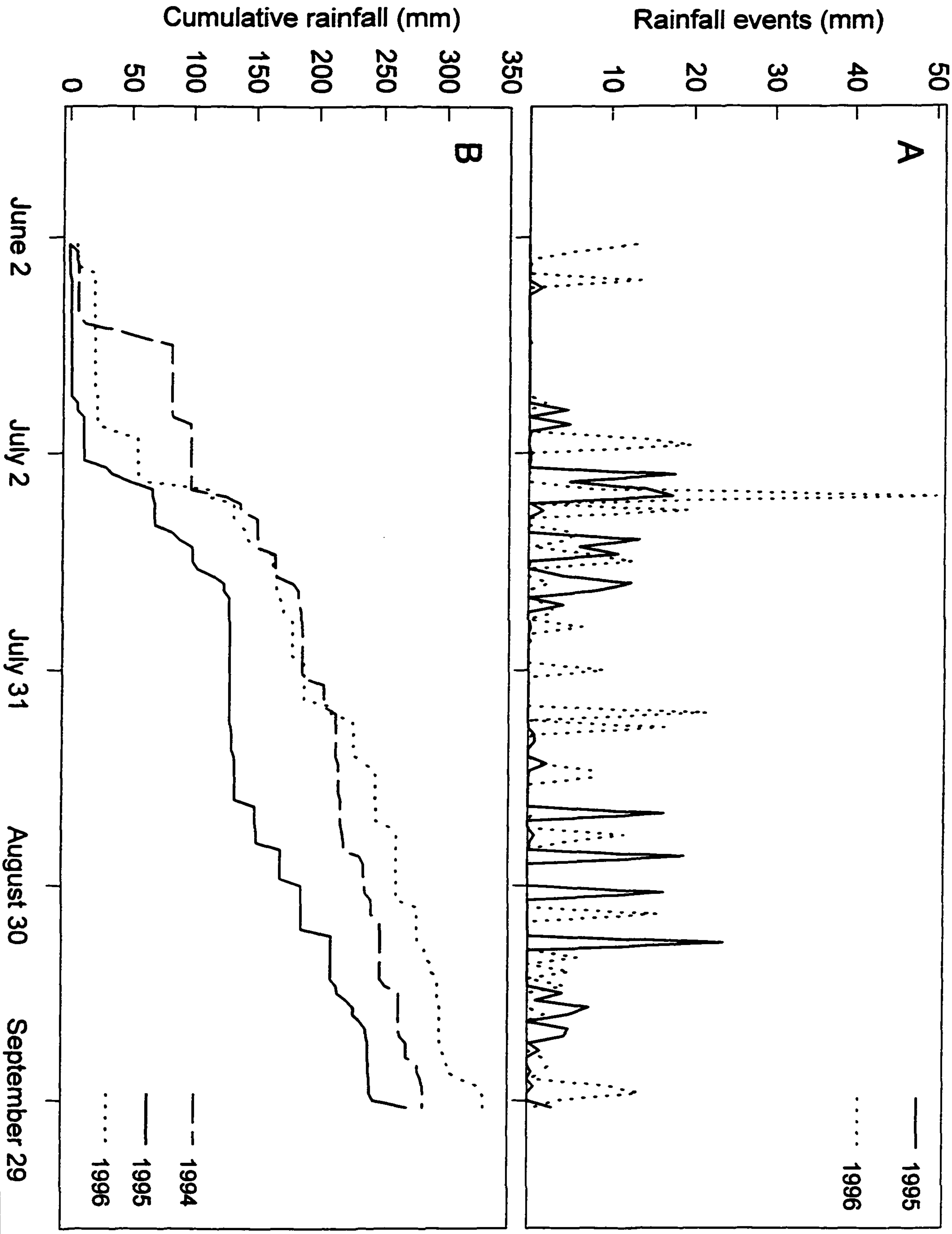

Rainfall events (mm)
10
20
30
40
50
A
1995
1996
Cumulative rainfall (mm)
0
50
100
150
200
250
300
350
B
1994
1995
1996
June 2
July 2
July 31
August 30
September 29

Table 4. Gastropods collected using cardboard sheets at the Fallingsnow Study Area during the summers of 1995 and 1996.

Sampling period	Total gastropods *		Mean gastropod density (m^{-2})	
	1995	1996	1995	1996
June	271	107	0.8 ± 0.1	0.3 ± 0.04
July	2078	2300	6.1 ± 0.3	6.6 ± 0.3
August	1532	3419	4.5 ± 0.3	10.1 ± 0.4
September	1944	3432	5.7 ± 0.3	10.7 ± 0.4

* totals and densities represent specimens collected from all four blocks during each sampling period

throughout the summer.

There were also differences in gastropod densities among blocks at each sampling time. These differences were greatest during the August and September sampling periods ($p < 0.0001$)(Figure 3A). In 1995, late summer densities on Block 2 and 3 remained the same or increased slightly, whereas densities on Block 1 and 4 decreased. Generally, in 1996, gastropod densities increased throughout the summer, with those on Block 3 exceeding all others in August and September ($p < 0.0001$)(Figure 3 B).

In 1995, gastropod densities did not differ significantly among the 4 conifer release treatments and the untreated control area in each experimental block. However, in 1996, significant overall treatment differences were detected among the 5 areas ($p = 0.007$). Densities on untreated control areas were significantly greater than on Vision® ($p = 0.03$) and Release® treated areas (p=0.008), but did not differ from brushsaw and Silvana selective treatments (Figure 4). Analyses of individual gastropod species showed treatment, time and treatment x time differences in both 1995 and 1996 (Figure 5)(Table 5).

These differences also varied among the four sampling periods (p=0.0246) and across experimental blocks (Figure 6)(Table 6). The June sampling period produced low gastropod densities across all treatments and blocks. However, densities increased in the following three sampling periods. In general, untreated control areas had high gastropod densities across all 4 experimental blocks. Gastropod density was also high on the brushsaw area on Block 1, Silvana Selective on Blocks 2 and 3 and Vision® on Block 4.

Overall mean summer densities on CRV plots and unharvested forest sites, estimated using cardboard sheets, were lower than on untreated controls in both 1995 and

Figure 3. Mean (± S.E.) terrestrial gastropod density on all four experimental blocks from each sampling period in 1995 (A) and 1996 (B) from the Fallingsnow Study Area.

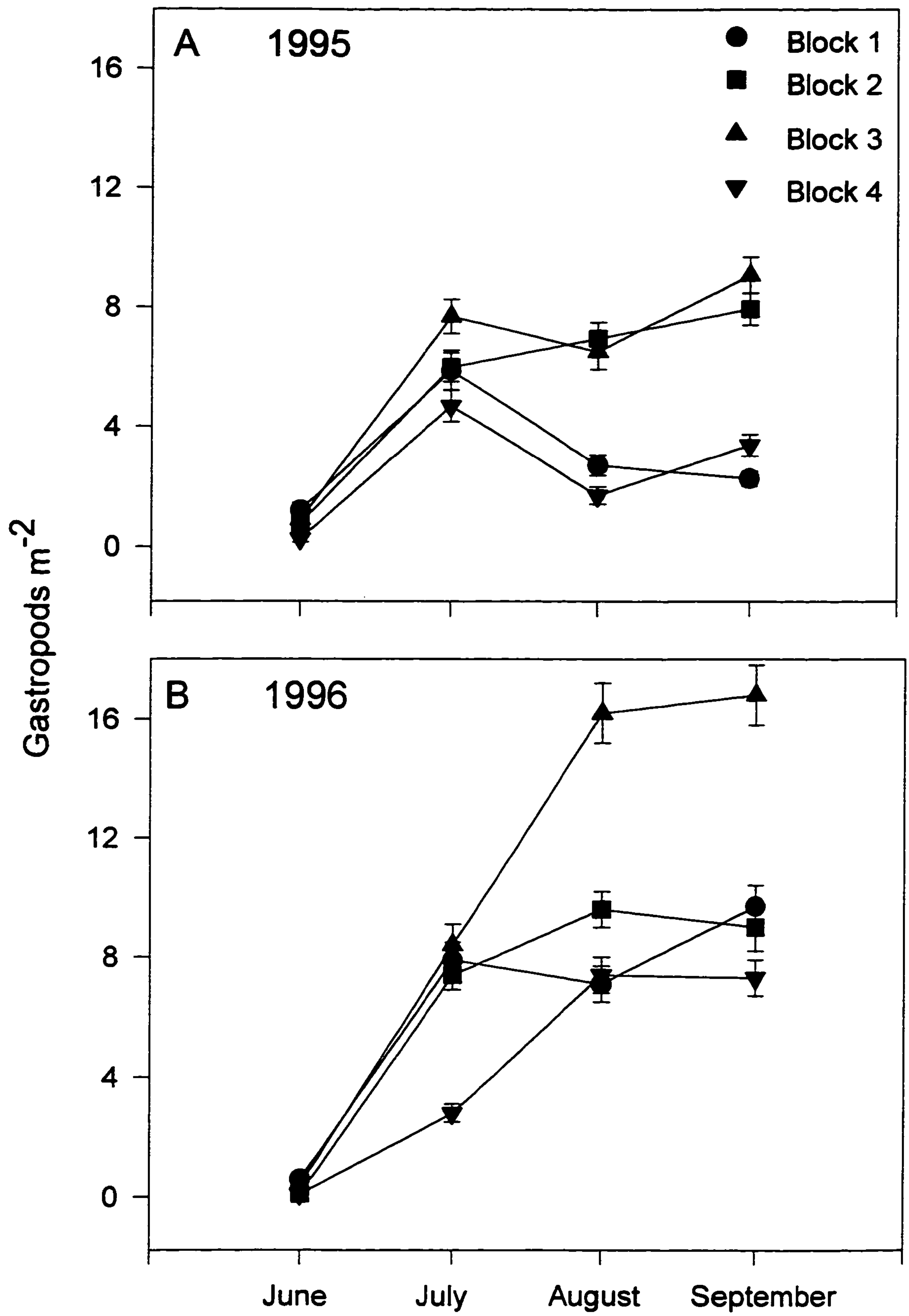

A 1995
Block 1
Block 2
Block 3
Block 4
16
12
8
4
0
Gastropods m-2
B 1996
16
12
8
4
0
June
July
August
September

Figure 4. Mean (± S.E.) terrestrial gastropod density from all four conifer release treatments and untreated control areas in 1995 and 1996 from all experimental blocks at the Fallingsnow Study Area. Bars headed by the same letter are not significantly different within each year at $p < 0.05$.

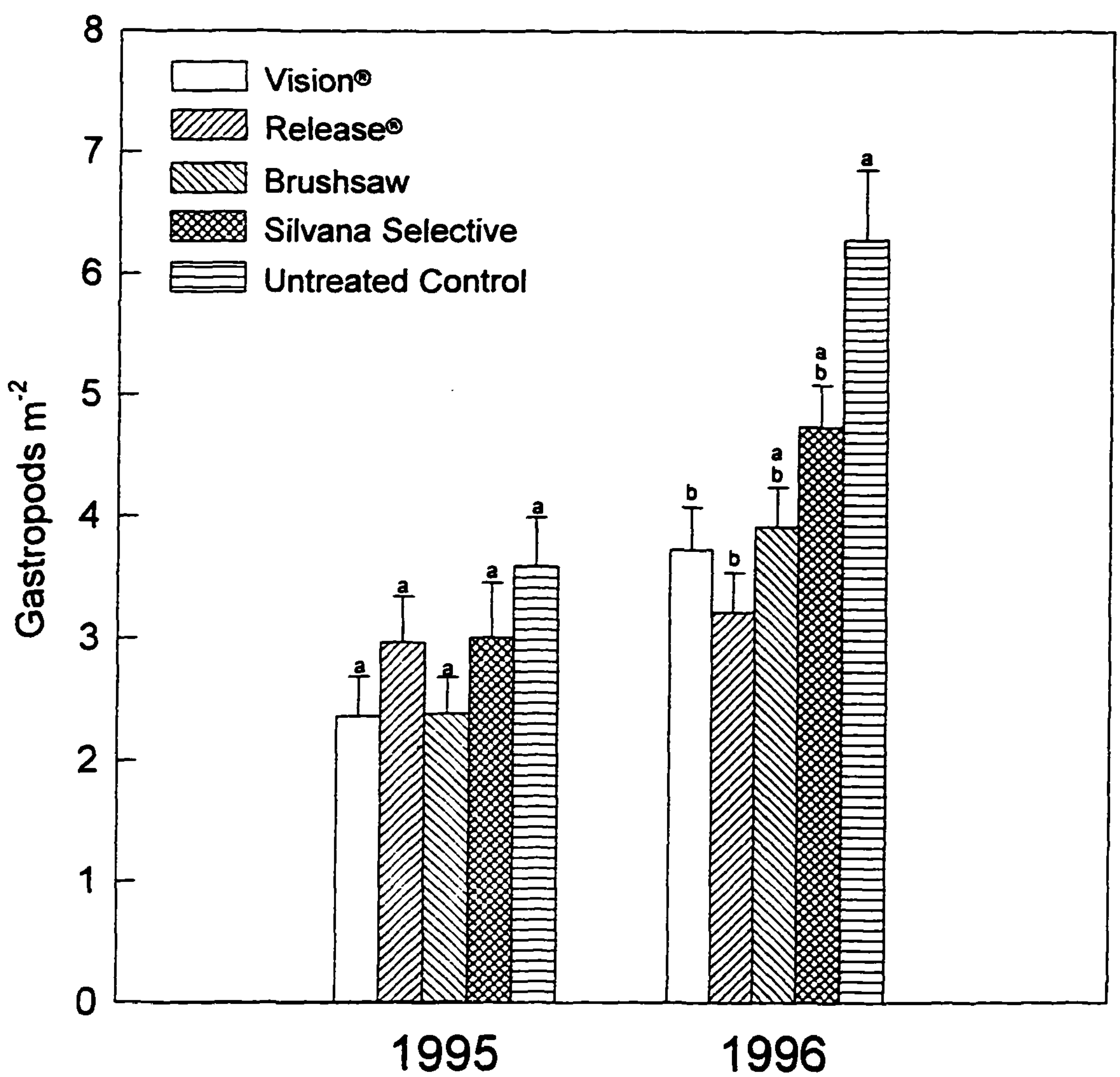
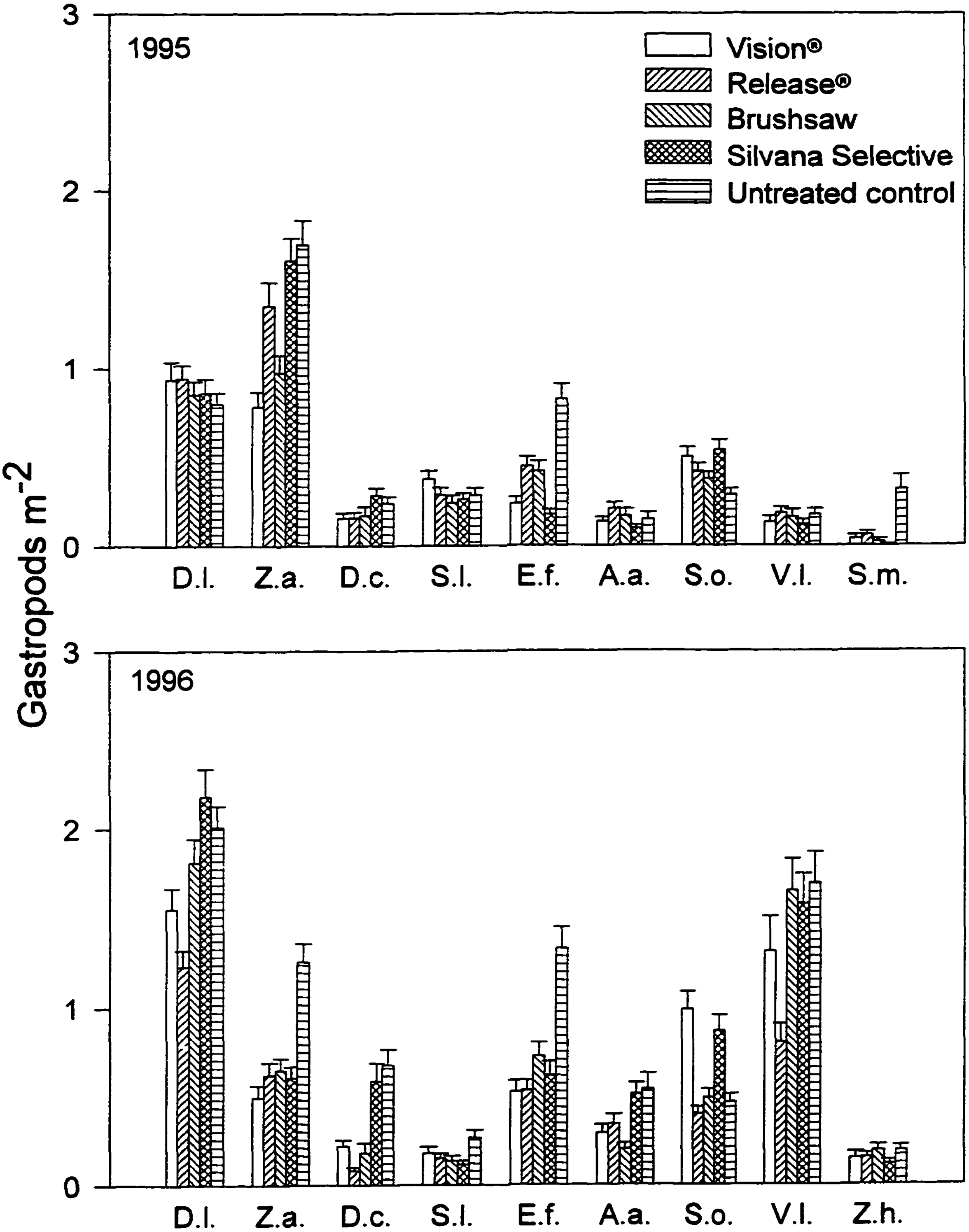

Vision®
Release®
Brushsaw
Silvana Selective
Untreated Control
Gastropods m-2
0
1
2
3
4
5
6
7
8
1995
1996
a
b

Figure 5. Mean densities (± S.E.) of each of the 9 most common species of terrestrial gastropod in the four conifer release treatment areas and the untreated control in 1995 (A) and 1996 (B). [D.l.=*Deroceras laeve;* Z.a. =*Zonitoides arboreus*; D.c.=*Discus cronkhitei*; S.l.=*Strobilops labyrinthica*; E.f.=*Euconulus fulvus*; A.a.=*Anguispira alternata*; S.o.=*Succinea ovalis*; V.l.=*Vitrina limpida*; S.m.=*Striatura milium*; Z.h.=*Zoögenetes harpa*]



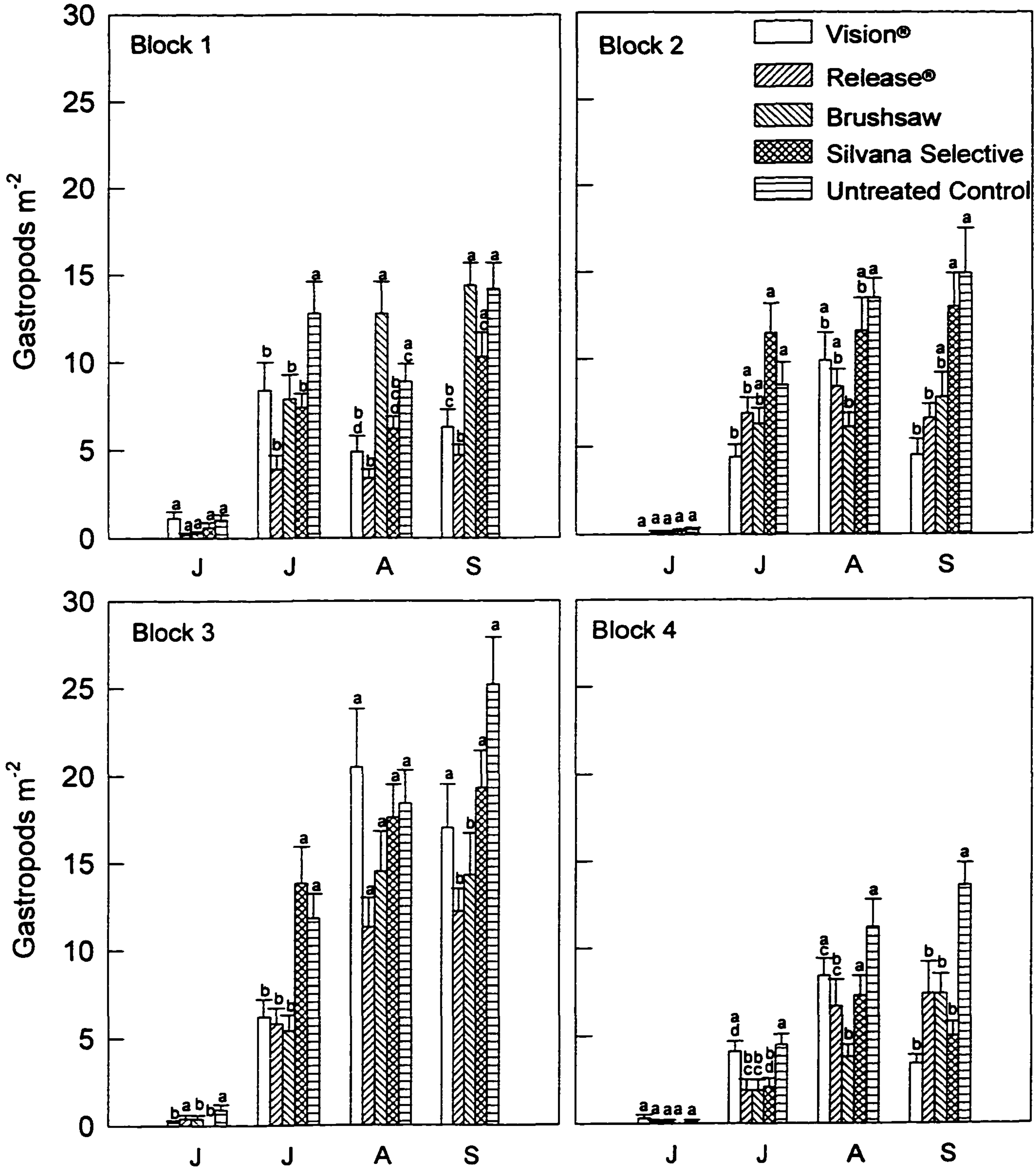
Gastropods m-2
1995
Vision®
Release®
Brushsaw
Silvana Selective
Untreated control
0
1
2
3
D.l.
Z.a.
D.c.
S.l.
E.f.
A.a.
S.o.
V.l.
S.m.
1996
D.l.
Z.a.
D.c.
S.l.
E.f.
A.a.
S.o.
V.l.
Z.h.

Table 5. 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 9 most common species in 1995 and 1996.

	1995			1996		
	Treatment	Time	Treatment x Time	Treatment	Time	Treatment x Time
Total	F[†]=1.89, p=0.177	F[‡]=16.83, p<0.01*	F[§]=1.07,p=0.411	F=5.9,p=0.0071*	F=61.7,p<0.01*	F=2.34,p=0.02*
Deroceras laeve	F=4.73, p=0.016*	F=38.479,p<0.01*	F=3.45,p=0.002*	F=4.09,p=0.026*	F=23.4,p<0.01*	F=0.74,p=0.706
Zonitoides arboreus	F=1.447, p=0.2784	F=96.997,p<0001*	F=1.38,p=0.2185	F=3.015,p=0.062	F=18.85,p<0.01*	F=1.48,p=0.176
Discus cronkhitei	F=1.589, p=0.2402	F=4.46,p=0.0352*	F=1.798,p=0.086	F=8.63,p=0.002*	F=11.85,p<0.01*	F=1.24,p=0.295
Euconulus fulvus	F=1.779, p=0.1979	F=27.681,p<0.00*	F=0.96,p=0.5016	F=6.85,p=0.004*	F=25.41,p<0.01*	F=4.97,p<0.01*
Zöogenetes harpa				F=0.47,p=0.7606	F=25.25,p<0.01*	F=1.07,p=0.416
Stobilops labyrinthica	F=2.558, p=0.093	F=7.58,p=0.0078*	F=2.04,p=0.049*	F=2.043, p=0.152	F=16.9,p<0.01*	F=0.998,p=0.47
Anguispira alternata	F=3.2495,p=0.050	F=12.07,p=0.002*	F=2.602,p=0.01*	F=1.22,p=0.3541	F=10.9,p<0.05*	F=0.91,p=0.546
Succinea ovalis	F=7.997,p=0.002*	F=42.43,p<0.001*	F=4.864,p<0.01*	F=4.18,p=0.024*	F=11.0,p<0.05*	F=1.77,p=0.092
Vitrina limpida	F=4.16,p=0.0242*	F=44.2,p<0.001*	F=3.51,p=0.002*	F=2.218,p=0.128	F=6.76,p=0.01*	F=1.52,p=0.163
Striatura milium	F=0.555,p=0.6997	F=9.897,p=0.003*	F=0.49,p=0.9074			

* 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

Figure 6. Mean (± S.E.) densities of terrestrial gastropods from all four conifer release treatments and untreated control areas during each sampling period in 1996 from each experimental block at the Fallingsnow Study Area. Bars headed by the same letter are not significantly different within each block and sampling period at $p < 0.05$.



Block 1
Block 2
Block 3
Block 4
Vision®
Release®
Brushsaw
Silvana Selective
Untreated Control
Gastropods m-2
J J A S

Table 6. F-statistics and p-values of 1-way ANOVA multiple comparisons for treatment effects based on total gastropod densities throughout the 4 sampling periods in 1996 within each experimental block of the Fallingsnow Study Area.

Sampling period	Block 1	Block 2	Block 3	Block 4
June	$F_{[4,95]}=2.47$; $p = 0.049$	$F_{[4,95]}=1.69$; $p = 0.157$	$F_{[4,95]}=4.33$; $p = 0.003$	$F_{[4,95]}=1.33$; $p = 0.263$
July	$F_{[4,95]}=4.32$; $p = 0.003$	$F_{[4,95]}=5.43$; $p < 0.001$	$F_{[4,95]}=8.06$; $p < 0.001$	$F_{[4,95]}=6.6$; $p < 0.001$
August	$F_{[4,91]}=12.59$; $p < 0.001$	$F_{[4,92]}=4.463$; $p = 0.002$	$F_{[4,94]}=2.098$; $p = 0.087$	$F_{[4,95]}=6.54$; $p < 0.001$
September	$F_{[4,91]}=15.24$; $p < 0.001$	$F_{[4,85]}=7.136$; $p < 0.001$	$F_{[4,86]}=4.47$; $p = 0.003$	$F_{[4,90]}=10.55$; $p < 0.001$

Table 7. Mean densities (± S.E.) of terrestrial gastropods in 1995 and 1996 from the untreated control, complete removal Vision® (CRV) and unharvested forest site on each of the four experimental blocks at the Fallingsnow Study Area.

Block	Untreated Control		CRV		Unharvested Forest	
	1995	1996	1995	1996	1995	1996
1	3.5 ± 0.4	8.9 ± 0.9	1.8 ± 0.4	11.0 ± 1.1	*n/a	9.3 ± 1.0
2	5.8 ± 0.6	8.7 ± 0.9	2.7 ± 0.7	3.2 ± 0.4	n/a	7.1 ± 0.7
3	9.1 ± 0.9	12.9 ± 1.3	2.7 ± 0.9	6.7 ± 1.1	n/a	6.1 ± 0.8
4	3.6 ± 0.5	7.3 ± 0.8	1.8 ± 0.5	4.5 ± 0.7	n/a	4.0 ± 0.5
Total	5.7 ± 0.5	9.4 ± 0.5	2.3 ± 0.3	6.4 ± 0.5	n/a	6.7 ± 0.4

* Terrestrial gastropods were only collected from the unharvested forest during 1996

1996 ($p < 0.0001$, $p = 0.001$, respectively) (Table 7). Densities also varied among the experimental blocks in both years and not all species were collected on all blocks (Table 8 and 9; Appendix 8 and 9).

Gastropod densities estimated from soil cores were similar among Vision®, CRV, unharvested forest and untreated control sites in 1996 and ranged from 178.57 ± 112.64 m^{-2} on CRV plots to 376.96 ± 221.29 m^{-2} on Vision® plots (Table 10). Density estimates based on individual soil cores ranged from 0 - 1428.56 m^{-2}. Soil moisture and pH in the organic layer were highest in the unharvested forest site and lowest in the CRV plot, but moisture and pH in mineral soil were highest in mineral soil in the Vision® and untreated control, respectively and lowest in the unharvested forest (Appendix 9).

Soil moisture was variable among the four experimental blocks and among the four sampling periods in 1995 and 1996 (Figure 7)(Table 11 and 12). Generally, in both 1995 and 1996, Blocks 2 and 4 were drier than Blocks 1 and 3. Moisture levels in both organic and mineral soils were higher in 1996. Overall, moisture levels were similar among the untreated control, CRV and unharvested forest. However, soil moisture was significantly greater in the unharvested forest organic layer on Block 1 than on the untreated control and CRV ($p = 0.0119$) (Figure 8), but that in the mineral soil layer was similar among these treatments across all blocks.

Within each block, organic soil pH was similar among CRV and untreated control areas in both 1995 and 1996. However, treatment differences existed in mineral soil on Block 3 ($p = 0.04$) in 1995 and Block 2 in 1996 (Figure 9 and 10). Organic and mineral soil pH in the unharvested forest varied among blocks, but was generally more acidic than the other treatments. Organic soii pH was usually higher than mineral soil pH, regardless

Table 8. Total numbers of each gastropod species collected from complete removal Vision® plots (CRV) within the four experimental blocks at the Fallingsnow Study Area in 1995* and 1996.

	1995					1996				
	Block					Block				
Species	1	2	3	4	Total	1	2	3	4	Total
Zonitoides arboreus	7	8	7	1	23	97	25	16	29	167
Deroceras laeve	3	24	5	3	35	45	38	21	13	117
Succinea ovalis	4	3	2	2	11	14	10	11	9	44
Euconulus fulvus	1	1	3	2	7	68	10	41	12	131
Strobilops labyrinthica	1	0	13	10	24	74	4	86	57	221
Discus cronkhitei	12	5	1	0	18	24	5	8	7	44
Vitrina limpida	0	0	2	0	2	4	4	3	0	11
Anguispira alternata	0	2	2	1	5	10	5	2	14	31
Cochlicopa lubrica	0	0	0	0	0	11	0	0	0	11
Striatura milium	0	0	3	1	4	5	0	11	5	21
Vertigo gouldi	1	1	2	6	10	3	0	8	1	12
Zöogenetes harpa	0	0	0	0	0	3	0	5	0	8
Pallifera dorsalis	1	1	0	0	2	13	0	0	1	14
Vertigo modesta	0	2	2	1	5	0	0	0	2	2
Columella edentula	0	0	1	0	1	6	0	5	2	13
Vertigo ovata	0	0	0	0	0	0	0	0	0	0
Gastrocopta tappaniana	0	0	3	4	7	2	0	7	2	11
Striatura exigua	0	0	1	0	1	1	0	5	0	6
Punctum minutissimum	0	0	0	0	0	0	0	0	0	0
Carychium exile canadense	0	0	0	0	0	0	0	1	0	1
Pupisoma minus	0	0	0	0	0	0	0	1	0	1
Total	30	47	47	31	155	380	101	231	154	866

* collected in June, July, August and September sampling periods in 1996, but only in August and September in 1995

Table 9. Total numbers of terrestrial gastropods collected using cardboard sheets from the unharvested forest site on each of the four experimental blocks of the Fallingsnow Study Area during the summer of 1996.

	Block				
Species	1	2	3	4	Total
Zonitoides arboreus	94	76	80	46	296
Deroceras laeve	53	39	16	14	122
Succinea ovalis	11	13	2	15	41
Euconulus fulvus	91	68	39	20	218
Strobilops labyrinthica	47	15	44	25	131
Discus cronkhitei	178	113	73	51	415
Vitrina limpida	19	18	10	9	56
Anguispira alternata	25	33	68	37	163
Cochlicopa lubrica	16	12	13	1	42
Striatura milium	8	0	2	3	13
Vertigo gouldi	14	2	0	5	21
Zöogenetes harpa	25	23	8	16	72
Pallifera dorsalis	6	10	2	3	21
Vertigo modesta	6	3	0	5	14
Columella edentula	9	3	5	1	18
Vertigo ovata	0	0	0	0	0
Gastrocopta tappaniana	9	0	0	0	9
Striatura exigua	3	0	4	5	12
Punctum minutissimum	0	0	1	2	3
Carychium exile canadense	2	0	0	0	2
Pupisoma minus	0	0	0	0	0
Total	616	428	367	258	1669

Table 10. Mean densities (± S.E.) of terrestrial gastropods (m^{-2}) extracted from soil cores taken from Block 3 of the Fallingsnow Study Area in 1996.

Species	Vision®	CRV	UF	UC	*p-value
Zonitoides arboreus	119.04 ± 66.55	0	119.04 ± 66.55	59.52 ± 42.09	$p = 0.10$
Strobilops labyrinthica	138.88 ± 65.05	119.04 ± 66.55	39.68 ± 26.25	79.36 ± 31.37	$p = 0.48$
Cochlicopa lubrica	19.84 ± 19.84	0	0	0	$p = 0.39$
Striatura milium	59.52 ± 42.09	39.68 ± 26.25	39.68 ± 26.25	79.36 ± 31.37	$p = 0.71$
Vertigo gouldi	0	0	0	19.84 ± 19.84	$p = 0.39$
Zöogenetes harpa	0	0	0	19.84 ± 19.84	$p = 0.39$
Columella edentula	39.68 ± 26.25	0	0	0	$p = 0.10$
Striatura exigua	0	0	19.84 ± 19.84	0	$p = 0.39$
Carychium exile canadense	0	19.84 ± 19.84	0	0	$p = 0.39$
Overall Mean	376.96 ± 221.29	178.57 ± 112.64	218.25 ± 138.89	257.93 ± 144.51	$p = 0.43$

*p-values based on a Kruskal-Wallis 1-way ANOVA.

Figure 7. Mean (± S.E.) soil moisture levels recorded from untreated control areas on all four experimental blocks in 1995 and 1996 from the Fallingsnow Study Area. Labels on x-axis refer to June (J), July (J), August (A) and September (S).

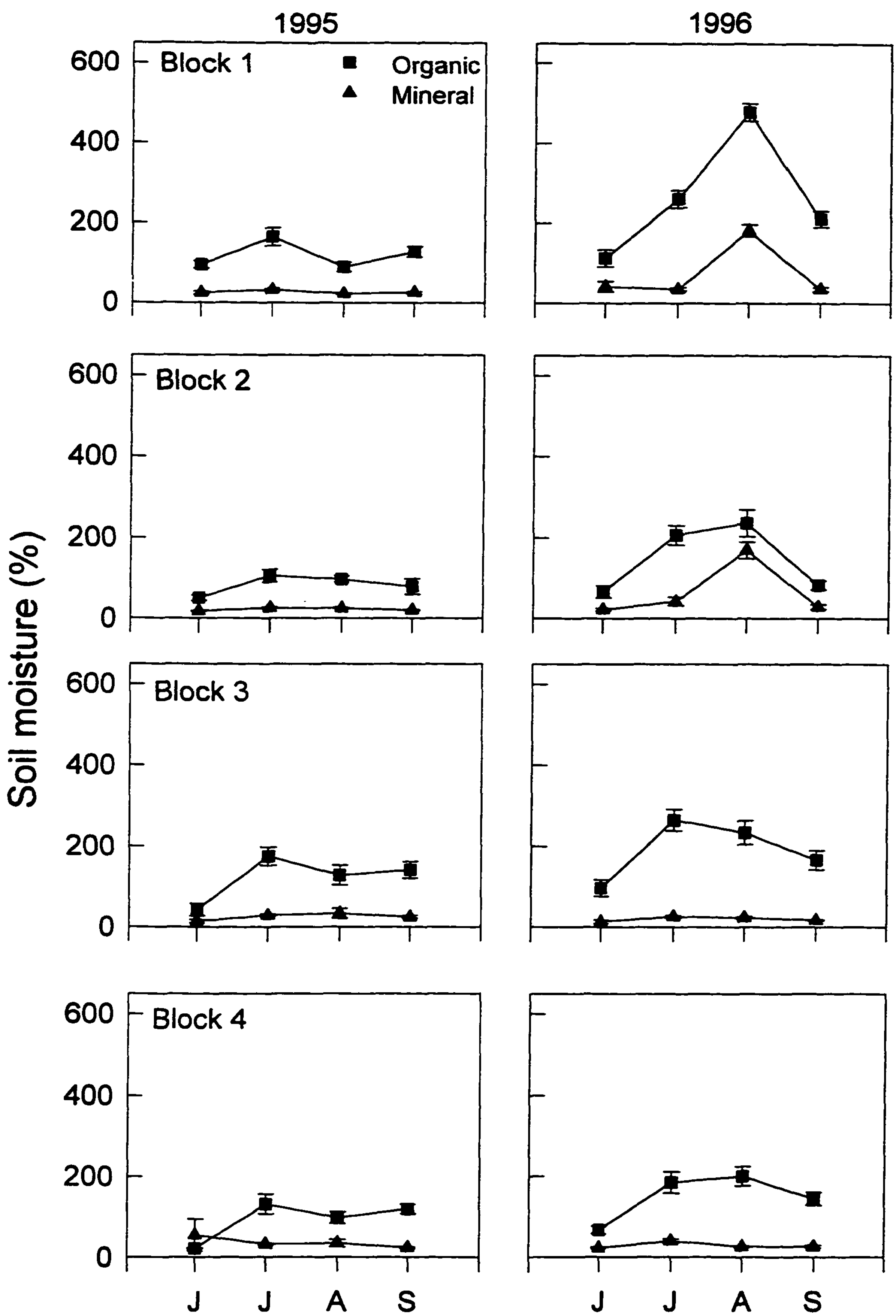

1995
1996
Block 1
Organic
Mineral
Block 2
Block 3
Block 4
Soil moisture (%)
600
400
200
0
J
J
A
S

Table 11. Mean (± S.E.) soil moisture levels (%)totals from untreated control areas on each of the four experimental blocks (all four sampling periods combined) of the Fallingsnow Study Area in 1995 and 1996.

	1995		1996	
	Organic	Mineral	Organic	Mineral
Block 1	115.7 ± 7.8	26.6 ± 1.7	264.4 ± 22.1	79.5 ± 12.1
Block 2	78.5 ± 6.7	22.5 ± 1.0	154.1 ± 18.2	61.1 ± 10.4
Block 3	119.6 ± 12.6	25.9 ± 3.8	190.9 ± 15.4	19.5 ± 1.6
Block 4	95.2 ± 9.7	34.2 ± 7.0	147.5 ± 13.3	28.7 ± 1.9
Mean total	102.3 ± 92	27.3 ± 3.4	189.2 ± 17.3	47.2 ± 6.5

Table 12. Mean (± S.E.) soil moisture levels (%) collected from untreated control areas during each sampling period (all four block combined) in 1995 and 1996 from the Fallingsnow Study Area.

	1995		1996	
	Organic	Mineral	Organic	Mineral
June	55.4 ± 6.8	26.7 ± 9.3	88.9 ± 9.2	26.8 ± 4.0
July	151.2 ± 12.0	29.8 ± 1.5	234.5 ± 13.3	38.5 ± 4.0
August	103.0 ± 8.3	28.9 ± 3.7	297.4 ± 22.9	104.8 ± 13.9
September	122.5 ± 8.3	23.3 ± 1.3	160.4 ± 12.2	27.4 ± 2.3
Mean total	108.0 ± 8.9	27.2 ± 4.0	195.3 ± 14.4	49.4 ± 6.1

Figure 8. Mean (± S.E.) soil moisture levels from complete removal Vision® (CRV), unharvested forest (UF) and untreated control (UC) areas on all four experimental blocks of the Fallingsnow Study Area in 1996. Bars headed by the same letter are not significantly different within each block at $p < 0.05$.

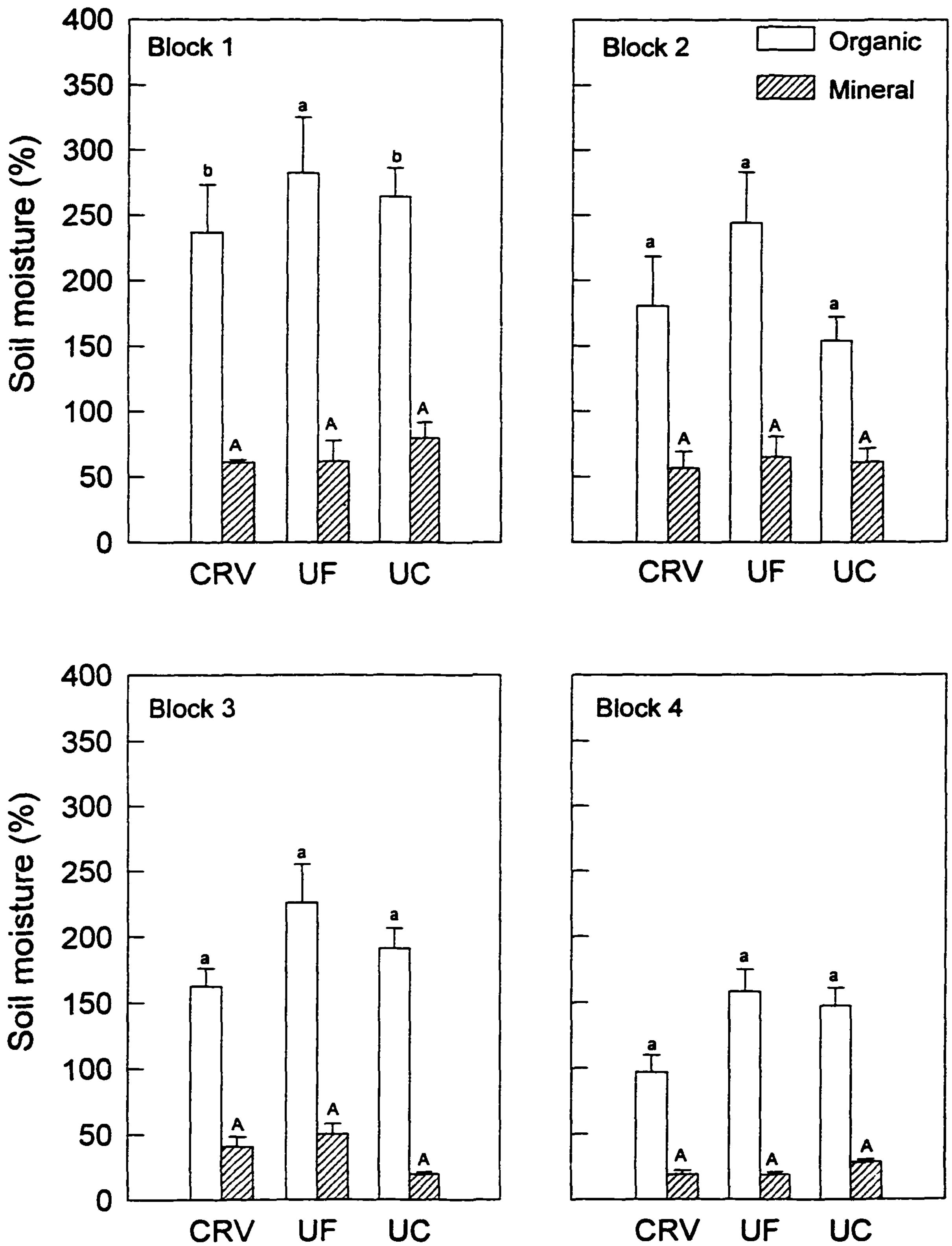

Block 1
Block 2
Block 3
Block 4
Organic
Mineral
Soil moisture (%)
0
50
100
150
200
250
300
350
400
CRV
UF
UC
a
b
A

Figure 9. Mean (± S.E.) pH values from the complete removal Vision® (CRV) and untreated control (UC) in 1995 on each of the four experimental blocks of the Fallingsnow Study Area. Bars headed by the same letter are not significantly different within each block at $p<0.05$.

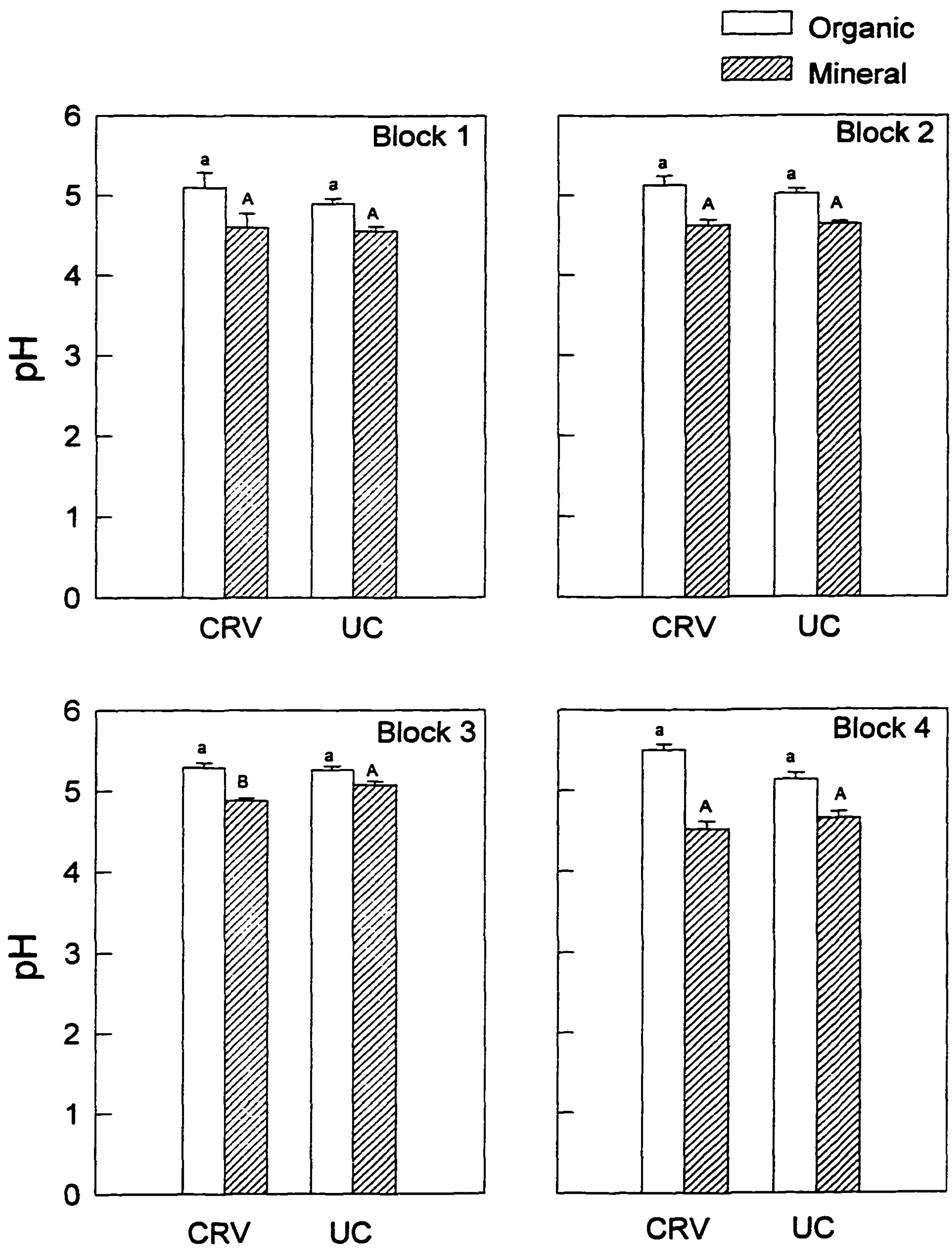
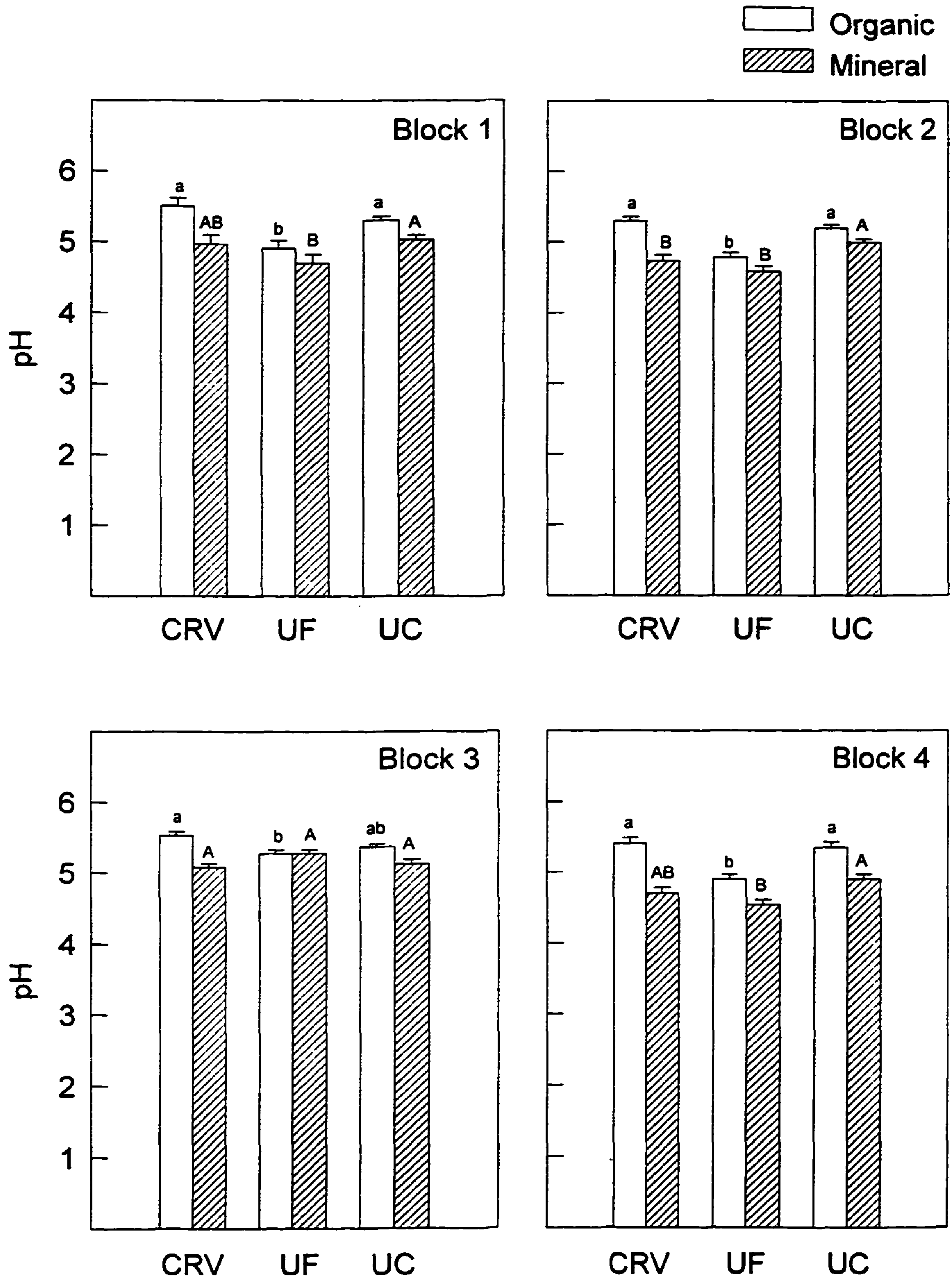

Organic
Mineral
Block 1
Block 2
Block 3
Block 4
pH
0
1
2
3
4
5
6
a
A
B
CRV
UC

Figure 10. Mean (± S.E.) pH values recorded from the complete removal Vision® (CRV), unharvested forest (UF) and untreated control (UC) in 1996 on each of the four experimental blocks of the Fallingsnow Study Area. Bars headed by the same letter are not significantly different within each block at $p<0.05$.

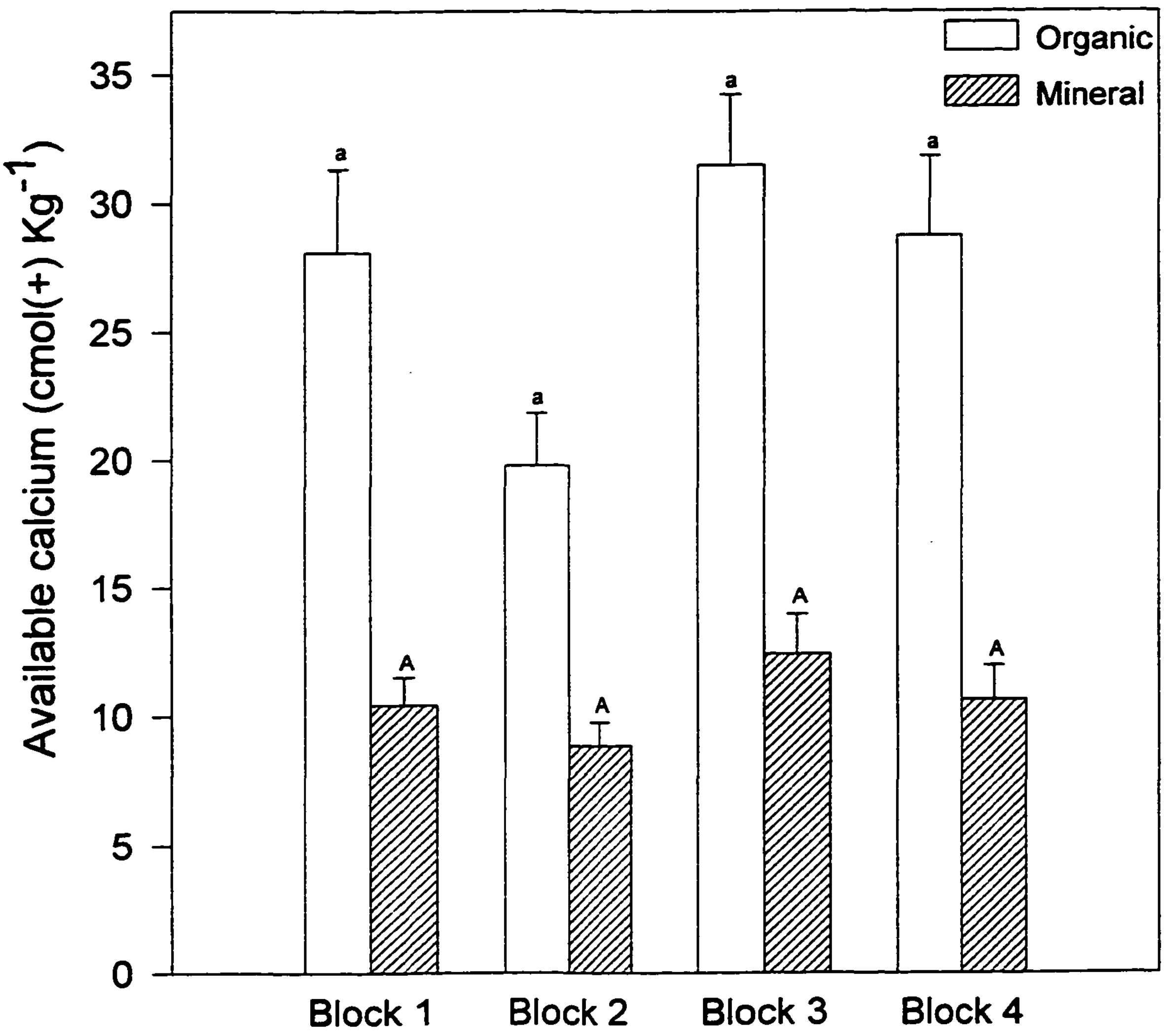

Organic
Mineral
Block 1
Block 2
Block 3
Block 4
pH
6
5
4
3
2
1
a
AB
b
B
A
ab
CRV
UF
UC

of treatment.

Available Ca concentration did not differ significantly among the four experimental blocks (Figure 11), but both organic and mineral soil Ca concentrations were slightly higher on Block 3. Calcium on untreated control and CRV plots varied among blocks (Figure 12). On Block 1, mineral soil Ca was higher in untreated control areas than in CRV plots ($p = 0.0096$). However, on Block 2, organic soil Ca was greater in CRV plots than in untreated control areas ($p = 0.0158$). Calcium concentrations were similar between untreated control areas and CRV plots on Blocks 3 and 4. No relationship existed between gastropod density and available Ca concentrations in organic or mineral soil (Figure 13).

Microclimatic conditions varied among the 4 areas in which gastropod soil cores were collected (Vision®, complete removal Vision®, untreated control, unharvested forest). Overall ambient (2 m) and near ground (0.25 m) temperatures were highest in the CRV plot (Table 13 A-D). Overall ambient and near ground relative humidity was lowest in the Vision® area. Duff soil temperatures were lowest in the unharvested forest and highest in the CRV plot. Fluctuations in temperature and relative humidity over 24 hours were greatest on CRV and Vision treatments (Figure 14-15). Differences between ambient and near-ground temperature were greatest on treated sites. In contrast, relative humidity differences between ambient and near ground locations were greater on untreated sites. Temperature and relative humidity were inversely related across the four areas.

Figure 11. Mean (± S.E.) available calcium levels from organic and mineral soil samples collected in 1995 from all four experimental blocks of the Fallingsnow Study Area. Bars headed by the same letter are not significantly different within each block at $p < 0.05$.



Organic
Mineral
Available calcium (cmol(+) Kg^{-1})
35
30
25
20
15
10
5
0
a
a
a
a
A
A
A
A
Block 1
Block 2
Block 3
Block 4

Figure 12. Mean (± S.E.) available calcium levels from the untreated control (UC) and complete removal Vision® (CRV) on each experimental block from the Fallingsnow Study Area in 1995. Bars headed by the same letter are not significantly different within each block at $p<0.05$.

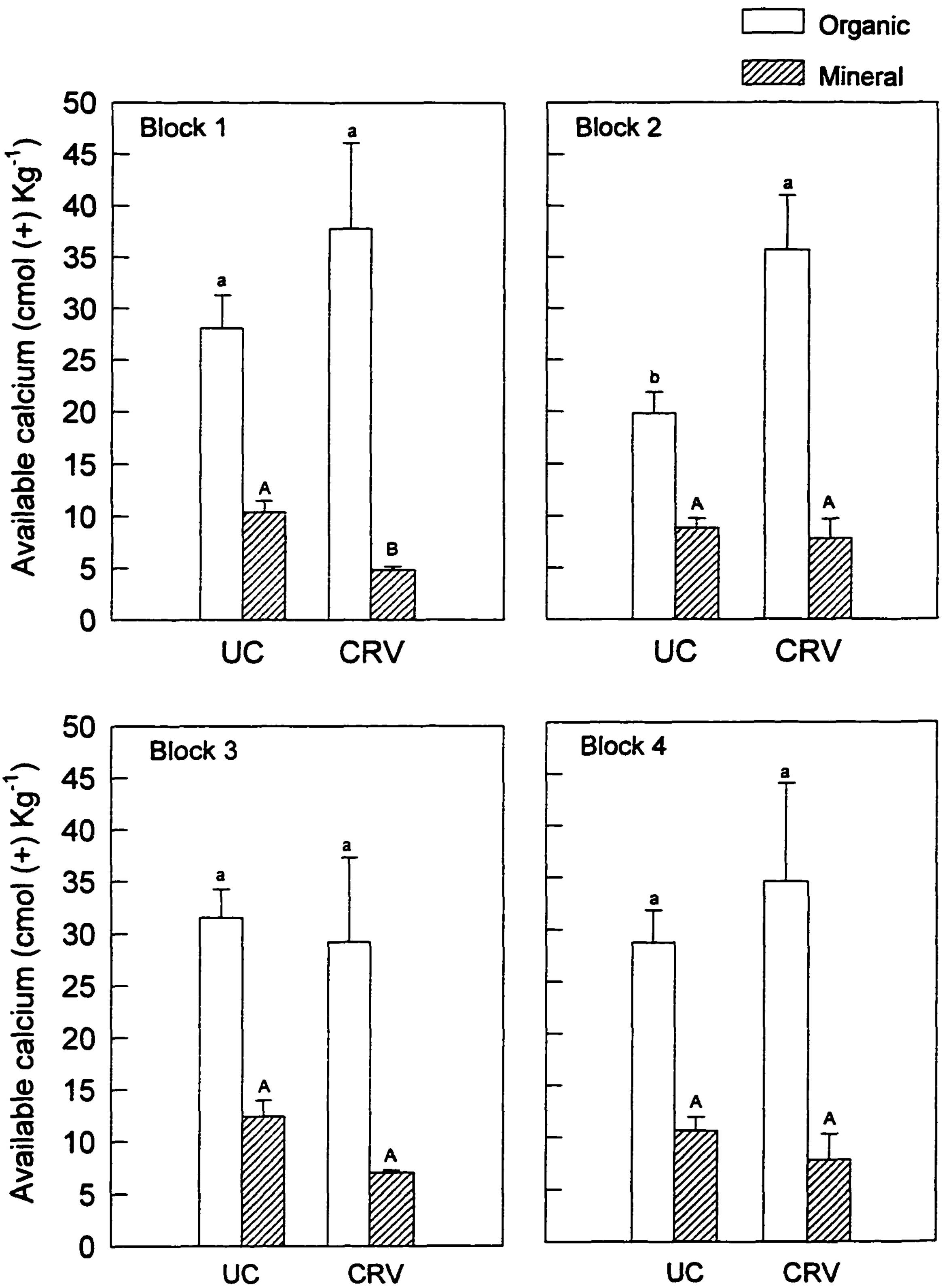

Organic
Mineral
Available calcium (cmol (+) Kg^{-1})
Block 1
Block 2
Block 3
Block 4
UC
CRV
0
5
10
15
20
25
30
35
40
45
50
a
b
A
B

Figure 13. Scattergram of gastropod density and available calcium levels measured from organic (A) and mineral (B) soil samples collected from all four experimental blocks of the Fallingsnow Study Area in 1995.

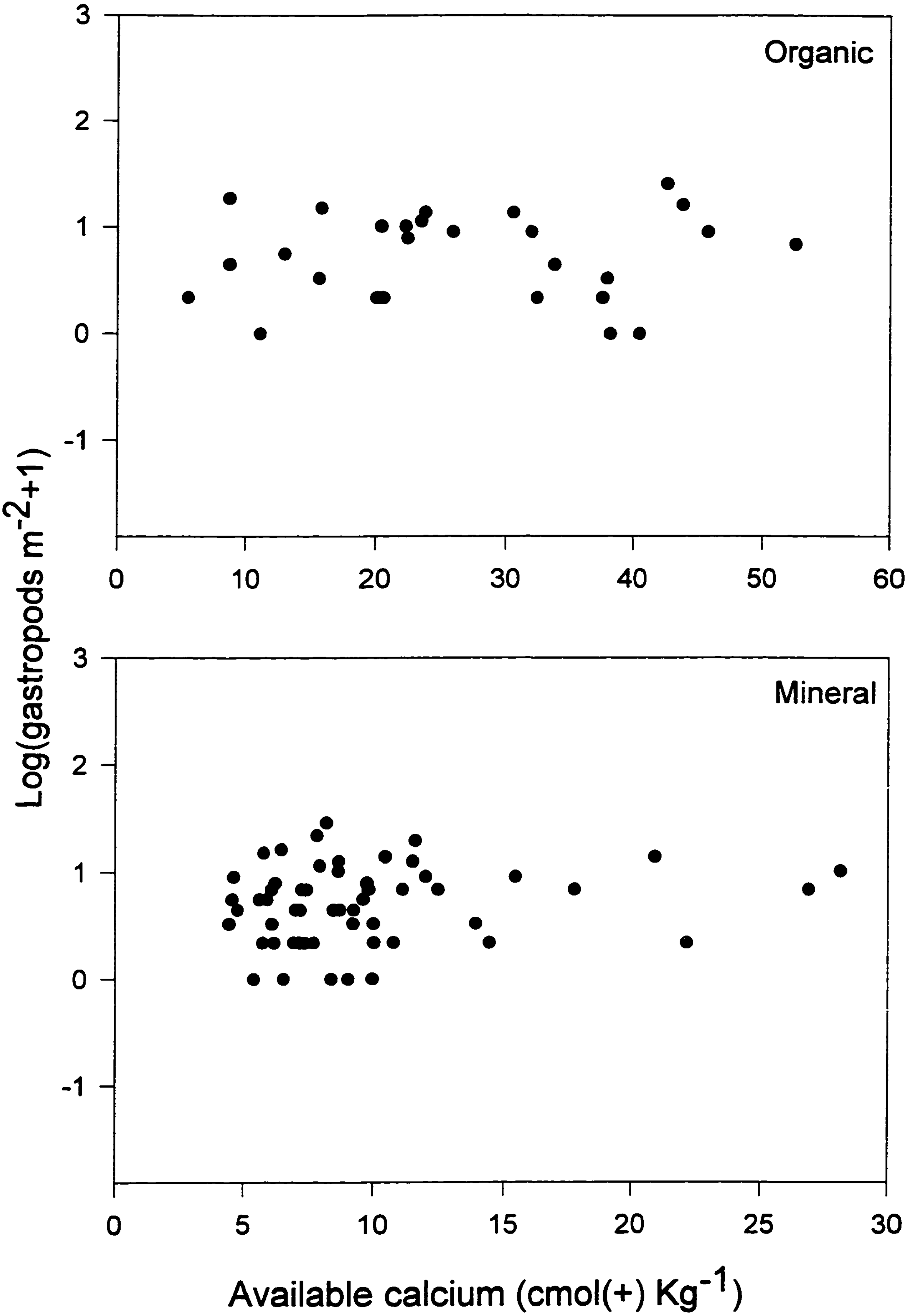

Organic
Mineral
Log(gastropods m^{-2}+1)
3
2
1
0
-1
0
10
20
30
40
50
60
5
15
25
Available calcium (cmol(+) Kg^{-1})

Table 13A. Microclimatic conditions in the complete removal Vision® plot from August 1-31 1996, on Block 3 of the Fallingsnow Study Area.

	Ambient (2m)		Near ground (0.25m)		Duff (-5cm)
Time	Temp.(°C)	RH(%)	Temp.(°C)	RH(%)	Temp.(°C)
0:00-2:59	14.1±0.13	95.4±0.49	11.7±0.15	97.7±0.35	16.3±0.1
3:00-5:59	12.7±0.09	97.6±0.45	10.2±0.12	99.3±0.19	15.4±0.1
6:00-8:59	13.7±0.12	95.9±0.48	11.3±0.13	98.8±0.24	14.8±0.1
9:00-11:59	21.2±0.11	74.1±1.11	21.7±0.14	72.4±1.1	16.5±0.13
12:00-14:59	24.3±0.12	59.7±1.0	27.0±0.15	52.6±1.1	21.5±0.16
15:00-17:59	24.9±0.11	58.2±01.2	29.1±0.19	50.2±1.2	22.5±0.17
18:00-20:59	21.0±0.14	69.4±1.2	21.3±0.17	68.4±1.2	20.4±0.13
21:00-23:59	15.2±0.12	92.5±0.6	13.1±0.13	93.9±0.4	17.7±0.1
Overall	18.4±0.7	80.32±0.5	18.16±0.1	79.14±0.6	18.16±0.1

Table 13B. Microclimatic conditions in the Vision® area from August 1-31 1996, on Block 3 of the Fallingsnow Study Area.

	Ambient (2m)		Near ground (0.25m)		Duff (-5cm)
Time	Temp.(°C)	RH(%)	Temp.(°C)	RH(%)	Temp.(°C)
0:00-2:59	15.3± 0.6	84.4± 1.4	13.2± 0.58	96.8± 0.5	16.5± 0.2
3:00-5:59	13.6± 0.7	90.1± 1.2	11.5± 0.71	99.0± 0.5	15.5± 0.2
6:00-8:59	12.3± 0.6	92.9± 1.2	10.4± 0.67	99.8± 0.5	14.8± 0.2
9:00-11:59	12.5± 0.6	93.5± 1.1	10.9± 0.6	100± 0.4	14.4± 0.2
12:00-14:59	18.9± 0.5	72.8± 2.2	19.5± 0.45	83.0± 1.5	15.7± 0.1
15:00-17:59	22.2± 0.6	60.3± 2.4	24.7± 0.71	64.0± 2.3	17.7± 0.2
18:00-20:59	23.1± 0.6	59.3± 2.5	23.7± 0.6	66.1± 2.4	18.3± 0.2
21:00-23:59	20.8± 0.6	65.6± 2.0	19.6± 0.49	78.9± 1.3	17.9± 0.2
Overall	17.3± 0.3	77.4± 1.1	16.7± 0.4	86.0± 1.0	16.4± 0.1

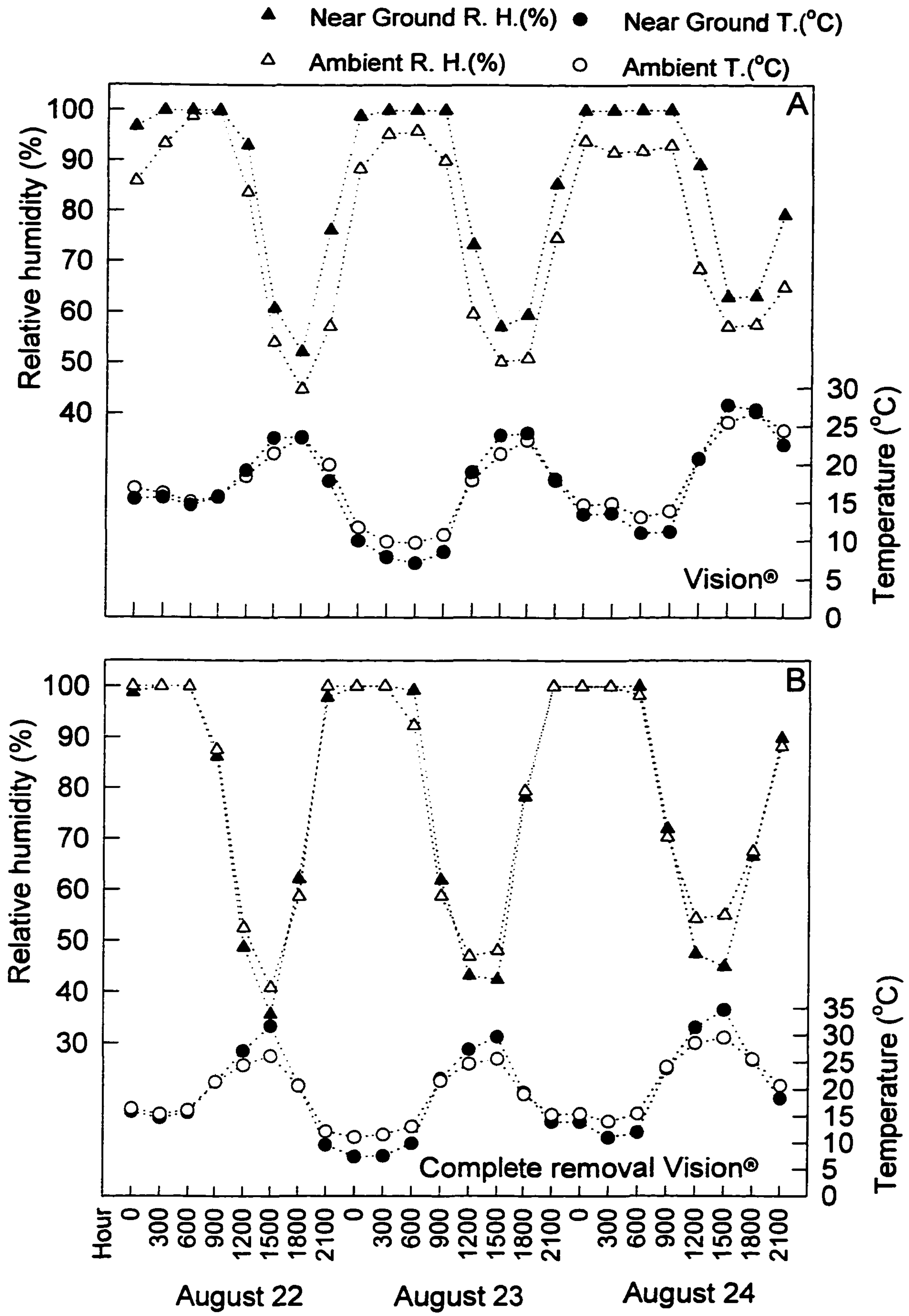
Table 13C. Microclimatic conditions in the untreated control area from August 1-31 1996, on Block 3 of the Fallingsnow Study Area.

	Ambient (2m)		Near ground (0.25m)		Duff (-5cm)
Time	Temp.(°C)	RH(%)	Temp.(°C)	RH(%)	Temp.(°C)
0:00-2:59	15.3±0.57	86.1±0.92	14.5±0.5	96.1±0.4	16.1±0.3
3:00-5:59	13.8±0.64	89.8±0.88	13.4±0.57	97.5±0.4	15.0±0.33
6:00-8:59	12.7±0.54	91.6±0.82	12.4±0.49	98.3±0.4	14.3±0.33
9:00-11:59	12.6±0.5	93.9±0.66	12.4±0.47	99.3±0.3	13.7±0.31
12:00-14:59	16.7±0.4	87.0±1.08	16.8±0.41	91.8±1.0	14.4±0.28
15:00-17:59	21.0±0.6	67.9±2.05	20.7±0.59	76.4±1.9	16.4±0.28
18:00-20:59	21.9±0.62	63.9±2.4	21.0±0.55	75.8±2.0	17.6±0.3
21:00-23:59	19.3±0.56	72.5±1.5	18.2±0.49	86.7±1.0	17.5±0.3
Overall	16.7±0.29	81.6±0.85	16.2±0.27	90.3±0.7	15.6±0.14

Table 13D. Microclimatic conditions in the unharvested forest site from August 1-31 1996, on Block 3 of the Fallingsnow Study Area.

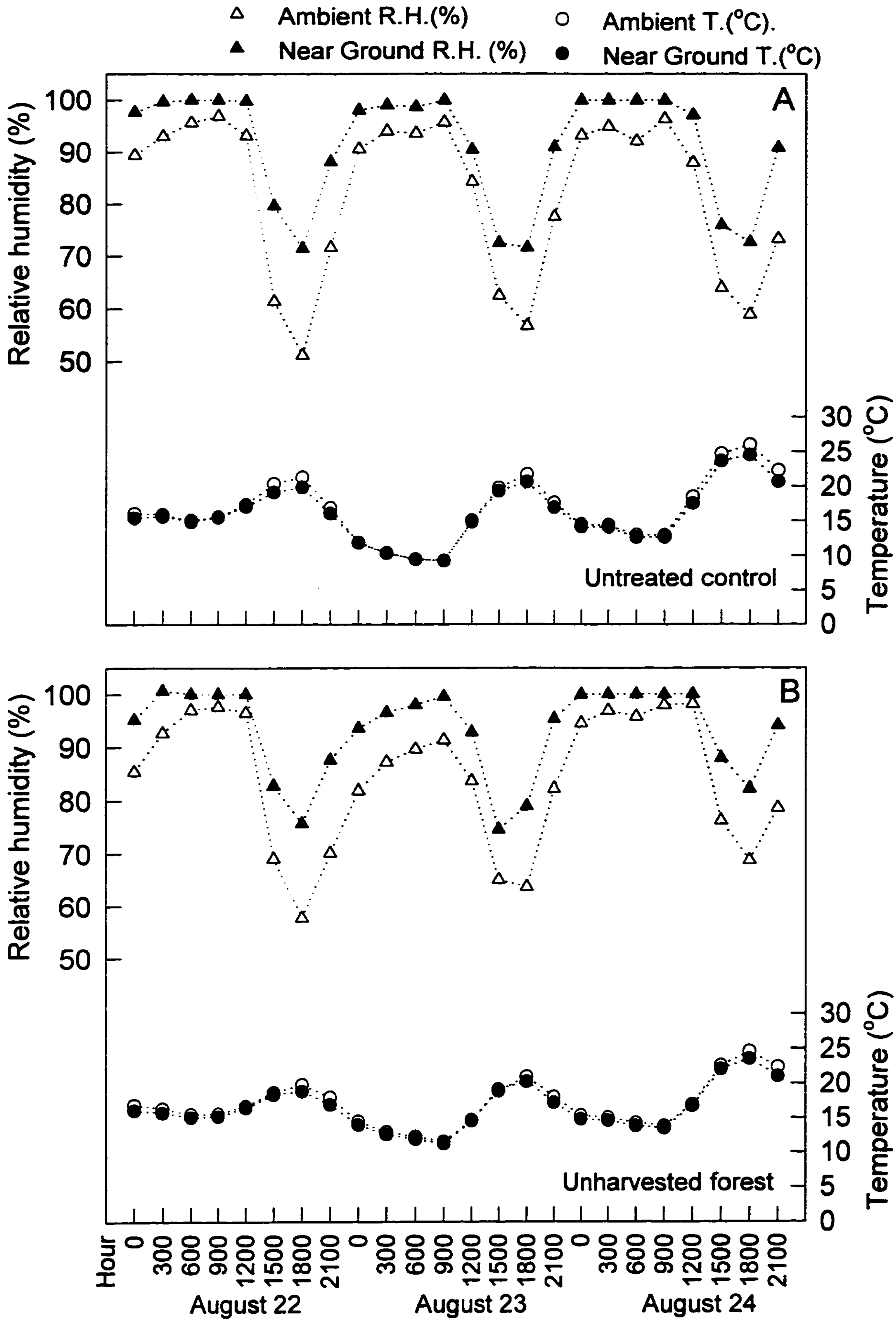
	Ambient (2m)		Near ground (0.25m)		Duff (-5cm)
Time	Temp.(°C)	RH(%)	Temp.(°C)	RH(%)	Temp.(°C)
0:00-2:59	16.7±0.47	81.4±1.22	14.8±0.68	96.1±1.16	15.6±0.18
3:00-5:59	15.2±0.51	85.4±1.11	13.9±0.85	98.4±1.08	15.1±0.19
6:00-8:59	14.0±0.48	87.6±1.0	12.9±0.88	99.8±1.05	14.7±0.19
9:00-11:59	13.3±0.45	90.0±1.0	12.0±0.83	100.0±1.0	14.4±0.18
12:00-14:59	16.2±0.42	88.1±1.19	15.2±0.6	97.5±1.21	14.8±0.17
15:00-17:59	20.2±0.55	69.9±2.0	19.9±0.69	80.9±2.1	16.4±0.21
18:00-20:59	21.0±0.57	67.8±2.18	20.0±0.70	82.4±2.09	16.7±0.2
21:00-23:59	19.4±0.49	75.5±1.46	17.7±0.67	92.4±1.38	16.3±0.18
Overall	17.0±0.24	80.7±0.72	15.7±0.4	93.6±0.69	15.5±0.08

Figure 14. Microclimatic conditions measured on the Vision® (A) and Complete removal Vision® (B) treatment areas from August 22-August 24, 1996, on Block 3 of the Fallingsnow Study Area. [Ambient = 2 m ; Near Ground=0.25 m above forest floor]



Near Ground R. H.(%)
Near Ground T.(°C)
Ambient R. H.(%)
Ambient T.(°C)
A
Relative humidity (%)
100
90
80
70
60
50
40
Temperature (°C)
30
25
20
15
10
5
0
Vision®
B
Relative humidity (%)
100
90
80
70
60
50
40
30
Temperature (°C)
35
30
25
20
15
10
5
0
Complete removal Vision®
Hour
0
300
600
900
1200
1500
1800
2100
0
300
600
900
1200
1500
1800
2100
0
300
600
900
1200
1500
1800
2100
August 22
August 23
August 24

Figure 15. Microclimatic conditions measured on the untreated control (A) and unharvested forest (B) areas from August 22-August 24, 1996, on Block 3 of the Fallingsnow Study Area. [Ambient = 2 m ; Near Ground=0.25 m above forest floor]



Ambient R.H.(%)
Near Ground R.H. (%)
Ambient T.(°C).
Near Ground T.(°C)
A
Relative humidity (%)
100
90
80
70
60
50
Temperature (°C)
30
25
20
15
10
5
0
Untreated control
B
Unharvested forest
Hour
0
300
600
900
1200
1500
1800
2100
August 22
August 23
August 24

DISCUSSION

The ability to detect treatment effects using terrestrial gastropods in large field experiments is confounded by several problems. One is the limitations of the cardboard sheet sampling method (Boag 1982). Hawkins *et al.* (1997) found that the number of gastropods collected on the litter surface using cardboard sheets was influenced by weather conditions. Greater numbers were collected when conditions were cool and wet; extended dry periods reduce the surface activity of gastropods. To minimize this type of sampling error in my study, all collection off cardboard sheets was conducted during periods of rain whenever possible, or at dawn when conditions were cool and wet. Another apparent problem is large fluctuations in surface activity of gastropods resulting from random changes in annual and seasonal rainfall.

The results of this study and those of Hawkins *et al.* (1997) suggest that terrestrial gastropod ecology is intimately associated with precipitation. Increasingly drier summer conditions from 1993-1995 (Reynolds *et al.* 1997) reduced gastropod densities collected from the Fallingsnow Study Area. In particular, summer precipitation (June 1- September 12) in 1995 decreased by 15% from the previous year and recorded gastropod numbers decreased by over 50%, yielding the lowest densities in the 3 year period. However in 1996, with an increase in rainfall of almost 40%, recorded gastropod densities increased by almost 60%.

During the summers of 1995 and 1996, monthly changes in recorded mean gastropod density parallelled changes in precipitation. The overall density of gastropods during the very dry June sampling periods in both 1995 and 1996 was extremely low, but densities increased in the remaining months with an increase in rainfall. Despite more favourable sampling conditions, density estimates from July-September were still lower than those of the two previous years (Hawkins *et al.* 1997), suggesting that the prolonged dry period in June of 1995 and 1996 may have reduced gastropod populations, either by increasing mortality, decreasing recruitment, or both. Despite the low densities found in 1995, all but one (*Pupisoma minus*) of the 21 species found by previous workers were present in samples (Hawkins *et al.*1997).

Gastropods were consistently more abundant in some locations than others, despite annual and seasonal changes in numbers related to rainfall. In both 1995 and 1996, animals were most dense on Block 3 and least dense on Block 4. Hawkins *et al.* (1997) similarly ranked Blocks 3 and 4 as having the highest and lowest densities, respectively. High densities on Block 3 may be attributed to several factors related to the species composition of the previously established forest.

Block 3 was mainly a broadleaf forest composed of *Populus tremuloides* prior to harvesting in the mid 1980's, whereas Blocks 1,2 and 4 had a large coniferous component (Bell *et al.* 1997a). Since the leaves of trees are the main contributor of organic matter to the forest floor of upland boreal sites (Lutz and Chandler 1946), the yearly input of broadleaf litter to the organic layer on Block 3, was presumably greater than that of the coniferous stands on the remaining blocks. Several studies have found that the overall depth of the organic layer influences the density and distribution of gastropods by providing better habitat conditions and increased food resources (Burch 1956; Phillipson 1983; Livshits 1983; Locasiulli and Boag 1987). Organic matter accumulation on the forest floor provides material that is important for water adsorption (Bleak 1970; Foth 1990) which increases suitability of the habitat for gastropods. Therefore, the high soil moisture levels on Block 3 in both 1995 and 1996 may have resulted from this organic accumulation.

As well, the decomposition of certain species of leaves can influence soil chemistry in the organic layer. The pH level in surface soil is often a function of the vegetation growing in that area. The breakdown of broadleaf leaf litter tends to result in less acidic soil conditions than coniferous needles (Karlin 1961; Millar 1974). Although soil acidity affects snails more than slugs (Boycott 1934), several studies have recorded higher gastropod densities in broadleaf stands compared with coniferous forests (Karlin 1961; Chichester and Getz 1969; Gleich and Gilbert 1976; Beyer and Saari 1977; Kearney and Gilbert 1978). The increased gastropod densities in broadleaf stands may have been attributed to less acidic conditions.

Tree species present on a site not only affect the amount of litter, pH and moisture retaining properties of soil, but certain species contribute more Ca than others. For example, *P. tremuloides* is able to concentrate large amounts of Ca in its tissues (Andersen and Halvorsen 1984) that can be returned to the system as breakdown products of decomposition (Kimmins 1987). Gastropods can utilize this Ca that would otherwise be lost from the immediate habitat. Studies have shown that gastropod density increases with increasing Ca levels in soil (Burch 1955; Wäreborn 1969; Howard and Howard 1990) and that low Ca levels may restrict reproduction in some species (Wäreborn 1970).

Although Ca levels were highly variable and no statistical difference could be found among blocks, mean values were highest in both organic and mineral layers on Block 3. The lower elevation of Block 3 and its position along a slope may account for increased Ca concentration due to seepage water.

Available Ca levels in soil are also affected by the rate of litter decomposition. High lignin concentration in coniferous litter tends to slow decomposition rates compared to higher decomposition of broadleaf litter with less lignin (Taylor *et al.* 1991). When decomposition rates are slow, nutrients tied up in litter are taken out of circulation for long periods of time, thus deceasing nutrient cycling and productivity. Organic matter decomposition rates are highest under warm, moist conditions and Ca (and other components) is rapidly returned to the soil (Kimmins 1987).

Gastropod densities in 1995 did not differ among the conifer release and control areas (two summers after application of treatments). Similarly, Hawkins *et al.* (1997) found no significant effects of the manual, mechanical or chemical removal of vegetation on gastropod densities one year after treatment. The rapid re-establishment of the herbaceous layer following application of the conifer release treatments was thought to minimize impacts on gastropod populations (Hawkins *et al.* 1997). In addition, it was estimated that only 12% of the applied herbicides reached the forest floor vegetation (Thompson *et al.* 1997). In 1995, gastropod density in the herbicide treated areas tended to be lower than the untreated controls, but significant differences were not detected.

In 1995, overall gastropod densities were lower than densities collected in the previous two years, but populations did not differ among the conifer release treatments and the untreated control. Gastropod densities in 1996 however, were significantly lower in the herbicide treatments than in the untreated control. The increase in precipitation and soil moisture in 1996 may have caused an increase in gastropod activity on the surface of the litter layer (Boag 1990) resulting in more effective cardboard sheet sampling. As a result, differences in 1996 may more accurately reflect changes in the abundance of gastropods below the surface of the soil on treated and untreated areas.

Higher densities on the untreated control may also be attributable to increased organic layer depth in these areas, resulting from potentially higher annual broadleaf litter input (Lutz and Chandler 1946). Vegetation indices (% cover x height) for broadleaf woody species increased 48% in the untreated control from 1993 to 1994 (Bell *et al.* 1997b). In contrast, decreases of 69% and 48% were measured in Vision® and Release® treatments, respectively.

On herbicide treated areas, the reduction of woody broadleaf species may have resulted in decreased accumulation of litter on a yearly basis. This lowered accumulation of litter may have been slowly affecting gastropod populations over the previous two years, finally making treatment differences measurable in 1996. As well, these poor litter layer conditions, compounded by increasingly drier summer conditions over two years may also have contributed to lower gastropod densities being measurable three summers after treatment.

As well, changes in microclimatic conditions resulting from the application of herbicides may have also contributed to lower recorded gastropod density in these areas. Conditions within the litter layer may have decreased suitability for gastropods. Specifically, duff temperatures were significantly higher in Vision® treated areas compared to untreated controls (Reynolds *et al.* 1997). Near ground relative humidity was highest and lowest in untreated and Vision® treated areas, respectively.

Conditions provided by the litter layer may also influence over-winter survivourship of terrestrial gastropods. Energy released from the decomposition of large quantities of organic matter can contribute to warming or thawing at the soil surface under the snow (Bleak 1970). In conjunction with this, early and increased snowfalls in 1995 may have improved over-winter survivourship of all gastropods, since they were often found in the upper stratum of the organic layer upon spring melt (personal observation). Temperature in the subnivean environment can provide gastropods with winter conditions that improve with increasing snow depth. When covered with 40-60 cm of snow, temperatures on the surface of the litter (max. -0.4 °C, min. -2.5 °C, $\bar{x}$ = -0.9°C; Forrester 1997) and 2 cm below (max. +1.1 °C, min. -2.2 °C; Bleak 1970) can be considerably higher than above snow air temperatures (max.+1.3°C, min.-33.7°C, $\bar{x}$ = -13.9 °C; Forrester 1997). Several gastropod species overwinter as eggs, as juveniles or as adults (Comfort 1957; Lankester and Anderson 1968; Uminski and Focht 1979; Boag and Wishart 1982) and winter conditions experienced in this layer can greatly influence densities found the following season. Livshits (1983) found densities of mature individuals to be high in autumn but low in spring. Furthermore it was also stated that up to 43.7% of adult and 18.3% of juvenile gastropods may experience winter mortality.

Low terrestrial gastropod densities recorded on plots where all vegetation regrowth was prevented by the annual application of Vision® (CRV plots) are more likely attributable to the herbicide-induced habitat disturbance, rather than the toxic effects of the chemical. Mobility of Vision® in soil is low due to this herbicide's high adsorption to soil particles (Sprankle 1974). It can degrade completely within a few days, with the rate depending on soil type (Grossbard and Atkinson 1985). Hawkins *et al.* (1997) reported no decline in gastropod populations within blocks associated with the application of this herbicide.

The removal of the herb layer drastically alters the near ground microclimate, with relative humidity decreasing and solar radiation/temperature increasing near the surface of the soil (Geiger 1957; Coates *et al.* 1991; Reynolds *et al.* 1997). Near ground humidity and temperature approached ambient (2 m) conditions and probably reduced gastropod mobility, recruitment to and retention of gastropods by the cardboard sheets. Since most gastropods are active on or near the surface of the soil during the summer months (Boag 1985; Locasiulli and Boag 1987), they require adequate microclimatic conditions for survival. Poor environmental conditions may cause gastropods to migrate deeper into the soil where cooler, wetter, conditions exist (Hawkins *et al.* 1996a).

Furthermore, gastropod densities obtained using soil cores, from the Vision®, CRV, untreated control and unharvested forest sites on Block 3 showed all populations to be similar. Densities in CRV plots were again lower than controls (as with cardboard sheets), but not statistically different. The discrepancy between sampling techniques suggests that no increase in gastropod mortality results in CRV plots where near ground vegetation is repeatedly removed, but instead that gastropods retreat deeper into the soil as a result of hot, dry conditions and become less active on the surface of the soil.

Species richness was similar among the CRV, untreated control and unharvested forest, but the frequency of species was different in the CRV plots. Four species (*D. leave, Z. arboreus, S. labyrinthica and D. cronkhitei*) which represented 64.5% of the total gastropods in 1995 and 73.4% in 1996 (*E. fulvus* replacing *D. cronkhitei)* were collected on all CRV plots. Several species were not collected on some or all CRV plots, especially in 1995 when only two collecting periods were conducted later in the summer.

Differing reproductive cycles may account for the absence of certain species. Populations of gastropod species peak at different periods throughout the summer

(Lankester and Peterson 1996). For example, densities of *S. ovalis* peak in spring whereas *V. limpida* increases toward autumn. Therefore, limiting collection in the CRV to August and September may have decreased the possibility of collecting species more abundant in early summer. However, the frequency of these species was similar in both years despite different sampling periods.

More importantly, the predominance of certain species may indicate a greater resistance to desiccation and an ability to survive or continue to be active on the surface of the soil under drier conditions. Getz (1959) found that *D. laeve* did not become more active after periods of rain and that this species can tolerate drier conditions than other slugs. *Stobilops labyrinthica* and *D. cronkhitei* are two other species able to tolerate, and even thrive in drier conditions. In contrast, certain species (*V. limpida* and *S. ovalis*) may be restricted to the cool, moist soil below the surface when inadequate herbaceous cover exists and are therefore not sampled as effectively using the cardboard sheet technique.

Removal of trees and shrubs by conifer release treatments was shown to increase soil moisture levels beyond those in untreated areas (Reynolds *et al.* 1997). Subsequent removal of the herb layer on CRV plots in the present study might be expected to have increased soil moisture even further, but this was not observed. The increased solar radiation reaching the forest floor may have negated reduced plant transpiration. Nonetheless, under these poor surface conditions, gastropods probably remained in the cool, moist soil below.

Terrestrial gastropod density was greater in the regenerating plantation (untreated control) area than in the unharvested forest that was adjacent to each experimental block. Hawkins *et al.* (1997) also found higher gastropod densities in a regenerating untreated control area than in a surrounding unharvested forest. Untreated control areas across all four blocks were characterized by a greater diversity of broadleaf species and an abundance of herbaceous ground vegetation (W. Bell, unpublished data, Ontario Forest Research Institute). However, all unharvested forest sites had closed canopies with sparse herb layers. Organic layers in the unharvested forest sites were thicker than untreated control areas, but were usually more acidic and contained a greater amount of coniferous material. Soil moisture between the sites was similar, except on Block 1 where the unharvested forest was significantly wetter.

Despite lower gastropod densities in herbicide treated areas in 1996, data collected from both summers suggest that gastropod populations respond more to changing environmental conditions (monthly and yearly) than to changes resulting from conifer release treatments. Gastropod densities, recorded using one sampling technique, declined annually from 1993-1995. However, this decline is thought to be a result of increasingly drier summer conditions; densities increased in 1996 with an increase in precipitation. In addition to rainfall, vegetation cover, soil moisture and temperature continually change within the gastropod microhabitat. Habitat changes resulting from conifer release treatments coupled with hot, dry summer conditions can decrease surface activity over summer and possibly population recruitment and over-winter survivourship of gastropods.

On the basis of this study, it is apparent that several factors contribute to the overall, long-term success of terrestrial gastropods in boreal ecosystems. Primarily, large recorded changes in gastropod density are directly correlated with annual fluctuations in rainfall. As well, differences in density occur among habitats with varying soil type, depth, chemistry and drainage. Finally, gastropods may show a decline in surface activity following the application of herbicides. Although the short-term effect of herbicides alone on gastropod populations appears to be minimal, when combined with poor climatic and habitat conditions, significant reduction in numbers may result.

LITERATURE CITED

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

Baker, H.B. 1958. Land snail dispersal. Nautilus. **71**:141-148.

Bell, F.W., K.R. Ride, M. St.-Amour and M. Ryans. 1997a. Productivity, cost, efficacy and cost effectiveness of motor-manual, mechanical and herbicide release of boreal spruce plantations. For. Chron. **73**: 39-46.

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

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

Bleak, A.T. 1970. Disappearance of plant material under a winter snow cover. Ecology **51**: 915-917.

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

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

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.

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, Englewood Cliffs, New Jersey. p. 388.

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, Iowa. p. 214.

Burt Perrin Associates. 1993. Public attitudes toward 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., K. Down and D.J. Pannett. 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.

Chichester, L.F. and L.L. Getz. 1969. The ecology and 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.

Coates, K.D., W.H. Emmingham and S.R. Radosevich. 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. Malacol. Soc. London **32:** 219-241.

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. 1992. National survey of Canadian public opinion on forestry issues, 1991. Highlights from a survey commissioned by Forestry Canada. For. Planning Can. **8**(3): 25-26.

Foth, H.D. 1990. Fundamentals of soil science. John Wiley and Sons, Toronto, Ont. p. 360

Forrester, S. 1997. Over-winter survivourship of *Parelaphostrongylus tenuis* first stage larvae. M.Sc thesis, Lakehead University, Thunder Bay, Ontario, p.35.

Fournié, J. and M. Chétail. 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., R. Morash and D. MacKinnon. 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, Massachusetts. p. 494.

Getz, L.L. 1959. Notes on the ecology of slugs: *Arion circumscriptus*, *Deroceras reticulatum*, and *D. laeve*. Am. Midl. Nat. **61**(2): 485-498.

Ghebremichael, A. 1993. Selected forest sector statistics and general economic indicators for Ontario, 1992. For. Can. Ont. Reg., Great Lakes For. Cen., Inf. Rep. O-X-426. 121 p.

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

Grossbard, E. and D. Atkinson. 1985. The herbicide glyphosate. Butterworth and Co. Ltd., Toronto, Ontario. p. 490.

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

Hawkins, J.W., M.W. Lankester and R.R.A. Nelson. 1996. Sampling terrestrial gastropods using cardboard sheets. Malacologia (submitted).

Hawkins, J.W., M.W. Lankester, R.A. Lautenschlager and F.W. Bell. 1997. Effects of alternative conifer release treatments on terrestrial gastropods in northwestern Ontario. For. Chron. **73**: 91-98.

Howard, P.J.A. and D.M. Howard. 1990. Titrable acids and bases in tree and shrub litters. Forestry **63**: 177-196.

Howell, D.C. 1997. Statistical methods for psychology. Duxbury Press, Toronto. p. 724

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

Kalra, Y.P. and D.G. Maynard. 1991. Methods manual for forest soil and plant analysis. Information Report, NOR-X-319, For. Can., Northwest Region. Northern Forestry Centre. p. 116.

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 F.F. Gilbert. 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, N.Y. p. 531.

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

Krause, H.H. 1991. Nutrient form and availability in the root environment. *In* Driessche, R. van den (Ed.). Mineral nutrition of conifer seedlings. CRC Press Boca Rotan. p. 274

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

Lankester, M.W. and W.J. Peterson. 1996. The possible importance of wintering yards in the transmission of *Parelaphostrongylus tenuis* to white-tailed deer and moose. J. Wildl. Dis. **32**(1): 31-38.

Lautenschlager, R.A. 1993. Response of wildlife to forest herbicide applications in northern coniferous ecosystems. Can. J. For. Res. **23**: 2286-2299.

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

Lutz, H.J. and R.F. Chandler. 1946. Forest Soils. John Wiley and Sons, London. p. 514

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

Meredith, M.P. and S.V. Stehman. 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* Dickinson, C.H. and G.J.H. Pugh. Biology of plant litter decomposition. pp. 105-128. Academic Press, New York, N.Y.

Norusis, M.J. 1992a. SPSS/PC+ Advanced Statistics Version 5.0. SPSS Inc., Chicago, Illinois. p. 481.

Norusis, M.J. 1992b. SPSS/PC+ Base System User's Guide Version 5.0. SPSS Inc., Chicago, Illinois. p. 910.

Oughton, J. 1948. A zoogeographical study of the land snails of Ontario. University of Toronto, Biological Series No. 57. p. 126.

Phillipson, J. 1983. Slug numbers, biomass and respiratory metabolism in a beech woodland, Wytham Woods, Oxford. Oecologia. **60**: 38-45

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

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

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

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

Reynolds, P.E. 1996. Evaluation of climatic and nutrient uptake differences associated with chemical vs. alternative methods for managing competing vegetation. Annual report for the Agriculture Research Institute of Ontario. p. 64.

Reynolds, P.E., J.A. Simpson, R.A. Lautenschlager, F.W. Bell, A.M. Gordon, D. Buckley and D. Gresch. 1997. Alternative conifer release treatments affect below- and near-ground microclimate. For. Chron. **73**: 75-82.

Rowe, J.S. 1972. Forest regions of Canada. Publication No. 1300, Department of the Environment, Canadian Forestry Service, Ottawa, Ontario. P. 172.

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. p. 428.

Sprankle, P.L. 1974. Factors affecting the herbicidal activity of N-(phosphonomethyl) glycine (glyphosate) on quackgrass (Agropyron repens (L.) Beauv.) and in soil, Dissertation Abstracts International, B. The Sciences and Engineering. **35**: 1144-B.

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

Stewart, R.E., L.L. Gross and B.H. Honkala. 1984. Effects of competing vegetation on forest trees: a bibliography with abstracts. USDA For. Serv. Gen. Tech. Rep. WO-43.

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

Taylor, B.R., C.E. Prescott, W.J.F. Parsons and D. Parkinson. 1991. Substrate control of litter decomposition in four Rocky Mountain coniferous forests. Can. J. Bot. **69:** 2242-2250.

Thompson, D.G., D.G. Pitt, B. Staznik, N.J. Payne, D. Jaspersaid, R.A. Lautenschlager and F.W. Bell. 1997. On-target deposit and vertical distribution of aerially released herbicides. For. Chron. **73**: 47-59.

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

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

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.

Wäreborn, I. 1969. Land molluscs and their environments in an oligotrophic area in southern Sweden. Oikos **20**: 461-479.

Wäreborn, I. 1970. Environmental factors influencing the distribution of of land molluscs of an oligotrophic area in southern Sweden. Oikos **21**: 285-291

Zar, J.H. 1984. Biostatistical analysis. Prentice Hall, Englewood Cliffs, New Jersey. p. 718.

APPENDIX

Appendix 1. Total numbers of terrestrial gastropods collected from Vision® treated areas on the four experimental blocks over the four sampling periods in 1995 and 1996.

Species	Vision® 1995				Vision® 1996			
	June	July	Aug.	Sept.	June	July	Aug.	Sept.
Deroceras laeve	7	89	63	99	15	67	151	194
Pallifera dorsalis	0	14	1	0	0	6	14	7
Zonitoides arboreus	18	121	50	27	5	61	60	10
Striatura milium	0	0	7	3	0	0	3	2
Discus cronkhitei	4	21	12	6	2	20	14	25
Cochlicopa lubrica	0	3	3	4	0	7	11	18
Zoögenetes harpa	0	0	6	5	1	13	19	8
Columella edentula	1	1	6	0	0	1	1	1
Strobilops labyrinthica	2	38	33	30	0	16	19	15
Euconulus fulvus	1	17	22	25	0	27	66	51
Anguispira alternata	0	9	22	6	2	43	32	3
Succinea ovalis	0	50	33	54	2	100	126	43
Vertigo modesta	1	0	0	0	0	0	0	3
Vertigo gouldi	0	2	3	4	0	12	9	5
Gastrocopta tappaniana	0	0	0	0	0	1	0	0
Carychium exile canadense	0	0	0	0	0	0	0	0
Vitrina limpida	0	1	0	35	0	13	214	134
Striatura exigua	0	0	0	0	0	1	3	0
Vertigo ovata	0	1	0	1	0	1	0	0
*Pupisoma minus**	0	0	0	0	0	3	1	0
Punctum minutissimum	0	0	0	0	0	0	0	0
Total	34	367	261	299	27	392	743	519

*tentative identification by the Royal Ontario Museum

Appendix 2. Total numbers of terrestrial gastropods collected from Release® treated areas on the four experimental blocks over the four sampling periods in 1995 and 1996.

Species	Release 1995				Release 1996			
	June	July	Aug.	Sept.	June	July	Aug.	Sept.
Deroceras laeve	7	74	90	88	8	55	120	150
Pallifera dorsalis	0	4	1	1	0	5	3	8
Zonitoides arboreus	36	249	56	32	5	104	39	20
Striatura milium	0	0	0	16	0	0	52	22
Discus cronkhitei	6	19	14	4	0	8	10	4
Cochlicopa lubrica	0	10	7	10	0	12	11	5
Zoögenetes harpa	0	6	2	12	0	9	15	18
Columella edentula	0	1	4	3	0	5	4	2
Strobilops labyrinthica	11	16	22	29	0	8	18	15
Euconulus fulvus	1	36	30	55	0	15	40	89
Anguispira alternata	1	17	31	8	0	51	33	9
Succinea ovalis	2	40	25	47	0	35	45	28
Vertigo modesta	0	2	3	4	0	0	0	4
Vertigo gouldi	0	4	3	16	0	1	9	7
Gastrocopta tappaniana	1	1	1	2	0	1	0	0
Carychium exile canadense	0	0	0	1	0	0	0	0
Vitrina limpida	0	4	6	40	0	5	103	109
Striatura exigua	0	0	0	1	0	0	0	0
Vertigo ovata	0	0	0	4	0	0	0	0
Pupisoma minus	0	0	0	0	0	0	1	0
Punctum minutissimum	0	0	0	0	0	0	0	0
Total	65	483	295	373	13	314	503	490

Appendix 3. Total numbers of terrestrial gastropods collected from Brushsaw treated areas on the four experimental blocks over the four sampling periods in 1995 and 1996.

Species	Brushsaw 1995				Brushsaw 1995			
	June	July	Aug.	Sept.	June	July	Aug.	Sept.
Deroceras laeve	8	51	88	88	8	87	177	223
Pallifera dorsalis	0	1	0	0	0	3	5	9
Zonitoides arboreus	26	154	61	28	2	105	48	22
Striatura milium	0	0	0	6	0	0	3	12
Discus cronkhitei	3	29	8	7	0	21	8	21
Cochlicopa lubrica	0	9	7	2	0	2	2	3
Zoögenetes harpa	0	3	0	7	1	6	34	12
Columella edentula	1	5	0	1	0	1	0	3
Strobilops labyrinthica	12	26	9	19	0	13	13	12
Euconulus fulvus	0	37	15	63	0	27	48	123
Anguispira alternata	1	21	16	7	0	27	21	7
Succinea ovalis	1	43	20	39	0	59	50	25
Vertigo modesta	0	1	1	11	0	0	0	16
Vertigo gouldi	2	0	0	7	0	2	0	7
Gastrocopta tappaniana	1	0	0	3	0	1	0	0
Carychium exile canadense	1	0	0	0	0	0	0	0
Vitrina limpida	1	2	3	38	0	11	222	218
Striatura exigua	0	0	0	1	0	0	0	0
Vertigo ovata	0	0	0	0	0	0	0	0
Pupisoma minus	0	0	0	0	0	0	0	0
Punctum minutissimum	0	0	0	0	0	0	0	0
Total	57	382	228	327	11	365	631	713

Appendix 4. Total numbers of terrestrial gastropods collected from Silvana Selective treated areas on the four experimental blocks over the four sampling periods in 1995 and 1996.

Species	Silvana Selective 1995				Silvana Selective 1996			
	June	July	Aug.	Sept.	June	July	Aug.	Sept.
Deroceras laeve	3	50	81	103	6	129	177	284
Pallifera dorsalis	0	10	2	1	0	7	9	14
Zonitoides arboreus	45	215	118	66	7	113	32	13
Striatura milium	0	0	0	1	0	1	2	10
Discus cronkhitei	10	21	26	21	1	71	22	66
Cochlicopa lubrica	0	7	5	8	0	15	18	15
Zoögenetes harpa	0	4	3	9	0	6	16	10
Columella edentula	0	0	0	0	0	4	3	6
Strobilops labyrinthica	9	17	23	23	2	11	5	14
Euconulus fulvus	3	7	7	31	0	14	65	89
Anguispira alternata	1	11	10	4	0	83	41	15
Succinea ovalis	0	61	23	64	1	109	100	27
Vertigo modesta	5	0	0	1	0	6	2	2
Vertigo gouldi	0	1	1	7	0	7	0	8
Gastrocopta tappaniana	0	0	1	2	0	2	0	0
Carychium exile canadense	0	0	0	0	0	0	0	0
Vitrina limpida	0	1	0	31	0	10	225	196
Striatura exigua	0	0	0	0	0	2	0	0
Vertigo ovata	0	0	0	0	0	0	0	0
Pupisoma minus	0	0	0	0	0	0	1	1
Punctum minutissimum	0	0	0	0	0	0	0	0
Total	76	405	300	372	17	590	718	770

Appendix 5. Total numbers of terrestrial gastropods collected from untreated control areas on the four experimental blocks over the four sampling periods in 1995 and 1996.

Species	Untreated Control 1995				Untreated Control 1996			
	June	July	Aug.	Sept.	June	July	Aug.	Sept.
Deroceras laeve	2	47	77	94	20	110	155	238
Pailifera dorsalis	0	15	4	7	1	7	4	9
Zonitoides arboreus	30	262	118	59	10	192	79	46
Striatura milium	0	7	20	60	0	6	6	39
Discus cronkhitei	0	18	15	33	5	72	24	75
Cochlicopa lubrica	0	6	10	14	0	14	19	9
Zoögenetes harpa	0	5	2	18	0	12	20	18
Columella edentula	3	1	14	3	0	8	8	9
Strobilops labyrinthica	2	13	28	35	0	18	20	32
Euconulus fulvus	0	25	73	129	1	34	120	191
Anguispira alternata	0	13	20	7	0	60	64	16
Succinea ovalis	2	24	29	23	2	48	46	25
Vertigo modesta	0	0	13	6	0	3	4	50
Vertigo gouldi	0	1	18	15	0	4	4	22
Gastrocopta tappaniana	0	1	0	8	0	4	3	1
Carychium exile canadense	0	0	0	0	0	0	1	0
Vitrina limpida	0	3	6	39	0	39	245	157
Striatura exigua	0	0	0	5	0	6	0	0
Vertigo ovata	0	0	1	15	0	0	0	2
Pupisoma minus	0	0	0	3	0	2	2	1
Punctum minutissimum	0	0	0	0	0	0	0	0
Total	39	441	448	573	39	639	824	940

Appendix 6. Precipitation totals (mm) on Block 3 of the Fallingsnow Study area from 1994-1996.

	1994		1995		1996	
	Month	Sample	Month	Sample	Month	Sample
June	98	n/a	11.75	0	68	2
July	89.25	n/a	117.5	38.75	133.5	50.5
August	49.75	n/a	57.25	0	72.5	56
September	45.25	n/a	83	40.25	69	27.5
Total	282.25	n/a	269.5		343	

Appendix 7. Total numbers of terrestrial gastropods collected from complete removal Vision® treated areas on the four experimental blocks over the four sampling periods in 1995 and 1996.

	Complete Removal Vision® 1995				Complete Removal Vision® 1996			
Species	June	July	Aug.	Sept.	June	July	Aug.	Sept.
Deroceras laeve	*	*	21	14	11	20	39	47
Pallifera dorsalis			1	1	0	10	2	2
Zonitoides arboreus			16	7	6	72	44	45
Striatura milium			0	4	5	0	11	5
Discus cronkhitei			6	12	4	17	8	15
Cochlicopa lubrica			0	0	0	2	7	2
Zoögenetes harpa			0	0	3	1	0	4
Columella edentula			1	0	4	1	3	5
Strobilops labyrinthica			7	17	35	37	68	81
Euconulus fulvus			1	6	22	20	42	47
Anguispira alternata			2	3	0	12	14	5
Succinea ovalis			4	7	1	18	16	9
Vertigo modesta			1	4	0	1	1	0
Vertigo gouldi			3	7	3	0	6	3
Gastrocopta tappaniana			3	4	2	0	6	3
Carychium exile canadense			0	0	0	0	1	0
Vitrina limpida			0	2	2	0	6	3
Striatura exigua			0	1	1	0	0	5
Vertigo ovata			0	0	0	0	0	0
Pupisoma minus			0	0	0	0	1	0
Punctum minutissimum			0	0	0	0	0	0
Total			66	89	99	211	275	281

*Samples collected during the August and September periods only, during 1995.

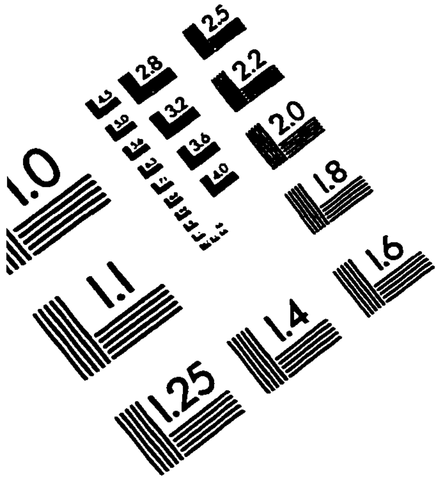
Appendix 8. Total numbers of terrestrial gastropods collected from unharvested forest areas on the four experimental blocks over the four sampling periods in 1996.

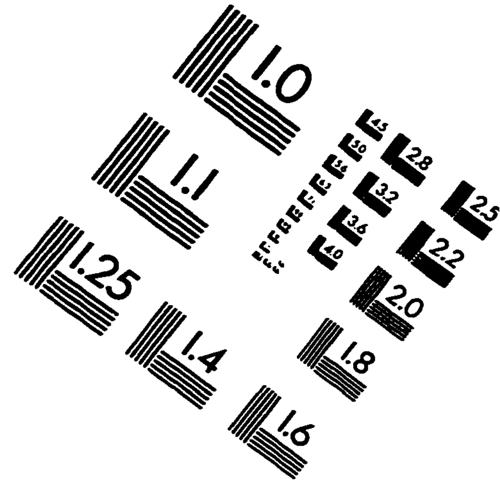
Species	Unharvested Forest 1996			
	June	July	Aug.	Sept.
Deroceras laeve	3	33	32	54
Pallifera dorsalis	0	10	5	6
Zonitoides arboreus	2	126	91	77
Striatura milium	0	0	0	13
Discus cronkhitei	1	179	96	139
Cochlicopa lubrica	0	10	13	19
Zoögenetes harpa	0	9	25	38
Columella edentula	0	5	2	11
Strobilops labyrinthica	0	21	47	63
Euconulus fulvus	0	25	76	117
Anguispira alternata	1	95	55	12
Succinea ovalis	1	10	22	8
Vertigo modesta	0	0	4	10
Vertigo gouldi	0	0	0	21
Gastrocopta tappaniana	0	3	1	5
Carychium exile canadense	0	0	2	0
Vitrina limpida	0	1	16	39
Striatura exigua	0	4	2	6
Vertigo ovata	0	0	0	0
Pupisoma minus	0	0	1	2
Punctum minutissimum	0	0	0	0
Total	8	531	490	640

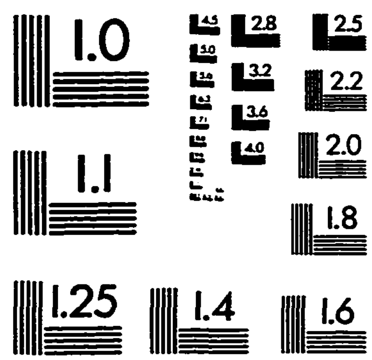
Appendix 9. Soil moisture and pH from sampling quadrats within Vision®, complete removal Vision® (CRV), unharvested forest (UF) and untreated control (UC) areas on Block 3 of the Fallingsnow Study Area.

	Moisture (%)		pH	
	O	M	O	M
Vision	122.77	24.43	5.7	4.6
CRV	84.87	22.57	5.1	4.9
UF	196.67	16.58	5.8	4.4
UC	192.28	20.69	5.7	5.8

IMAGE EVALUATION TEST TARGET (QA-3)







150mm

6″