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Snowmobile Impact on Old Field and Marsh Vegetation in Nova Scotia, Canada: An Experimental Study

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ABSTRACT / A study was carried out in Nova Scotia, Canada, to experimentally assess the effect of snowmobiles on old field and marsh vegetation. Snowmobile treatments ranging from a single pass to 25 passes (five passes on five separate days) were administered. The first pass by a snowmobile caused the greatest increase in snow compaction—roughly 75% of that observed after five sequential passes. Snowmobile treatment resulted in highly significant increases in snow retention in spring. Frequency was more important than intensity in this regard.

Standing crop and species composition were measured the following summer. Standing crop in the field showed a significant reduction with increasing snowmobile use; frequency of treatment ($p < 0.01$) was more important than intensity ($p = 0.125$). *Stellaria graminea, Aster cordifolius, Ranunculus repens*, and *Equisetum arvense* all showed significant ($p < 0.05$) differences in percent cover resulting from the treatment. Marginally significant changes were observed in *Agrostis tenuis* and *Phleum pratense*. Marsh vegetation showed no significant effects of snowmobile treatment. This may have been because of solid ice cover during the winter.

The literature is critically reviewed. It is concluded that snowmobile use can have a highly significant effect upon natural vegetation. Management suggestions are made.

Introduction

The use of snowmobiles is increasing in North America, yet a limited amount is known regarding their ecological impact on vegetation. Hence, it is difficult for resource managers to make decisions about snowmobile use in natural areas.

The effects of direct human trampling on vegetation are much better known than the effects of snowmobiles. Quantitative studies by Burden and Randerson (1972) and reviews by Speight (1973), Goldsmith (1974), and Satchell and Marren (1976) are but a few examples of work that has greatly increased the information available to the resource manager.

Some of the "research" carried out on snowmobile impact, however, is of little use to resource managers. For example, Whittaker and Wentworth (1971) estimated the effects of snowmobiles on vegetation standing crop by multiplying up from unreplicated single square-foot samples to tons per acre. Whittaker and Wentworth (1971) and Larson (1971) relied heavily on photographic records, which contribute little, if anything, to a scientific understanding of snowmobile impacts.

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There have been several detailed studies on the effects of snowmobile use on standing biomass of agricultural crops. Foresman and others (1973) found that under some conditions snowmobile use caused significant reductions in yield of certain crops in some localities. Foresman and others (1976) reported that the early summer yields of bluegrass (*Poa pratensis*) forage were significantly reduced by winter snowmobile traffic, although yields later in the summer were not affected. Wanek (1974) found that snowmobile traffic significantly reduced alfalfa yields.

Effects on natural vegetation are more poorly documented. Both Neumann and Merriam (1972) and Wanek (1974) showed that shrubs were damaged by snowmobile use. Wanek (1974) demonstrated that levels of damage increased with higher levels of snowmobile use. He also presented a large amount of data on changes in natural and seminatural vegetation with snowmobile use. Early spring flowers, plants of a power line right of way, and bog plants were examined in control and treated plots. All spring flowers were smaller in treated areas, and many species showed a reduction in the proportion of plants flowering. Responses were mixed in the plants growing on power line rights of way. All bog species declined in treatments relative to controls. Measures of sampling variability or significance tests were not presented with this data. It is therefore difficult to be certain which particular species are sensitive to snowmobile traffic.

However, it is possible to analyze some of Wanek's data using nonparametric statistics (see Appendix to this contribution for details). The conclusions are that early spring

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plants are significantly smaller ($p = 0.008$) and significantly less frequent ($p = 0.016$) under snowmobile trails. Similarly, bog shrub populations showed a highly significant decrease with increasing snowmobile use ($p < 0.01$).

Foresman and others (1976) observed that snowmobile impacts on bluegrass were greatest in areas that were not clipped prior to the winter. This suggests that natural and seminatural fields and grasslands may be more sensitive than agricultural lands to snowmobile impact.

It has been stated (without supporting evidence) that snowmobile traffic causes less environmental impact than human traffic simply because snowmobiles exert less pressure per unit area on the snow (Larson 1971, Doyle 1974). It is unfortunate that overly simple assertions such as this often substitute for experimental studies.

This study reports experimental work carried out to assess the impact of snowmobiles on two vegetation types in Nova Scotia, Canada. The objectives of this study were:

1. To measure snow compaction associated with various intensities of snowmobile use
2. To measure delay in spring melting associated with several frequencies and intensities of snowmobile use
3. To test for changes in herbaceous species composition and standing crop associated with several frequencies and intensities of snowmobile use
4. To assess the relative importance of frequency and intensity of use and attempt to relate these to measurements of compaction and melting time
5. Based on the above, to propose tentative guidelines to help minimize vegetational impact associated with snowmobile use

Throughout this paper "frequency" refers to the number of days (one or five) on which a treatment was given. "Intensity" refers to the number of passes (one or five) made by a snowmobile on each treatment day.

Study Area and Methods

The study area was abandoned farmland near Enfield in Hants County, Nova Scotia, Canada. A plot of homogeneous field vegetation on a level hilltop and a plot of homogeneous marsh vegetation in an adjacent depression were selected. No woody plants occurred in these plots.

Each 9 × 10 m study plot was divided into nine lanes, each 1 × 10 m. Five of these lanes (each alternate one) were designated controls, and four treatment levels were randomly assigned to the remaining four lanes. The four treatments consisted of a 2 × 2 factorial combination of frequency and intensity of use (Table 1) while the controls received no snowmobile use. "Low frequency" was defined

Table 1 Factorial arrangement of the four snowmobile treatment levels

Intensity (passes/day)	Frequency (days) 1	Frequency (days) 5
1	No. 1	No. 3
5	No. 2	No. 4

as use on one day, whereas "high frequency" was defined as use on five widely separated days. "Low intensity" was a single pass on a given day; "high intensity" was five passes on a given day. A "pass" was defined as one trip by a snowmobile along a lane. Each treatment day followed a snowstorm; the dates and snow depths of each treatment day were: December 18, 1976 (10 cm) and, in 1977, January 2 (11 cm), January 10 (13 cm), February 7 (6 cm) and February 20 (12 cm). All low-frequency treatments were carried out on January 10, 1977.

Snow compaction was measured both by depth and by volume. Snow depth was measured to the nearest centimeter on a level surface by digging a profile. Volume on melting was obtained by carefully sliding a 175-ml aluminum cylinder horizontally into the snow profile and removing a snow core. The core was placed in a sealed plastic bag and returned to the laboratory for melting.

Spring snow cover was measured in the field study plot, but not in the marsh, which was flooded. It was measured by means of cover pins (Goldsmith and Harrison 1976), with six sample units for each treatment and the control. Each sample unit consisted of 20 cover pins. Control sample units were randomly assigned among four control lanes (one control lane was omitted because of vandalism). The total number of pins (out of 20) touching on snow was recorded in each sample unit. Snow cover was measured in this way on April 2, 12, and 16.

Species abundances were measured on August 1 and 2 of the following summer, when standing crop had peaked. Percent cover of each species was measured by means of cover pins, with 10 sample units for each treatment and the control. Ten cover pins were used in each sample unit. Control sample units were randomly assigned among the five control lanes. Arcsine square root transformations were applied prior to statistical analysis because the data were of a binomial nature.

Standing crop was measured by clipping fifteen 25 × 25 cm sample units in each treatment and the control. As with percent cover, the control sample units were randomly assigned over all five control lanes. Any dead material re-

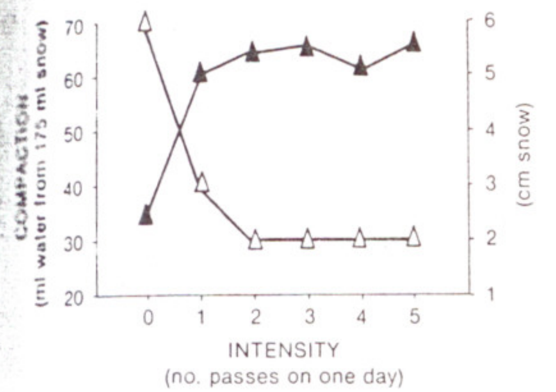

Figure 1. Two measures of compaction of 6 cm of fresh snow plotted against intensity of use (the number of passes on 1 day by a snowmobile). Open triangles, snow depth; solid triangles, volume on melting.

maining from the previous growing season was removed from each clipped sample unit. The remaining clipped vegetation was placed in a paper bag where it was air dried at 100°C to constant weight.

The appropriate statistical analysis for this design involves analysis of variance (ANOVA) which was carried out with the SPSS statistical package (Nie and others 1975). The species nomenclature follows Roland and Smith (1969).

Results

Snow Compaction

Figure 1 shows snow compaction plotted against the intensity of snowmobile use. Figure 2 shows the results for a mixture of snow types: 13 cm of fresh snow over 7 cm of old icy snow. Similar snow compaction results were obtained in the actual experimental field plot. (Milliliters of water yielded when 175 ml of snow are melted, mean (with 95% CI) for the five treatment days: control, 27.6 ± 7.5, one pass, 48.3 ± 5.2, five passes, 59.1 ± 9.4. One by three ANOVA, $df = 2, 12$; $F = 34.53$; $p < 0.001$.)

Most of the compaction of fresh snow occurs after a single pass. Therefore, frequency would be anticipated to be more important than intensity in determining the compaction of snowfall during a winter. (That is, the compaction would be expected to be greater after five single passes interspersed with snowfall than after five passes on a single day.)

Snow Melting

Snow cover was measured during the April spring melt period. On each date (April 2, 12, and 16) snow cover was significantly greater in the treatments than in the controls (1×2 ANOVA, $df = 1, 28$; $F = 13.28$, $p < 0.01$; $F = 16.81$, $p < 0.001$; $F = 5.66$, $p < 0.025$ respectively).

To test for frequency and intensity effects among the treatments, 2×2 ANOVA was used (Table 2). At all three times, increased frequency of use resulted in increased spring snow cover (Table 2, Fig. 3). The effects of increased intensity were less obvious, and the table shows that there was a highly significant interaction term. At high frequency, increased intensity resulted in increased snow cover; at low frequency, increased intensity appeared to result in decreased snow cover.

Standing Crop

Figure 4a shows the observed standing crops (with 95% CI) for control and treatment lanes in the old field plot. There were significant differences among treatments and control (one-way ANOVA, $df = 4, 74$; $F = 3.57$; $p < 0.01$). Analysis of the treatment lanes revealed (Table 3) that increased frequency resulted in decreased standing crop (p <

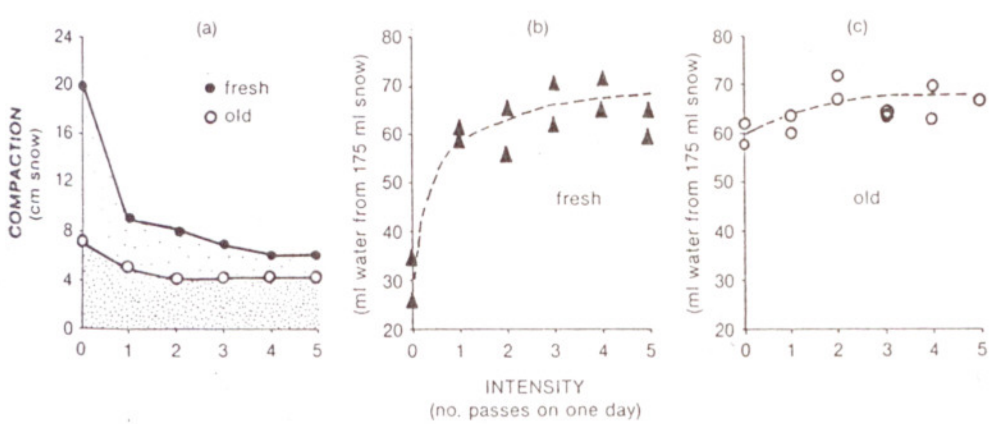

Figure 2. Compaction of 20 cm of snow plotted against the intensity of use (the number of passes on 1 day by a snowmobile). Curves are fitted by eye. (a) Snow depth profile showing fresh snow over old icy snow. (b) Fresh snow compaction measured by volume of water yielded on melting. (c) Old icy snow compaction measured by volume of water yielded on melting.

Table 2 Analysis of frequency and intensity effects on spring snow retention[a]

Source	Sum of squares	DF	MS	F	p
April 2					
Frequency	165.38	1	165.38	82.35	<0.001
Intensity	5.04	1	5.04	2.51	0.129
Interaction	30.38	1	30.38	15.13	<0.001
Residual	40.17	20	2.01		
April 12					
Frequency	88.17	1	88.17	151.15	<0.001
Intensity	6.00	1	6.00	10.29	<0.01
Interaction	24.00	1	24.00	41.14	<0.001
Residual	11.67	20	0.58		
April 16					
Frequency	18.38	1	18.38	10.07	<0.01
Intensity	7.04	1	7.04	3.86	0.064
Interaction	51.04	1	51.04	27.98	<0.001
Residual	36.50	20	1.83		

[a] 2×2 ANOVA of treatment lanes.

0.01), but that increased intensity had no statistically significant effect.

Figure 4b gives the observed standing crops (with 95% CI) for control and treatments in the marsh study plot. There was no significant difference (one-way ANOVA, df $= 4, 74$; $F = 0.924$; $p = 0.455$).

Species Composition

The species composition of the field in control and treatment lanes is shown in Table 4. Four species (*Stellaria graminea, Aster cordifolius, Equisetum arvense*, and *Ranunculus repens*) showed significant differences in percent cover among treatments and control (first three species, 1×5 ANOVA; *R. ripens, a priori* contrast between treatments and control; $p < 0.05$). Two other species (*Agrostis tenuis* and *Phleum pratense*) showed differences at the 0.10 level (1×5 ANOVA). Table 5 shows the results of a 2×2 (frequency $\times$ intensity) ANOVA for these species. It can be seen that different species reacted differently to frequency and intensity of use.

Marsh species composition is shown in Table 6. There were no significant differences among treatments and controls (1×5 ANOVA; a priori contrast between treatments and controls; $p \gg 0.05$ in all cases). The marsh flooded in November and was covered by a thick layer of ice throughout the treatments.

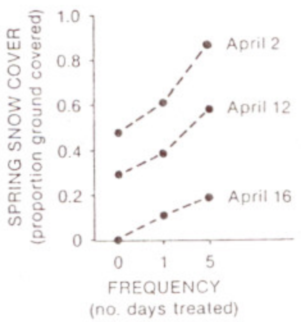

Figure 3. Spring snow cover (proportion of ground covered with snow during the spring melt period) plotted against frequency of use (the number of days treated during the preceding winter).

Discussion

Differences Between Field and Marsh

Field and marsh vegetation were affected differently by the experimental treatments. The marsh, being flooded in November, was covered by solid ice all winter, which could have reduced the effects of compaction. Similarly, the low species richness of the marsh and the high level of dominance by *Carex aquatilis* would make it more difficult to detect changes in species composition.

Compaction and Field Vegetation

The compaction data indicated that several passes throughout the winter after snowstorms would cause more overall snow compaction than an equivalent number of passes on a single occasion. The spring snow melting data are consistent with this hypothesis, as are the data on standing crop reductions.

The changes in percent cover of individual species are much more complex. A range of possible interactions between plant species and snowmobiles can be postulated. Temperature reduction beneath compacted snow may af-

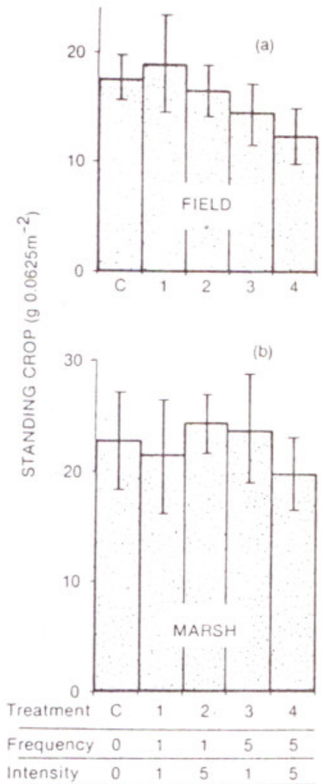

Figure 4. Standing crop estimates (with 95% CI) for control and four snowmobile treatment levels. Treatment numbers correspond to those in Table 1. (a) Old field study plot. (b) Marsh study plot.

fect seed vernalization or perennial plant overwinter storage organs and buds. Compaction may affect the soil surface microstructure, which Harper and others (1965) have shown will greatly determine the suitability of a site for seed germination. Compaction of the previous year's vegetation and/or spring snow retention may also affect early spring germination and growth. Compaction of vegetation may affect seed dispersal from capsules still attached to dead stalks. Snow compaction may modify seed predation patterns by subnivean rodents. Considering the multitude of possible effects and the variety of plant structures and life histories, it is not surprising that no overall trend emerges for species composition changes.

Cumulative Effects

This study dealt only with short-term changes in vegetation after one winter with a maximum of 25 snowmobile passes. The possibility of cumulative effects over several years deserves serious consideration in other studies of this sort.

Management Proposals

It is difficult to draw generalizations based on one study of two vegetation types for a single winter in a single geographic area and climatic zone. However, because resource managers must make decisions before all necessary studies are carried out, we should like to make the following management-oriented remarks. We emphasize that they are based *only* on vegetation considerations.

1. Vegetation species composition and standing crop can be affected by snowmobile use. Snowmobiles should be excluded from areas set aside to preserve natural stands of vegetation. If snowmobiling is allowed, managers of seminatural vegetation may also wish to exclude snowmobiles from areas judged to have vegetation of high ecologic value. Based on our results, which show the reduction of standing crop in old pasture, as well as on the results of Foresman and others (1973) and Wanek (1974), prohibiting snowmobile use in some agricultural lands may deserve serious consideration.
2. Because the first pass causes most compaction and increased intensity (at the levels studied) causes less damage than increased frequency, localization of snowmobile traffic should reduce its impact on vegetation. Encouraging the use of trails is more appropriate than attempting to diffuse use.
3. Results from the marsh study plot suggest that vegetation covered by ice may receive some protection. Diversion of snowmobiles to ice-covered areas also deserves consideration.

Table 3 Analysis of frequency and intensity effects on field standing crop[a]

Source	Sum of squares	DF	MS	F	p
Frequency	226.70	1	266.70	8.72	<0.01
Intensity	74.15	1	74.15	2.43	0.125
Interaction	0.32	1	0.32	0.01	0.920
Residual	1713.45	56	30.60		

[a] 2 × 2 ANOVA of treatment lanes.

Table 4 Species composition of old field vegetation[a]

Species	Control	Treatments 1	2	3	4
Agrostis tenuis	76	72	90	69	81
Centaurea nigra	60	60	52	62	55
Vicia cracca	40	50	40	41	44
Stellaria graminea	36	29	27	19	19
Potentilla simplex	26	31	22	13	21
Phleum pratense	8	12	12	29	16
Solidago canadensis	16	13	7	11	12
Trifolium pratense	5	8	14	9	8
Aster cordifolius	6	1	14	8	13
Ranunculus repens	13	2	7	8	7
Poa compressa	6	8	1	6	6
Equisetum arvense	3	1	1	14	6

[a] Values are point estimates of percent cover for species with mean >5%. Treatments are described in Table 1 and under "Study Area and Methods."

Table 5 Frequency and intensity effects on six old field species[a]

Species	Frequency	Intensity	Interaction
Agrostis tenuis	0.095	2.952[b]	1.496
Stellaria graminea	3.052[b]	0.225	4.148[c]
Phleum pratense	3.310[b]	0.043	1.556
Aster cordifolius	0.617	4.673[c]	0.617
Ranunculus repens	2.028	0.294	2.327
Equisetum arvense	4.800[c]	1.209	1.209

[a] 2 × 2 ANOVA of percent cover data from treatment lanes. Arcsine $\sqrt{x}$ transformed; calculated F values given; df = 1, 36 for both main effects and interaction.
[b] $p < 0.10$
[c] $p < 0.05$

Table 6 Species composition of marsh vegetation[a]

Species	Control	Treatments 1	2	3	4
Carex aquatilis	98	100	100	94	100
Solidago canadensis	7	14	8	10	16
Galium palustre	4	3	1	6	8
Agrostis stolonifera	2	5	0	11	5

[a] Values are point estimates of percent cover for species with mean >5%. Treatments are described in Table 1 and under "Study Area and Methods."

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Appendix: Analysis of Published Data

Wanek (1974) does not always provide precise details of sampling or measures of sampling variability. However, the data presented in several of his tables can be analyzed using nonparametric statistics (Siegel 1956).

Individual species cannot be evaluated; however it is possible to test whether all species considered together show a similar reaction to snowmobile use. If it is assumed (1) that each species is independent of all others, and (2) that snowmobiles have no effect, then for each species there is a 0.50 probability of treatments being greater than the control and a 0.50 probability of treatments being less than the control. [That is, the null hypothesis is $p(T > C) = p(T < C) = 0.5$.] It is then possible to use the sign test (Siegel 1956) to test whether more species than expected simultaneously decrease in treatments relative to controls.

This test is crude. It does not consider the magnitudes of the changes, and it combines the results obtained for all species. It is also conservative, being sensitive only to simultaneous unidirectional changes in abundance of an entire assemblage of species. Note that failure to reject the null hypothesis does not mean that significant vegetation changes did not occur. The null hypothesis (no effect of snowmobiles) would be accepted using this test if half the species increased significantly and half decreased significantly. The sign test does not distinguish between this and the situation in which random fluctuations lead to the identical result.

The sign test was applied to Table 1 in Wanek (1974), where N = 7 species (N = 6 where one species was identical in the treatment and control). It was found that early spring plants were significantly smaller ($N = 7$, $p = 0.008$) and significantly less frequent ($N = 6$, $p = 0.016$) under snowmobile trails; there was no significant reduction in the proportion reproducing ($N = 6$, $p = 0.109$).

Table 9 in Wanek (1974) presents "populations" of common bog herbs and shrubs in control plots and those in plots receiving light, medium, and heavy snowmobile use. Again, it is possible to test whether all species show a similar trend with increasing intensity of use. The Friedman

…way analysis of variance for ranks (Siegel 1956) is an appropriate test. Generally, the ranked abundances decline with increasing snowmobile use; this decline is highly significant ($k = 4$, $n = 7$, $df = 3$, $\chi_r^2 = 12.09$, $p < 0.01$).

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