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Growth Conditions and Vitality of *Sphagnum* in a Tundra Community Along the Alaska Pipeline Haul Road

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ABSTRACT. Effects of road dust and road related construction upon *Sphagnum lenense* were found in one *Sphagnum*-rich tundra community along the Alaska Pipeline haul road. Dust, arising from vehicular traffic, settled in greatest quantities near the road with the amount rapidly decreasing away from the road. Water content of *Sphagnum lenense* in quadrats close to the road and to a buried gasline was generally low when compared with those of *S. lenense* in more distant quadrats. Total conductivity, pH, and calcium content of water extracted from the *Sphagnum* was greatest in heavily dust-impacted quadrats. Chlorophyll content (μg chlorophyll *a*/g dry weight plant tip) was greatest in *Sphagnum lenense* little exposed to dust and lowest in *Sphagnum* heavily exposed. Carbon uptake rates in *Sphagnum lenense* from quadrats far from the road were higher than uptake rates in quadrats near the road, as determined by fixation of ^{14}C labeled CO_2.

RÉSUMÉ. Le long de la route d'accès à l'oléoduc de l'Alaska, dans un environnement de toundra, riche en mousse *Sphagnum*, la poussière de la route et les travaux sur celle-ci ont eu des effets sur cette mousse.

Avec la croissance de la circulation, la poussière se déposait en plus grande quantité, à proximité de la route mais elle diminuait rapidement en s'éloignant de celle-ci.

La proportion d'eau dans *Sphagnum lenense*, dans les carrés mètriques adjacents à la route et près de l'oléoduc enterré, était généralement inférieure à celle observée dans les carrés plus éloignés.

Dans les carrés à dépôts abondants de poussière, l'eau extraite de *Sphagnum* avait une conductivité totale, un P.H. et une teneur en calcium plus élevés. Le rapport en chlorophyle par rapport au poids d'un bout désséché de plante, était le plus élevé pour *Sphagnum lenense* quand cette mousse était peu exposée à la poussière; il était le plus bas quand la mousse était très exposée. Les teneurs en carbone assimilé par *Sphagnum lenense* dans les carrés unitaires éloignés de la route étaient plus élevées que celles observées dans les carrés voisins de la route — celà suivant la méthode de fixation du carbone 14 á partir de Co_2.

Traduit par Alain de Vendegies, Aquitaine Company of Canada Ltd.

INTRODUCTION

Habitats are altered when highways are constructed through them, and ground water movement, in particular, is often affected (Backman *et al.*, 1980). The use and maintenance of these roads may present new and potentially damaging impacts, especially on plants growing near the roads. For example, road salt runoff can damage vegetation (Piatt and Krause, 1974), vehicular exhaust gases may alter pH values on leaf surfaces (Fluckiger-Keller *et al.*, 1979), and road dust accumulation on leaves may raise their temperature (Eller, 1977).

The construction of the Alaska Pipeline haul road raised concern about potential effects of gravel roads upon tundra and taiga habitats. With the road's completion in September 1974, various studies focused attention on effects of the road upon terrestrial and aquatic biota in northern Alaska (Brown, 1978). Extensive road dust, raised primarily by heavy construction vehicle traffic, was recognized as an immediate and obvious problem. Not only did it present a hazard for users of the road, but it settled extensively upon nearby ponds and lakes, adding nutrients and minerals (Alexander and Miller, 1977). Dust also settled on terrestrial vegetation, and has had unknown effects. In the present study the moss *Sphagnum* was chosen as a representative organism from one tundra community adjacent to the road to examine how the growth conditions and physiology of this plant were altered directly or indirectly by road dust. *Sphagnum* can be an important and extensive ground cover in moist tundra. Its disturbance is likely to effect the water-holding capacity of the community in which it is found. Permafrost underlying tundra may thaw if the overlying vegetation cover is disturbed or removed (Péwé, 1967).

Sphagnum requires specific habitat conditions and is sensitive to changes in its environment (Greene and Pearson, 1968; Vitt and Slack, 1975; Steere, 1976). The plants grow best in acidic, low-calcium conditions (Gorham and Pearsall, 1956; Clymo, 1973) and the mineral concentrations in *Sphagnum* are often related directly to the mineral supply in the substrate (Pakarinen and Tolonen, 1977). Minerals can be added to the substrate from the air or from ground water; hence, air and water quality may affect mineral concentration in *Sphagnum* tissues (Pakarinen, 1977). *Sphagnum* spp. take up some mineral cations passively and others by cation exchange (Bell, 1959; Clymo, 1967; Pakarinen, 1977); the degree of uptake is influenced by elevation above the water table (Clymo, 1963; Spearing, 1972) and the amount of minerals available (Pakarinen and Tolonen, 1977).

Sphagnum taxa are best known from the taiga and tundra of the Northern Hemisphere where they sometimes comprise a significant portion of the vegetation (Moss, 1955; Crum, 1972). *Sphagnum* spp. are often a principal component of "peat", which covers a large part of the earth's surface north of 60° N latitude (Clymo, 1970). In the Alaska Pipeline transportation corridor north of the continental divide their distribution is restricted to areas in the Brooks Range foothills (B. Murray, pers. comm.; Steere, 1976, 1978), where they are locally quite abundant.

This study assessed the relative health of *Sphagnum* along a dust gradient in a tundra community and thus was

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comparative in nature. *Sphagnum* was sampled along transects from the haul road outward to examine:

1) moisture content of plants at various distances from the road;
2) mineral concentration in water extracted from the plants;
3) chlorophyll *a* content of "tips" (capitula regions); and
4) carbon uptake of the *Sphagnum* in ^{14}C fixation assays done under experimental conditions.

METHODS

Study Area

Research was conducted during July and August, 1978, in the foothills of the Phillip Smith Mountains in northern Alaska with some preliminary investigations done during the summer of 1977, which was the third year of operation of the road. The road, which is unpaved and 8.5 m wide (crown level), was constructed to a height several meters above the ground surface. One moist, flat, *Sphagnum*-rich and floristically uniform site of low tussock-tundra was selected (site located approximately 15 km north of Toolik Lake, at haul road km 384; 68°41′N, 149°11′W). Dominant higher plants in the site included *Andromeda polifolia* L., *Betula nana* L., *Eriophorum vaginatum* L., *Ledum palustre* L., *Rubus chamaemorus* L., and *Vaccinium vitis-idaea* L. (Spatt, 1978; Webber *et al.* in Brown, 1978). Five *Sphagnum* species were found: *Sphagnum aongstroemii* C. Hartm., *S. compactum* D.C., *S. lenense* H. Lindb. ex Pohle, *S. recurvum sensu lato* P.-Beauv., and *S. rubellum* Wils. Representative *Sphagnum* specimens are deposited in the herbarium of the University of Alberta.

Sphagnum lenense and *S. rubellum* were co-dominant and grew intermixed in all tussocks examined. *Sphagnum aongstroemii, S. compactum*, and *S. recurvum s.l.* occurred in low frequency throughout the site. All species grew intermixed with the possible exception of *S. aongstroemii*, which tended to occur more often in moist depressions between tussocks. This indicates that the growth conditions were likely uniform throughout the site. Because some *Sphagnum* spp. show differences in physiological responses to environmental parameters (Clymo, 1970; Spearing, 1972), the study was limited to measurements on *S. lenense*. However, the results are probably relevant to all *Sphagnum* in the community.

Paired 1-m^2 quadrats, each with a high *Sphagnum* cover, were established at distances perpendicular to the road on both sides, east and west, as follows: 250 m, 125 m, 25 m, 9 m (west side only) and 5 m (east side only). Quadrats were chosen at 9 m west rather than 5 m because of surface disturbance at 5 m west caused by the 1976 burial of a 15-cm gas pipeline along the road.

Dustfall Analysis

The amount of dustfall at each quadrat pair was determined with a dust collector. A collector consisted of two 9×9×7 cm open plastic containers ¾ filled with 200 ml of distilled water and set in a dry enamel pan. Collectors were exposed for one-week periods three times during the summer. During exposures, the water did not evaporate from the containers or overflow with added rain. Following each interval the water was filtered through preweighed Gelman A-E 47-mm glass fiber filters. The filters were dried and weighed and the mean of dust accumulated in both containers was extrapolated to dustfall m^{-2} day^{-1} at each distance. Dust accumulation patterns on *Sphagnum lenense* were determined three times during the summer by sonically removing all dust in distilled water from 25 randomly chosen (by subjective judgment) "tips" at each distance. A "tip" consisted of a capitulum and upper two to three branches. Following sonication (1-5 minutes) the water was filtered and the dust was dried and weighed.

Sphagnum Water Chemistry

Water was mechanically extracted from *Sphagnum lenense* from each quadrat four times at one-week intervals by gently squeezing a pure tuft of plants between two plexiglass® plates. The sample was measured for pH (within three hours) with a Corning 610A pH meter, conductivity at 25° with a YSI-31 conductivity bridge (result not corrected for H^+ conc.), and ppm calcium using a Coleman model 21 flame photometer.

Sphagnum *Water Content, Chlorophyll* a, *and Temperature*

At the same intervals a sample of *Sphagnum lenense* was obtained from each quadrat and measured for water and chlorophyll *a* content. Five *Sphagnum* tips, randomly chosen from each sample, were weighed for fresh weight (FW). FW was defined as *Sphagnum* in field condition. The tips were oven dried for three hours at 100°C and weighed for dry weight (DW). Water content (WC) on a dry weight basis was determined with the formula

$$\frac{FW - DW}{DW} * 100 = WC.$$

Five other tips were chosen, weighed (FW), and placed in separate vials with five ml of 90% acetone. The vials were capped, covered, and refrigerated for 48 hours. The quantity of chlorophyll *a* extracted in acetone was determined using a Turner model 111 fluorometer. Readings were calibrated against pure Sigma chlorophyll *a* and each sample reading was converted into µg chlorophyll *a* (g dry weight)$^{-1}$, uncorrected for phaeophytin *a*, with the formula

$$\frac{\mu g \text{ chlorophyll } a \text{ extracted}}{\text{FW tip} * (\text{DW values}/\text{FW values})} = \mu g \text{ chlorophyll } a \text{ (g DW tip)}^{-1}$$

using mean FW and DW values from the *Sphagnum* used concurrently in the WC determination.

Sphagnum surface temperature was measured on the capitula of 10 plants at each of three distances on one date in August 1977, using a wafer-thin YSI-400 temperature probe.

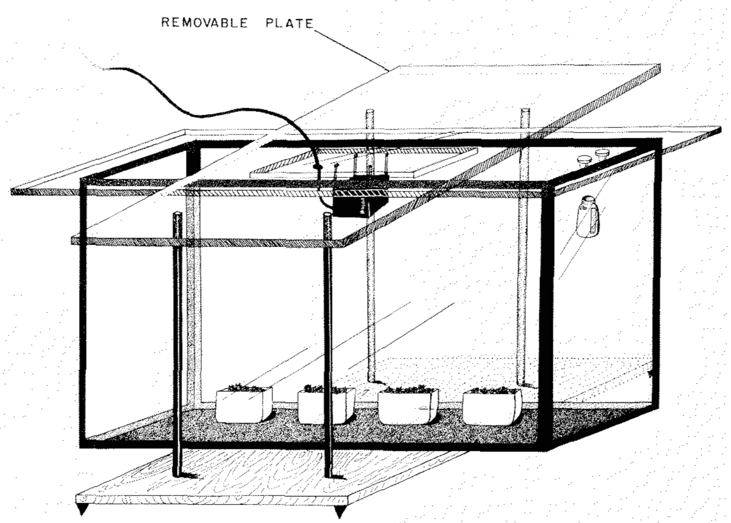

FIG. 1. The chamber used for exposing *Sphagnum*. *Sphagnum* was held in containers placed into the chamber through the opening under the removable cover. A fluorescent light bank was placed atop the chamber, and the entire unit was covered with an opaque hood at the start of exposures.

Sphagnum Carbon Uptake

A 56.7-liter rectangular glass air-tight photosynthetic chamber, equipped with an internal fan and removable cover, was constructed to measure short-term *in-vitro* ^{14}C fixation by *Sphagnum lenense* (Fig. 1).

Sphagnum samples measuring $9 \times 9 \times 7$ cm were collected at four one-week intervals from each distance, inserted into plastic containers, and placed into the chamber within four hours. Exactly four ml of $H^{14}CO_3$ (29μCi/ml ^{14}C) were placed into a glass vial cemented to an internal wall. The chamber was sealed with the cover, and $^{14}CO_2$ was released by injecting 1N HCl into the bicarbonate with a syringe through a rubber stopper. A fluorescent light bank, placed atop the chamber, delivered 232 μE m^{-2} sec^{-1} of photosynthetically active radiation to the *Sphagnum* (light was measured with a Licor quantum radiometer-photometer; Lambda Instruments, Lincoln, Nebraska).

The unit was covered with an opaque hood, and the *Sphagnum* was exposed to $^{14}CO_2$ for two hours under continuous light with the fan running. Temperature was noted with an internal thermometer, and never varied $\pm 2°$ from ambient air temperature. Fifty ml of air, extracted through a rubber stopper with a syringe, was mixed with 0.5 ml of phenethylamine in the syringe. The mixture was injected into 10 ml of RPI Complete Counting Cocktail (3A70B) and counted on a Nuclear Enterprise LSM-1 scintillation counter.

Following exposure, 10 *Sphagnum* tips were chosen subjectively at random from each sample, weighed for FW, and placed in separate plastic scintillation vials. DW for these tips was estimated using water content values of adjacent *Sphagnum* plants. Each tip was macerated and ^{14}C fixation (g DW tip)$^{-1}$ was measured directly by scintillation technique in six ml of Bray's solution (Bray, 1960). Carbon uptake was calculated:

1) assuming that ^{12}C available inside the chamber was equivalent to average exterior air (328 ppm), with which it was flushed at the beginning of each experiment;
2) assuming a 6% discrimination of ^{12}C against the heavier ^{14}C, multiplying the calculated uptake by 1.06 (Steeman, 1955);
3) correcting the counts (tip)$^{-1}$ for quench using channel ratios method calibrated with ^{14}C toluene and a quench agent; and
4) empirically measuring the ^{14}C added by the amount of $^{14}CO_2$ absorbed by the phenethylamine.

Thus, the carbon uptake for each tip can be calculated:

$$(1.06)\frac{\mu g\ ^{12}C \text{ available in chamber air} * {}^{14}C \text{ cpm fixation (g DW tip)}^{-1}\text{hr}^{-1}}{g\ ^{14}C \text{ cpm added to chamber}} = \mu g\ ^{12}C \text{ uptake (g DW tip)}^{-1}\text{hr}^{-1}.$$

We recognize that the calculated ^{12}C uptake is possibly an underestimate because ^{12}C may be available in intercellular spaces in the *Sphagnum* at the start of the experiments. Done under standard conditions, fixation of gaseous $^{14}CO_2$ is a satisfactory bioassay method, although the absolute rates may be higher.

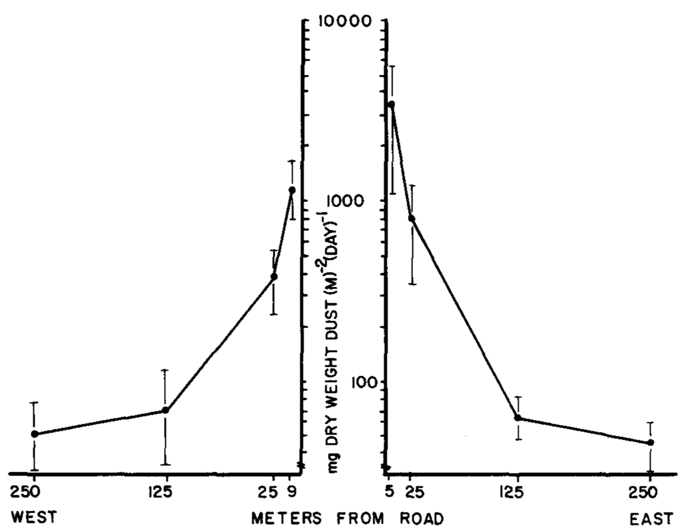

FIG. 2. Dustfall m^{-2} day^{-1} along transects, log scale, extrapolated from dust weight accumulation values in collectors. Each data point is a mean value determined from three one-week sampling periods (n = 6). Standard deviations are indicated.

RESULTS

Dustfall was most intense near the road and declined exponentially with increasing distance from the road margin on both sides (Fig. 2). Dust accumulated on *Sphagnum* in a pattern similar to that in the dustfall collectors (Fig. 3).

Chemical and physical conditions in the plants differed along the transects. Water squeezed from *Sphagnum lenense* near the road had greater conductivity, calcium levels, and pH than did water from more distant quadrats

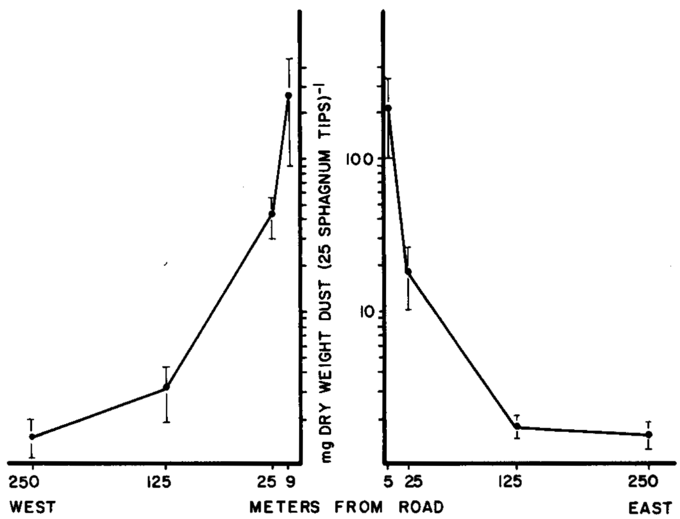

FIG. 3. Accumulation of dust, log scale, on samples of *Sphagnum lenense* along transects. Each data point is a mean value determined from three sample dates (n = 3). Standard deviations are indicated.

(125 m E-W, 250 m E-W) (Table 1). The surface temperature of *Sphagnum* was also higher in heavily dusted quadrats (Table 1).

Water content of *Sphagnum lenense* was depressed in plant samples at 5 m E and 9 m W, in contrast to *Sphagnum* at 125 or 250 m E-W (Table 1). *Sphagnum* from quadrats near the gasline burial (9 m W) had the lowest water content, indicating that drainage of the soil occurred at this distributed construction site.

Similarly, *Sphagnum lenense* chlorophyll *a* content and carbon uptake rates were lowest in quadrats at 5 m E and 9 m W and progressively increased with increasing distance from the road (Table 2). Therefore, chlorophyll levels were highest in *Sphagnum* with a high water content (Fig. 4). Carbon uptake appeared to be directly related to *Sphagnum* water content (Fig. 5), showing a significant linear correlation of $r = 0.833$ ($p < 0.05$) (Table 3). An analysis of variance for carbon uptake values at the various distances from the road was significant ($F = 5.21, p < 0.01$). A Scheffe Multiple Comparisons test (at $p = 0.05$) indicated that carbon uptake at 9 m W was significantly lower than at all other distances except 5 m E and that uptake at 5 m E was significantly lower than uptake at 125 and 250 m E-W.

DISCUSSION

Along with decreases in dustfall several gradients were noted outward from the road. Decreases in *Sphagnum lenense* temperature and mineral ion concentrations and

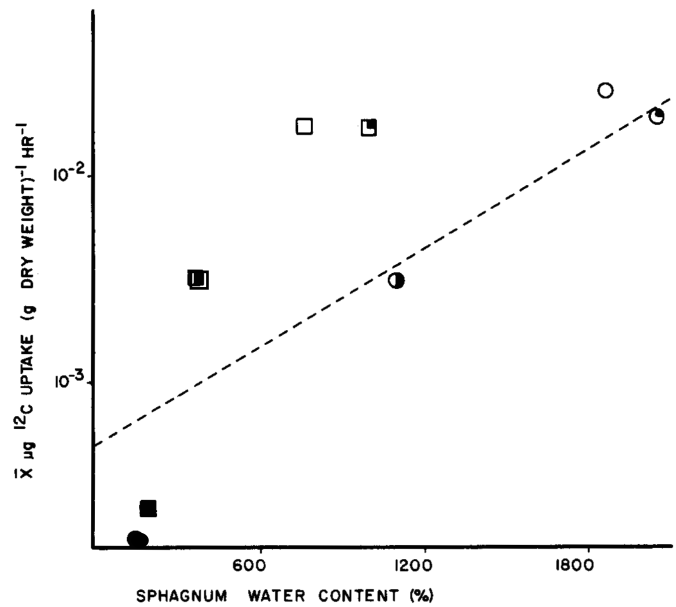

FIG. 4. Mean chlorophyll *a* content of *Sphagnum lenense* capitula in relation to water content of contiguous *Sphagnum* plants in quadrats along transects. Each data point represents a seasonal mean of 40 plants for chlorophyll assays and 40 plants for water content determinations. Legend: ■ 5m E; ◨ 25M E; ◩ 125m E; □ 250m E; ● 9m W; ◑ 25m W; ◔ 125m W; ○ 250m W.

TABLE 1. Chemical data of *Sphagnum* water, percent water content of *Sphagnum* (dry weight basis), and *Sphagnum* surface temperature in relation to distance from the haul road

Location of quadrat	Conductivity (µmho)		Ca^{2+} Conc. (ppm)		pH		*Sphagnum* Water Content (%)		*Sphagnum* Surface Temp.	
	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s	$\bar{X}$	s
9m-west	291.6	93.9	15.3	11.4	6.1	0.4	154.9	231.3	31.8	4.7
25m-west	248.4	88.6	8.5	4.6	5.4	0.5	1112.4	2171.9	18.0	0.9
125m-west	66.7	18.4	0.8	0.4	4.4	0.1	2037.5	1408.7	20.3	2.5
250m-west	60.8	10.5	0.8	0.3	4.2	0.1	1876.8	1820.6	nd*	—
5m-east	250.2	80.5	12.5	7.7	6.5	0.5	200.3	82.3	nd	—
25m-east	115.2	33.2	4.0	5.5	5.4	0.3	383.6	179.8	nd	—
125m-east	53.9	10.9	1.0	0.7	4.3	0.1	1092.3	874.5	nd	—
250m-east	49.6	19.9	0.8	0.3	4.3	0.1	769.4	384.3	nd	—

*— no data

Means for chemical data represent eight *Sphagnum* water samples taken during the 1978 season. Percent water content means are each of eight *Sphagnum* samples (each sample = five individual plants) from 1978. Surface temperature means are of ten readings taken in August, 1977.

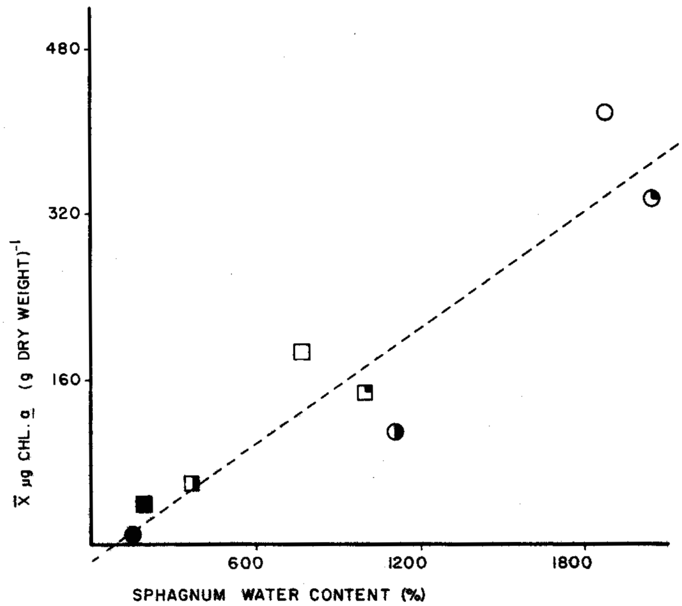

FIG. 5. Mean uptake of µg carbon-12 in *Sphagnum lenense* in relation to *Sphagnum* water content values in quadrats along transects. Each data point represents a mean seasonal value for 40 plants for carbon uptake and a seasonal mean of 40 plants for water content. Legend is same as in Fig. 4.

pH in plant water, and increases in *Sphagnum* water content, chlorophyll levels, and carbon uptake rates were seen (Tables 1, 2). Significant correlations with distance were seen for many of the parameters (Table 3) and dust accumulation may have directly or indirectly accounted for some of the gradients. While settled dust has been observed to promote early snow melt along the road in late spring (Everett, 1979), dust may have reduced albedo in the infrared spectrum of the *Sphagnum* surfaces, resulting in their warming. Increases in the temperature of dusty *Rhododendron* leaves, resulting from their increased absorption of 700-1350 nm radiation, has been observed (Eller, 1977). It is reasonable to expect a dust coating to physically restrict gas exchange and attenuate photosynthetically active light received by the plants. Dust may also absorb water through non-cutinized plant surfaces such as the leaves, stems, and branches of *Sphagnum*. This, along with increased evaporation from the plants (because of higher temperatures) would contribute to decreased water content. In this study *Sphagnum lenense* water content was negatively correlated with the log of accumulated dust (Table 3) but was most markedly low at 9 m W, suggesting that local drainage significantly affected surface moisture at this distance. The water content of *Sphagnum* was most probably affected by a combination of dust and construction effects.

Physiological effects of water stress in plants are varied. Photosynthesis may be retarded when cell protoplasm is dehydrated (Meyer *et al.*, 1973). A water deficit in tissues may reduce chlorophyll levels by reducing the production of protochlorophyll (Virgin in Bourque and Naylor, 1971). Studies with mosses have shown that plant moisture content can appreciably affect CO_2 assimilation and productivity rates. In one study CO_2 assimilation in *Hylocomium splendens, Ptilium crista-castrensis, Pleurozium schreberi,* and *Tomenthypnum nitens* ceased when plant water content dropped below 0.4 g g^{-1} dry weight (Busby and Whitfield, 1978). In another study photosynthesis in *Dicranum polysetum* ceased when plant water potential dropped to −23 atm but resumed when water contents were raised (Peterson and Mayo, 1975). Habitat differences in water availability can influence moss productivity. Mosses in wet habitats (streamsides, wet meadows) on Devon Island, Canada, had higher productivity and nitrogen levels than did mosses in mesic habitats (hummock sedge meadows) (Pakarinen and Vitt, 1973). Productivity (annual shoot production) in *Pohlia wahlenbergii* was greater in sites with running water and shading than in sites

TABLE 2. µg ^{12}C uptake (10^{-4}) (g DW tip)$^{-1}$ (hr)$^{-1}$ in *Sphagnum* under test conditions and *Sphagnum* chlorophyll *a* µg (g DW tip)$^{-1}$

Location of quadrat	µg ^{12}C Uptake $\bar{X}$	µg ^{12}C Uptake s	Chlorophyll *a* $\bar{X}$	Chlorophyll *a* s
9m-west	4	2	12	13
25m-west	52	20	108	160
125m-west	232	151	333	266
250m-west	246	207	417	568
5m-east	2	2	40	20
25m-east	50	29	60	46
125m-east	276	208	148	137
250m-east	400	189	187	120

TABLE 3. Correlation coefficients (r) between environmental parameters and *Sphagnum* measurements

	^{12}C Uptake	Chloro. *a*	*Sphagnum* Water Content	Conduct.	Ca^{2+}	pH
Distance	.916**	.794*	.607	−.803*	−.776*	−.858**
Dustfall ($\log_{10}$)	−.892**	−.775*	−.779*	.847**	.876**	.985**
Sphagnum water content	.833*	.927**	—	−.615	−.705	−.774*

*Significant at $p < 0.05$
**Significant at $p < 0.01$
The units for variable expression are the same as reported in Tables 1 and 2, and Figures 3 and 4.

without these factors (Clarke *et al.*, 1971). Plant water contents optimal for photosynthesis are known for some *Sphagnum* spp. (Clymo, 1970, 1973). In this study chlorophyll content and carbon uptake rates were both significantly lower in dry than in wet *Sphagnum lenense* (Fig. 3, 4; Table 3). Plants with the greatest uptake rates also had the greatest chlorophyll concentrations. It appeared that plant water content was an important determinant of the physiological state of *Sphagnum lenense*. Using carbon uptake and chlorophyll levels as indices of productivity, *Sphagnum* near the road was less productive than *Sphagnum* farther out.

Sphagnum is responsive to its chemical environment. Tissue analysis was not performed in this investigation, but in one study calcium concentration in *Sphagnum* tissue was positively correlated with calcium concentration in waters surrounding the plants (Pakarinen and Tolonen, 1977). Road dust adds calcium and other mineral ions to the tundra surface (Everett, 1979; Table 1). Alkalinity is increased by dust in water, resulting in a pH rise (Alexander and Miller, n.d.), but decreased cation exchange physiology in *Sphagnum* may, additionally, account for high pH values in dusty quadrats. Growth rates of *Sphagnum rubellum*, one of the co-dominant *Sphagnum* spp. in the site, were found in one investigation to be reduced when the plants were experimentally exposed to unnaturally high levels of calcium and pH ($Ca^{2+} > 10$ ppm; pH > 5.5) (Clymo, 1973). These conditions were found only in heavily dusted quadrats (5 m E, 9 m W) (Table 1). Thus, the chemical conditions in these quadrats were not conducive to optimal *Sphagnum* growth.

Although dust affects the *Sphagnum* community in various ways, generalizations of growth conditions for plants adjacent to the road are potentially confounded because the road may block ground water movement in some areas. Moisture can be increased on one side and effects of dust accumulation can be ameliorated. Further, nutrients may also be leached from the road bed material

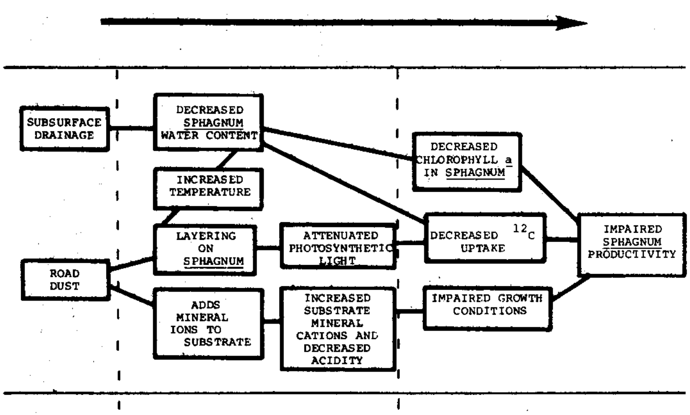

FIG. 6. Model of potential short-term, long-term, and immediate effects of road dust and subsurface drainage upon *Sphagnum* along transects.

by rain. Nutrients may also be leached from deposited dust (Alexander and Miller, 1977), possibly stimulating the growth of some higher plants (Webber, pers. comm.). However, heavy dust accumulation is recognized as a factor affecting *Sphagnum* health and vitality.

A long-term effect of heavy road dust accumulation upon *Sphagnum* may be decreased productivity and growth. The major points of this paper and the potential impacts of road dust upon *Sphagnum* are summarized in Figure 6.

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