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Vegetation Response to a Subsurface Crude Oil Spill on a Subarctic Right-of-Way, Tulita (Fort Norman), Northwest Territories, Canada

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ABSTRACT. The plant species on a simulated pipeline corridor near Tulita (Fort Norman), Northwest Territories were studied prior to and for three years after an experimental point-spill of 3273 L (20 imperial barrels) of crude oil. Two distinct environments were examined: a cleared right-of-way (ROW) and a simulated pipeline trench. Each environment was subdivided on the basis of oil concentration into heavily oiled, lightly oiled, and unoiled sections. Total plant cover on the heavily oiled ROW declined by 73% in the first growing season; however, significant recovery took place in subsequent years. All other oiled environments had significant increases in total plant cover, but not until at least the second year after the spill. Of the 34 taxa identified, 13 declined significantly in abundance by the third growing season after the oil spill, mainly on the heavily oiled ROW. By the third post-spill growing season, mosses, *Carex* spp., *Eriophorum* spp., and agronomic grasses (*Alopecurus arundinacea*, *Phleum pratense*, *Poa glauca* and *P. pratensis*) had increased in abundance on at least one type of oiled substrate. However, the agronomic grasses, species sown on the Norman Wells pipeline, also declined significantly on the heavily oiled Trench. In contrast, the native grass *Arctagrostis latifolia* declined only on the heavily oiled ROW.

Key words: oil spill, subarctic, plant species, vegetation, disturbance, revegetation, plant recovery, oil pipeline

RÉSUMÉ. On a étudié les espèces végétales présentes sur un corridor pipelinier simulé près de Tulita (Fort Norman), dans les Territoires du Nord-Ouest, avant un déversement expérimental ponctuel de pétrole brut de 3273 L (soit 20 barils impériaux) et durant les trois années suivantes. On a examiné deux environnements distincts: une emprise dégagée et une tranchée simulée de pipeline. On a divisé chaque environnement en sections en se basant sur la concentration en pétrole: forte, faible et nulle. Durant la première saison de croissance, l'ensemble du couvert végétal a diminué de 73 p. cent sur les sections de l'emprise où existait une forte concentration; un important reverdissement a toutefois pris place durant les années suivantes. Tous les autres endroits qui avaient reçu du pétrole ont connu d'importantes augmentations de l'ensemble du couvert végétal, mais, au plus tôt, à partir de la deuxième année suivant le déversement. Sur les 34 taxons identifiés, 13 avaient largement diminué en abondance à la troisième saison de croissance suivant le déversement, surtout dans les sections de l'emprise à forte concentration de pétrole. À la troisième saison de croissance suivant le déversement, les mousses des espèces *Carex* et *Eriophorum* et les herbes agronomiques *(Alopecurus arundinacea, Phleum pratense, Poa glauca* et *P. pratensis)* avaient augmenté en abondance à au moins un type de milieu où avait été déversé du pétrole. Toutefois, les herbes agronomiques — espèces semées sur le parcours du pipeline de Norman Wells — avaient aussi diminué de façon significative sur la tranchée où se trouvait une forte concentration de pétrole. Par contre, l'herbe indigène *Arctagrostis latifolia* n'avait diminué que sur l'emprise à forte concentration.

Mots clés: déversement de pétrole, subarctique, espèce végétale, végétation, perturbation, restauration, reverdissement, oléoduc

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INTRODUCTION

A number of experimental crude oil spills have been conducted in arctic (Wein and Bliss, 1973; Freedman and Hutchinson, 1976; Holt, 1987) and subarctic (Hutchinson and Freedman, 1978; Jenkins et al., 1978) ecosystems. These experiments used a spray application, to ensure uniform oil coverage on all vegetation. While such a technique may successfully mimic an aboveground pipeline rupture, in which pressurized oil is sprayed from the pipe, it does not simulate a subsurface pipeline rupture, in which the oil would be concentrated in the soil at or near the surface.

A spray application creates a thin film, which enhances evaporation and weathering of the oil (Jenkins et al., 1978). Such a method also results in high surface area contact for plants, thus killing most green tissue. A subsurface spill may have more long-term effect on the rooting systems of plants, but fewer immediate effects on aboveground plant tissue that is not in direct contact with the oil. In addition, as most experimental studies have been conducted in undisturbed

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ecosystems, they do not provide information on the effects of such a spill on the operating environment of an actual pipeline. Currently, there is one major oil pipeline in use in northern Canada: the Norman Wells Project, operated by Interprovincial Pipe Lines Inc., which stretches almost 900 km from Norman Wells, Northwest Territories to Zama, in northwestern Alberta.

This investigation was conducted at the Studies of the Environmental Effects of Disturbances in the Subarctic (SEEDS) project site (64°58′N, 125°36′W), near Tulita, Northwest Territories, 10 km northwest of the confluence of the Mackenzie and Great Bear Rivers (Fig. 1). Two distinct habitats were examined on this study site: (1) the simulated transport corridor right-of-way (ROW), which was cleared of trees and shrubs, while the surface vegetation and organic layer were left intact; and (2) the simulated buried pipeline Trench, where trees and shrubs, low-growing plants, mosses, and lichens had been removed along with the surface organic soil layers during excavation and backfilling, to simulate the construction of a buried pipeline. Because of disturbance to the active layer, the Trench had subsided. The North Link (Fig. 1) was cleared and trenched in 1985, and ROW 2 in 1986. About half of the experimental crude oil spill area was on ROW 2 (Fig. 1). The Trench had also been fertilized and seeded with an agronomic species mixture (*Alopecurus arundinacea*, *Phleum pratense*, *Poa glauca*, and *P. pratensis*) identical to that used on the Norman Wells pipeline (Interprovincial Pipe Line Inc., 1985) two (ROW 2) or three (North Link) growing seasons prior to the experimental spill.

This study assessed the effects of a small-scale crude oil spill on the species composition and cover characteristics within a simulated transport corridor in a subarctic upland black spruce (*Picea mariana*) forest. Because many plant species are common across much of the Subarctic, our results have broad management implications for the reclamation of oil spills on pipeline rights-of-way in the North.

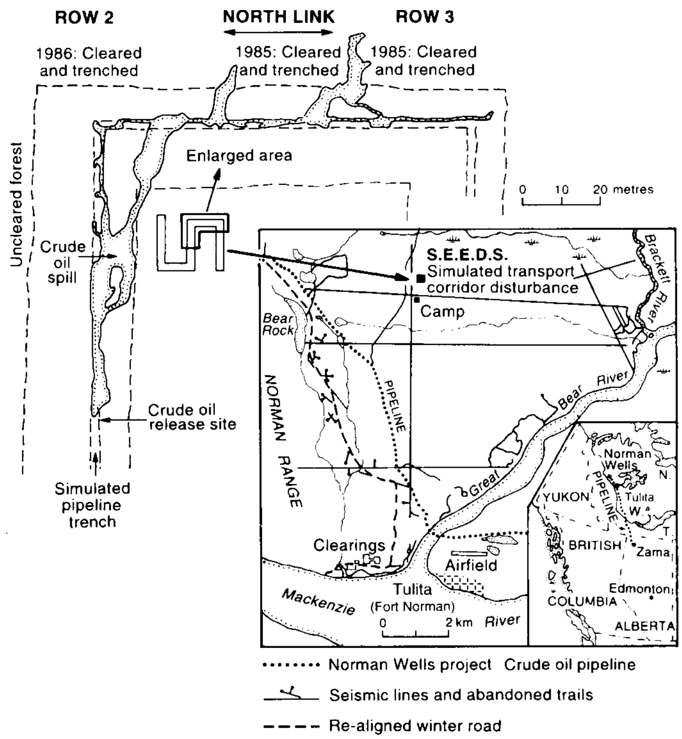

FIG. 1. The SEEDS site is 10 km north of Tulita and 5 km east of the Norman Wells Project pipeline. The experimental crude oil spill of 1988 affected ROW, Trench, and forest environments.

METHODS

Field Methods

On 28–30 August 1988, 3273 L (20 imperial barrels) of Norman Wells crude oil were pumped directly into an open-ended pipe buried one metre deep in a simulated pipeline trench (Kershaw, 1990). Because of saturated soil conditions, most of the oil came to the surface and flowed along the low-lying areas of the site. The oil initially spread quickly and eventually contaminated a surface area of 673 m^2, achieving an average concentration calculated at 4.9 $L \cdot m^{-2}$, although the actual concentration varied within the spill perimeter from no evidence of oil to heavily oiled because of the hummocky terrain.

Prior to the spill, and without precise knowledge of the final disposition of the oil, permanent 25 × 25 cm quadrats were located by surveying a 1 × 1 m grid system over the study area (Kershaw, 1990). The sample quadrats were located at grid intersect points. Within these quadrats, the cover of each plant species was visually estimated (to the nearest 1% below 10%, and to the nearest 5% above 10% cover). This survey was carried out before the spill in 1988, and then after the spill in 1989, 1990, and 1991 during the first week of August, the height of each growing season. Taxa with < 1% cover (< 6.25 cm^2) were assigned a value of 0.1% for purposes of analysis.

Shortly after the release of the oil, ROW and Trench quadrats were classified through visual assessment of the surface oil concentration into three categories: heavily oiled (pooling of oil and oil on plant surfaces, obvious odour and blackening of the surface); lightly oiled (only a sheen could be detected on surface water); or apparently unoiled (no visible or olfactory evidence of oil). This last group included predominantly raised sites above the wetting line of the oil. There remains the possibility that oil could have been present below the surface (Jenkins et al., 1978; Collins, 1983). However, since soils on the site are fine-grained with soil water at field capacity (Kershaw, 1990), it is unlikely that oil could penetrate to any depth below the surface. This is why the spill covered a much larger area at lower concentrations than initially expected on the basis of other point-spill experiments (Kershaw, 1990). Subsurface sampling of soils was conducted with a 3 cm diameter corer. The high water content made it difficult to remove intact samples, but no oil was observed below the surface in these samples. There was seldom any difficulty in classifying a quadrat, and it would have been logistically and financially costly to conduct chemical analysis for all quadrats to quantitatively assess oil contamination. Because of subsidence as a result of permafrost

TABLE 1. Mean pre-spill species cover values (% with standard deviation below in parentheses) on the SEEDS experimental crude oil spill site, 1988.

	ROW			Trench	
	Heavily oiled	Lightly oiled	Apparently unoiled	Heavily oiled	Lightly oiled
Nonvascular Species					
Cetraria spp.	—	T[1]	0.2 (1.8)	—	—
Cladonia spp.	2.4 (8.8)	2.9 (8.2)	3.7 (8.7)	—	—
Peltigera spp.	0.2 (0.7)	0.2 (0.9)	0.1 (0.6)	—	—
Moss spp.[2]	47.6 (27.8)	37.4 (28.7)	16.1 (22.2)	27.4 (21.9)	50.1 (23.1)
Vascular Species					
Agronomic grasses[3]	0.3 (1.7)	0.1 (0.4)	T	8.8 (9.1)	10.3 (7.8)
Andromeda polifolia	T	T	—	—	—
Anemone richardsonii	T	T	0.2 (1.2)	—	—
Arctagrostis latifolia	1.2 (1.6)	0.7 (1.9)	0.3 (0.7)	0.8 (1.3)	1.3 (3.4)
Arctostaphylos rubra	3.5 (6.4)	5.9 (10.1)	2.9 (5.9)	0.1 (0.4)	0.1 (0.4)
Betula glandulosa	0.5 (2.3)	0.7 (3.3)	0.7 (3.1)	—	0.6 (3.1)
Betula pumila	0.6 (3.2)	0.1 (0.6)	0.2 (1.3)	—	—
Carex spp.	1.1 (2.1)	1.6 (3.3)	0.6 (1.0)	0.2 (0.6)	0.1 (0.3)
Empetrum nigrum	1.9 (4.0)	0.3 (1.6)	0.3 (1.4)	—	T
Epilobium angustifolium	—	T	—	T	T
Equisetum arvense	0.5 (1.2)	1.8 (5.7)	0.4 (1.0)	2.7 (7.8)	1.5 (3.3)
Equisetum scirpoides	0.4 (0.8)	0.6 (1.6)	0.4 (0.8)	0.1 (0.3)	0.1 (0.2)
Eriophorum spp.	0.5 (1.7)	0.1 (0.5)	0.1 (1.2)	0.7 (1.6)	0.2 (0.8)
Vascular Species – continued:					
Festuca spp.	T	0.1 (0.5)	T	0.3 (0.8)	1.5 (1.8)
Larix laricina	0.2 (0.9)	T	0.1 (0.6)	—	—
Ledum groenlandicum	4.7 (6.4)	5.0 (7.0)	4.5 (5.6)	0.2 (0.7)	0.5 (1.7)
Orchis rotundifolia	T	T	—	—	—
Picea mariana	0.2 (0.9)	0.4 (2.4)	0.1 (0.5)	—	—
Potentilla fruticosa	0.1 (0.2)	0.4 (1.8)	2.0 (5.3)	—	—
Pyrola secunda	0.1 (0.3)	T	T	—	—
Rosa acicularis	—	T	0.1 (0.5)	—	—
Rubus chamaemorus	0.7 (2.0)	1.3 (3.0)	0.8 (2.1)	T	—
Salix arbusculoides	0.4 (2.3)	1.4 (5.8)	0.3 (1.4)	T	T
Salix myrtillifolia	3.3 (7.4)	0.8 (2.6)	3.8 (9.2)	2.0 (10.6)	0.2 (0.6)
Saussurea angustifolia	0.1 (0.4)	0.3 (1.2)	0.3 (1.0)	—	T
Senecio atropurpureus	—	T	T	—	—
Spiranthes romanzoffiana	T	T	—	—	—
Stellaria longipes	T	T	T	—	—
Vaccinium uliginosum	2.6 (4.6)	2.2 (2.6)	1.6 (3.3)	T	0.2 (0.6)
Vaccinium vitis-idaea	0.8 (1.6)	0.6 (1.4)	0.5 (1.3)	T	0.1 (0.4)
Mean Total Cover	73.9	64.9	40.3	43.3	66.8
Number of quadrats	49	38	72	27	24

[1] T = trace; — = absent.

[2] Moss species were predominantly *Aulacomnium palustre*, *Hylocomium splendens*, *Tomenthypnum nitens*, and *Dicranum* spp.

[3] The agronomic grasses were *Alopecurus arundinacea*, *Phleum pratense*, *Poa glauca*, and *P. pratensis*.

degradation, most oil flowed along the Trench (Kershaw 1990), and consequently no Trench quadrats were classified as apparently unoiled. Taxonomy follows Porsild and Cody (1980) for vascular plants, Steere (1978) for mosses, and Thomson (1979) for lichens.

Data Analysis

For the purpose of analysis, a number of related species were grouped together (Table 1). This was done initially because identification of some species was difficult in the field but, more importantly, because some species were too rare to include in the analysis unless they were lumped into broader, but related groups (e.g., agronomic grasses that had been planted on the Trench). Because the number of quadrats sampled varied from year to year, primarily in response to fluctuating water levels and flooding of sample quadrats, only those quadrats sampled in all four years were analyzed. This reduced the data set from 288 to 210 quadrats.

Total plant cover data were normalized using a logarithmic transformation. Analysis of Variance was used to test for differences (Sokal and Rohlf, 1981). When required, multiple comparison tests were performed, using the Tukey-Kramer method when sample sizes were equal, or the GT2-Method when there were substantial differences in sample size (Sokal and Rohlf, 1981).

No transformation successfully normalized the plant cover data for individual species. Hence, a nonparametric test was required, and the Kruskal-Wallis test was selected (Sokal and Rohlf, 1981). Because of the number of tests performed, alpha was set at $p < 0.01$. When an overall difference was found to be significant, pairwise comparisons were conducted using an experimentwise error rate calculated using the Dunn-Sidak method (Sokal and Rohlf, 1981).

RESULTS

Total Plant Cover

The heavily oiled ROW had the most dramatic change, its mean total plant cover declining from almost 75% before the

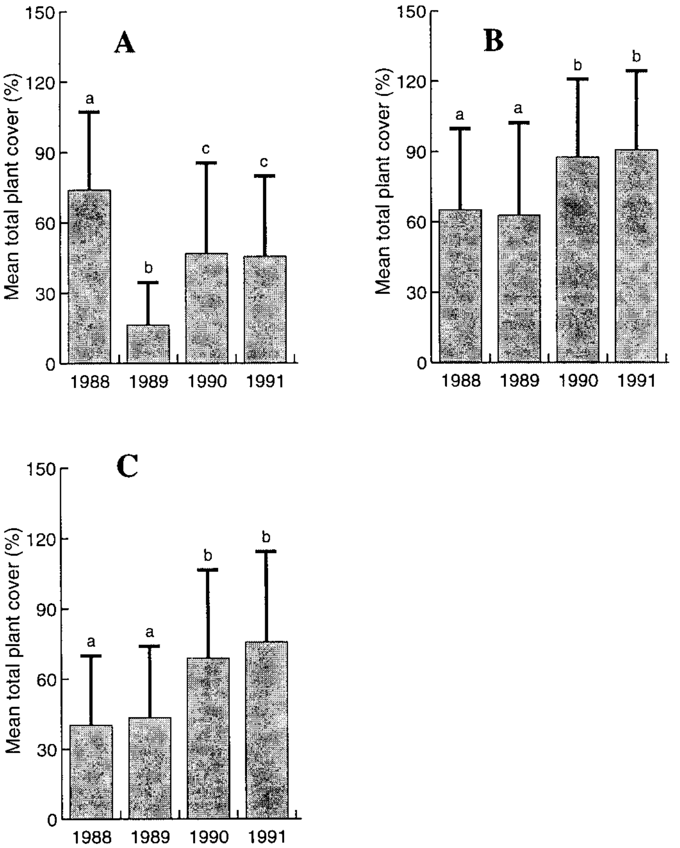

FIG. 2. ROW mean total plant cover (%): A) heavily oiled ROW (n = 49); B) lightly oiled ROW (n = 38); and C) apparently unoiled ROW (n = 72) before (1988) and after (1989–91) the experimental crude oil spill. Error bars indicate one standard deviation. Bars with the same letter above them do not differ significantly ($p > 0.05$).

oil spill to less than 20% the year after the spill (Fig. 2). Over the four years, the change in total cover was significant ($F = 22.4$, $p < 0.0001$). The pre-spill mean plant cover was significantly greater than mean plant cover in all subsequent years.

The lightly oiled ROW ($F = 7.0$, $p < 0.001$) and apparently unoiled ROW ($F = 14.0$, $p < 0.0001$) quadrats also had significant changes in total plant cover over time (Fig. 2). There was no

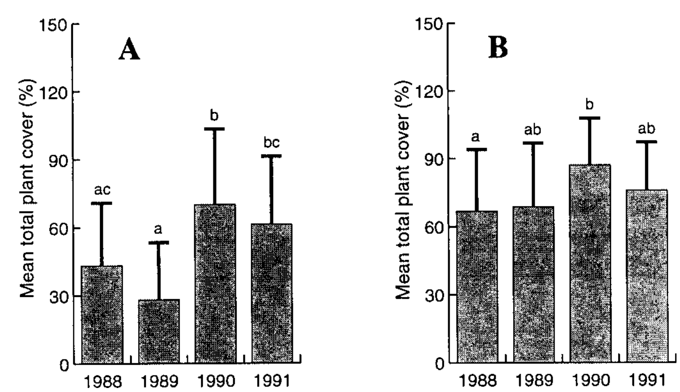

FIG. 3. Simulated pipeline trench mean total plant cover (%): A) heavily oiled trench (n = 27), and B) lightly oiled trench (n = 24) before (1988) and after (1989–91) the experimental crude oil spill. Error bars indicate one standard deviation. Bars with the same letter above them do not differ significantly ($p > 0.05$).

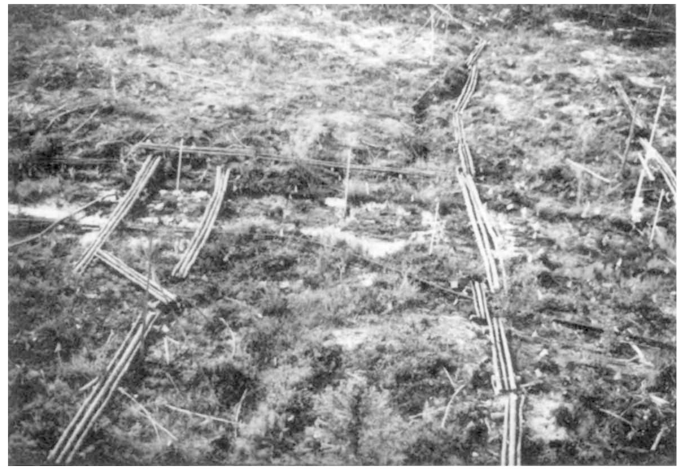

FIG. 4. A) The simulated pipeline trench at the time of the experimental crude oil spill was wet, with some surface water flowing; total plant cover was approximately 43% in low areas and 67% on the microtopographic higher sites (29 August 1988).

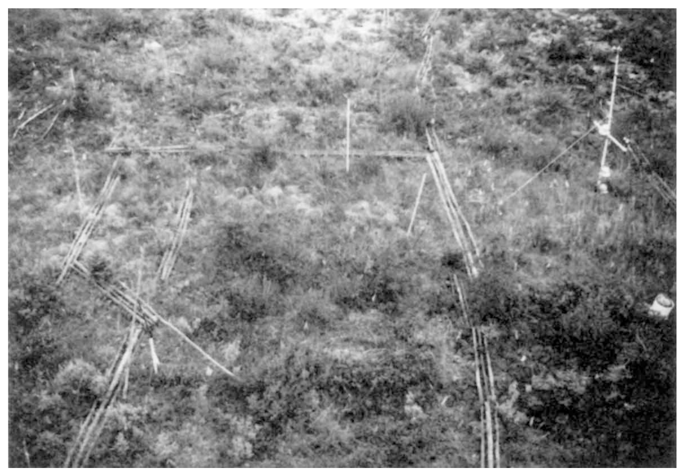

FIG. 4. B) Six growing seasons after the crude oil spill the Trench had a continuous plant cover dominated by a mix of agronomic grasses and native species (10 August 1994).

significant change the year after the spill, but in subsequent years there were significant increases above pre-spill values.

On the Trench, both the heavily oiled ($F = 8.8$, $p < 0.001$) and lightly oiled ($F = 3.4$, $p < 0.025$) sites had significant changes in the mean total plant cover over time (Fig. 3). Neither experienced any significant change the year after the spill, but both had increased plant cover significantly above pre-spill values by 1990. Total plant cover continued to increase in subsequent growing seasons (Fig. 4), but cover has not been assessed since 1991.

Species Cover

On the heavily oiled ROW, cover of 16 out of the 30 taxa changed significantly in response to the presence of the oil (Tables 1, 2). All but 2 of these 16 taxa were either eliminated from the study plots or were significantly less abundant at some point after the spill. The two exceptions were the agronomic grasses and the cotton grasses

TABLE 2. Species that significantly changed in absolute cover values[1] after the crude oil spill compared with the pre-spill value, as determined by the Kruskal-Wallis test (H).

Species	H	p	1989	1990	1991
Heavily Oiled ROW (49 quadrats)					
Nonvascular Species					
Cladonia spp.	42.8	< 0.0001	—	—	—
Peltigera spp.	24.0	< 0.0001	0	0	—
Moss spp.[2]	33.9	< 0.0001	—	nc	nc
Vascular Species					
Agronomic grasses[3]	13.9	< 0.01	nc	nc	+
Arctagrostis latifolia	55.3	< 0.0001	—	—	—
Arctostaphylos rubra	36.5	< 0.0001	—	—	—
Empetrum nigrum	18.8	< 0.001	—	—	—
Equisetum arvense	23.6	< 0.0001	—	—	0
Equisetum scirpoides	22.2	< 0.0001	—	—	—
Eriophorum spp.	16.6	< 0.001	nc	nc	++
Ledum groenlandicum	21.2	< 0.0001	—	—	—
Rubus chamaemorus	16.4	< 0.001	nc	nc	—
Salix myrtillifolia	13.4	< 0.01	nc	—	—
Saussurea angustifolia	24.9	< 0.0001	0	0	0
Vaccinium uliginosum	33.6	< 0.0001	—	—	—
Vaccinium vitis-idaea	45.4	< 0.0001	—	—	—
Lightly Oiled ROW (38 quadrats)					
Nonvascular Species					
Moss spp.[2]	14.8	< 0.01	nc	nc	++
Vascular Species					
Carex spp.	14.0	< 0.01	nc	nc	+++
Equisetum arvense	24.6	< 0.0001	nc	nc	—
Apparently Unoiled ROW (72 quadrats)					
Nonvascular Species					
Moss spp.[2]	33.9	< 0.0001	nc	+++	+++
Vascular Species					
Agronomic grasses[3]	18.2	< 0.001	nc	nc	+
Carex spp.	17.6	< 0.0001	nc	nc	+++
Equisetum arvense	30.8	< 0.0001	nc	+	—
Equisetum scirpoides	15.9	< 0.01	nc	+++	+++
Saussurea angustifolia	14.4	< 0.01	nc	nc	0
Heavily Oiled Trench (27 quadrats)					
Nonvascular Species					
Moss spp.[2]	23.2	< 0.0001	nc	+++	+
Vascular Species					
Agronomic grasses[3]	11.7	< 0.01	—	—	nc
Equisetum arvense	23.0	< 0.0001	nc	nc	—
Lightly Oiled Trench (24 quadrats)					
Nonvascular Species					
Moss spp.[2]	12.9	< 0.01	nc	+++	+
Vascular Species					
Agronomic grasses[3]	11.9	< 0.01	—	—	—
Equisetum arvense	19.1	< 0.001	nc	nc	—

[1] — = significant decrease from the pre-spill value; + = significant increase from the pre-spill value; 0 = absent from all quadrats; nc = no significant change from the pre-spill value. The significance level for the pairwise comparisons is indicated by the number of plus or minus signs: e.g. + $p < 0.1$; ++ $p < 0.05$; +++ $p < 0.01$.

[2] Moss species were predominantly *Aulacomnium palustre, Hylocomium splendens*, *Tomenthypnum nitens,* and *Dicranum* spp.

[3] The agronomic grasses were *Alopecurus arundinacea*, *Phleum pratense*, *Poa glauca*, and *P. pratensis*.

(*Eriophorum* spp.). These plants experienced no significant cover change the year after the spill, but by the third year plant cover had increased significantly above pre-spill levels.

On the lightly oiled ROW, cover of 3 out of the 34 taxa changed significantly by the third year after the oil spill (Tables 1, 2). Only *Equisetum arvense* declined significantly in abundance, but this was observed only in the third year after the spill. The mosses and *Carex* spp. had significantly more cover after the spill than before, but not until the second or third post-spill growing season.

On the apparently unoiled ROW, cover of 6 out of the 31 taxa changed significantly after the oil spill (Table 2). No taxa significantly changed the year after the spill. Four of the six taxa (the mosses, the agronomic grasses, *Carex* spp., and *Equisetum scirpoides*) increased in abundance during the second or third year after the spill. *Equisetum arvense* significantly declined, but it did so only after significantly increasing above its pre-spill abundance; *Saussurea angustifolia* was not present the third year after the spill.

On the heavily oiled Trench, 3 of the 21 taxa changed significantly in abundance after the oil spill (Tables 1, 2). The agronomic grasses and *Equisetum arvense* decreased significantly in abundance after the spill, although *E. arvense* did not respond until the third year. The mosses increased significantly in the second and third years after the spill.

On the lightly oiled Trench, 3 of the 21 taxa also changed significantly in abundance following the oil spill (Table 2). As on the heavily oiled Trench, both the agronomic grasses and *Equisetum arvense* significantly declined in cover, although *E. arvense* did not do so until three years after the spill. The mosses significantly increased in both the second and third years after the spill. Without an apparently unoiled trench treatment to compare with oiled trench treatments, it was not possible to evaluate changes in cover produced by natural successional processes.

DISCUSSION

Interpretation of the results is complicated by the fact that the vegetation on the spill environments was still responding to the clearing and trenching operations. Nonetheless, large and persistent declines in taxa are undoubtedly attributable to the crude oil.

Total Plant Cover

The year after the oil spill, only the heavily oiled ROW experienced a significant drop in total plant cover: a 73% decrease from the pre-spill value. Other researchers have reported decreases of 95% or more one year after a spray application oil spill (Wein and Bliss, 1973; Freedman and Hutchinson, 1976). Reductions in plant cover have implications for the thermal budget of the soil. Removal of surface vegetation can increase the active layer depth (Linell, 1973; Haag and Bliss, 1974), which in turn can lead to subsidence as ice-rich soils thaw (Brown, 1970). At the SEEDS site, the depth of the active layer has more than doubled on the ROW and more than tripled on the Trench after eight thaw seasons (Seburn, 1993).

Neither the lightly oiled ROW nor the apparently unoiled ROW showed any significant change in mean total plant cover the first growing season after the spill. By the second year, however, the plant cover had increased significantly on both. Undoubtedly this reflects the natural plant community's changes on the ROW in response to the disturbance of creating the corridor two or three years before the spill.

Neither the heavily oiled nor the lightly oiled Trench quadrats had a significant decrease in total plant cover immediately following the spill, and by the second year both had significant increases in total cover. This suggests that the standing and flowing water on the subsided Trench kept these soils saturated, thereby reducing oil penetration and pooling. The one-year delay in plant cover increase was similar to the response on the lightly oiled and apparently unoiled ROWs. These cover changes suggest that the crude oil temporarily halted cover increases, but the effect was restricted to a single growing season.

Species Cover

The effects of the oil on the various environments differed dramatically (Table 2). On the heavily oiled ROW, over half of the taxa significantly changed in abundance, with all but two declining. No species with a pre-spill cover of more than 1% was unaffected by the oil. In contrast, on the heavily oiled Trench, the mean cover of only three species changed. The absorption and retention of the oil in the organic soil horizon on the ROW negatively affected plant recovery. On the mineral soil-dominated Trench, high moisture content prevented the oil from infiltrating the soil. Oil was observed being transported into ROW and forest sites by surface water flowing along the Trench. Furthermore, the Trench lacked surface organic deposits that would have absorbed and retained the oil. Thus, on the simulated pipeline Trench, little oil was retained to inhibit plant recovery during the three post-spill growing seasons.

No species responded in the same way to all types of treatments. *Equisetum arvense* did decline significantly on all types of environments, but it also increased significantly on the apparently unoiled ROW before declining in the final year. While most taxa declined in abundance following the oil spill, a few actually increased. For example, on all but the heavily oiled ROW, the mosses became significantly more abundant by the second or third growing season after the spill. This result is in stark contrast to other studies where spray application experiments produced rapid and complete death of mosses and lichens (Wein and Bliss, 1973; Freedman and Hutchinson, 1976; Hutchinson and Freedman, 1978). However, Kershaw and Kershaw (1986) found many mosses and lichens growing on 35-year-old crude oil spills in the Mackenzie Mountains, Northwest Territories. While nonvascular plants are sensitive to direct contact with oil, they can survive if they remain even slightly elevated above the flow of the oil because, lacking roots and specialized vascular tissues, most do not draw water from the soil.

The sedges (*Carex* and *Eriophorum*) were unaffected or significantly increased in abundance. Other researchers have also noted that species of *Carex* (McCown et al., 1973; Wein and Bliss, 1973) and *Eriophorum* (Racine, 1994) were relatively tolerant of crude oil. Part of the success of *Eriophorum* is likely due to its rooting habit. Unlike many plants, *Eriophorum* species send down entirely new root systems each year, following the thawing of the soil (Billings et al., 1978). Establishing new root systems each year could reduce disruptions in the translocation of water and nutrients from the soil.

By the third growing season, the agronomic grasses had become significantly more abundant on both the heavily oiled and apparently unoiled ROW quadrats; yet, they were significantly less abundant on the Trench quadrats the first years after the spill. This group included *Alopecurus arundinacea*, *Phleum pratense*, *Poa glauca*, and *P. pratensis*, which were sown on the SEEDS site after the Trench had been created in 1985 and 1986. In comparison, the native grass *Arctagrostis latifolia*, which was relatively uncommon in both environments (approximately 1% mean cover), declined only on the heavily oiled ROW; however, it never increased above pre-spill levels during the study.

The differing results for the agronomic grasses on the ROW and Trench reflect, in part, the different pre-spill states of the two environments. The ROW had very little grass cover initially (less than 1%), while the Trench was grass-dominated. These agronomic grasses can recover quickly following an oil spill, although they may be dramatically affected at first. The inability of the water-saturated mineral soil of the Trench to retain or absorb oil would also facilitate a quick recovery. In drier areas, where more oil could be absorbed, the recovery might not be as quick. This fact could be important in areas where these species dominate the plant community, such as on a pipeline corridor.

Three growing seasons after the spill, cover of 17 taxa was significantly affected by the oil: two disappeared locally, ten consistently had lower cover, three increased in cover, and one displayed a mixed response. Lichens, native grasses, shrubs, and forbs appear to be most negatively affected by oil, while mosses, agronomic grasses, and sedges appear to tolerate oil or, in the cases of *Carex* spp., thrive in its presence. Negative effects were most evident in the low-lying areas of the ROW, where the plants were subjected to high concentrations of crude oil. In lightly contaminated areas, there was little or no negative response to the oil after three years.

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