**ARCTIC**
VOL. 31, NO. 3 (SEPT. 1978), P. 277-295.

# Effects of Burning Crude Oil Spilled Onto Six Habitat Types in Alaska

JAY D. McKENDRICK and WM. W. MITCHELL

ABSTRACT. The effects on vegetational recovery of removing spilled Prudhoe Bay crude oil from terrestrial sites by burning were observed at three Alaskan locations; Palmer, Fairbanks, and Prudhoe Bay. Five habitat types were studied: 1) abandoned agricultural grass field; 2) the high-brush stage in the secondary succession of interior Alaskan spruce forests, 3) sedge meadow, 4) spruce forest, and 5) wet and mesic arctic tundra. Oil burning was carried out on snow during winter, during the summer growing season and in autumn as soils were freezing.

Burning in summer during the growing season was much more detrimental to plant survival than winter burning. Significant amounts of dormant or near dormant vegetation survived hot burns in September where the soil was frozen to a depth of at least four centimeters. Burning spilled oils on frozen soil surfaces at all three locations affected subsequent plant survival less than when soil surfaces were thawed. Plant dormancy, reduced soil permeability, high soil moisture levels and low soil temperatures were the most probable factors contributing to plants surviving oil spills and burns.

Heating during the burn failed to raise soil temperatures to levels in the upper soil zone lethal to the perennating buds of grasses and forbs. Spilled oil, permitted to stand (aged), ignited with difficulty or not at all, suggesting the effects of volatilization on combustion potential. Oil that soaked into surface mats of organic matter was also impossible to burn. Attempts to ignite oil spilled on snow during winter at Prudhoe Bay were unsuccessful, possibly because strong winds were rapidly removing volatile fractions.

Certain herbaceous plants were relatively unharmed, either by the oil or burning when dormant. Limited damage occurred in winter if the oil was burned immediately after spilling. Delaying burning of oil either 48 hrs or one month after spilling significantly decreased plant survival.

In woody vegetation types, plant survival improved slightly where oil was removed by burning. Woody species apparently survived burning and oiling and regrew from stump sprouts.

There were two extremes and no intermediate burning situations. Fires either burned rapidly and hot or were impossible to ignite. Heavy black smoke produced during the rapid burns was soon dissipated by light breezes.

RÉSUMÉ. On a observé dans trois endroits, Palmer, Fairbanks, et Prudhoe Bay, les effets dur le retablissement végétatif, d'un brut de Prudhoe Bay répandu en l'éliminant par brûlage. Cinq types d'habitat étaient étudieés:

1) une prairie agricole abandonnée;
2) des taillis de seconde génération dans des forêts de sapins de l'Alaska intérieure;
3) une prairie de joncs;
4) une forêt de sapins, et
5) une toundra plus ou moins humide.

L'incendie du brut était effectué sur la neige en hiver, pendant la saison de croissance d'été et à l'automne, quand les sols étaient gelés.

Agricultural Experiment Station, University of Alaska, Palmer, Alaska

Les brulis d'été, pendant la saison de croissance, étaient beaucoup plus dommageables aux plantes survivantes que celles d'hiver. Une quantité significative de vegétation, assoupie ou presque, survivait aux incindies, en septembre, quand le sol était gelé sur au moins quatre centimetres. L'incendie du pétrole répandu sur les surfaces de sol gelé, à trois endroits, affectait les plantes survivantes, moins qu'à l'époque où ces surfaces étaient dégelées. L'assoupissement des plantes, la perméabilité réduite du sol, les hauts niveaux d'humidité du sol et les basses temperatures de celui-ci étaient les facteurs les plus probables contribuant à la survivance des plantes à l'épandage du pétrole et à son incendie. Pendant l'incendie, la chaleur ne réussissait pas à accroître, dans sa tranche supérieure, la température du sol, à des niveaux mortels pour les pousses persistantes d'herbes et de "forbes." Le pétrole répandu leur permettait de tenir le coup; il brûlait avec difficulté ou pas du tout, suggerant les effets des éléments volatiles sur le potentiel de combustion. Le pétrole qui imbibait en surface le tapis de matière organique, n'arrivait pas à brûler. Les tentatives de brûler le pétrole répandu sur la neige en hiver à Prudhoe Bay, restaient sans succès, peut-être à cause des vents violents qui dispersaient rapidement les fractions volatiles. Assoupies, certaines plantes herbacées étaient relativement épargnées par le pétrole, brûlant ou pas. En hiver, le dommage était limité si on brûlait le pétrole aussitot qu'il était répandu. En retardant l'incendie du pétrole de 48 heures ou d'un mois après son épandage, on diminuait nettement la quantité de plantes survivantes.

Pour les types de végétation boisée, le nombre de plantes survivantes s'améliorait légèrement quand le pétrole était éliminé par incendie. Les espèces forestières survivaient apparement à la pollution et à son incendie et les pousses repartaient à partir des souches.

Il y avait deux cas extrêmes d'incendie et pas de cas intermediaires; ou les feux brûlaient rapidement en fournaise ou il était impossible de les allumer. Une légère brise dissipait souvent l'épaisse fumée noire produite pendant les incendies rapides.

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

## INTRODUCTION

Terrestrial oil spills are considered major threats to the quality of soil, vegetation and water resources. Oil spill damages are believed to persist for long periods in cold regions because net annual decomposition of oil is low due to cool temperatures and brief summers (Hunt *et al.* 1973). Once oil penetrates the soil profile, mechanical cleanup and natural decomposition become most difficult. Thus, when spills occur, prompt steps to reduce the quantity of oil at the site while it remains on the soil surface should ultimately reduce the severity and period of impact.

Using fire to remove spilled oil from a terrestrial site is a method worth considering. In many instances, adverse effects of fire on biota ought to be minimal since fire is a normal part of a number of plant communities (Old, 1969; Mutch, 1970; Saku *et al.,* 1970). Fire is commonly used in vegetation management (Anderson, 1965; McMurphy and Anderson, 1965; Pase and Lindenmuth, 1971) and it should have little lasting effects on soil with respect to plant growth where is occurs naturally. Fire is also a common component of the taiga and arctic tundra environments (Barney, 1971; Wein and Bliss, 1972, 1976; Bliss and Wein, 1972; Barney and Comiskey, 1973). Consequently, its use as a management tool for oil spill cleanup in Alaska is a reasonable alternative.

Undesirable consequences from fire include water repellancy (DeBano, 1969; DeBano *et al.,* 1970). But adverse changes in soil chemical properties have usually been either temporary or gone undetected where vegetation was burned (Bower, 1966; Moehring *et al.*, 1966). Fire's influences on soil are partially limited by the presence of water, which keeps soil temperatures relatively low during the burn (Scotter, 1970).

The Alyeska Pipeline Service Company desired to know consequences and effects of burning crude oil on natural vegetation and vegetation recovery in order to develop spill contingency plans for operating the Trans-Alaska Pipeline. The Agricultural Experiment Station of the University of Alaska was asked to study the problem. Results from those studies, conducted during the 1972-1977 period were reported to Alyeska Pipeline Service Company. This report consists of data from those reports.

## METHODS

### *Experimental spills*

Crude oil obtained from the Atlantic Richfield topping plant at Prudhoe Bay was used to simulate various rates of oil spills at three study locations in Alaska: The Matanuska Valley, Fairbanks, and Prudhoe Bay. Measured amounts of crude oil were poured onto rectangular plots. Three oil application rates were selected, 1, 2 and 4 cm, which corresponded to 10, 20 and 40 $l/m^2$, respectively (Table 1). Because these studies were designed at different times and by more than one individual, plot sizes and shapes varied among locations. Pertinent experimental design variations are apparent in the respective site descriptions.

Thermocouples were usually embedded in the soil at the level of graminoid rhizomes and perennating buds to monitor temperatures during burning. During winter, thermocouples were not installed due to the frozen soil state.

Higher plant species were identified and their survival and recovery were monitored by photographic records, periodic plant inventories and evaluations, and by yield measurements. Due to fiscal and personnel constraints, maintaining continuous sequences in those data records throughout the study was impossible. Unfortunately, the role of mosses was unanticipated; consequently, field crews failed to either identify or collect specimens for subsequent identification. The possibilites for that activity exist yet among several of the remaining experimental plots.

## SITE DESCRIPTIONS AND SUCCESS OF BURNING

### *Agricultural grassland*

Prudhoe Bay crude oil was applied at the 2 cm rate (Table 1) and burned on snow-covered plots at the agricultural grassland site near Palmer during March of 1973. A summer test was initiated during August of 1973. Burning of the oil was successful immediately following application and 48 hours later, and accomplished with great difficulty after a one-month delay.

TABLE 1. Guidelines used at the Alaska Agricultural Experiment Station for relating volume of oil applied per unit area to fluid depth.

| Volume per unit area | | | | | | |
|---|---|---|---|---|---|---|
| U.S. gallon/ft² | U.S. gallon/acre | U.S. barrel/acre | U.S. drum/acre | l/m² | l/ha | fluid depth |
| .155 | 6,789 | 162 | 123 | 6.35 | 63,500 | 0.25 inch |
| .245 | 10,691 | 255 | 194 | 10.00 | 100,000 | 1 cm |
| .312 | 13,578 | 323 | 247 | 12.70 | 127,000 | .50 inch |
| .428 | 18,710 | 446 | 340 | 17.50 | 175,000 | 1.75 cm |
| .490 | 21,388 | 509 | 389 | 20.00 | 200,000 | 2 cm |
| .623 | 27,155 | 647 | 494 | 25.40 | 254,000 | 1 inch |
| .980 | 42,767 | 1,018 | 778 | 40.00 | 400,000 | 4 cm |
| 1.247 | 45,198 | 1,293 | 987 | 50.80 | 508,000 | 2 inches |

During the winter test, snow depths ranged between 10 and 20 cm. Grass plants had reached their maximum heights during the summer test. Fires under both summer and winter conditions were quite hot and usually lasted from 1 to 1.5 hr. Smoke dissipated readily under influence of light breezes. Weed burners were used to burn vegetation from unoiled-control plots.

Plant species on the plots included: smooth brome (*Bromus inermis* Leyss.), bluegrass (*Poa pratensis* L.), quackgrass (*Agropyron repens* (L.) Beauv.) and *Hedysarum alpinum* subsp. *americanum* (Michx.) Fedtsh. a native legume.

*High brush stage of interior forest*

This habitat type was located on an abandoned agricultural field south and west of the Agricultural Experiment Station's farm headquarters at Fairbanks. Birch (*Betula papyrifera* Marsh.) and willow were the dominant tall-growing woody species. Low-grading shrubs included currant (*Ribes* sp.), rose (*Rosa acicularis* Lindl.), blueberry (*Vaccinium uliginosum* L.) and lingonberry (*Vaccinium vitis-idaea* L.).

Prudhoe Bay crude oil was applied at two rates. Two plots were oiled at the 2 cm rate and one at the 1 cm rate. One plot, oiled at the 2 cm rate, was burned immediately after oiling. The surface of the soil was thawed, but a few millimeters below the surface, the soil was frozen to a depth of 4 cm.

*Sedge meadow of interior forest*

The sedge meadow site was located on the Alaska Agricultural Experiment Station's farm near Fairbanks. The site was dominated by water sedge (*Carex aquatilis* Wahlenb.) and surrounded by the high brush stage of forest succession. Moss, wild flag (*Iris setosa* Pall.), *Rubus arcticus* L.) bluejoint reedgrass (*Calamagrostis canadensis* (Michx.) Beauv.), horsetail (*Equisetum arvense* L.), yarrow (*Archillea sibirica* Ledeb.), and one willow species comprised the major plant species. When ignited, the oiled plot burned rapidly, but temperatures of the moist soil failed to reach lethal levels.

*Interior spruce forest site*

This test area was also located on the Alaska Agricultural Experiment Station's farm near Fairbanks. The area had not been cleared for agricultural use, but charcoal at the mineral soil surface evidenced fires of past years. The stand of white spruce (*Picea glauca* (Moench) Voss) dominated the overstory. Birch and willow were also present. The understory vegetation consisted of the typical array of muskeg plants, including mosses, lingonberry, Labrador tea (*Ledum groenlandicum* (Oeder) Hult.), horsetail, coltsfoot (*Petasites frigidus* (L.) Franch.), dwarf birch (*Betula nana* L.) bunchberry (*Cornus canadensis* L.), polargrass (*Arctagrostis latifolia* (R. Br.) Griseb.) bluegrass (*Poa* ssp.) and bluejoint reedgrass.

Attempts to burn the oil on the day of application were unsuccessful, even when gasoline was sprayed onto a portion of the plot, apparently because the oil had soaked into the thick organic mat. As soon as the gasoline "starter" was burned, the fire died out. Had the vegetation mat been dry, it may have carried the fire, but recent rains had moistened the forest floor sufficiently to prevent burning.

*Mesic and wet arctic tundra*

These habitat types were located at 70° 15' N. latitude Prudhoe Bay. Test plots were south of Drill Site 5 in the eastern portion of the oil field. The wet tundra site was dominated by *Carex aquatilis* and willows (*Salix alaxensis* (Anderss.) Cov., *S. reticulata* L., *S. arctica* Pall.), *Eriophorum* sp., cottongrass, was also present. The mesic tundra was dominated by scattered tillers of *Carex aquatilis* interspersed with dryas (*Dryas integrifolia* M. Vahl.), mosses and a lichen, *Thamnolia subuliformis* (Ehrh.) W. Culb. *Dactylina arctica* (Hook.) Nyl., a second lichen, was also present but not as abundant as *T. subuliformis*.

Four centimetres of oil was applied 8 August 1973 to five of the plots. Two plots, one on mesic tundra and one on wet tundra, were burned immediately after oiling. Attempts to ignite a third plot after a 3-week delay proved unsuccessful, because volatile fractions had evaporated and most of the oil had seeped into the spongy organic layer. Another mesic tundra plot, located at the intersection of two frost wedges, was heavily oiled (4 cm) and burned immediately, in anticipation that such areas would be most vulnerable to oil spills and consequential thermokarst.

Two warm oil applications at the 0.9 cm rate were made on snow-covered tundra on 24 May 1973. Burning was attempted without success because volatile fractions rapidly dissipated with the wind even at subzero temperatures.

*Accidental spill*

A return line from the Atlantic Richfield Company's topping plant ruptured in late winter of 1972, spilling topped crude onto a wet tundra site. Cleanup efforts included burning and using commercial absorbents and straw to mop up the oil. We first visited the area 30 June 1972 and established six fertilizer plots in the burned portion of the spill site to evaluate vegetation recovery.

## RESULTS AND DISCUSSION

### Vegetation Survival and Recovery After Burning Experimental Spills

*Agricultural grassland*

Table 2 shows total dry matter production and plant densities for the three dominant plant species on the Matanuska Farm. These data were obtained at the end of the first growing season following winter oiling and burning by inventoring four 0.1 m² circular plots in each treatment replication. According to these initial observations, winter spills were less damaging than summer spills, and immediately burning winter spills substantially reduced damaging effects of the oil compared to either delaying the burn or not burning (Fig. 1). The legume, *Hedysarum alpinum,* only survived oiling in the winter-spill plot which was burned immediately. Since that species was distributed unevenly

TABLE 2. Dry-matter yields and densities for three major plant species occurring in agricultural grassland plots 14, 17 Sept. 1973, seven and one month, respectively, following winter and summer oil spill and burn treatments at the Matanuska Farm.

| | TOTAL dry-matter ($g/m^2$) | *Bromus inermis* ($tillers/m^2$) | *Hedysarum alpinum* ($plants/m^2$) | *Poa pratense* ($tillers/m^2$) |
|---|---|---|---|---|
| | | (Winter oil) | | |
| Control Rep 1 | 233.7 ± 9.5 | 357.5 ± 18.2 | ± | 277.5 ± 6.1 |
| Control Rep 2 | 226.2 ± 7.5 | 402.5 ± 9.1 | 12.5 ± .8 | 350.0 ± 45.3 |
| Burn only Rep 1 | 327.5 ± 5.7 | 705.0 ± 49.2 | 20 ± 6.4 | 130.0 ± 10.8 |
| Burn only Rep 2 | 280.0 ± 4.1 | 120.0 ± 12.1 | 30 ± 3.4 | 1275.0 ± 7.9 |
| Oiled, burn immediately Rep 1 | 235.5 ± 11.8 | 597.5 ± 35.9 | ± | 55.0 ± 13.6 |
| Oiled, burn immediately Rep 2 | 295.2 ± 9.4 | 372.5 ± 12.4 | 5 ± .9 | 1287.0 ± 30 |
| Oiled, burn delayed 1 mo. | 159.5 ± 14.0 | 265.0 ± 27.5 | ± | 227.5 ± 16.4 |
| Oiled, burn 48 hrs. Rep 1 | 63.7 ± 11.6 | 405.0 ± 48.1 | ± | 5.0 ± 1.6 |
| Oiled, burn 48 hrs. Rep 2 | 14.7 ± 2.2 | 40.0 ± 7.4 | ± | 175.0 ± 15 |
| Oiled, no burn Rep 1 | 5.7 ± 0.8 | 20.0 ± 3.4 | ± | 2.5 ± .8 |
| Oiled, no burn Rep 2 | 16.7 ± 4.6 | 12.5 ± 2.4 | ± | 57.5 ± 7.4 |
| | (Summer oil) | | | |
| Oiled, burn immediately | ± | ± | ± | ± |
| Oiled, no burn | 5.2 ± .3 | 30 ± 1.29 | ± | ± |
| Oiled, burn delayed | ± | ± | ± | ± |
| Burn only | 40.5 ± 1.75 | 817.5 ± 64.5 | 7.5 ± 1.5 | 500 ± 22.5 |

1) 95% confidence intervals are shown as ± values of the mean.

FIG. 1. Photos of four agricultural grassland plots at the end of one growing season (14 Sept. 1973) after all plots had been treated with 2 cm of crude oil during previous winter (13 March 1973). Upper left photo shows a plot in which oil was burned immediately. Upper right photo shows a plot which was burned 48 hrs following the oil application. Lower plots are plots where oil was burned one month after application (left) and where oil was left intact (right).

across the experimental area, its absence was possibly confounded with certain treatments.

Effects of oils and burning were most apparent in the summer spill plots. A few brome tillers regrew during the month following the summer oil treatments in most of the plots (Fig. 2). Plants surviving both oil and burning treatments were too sparse to sample in the immediate and delayed summer burn plots. Comparing these data with those from the plot that was burning without oil suggested that damaging effects were from the oil and oil burning and not from burning alone. Populations of the dominant species were not reduced by burning in the absence of oil even though it occurred during the plant's active growth period.

The plots were examined most recently 20 March 1977, four years after the first treatments were imposed. At that time, the effect of the treatments showed a difference in species composition, in plant vigor as indicated by height and stem diameters, and in general stand quality as evidence by spacing and density of plants. Table 3 contains those evaluations.

Some plants were alive in all plots; however, the poorest plant recoveries were in the summer-oiled plots. *Hedysarum alpinum* failed to re-invade any

FIG. 2. Photos of three agricultural grassland plots one month (14 Sept. 1973) after a summer application of crude oil (left) and during late winter (20 March 1978) four and one half years after the summer oil treatments. Oil was let stand on the upper photo plot. Oil was burned immediately from the middle photo plot. Notice the grey crust on the soil surface in the middle right photo. Burning of the oil was delayed 48 hrs on the lower photo plot. After four growing seasons vegetation responses among these three treatments were quite similar, and plant recovery was poorer than on plots similarly treated during winter.

oil-treated plots during the four-year period following treatment. Plots oiled and burned immediately in the summer contained large bare areas which seemed to be heavily crusted with a hydrophobic residue (Fig. 2). That condition undoubtedly prevented seedling establishment. It may also have been retarding vegetative invasion by brome and bluegrass tillers. Such crusts

TABLE 3. Visual ratings of grass stand on oiled and burned plots relative to controls on the agricultural grassland site at the Matanuska Farm 20 March 1977, 3.5-4 years after oil treatments.

| | Plant Characteristics | | | |
|---|---|---|---|---|
| Burning trt | Composition | Spacing | Density | Tiller Vigor |
| | (Winter oil spills) | | | |
| oiled, burn immediately | grass & forbs | even | normal | normal |
| oiled, burn delayed 48 hrs. | mostly grass | uneven | subnormal | normal |
| oiled, burn delayed 1 mo. | mostly grass | uneven | subnormal | superior |
| oiled, no burn | grass & moss | even | subnormal | subnormal |
| | (Summer oil spills) | | | |
| oiled, burned immediately | mostly grass | uneven | subnormal | superior |
| oiled, burn delayed | only grass | uneven | subnormal | superior |
| oiled, no burn | only grass | uneven | subnormal | superior |

were not noticeable in the burned winter-spill treatments, even though small bare areas were observed in those treatment plots. Effects of delaying the winter burns were still evident in plant vigor, species composition and stand quality.

The winter-spill plot which was not burned contained a fair amount of moss, possibly developing as a result of thinning of the grass stand by the oil. Effects of winter oiling seemed to be a uniform thinning of the brome stand and depressing vigor. That effect could have been due to drought and/or soil fertility depressions induced by the presence of oil. The survival of grass plants indicated that, if toxicity from oil was a factor, it must have been sub-lethal to brome. The absence of *Hedysarum alpinum* in the oiled plots suggested a differential tolerance to oil between that legume and the grasses.

*High brush stage of interior forest*

Burning spilled oil immediately seemed to benefit the survival of species on this site, Table 4. This habitat is a typical seral stage of secondary forest succession which develops after fire disturbances in the Alaskan taiga (Viereck, 1975) and probably consists of species adapted to burning (Fig. 3). However, less plant cover developed during the subsequent growing season

FIG. 3. Photos of the sedge meadow (upper) and high brush oil plots (lower) after oil applications and burning (22 Sept. 1972, left) and 10 months later (31 July 1973, right). Notice vegetation recovery on the sedge meadow was better than for the high brush in terms of plant cover, but there were a greater number of plant species surviving in the high brush plots.

TABLE 4. Numbers of species present before and two years after oil application on the high brush site, and plant densities 1 m² two years after oil applications.

| Plant Life Form | Number of Species: before treatment | 1 cm oil | 2 cm oil | 2 cm oil + burning |
|---|---|---|---|---|
| Horsetails & Mosses | 3 | 1 | 1 | 1 |
| Grasses & Sedges | 5 | 2 | 3 | 2 |
| Forbs | 8 | 6 | 2 | 6 |
| Shrubs | 12 | 8 | 3 | 8 |
| Trees | 3 | 1 | 1 | 1 |
| Total no. species | 31 | 18 | 10 | 18 |
| Total plants/$m^2$ | — | 42.7 | 15.0 | 27.5 |

on these plots than on the wet meadow site, described later. Because treatments were imposed in autumn when most plants were dormant, they were in a state most resistant to burning. Furthermore, the upper layer of soil was frozen at the time of burning. Of the 31 genera recorded on this site, nearly two-thirds were eliminated in the heavily oiled plots. In contrast, a representative of almost two-thirds of the genera survived the 1 cm oil treatment (Table 4). Also, the total plant density in the lightly oiled plot was more than double that of the heavily oiled plots, confirming that damages were positively correlated with oil application rates.

Five plant species that were prominent among those surviving oil applications included horsetail, bluejoint reedgrass, fireweed, bunchberry and blueberry. Willow survived by sprouting. Moss was completely eliminated from the oiled plots. Two common forest community shrubs, lingonberry and

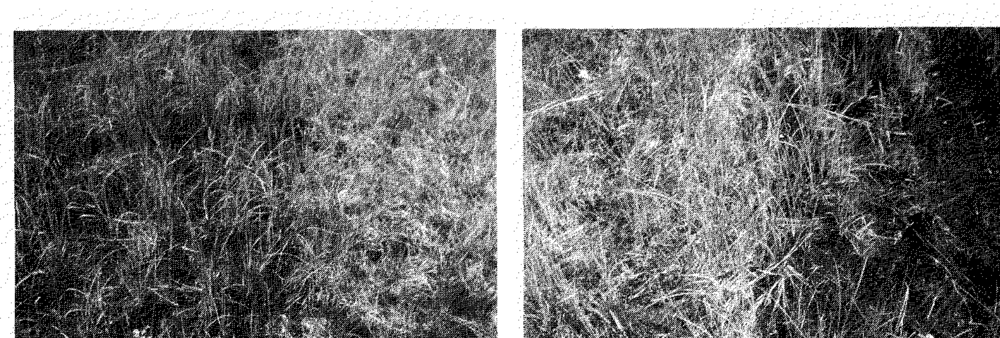

FIG. 4. Two photos (31 July 1973) of sedge meadow plots that were oiled with 10 cm (left) and 20 cm (right), respectively of Prudhoe Bay. Crude oil had been on these plots for 10 months, and the heavier rate was visibly more detrimental to *Carex* survival.

TABLE 5. Numbers of species present before and two years after oil applications on the wet meadow site.

| Plant Life Form | Number of Plant Species | | | |
|---|---|---|---|---|
| | before treatment | 1 cm oil | 2 cm oil | 2 cm oil + burning |
| Mosses | 1 | 0 | 0 | 0 |
| Grasses & Sedges | 2 | 2 | 2 | 2 |
| Forbs | 1 | 0 | 0 | 0 |
| Shrubs | 1 | 0 | 0 | 0 |
| Totals | 5 | 2 | 2 | 2 |

crowberry, also proved very susceptible to oil damages. Of the trees, only birch survived by stump sprouting.

*Sedge meadow of interior forest*

Only four higher plant species predominated in this plant community, as opposed to the larger number of types and genera common to the interior forest. Survival of *Carex* was inversely related to oil application rates (Fig. 4). Oil impacts and burning substantially reduced plant species (Table 5). Those data failed to reflect the increase in vigor observed in *Carex aquatilis* a year after burning. Inflorescence production by *Carex* was abundant in the burned plot, whereas little inflorescence development occurred on plants in either the untreated surrounding area or the unburned oil plots. Moss was eliminated from all oiled plots; bluejoint reedgrass survived only in the lightly oiled plots. That grass was overlooked in the original plant inventory, probably because of season and lack of inflorescence production in autumn when oil was applied.

*Interior spruce forest*

The experimental oil spills on this vegetation type severely damaged the plant community (Table 6). Two-thirds of all genera represented were eliminated from the plots. Certain shrubs and grasses were the only life forms surviving the oil. According to the plant density data few individuals of those plants survived the oiling, the most prominent being blueberry, which we noted earlier as surviving well in the high brush site, and Labrador tea. Unfortunately, mosses and lingonberry, important forest floor shrubs, were eliminated. Coltsfoot is a genus that one of us observed invading several mine spoils in parts of the Soviet Union and commonly increases on disturbances in the wet tundra of arctic Alaska, but coltsfoot was intolerant to oil on this forest site.

Because of the deep organic mat and shade from the tree overstory, natural seedling establishment may be difficult, and recovery of vegetation by succession may be slow unless mineral soil is exposed. The frozen soil layer may perch spilled oil, preventing it from percolating deeply into the soil profile; the relative effects of that situation on vegetation recovery and oil decomposition ought to be examined.

*Mesic and wet arctic tundra*

These study plots were treated with oil while plants were actively growing. The major impact was drastic reductions in live plant cover and elimination of most vascular plant species (Table 7), especially on the mesic site (Fig. 5). Only two genera survived oil applications, *Carex* and *Salix*. Mosses and lichens were completely eliminated from all oil-affected areas. Oiling plus burning appears to have been a more drastic treatment than oiling alone, reducing *Carex* survival and eliminating *Salix*.

*Accidental spill*

*Carex* survival and vegetative reproduction on this spill site was reported earlier in a photo plot sequence (McKendrick, 1976). Natural seedling establishment of plants eliminated by the oil was not observed during six growing seasons following the spill. Data in Table 8 show that *Carex* sp., cottongrass, a rhizomatous grass (*Dupontia fischeri*), and willow survived the winter oil and burning treatments. Mosses were entirely eliminated and remained absent, except where fertilizers were added. In certain fertilized plots, mosses began re-establishing during the first growing season following the winter spill. *Dupontia* density increased about 25 times under fertilization and was the most responsive of the surviving vascular plants to fertilizers. Both *Carex* and *Dupontia* produced inflorescences during 1976 in the fertilized

TABLE 6. Numbers of plant species present before and one year after oil applications on the spruce forest site, and total plant densities/m².

| Plant Life Form | Number of Species: before treatment | oil | oil + attempted burn |
|---|---|---|---|
| Horsetails & Mosses | 2 | 0 | 0 |
| Grasses & Sedges | 4 | 0 | 1 |
| Forbs | 3 | 0 | 0 |
| Shrubs | 10 | 4 | 5 |
| Trees | 2 | 0 | 0 |
| Total no. species | 21 | 4 | 6 |
| Total plant density* | 65.2 | 14.4 | 1.3 |

*not counting moss and lingonberry which provided 168% cover before treatment and none after.

TABLE 7. Numbers of species and percent cover present in six arctic tundra experimental oil plots at Prudhoe Bay before treatments (1973) and one year after (1974). Oil was applied at the 4 cm rate.

| | Number of Plant Species | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Mesic Tundra | | | | Wet Tundra | | | |
| Plant | Oil | | Oil & burn | | Oil | | Oil & burn | |
| Life Form | 1973 | 1974 | 1973 | 1974 | 1973 | 1974 | 1973 | 1974 |
| Grasses & Sedges | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Forbs | 5 | 0 | 4 | 0 | 2 | 0 | 2 | 0 |
| Shrubs | 3 | 1 | 3 | 0 | 1 | 1 | 1 | 0 |
| Total no. species | 10 | 3 | 9 | 2 | 5 | 3 | 5 | 2 |
| Total % cover | 139 | 28 | 145 | 5 | 101 | 27 | 96 | 5 |

plots. Both species failed to develop flowering parts without soil fertilization. Effects of fertilization on the recovery of vegetation on the spill site are presented in another report (McKendrick and Mitchell, 1978).

*Effects of Burning on Soil Temperatures and Thermokarst*

Soil temperatures monitored during burns at Palmer, Fairbanks, and Prudhoe Bay confirmed that burning failed to elevate soil temperatures at the four centimetre depth to lethal levels, even when fires were at their maximum. Figure 6 shows typical soil temperature patterns at the surface and four centimetre depth. Burning was usually rapid and hot during the first 20 minutes. On the sedge meadow site (Fig. 3), surface temperatures of the moist soil briefly reached a maximum of about 175 °C. At the four centimetre depth, the heat pulse lagged surface temperatures by about 30 minutes and peaked at 27 °C. Two hours after ignition temperatures at the surface and at four centimetres were equal, about 7 °C.

Burning on the high brush site raised surface temperatures beyond the range of our potentiometer, 300 °C, during the first 20 minutes following ignition. The higher temperatures noted on this site compared to those for the sedge meadow may have resulted from lower soil moisture levels at this mesic site. Even though surface temperatures exceeded 300 °C on the high brush burn, the soil at four centimetres remained frozen for nearly an hour after ignition, well past the peak burning period. Stumps ignited during the high brush burn smoldered for 30 hours, until quenched by rain. Such prolonged burning was not characteristic of fires on herbaceous vegetation types.

An attempt to induce thermokarst in arctic tundra by burning spilled crude oil at the intersection of two shallow frost wedges indicated that soil thermal stability was not adversely affected by such treatment (Fig. 7). Even after four years thermokarst failed to develop. Probing active layer depths at that

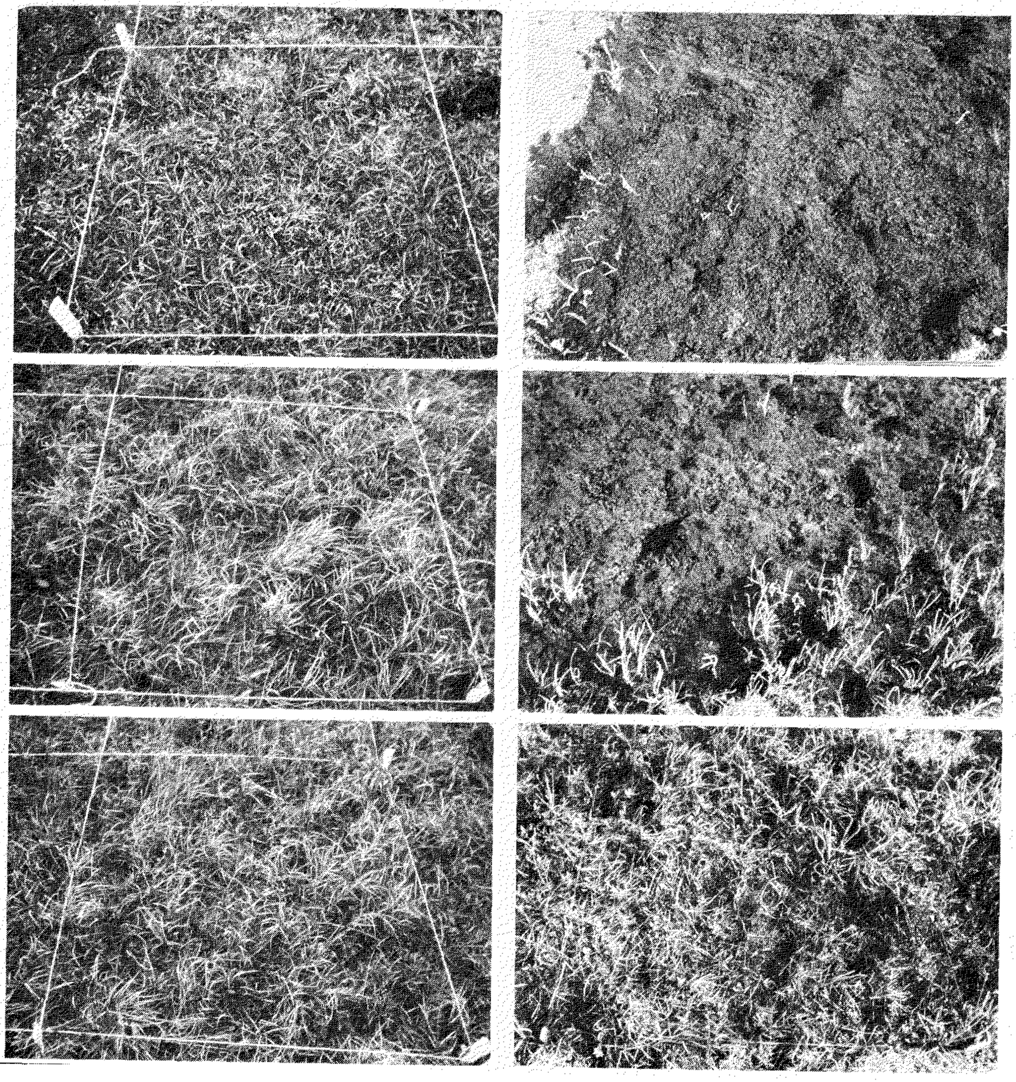

FIG. 5. Three photos of mesic (upper) and wet (middle and lower) tundra at Prudhoe Bay, before oil summer treatments (7 Aug. 1973, left) and 11 months later (17 July 1974, right). The upper and middle plots were also burned immediately after oil applications. Notice the mesic community was more susceptible to oil treatments than the wet tundra, and the summer burning treatment was more damaging to vegetation than leaving the oil intact.

location and on the other burned plots at Prudhoe Bay revealed no increases in thaw depth due to either oil spills or the burning of spilled oil.

## CONCLUSIONS AND RECOMMENDATIONS

At certain times and locations, burning crude oil spills was an effective means for reducing impacts of oil spills on plant communities. It appeared to be most useful during winter and least damaging to herbaceous plant communities, such as grasslands and wet meadows. Burning in autumn ameliorated impacts of oil on high brush communities, a seral stage of the Alaska interior forest. Oil and a light burn were severely damaging to forest floor species. During the growing season, burning increased the damaging effects of oil spills in every instance studied. Delaying burns reduced the beneficial effects of the fire and increased the difficulty of igniting the oil.

Sound judgment should be used when considering burning as a tool for oil spill cleanup. The final decision of whether or not to burn depends upon answers to such questions as: 1) Would the fire increase or decrease long-term damages of the spill?; 2) Would the fire risk human life and valuable property?; 3) Is fire a natural part of the ecosystem?; 4) Is the oil exposed and available to burn or has it percolated into the soil?; and 5) Would burning reduce or prevent long-term ground and surface water pollution? A comprehensive research project that would systematically evaluate effects of burning oil spilled on various cold-region plant communities should be undertaken. Quantities of oil removed by burning versus those that naturally evaporate and quickly degrade should be measured. Above all, long-term

FIGURE 6

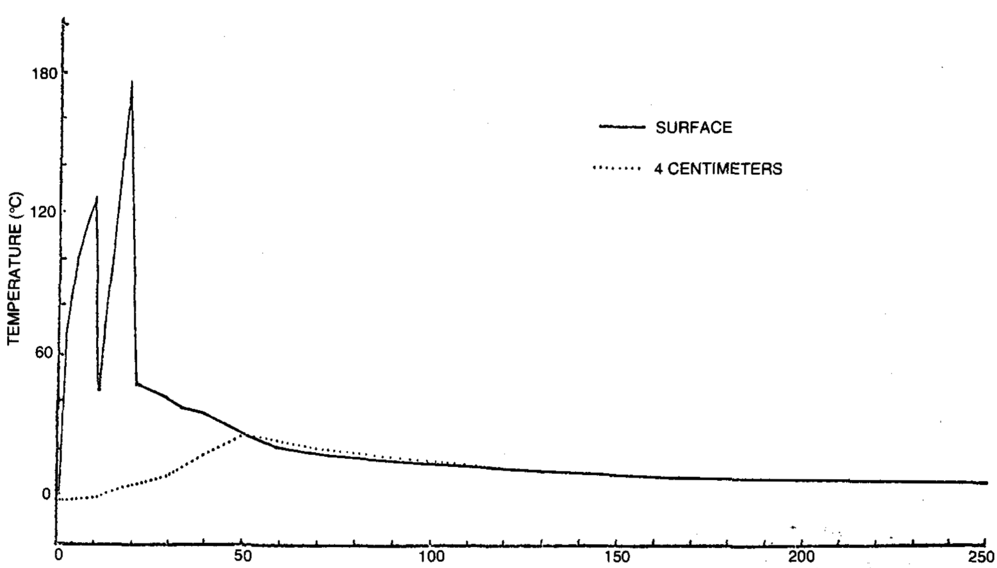


FIG. 6. Soil temperatures at the surface and at the four centimeter depth during burning of 4 cm of Prudhoe Bay crude oil spilled on the wet meadow site 22 Sept. 1972.

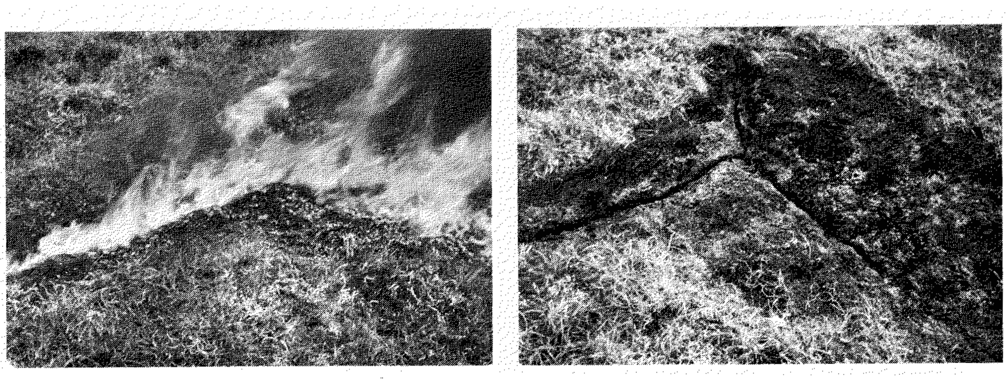

FIG. 7. Photos of the intersection of two frost wedges in mesic arctic tundra when 4 cm of Prudhoe Bay crude oil was being burned (7 Aug. 1973, left) and two growing seasons later (4 Sept. 1975, right). Notice the severe effect on plant life but the absence of thermokarst.

monitoring of such tests is imperative. In a review of terrestrial oil spill records for cold regions (in preparation) it was clearly shown that the overwhelming concern over long-term effects of oil spilled in cold climates has been inadequately addressed in terms of government and industry sponsored research.

Where our plots have remained intact, they probably represent the longest continuous monitoring of terrestrial oil spill research in Alaska. Even though industry has faithfully sponsored these studies for six years, these were not designed under a long-term commitment. Consequently, research designs were not conscientiously aimed at either consistently monitoring or identifying long-term effects from spills and the treatments tested to ameliorate oil spill damages. More comprehensive efforts will be needed to adequately study the long-term effects and provide better information for the

TABLE 8. Moss cover percentages and densities of other plant species in fertilized and unfertilized tundra during the fifth growing season following oil spillage and burning at Prudhoe Bay, Alaska.

| Plant Species | fertilized | | unfertilized |
|---|---|---|---|
| | | (% cover) | |
| Mosses | 72.8 | | 0 |
| | | (plant/m²) | |
| Liverworts | 130 | | 0 |
| Sedges and grasses | | | |
| *Carex* sp. | 583 | | 316 |
| *Eriophorum* sp. | 81 | | 27 |
| *Dupontia fischeri* | 333 | | 13 |
| Salix sp. | 0 | | 30 |
| TOTAL plant densities | 1127 | | 386 |

treatment and rehabilitation of spill sites in a cold-dominated environment. It is in the interest of government, industry, and other interested parties to cooperate in sponsoring such efforts.

ACKNOWLEDGEMENTS

Financial support for this research was provided by the Alyeska Pipeline Service Company. Crude oil was provided by the Atlantic Richfield Company. Several individuals participated in oil application, burning trials and vegetation analysis, including: Dr. Milton A. Barzee (deceased); Mr. Charles Knight; Dr. Thomas E. Loynachan; Mr. Allen K. Mansfield; Dr. George A. Mitchell; Mr. Pete Scorup; Ms. Kathy Moffitt and Mr. Keith Poppert. Mr. D. S. Braden, formerly with BP Alaska, provided one of us with the opportunity to assist with experimental winter spills at Prudhoe Bay. The authors express their sincere gratitude to the companies and individuals who supported this research and to our typist, Ms. Donna Fowler.

LITERATURE CITED

ANDERSON, K. L. 1965. Timing of burning as it affects soil moisture in an ordinary upland bluestem prairie in the Flint Hills. *J. Range Manage.* 18:311-316.

BARNEY, R. J. 1971. Selected 1966-69 interior Alaska Wildfire statistics with long-term comparisons. USDA For. Serv. Res. Note PNW-154. 13p.

BARNEY, R. J. and A. COMISKEY 1973. Wildfires and thunderstorms on Alaska's North Slope. USDA For. Serv. Res. Note PNW-212. 8p.

BLISS, L. C. and R. W. WEIN 1972. Plant community responses to disturbances in the Western Canadian Arctic. *Can. J. Bot.* 50:1097-1109.

BOWERS, D. R. 1966. Surface soil recovers quickly after burn. U.S. For. Res. Note SO-46. 2p.

DeBANO, L. F. 1969. Water repellant soils: a worldwide concern in management of soil and vegetation. *Agr. Sci. Rev.* 7(2):11-18.

DeBANO, L. F., L. D. MANN and D. A. HAMILTON. 1970. Trans-location of hydrophobic substances into soil by burning organic litter. *Soil Sci. Soc. Amer. Proc.* 34:130-133.

HUNT, P. G., W. E. RICHARD, F. J. DENEKE, F. R. KOUTZ and R. P. MURRMAN. 1973. Terrestrial oil spills in Alaska: Environmental effects and recovery. Proc. joint conference on prevention and control of oil spills 13-15 March 1973, Washington D. C. Amer. Pet. Inst., Environmental Protection Agency and U. S. Coast Guard. Washington D. C. p. 733-740.

McKENDRICK, JAY D. 1976. Photo-plots reveal arctic secrets. *Agroborealis.* 8(1):25-29,

McKENDRICK, JAY D. and WM. W. MITCHELL. 1978. Fertilizing and seeding oil-damaged arctic tundra to effect vegetation recovery, Prudhoe Bay, Alaska. *Arctic* (this volume)

McMURPHY, W. E. and K. L. ANDERSON. 1965. Burning Flint Hills range. *J. Range Manage.* 18:265-296.

MOEHRING, D. M., C. X. GRANO and J. R. BASSETT. 1966. Properties of forested loess soils after repeated prescribed burns. *U.S. For. Serv. Res. Note* SO-40. 4p.

MUTCH, R. W. 1970. Wildland fires and ecosystems — a hypothesis. *Ecology.* 51:1046-1051.

OLD, S. M. 1969. Micro-climates, fire and plant production in an Illinois prairie. *Ecology. Monogr.* 35:355-384.

PASE, C. P. and A. W. LINDENMUTH, JR. 1971. Effects of prescribed fire on vegetation and sediment in oak-mountain mahogany chaparral. *J. For.* 69:800-805.

SCOTTER, D. R. 1970. Soil temperatures under grass fires. *Aust. J. soil Res.* 8:273-279.

SKAU, C. M., R. O. MEEUWIG and T. W. TOWNSEND. 1970. Ecology of eastside Sierra chaparral a literature review. Univ. Nevada Agr. Exp. Sta. R71. 14p.

VIERECK, L. A. 1975. Forest ecology of the Alaska taiga. Proceedings of the circumpolar conference on northern ecology. September 15-18, 1975. Ottawa. I-1 to I-22.

WEIN, R. W. and L. C. BLISS. 1972. Changes in arctic Eriophorum tussock communities following fire. *Ecology.* 54:845-852.

——— and ———. 1976. Tundra fires in the District of Keewatin. Geol. Surv. Can. paper 76-1A. p. 511-515.