Effect of Prudhoe Crude Oil on Carbon Assimilation

by Planktonic Algae in an Arctic Pond

Michael C. Miller

Gary R. Water

J. Robie Vestal

NOTICE
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights.

Department of Biological Sciences

University of Cincinnati

Cincinnati, Ohio 45221

MASTER

Submitted to:

Boston

Proceed. Mineral Cycling Symposium

Savannah River Ecol. Lab. April 24-1978

E.R.D.A.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

ABSTRACT

During the summer of 1975, 240ml/m of Prudhoe crude oil was spilled on an experimental coastal pond similar to those around Prudhoe Bay. Deviation of algal production, algal biomass and species composition was compared to an adjacent control pond. Planktonic primary productivity was initially inhibited but recovered. Algal density did not deviate in the two ponds; however, the biomass and the species composition was changed, by the elimination of the Cryptophyte Rhodomonas minuta. The time course of the effects was related to the weathering and degradation of the oil. On these ponds the effects on the phytoplankton were not significantly different than those observed in 1970 after a controlled spill at 45 times the 1975 dose rate.

INTRODUCTION

The development of oil reserves on the North Slope of Alaska has increased the probability of crude oil leakage to a near certainty during the projected 20 years of production. On the coastal plain of the North Slope, 30-50% of the land area is covered by water isolated in small polygonal thaw ponds (less than 100m on a side) and in shallow (less than 3m deep), elongated lakes with a NE-SW orientation. Finds of oil at Prudhoe Bay, exploration of Naval Petroleum Reserve No. 4 to the West, transportation of oil to central collecting sites and pumping the oil to southern ports will undoubtedly lead to several instances of oil loss on the land and waters of one of the most sensitive ecosystems in the world. Our basic knowledge of the effects of Prudhoe type crude oil on whole aquatic ecosystems and the recovery of impacted ecosystems is very limited.

Most of the data available from experiments done in the Arctic attempt to project what the effects of crude oil leakage will be on marine systems, such as in Cook Inlet or the Gulf of Alaska (Kinney, Button and Schell, 1969; Robertson, et al. 1973; Button, et al., 1973; Moore, et al. 1974). Only a few have examined effects in freshwater (Arhelger and Button, 1972; Barsdate and Alexander, 1973; Atlas, 1973; Hobbie et al. in prep.) The bulk of the work documenting the effects of oil on arctic lakes has been completed by the Fisheries Research Board of Canada and others (Dickman, 1971; Brunskill, et al., 1973, Snow and Scott 1975, Snow and Rosenberg, 1975a; 1975b; Roeder, et al.,

1975: Snow and Brunskill, 1975. Although some similarities exist between the effects of Pembina and Norman Wells crude oils from the MacKenzie Delta, and Prudhoe crude oil, significant differences also exist as we shall point out.

An experimental crude oil spill on North Slope waters has been followed at several trophic levels for several years by the U.S. IBP Tundra Biome aquatic program (Hobbie et al. in press). An experimental spill in 1970 on a typical thaw pond, Pond E, near Barrow, Alaska was dosed at the rate of 10 liters/meter². A comparative oil spill designed to evaluate the effects and recovery from a much smaller dose rate (0.24 l/m²) was effected on July 10, 1975, and is the subject of this paper.

This report summarizes the effects of Prudhoe Bay crude oil on photosynthetic carbon fixation by phytoplankton, algal density, biomass and species composition on a typical polygonal pond similar to those at Prudhoe but located for convenience near Barrow, Alaska (71° N lat.) where laboratory facilities were available. We will show a relationship between the loss of and changes in oil composition, to its toxic effects and changes in carbon cycling in a typical tundra thaw pond.

MATERIALS AND METHODS

Crude Oil---The Prudhoe Bay crude oil used in this study was provided by the Atlantic Richfield Oil Company.

Effect of Temperature on Crude Oil--Measured amounts of crude oil were placed in tared scintillation vials. One set of 3 vials was placed at 25°C in flowing air, the other set of 3 vials placed at 5°C. Both sets were not in direct sunlight. At periodic intervals, the vials were weighed to determine loss of oil.

Effect of Solar Radiation on Crude Oil---Measured amounts of crude oil were placed in sets of tared plastic petri dishes (100 X 20 mm). Three petri dishes were open and exposed to the elements (clear-open), two were closed (clear-closed) and two were covered top and bottom with black opaque plastic tape to prevent light from reaching the oil sample (dark-closed). Periodically, gravimetric measurements were made of the oil remaining. At the end of the experiment, the oil was extracted and its class composition determined as described below.

Controlled Spill of Crude Oil on a Tundra Pond---In order to determine the biotically and abiotically induced changes in crude oil composition after being spilled on a tundra pond (Pond Omega), ple glass cores (50cm X 7.5 cm, I.D.) were placed vertically into the water column and bottom mud. Each core was inoculated with a measured amount (0.908 g) of Prudhoe crude oil. This amount was about the same (in g/m) as was spilled on the whole pond (described below). In a plastic tub incubated in the pond and containing pond water, 5 g/l of HgCl_2 was added. A set of

cores was placed into the tub and inoculated with oil. These cores served as the abiotic controls. At periodic intervals, the cores were removed and the oil extracted by the following procedure: A rubber stopper was placed on the top of the core and the core carefully lifted until a second stopper could be placed in the bottom of the core. This allowed for the water column and bottom mud to be sampled intact. The core was removed to the laboratory where the oil and water column were sucked directly into a separatory funnel. The oil which had adhered to the sides of the core was washed into the separatory funnel by Freon 113. The Freon - water mixture in the separatory funnel was shaken and the oil extracted into the Freon phase. The water was reextracted with 50 ml portions of Freon, two times. The combined extracts were evaporated at 25°C in flowing air, overnight. The quantities of total oil extracted were measured gravimetrically. The oil was then chromatographed for class composition (described below).

Determination of Class Composition of Crude Oil---Samples for class composition were separated on solid/liquid chromatograph columns as described by Jobson, et al (1972). The fractions separated were benzene soluble asphaltene (BSA), benzene insoluble asphaltene (BIA), saturate fraction (SF), aromatic fraction (AF) and the nitrogen, sulfur or oxygen containing fraction (NSO).

Gas Liquid Chromatography of Saturate Fraction-The saturate portion from the oil spilled in cores was further analysed by gas-liquid chromatography. A Perkin-Elmer Model 900 gas-liquid chromatograph equipped with a flame ionization detector was used.

The six foot, 1/8" i.d. stainless steel columns were packed with 1% SE-30 (Applied Sciences, State College, PA) on 80/100 Gas Chrom Q. After sample injection (1 μ l) the following temperature program was run: 60°C for 3 minutes, followed by a linear temperature increase at 5°C/minute to a final temperature of 250°C for 5 minutes. The injection port and manifold temperatures were 260°C and the helium carrier gas flow was 35 ml/minute. Peaks were identified by their elution temperature maxima and comparison to retention times of a control mixture of n-alkanes (C_7 to C_{19}).

Uncontrolled Oil Spill on a Tundra Pond---On July 10, 1975, Prudhoe Bay crude oil was spilled on a small (260m²) tundra pond (Pond Omega) at a dose of about 240 ml/m². Various samples were taken as described below, to follow the effects of the oil on the production of the pond. Samples were also collected from a nearby pond (Pond E) which had oil spilled on it in 1970 at about forty-five times the 1975 dose. The thick tar remaining was also sampled for class composition.

Physical factors, which were monitored at least weekly and at all sampling dates, included 1) temperature measured with a mercury thermometer or tele-thermometer; 2) pH measured electrometrically; 3) alkalinity by 0.02 N H₂SO₄ titration to the bromcresol green-methyl red endpoint (Standard Methods, 1971); 4) oxygen concentration with a YSI Model 54 oxygen meter; 5) wind speed recorded as run-meters/day, 30 cm above water surface; 6) solar radiation monitored continuously by a Weather Measure recording solarimeter.

Phytoplankton biomass and density were measured by settling (35 ml) volumes of whole pond water killed with Lugols Iodine (Edmondson, 1959) in Utermohl chambers (Utermohl, 1958). Ten to twenty fields were counted under phase contrast using an inverted microscope (Wild, m40). Cell volumes were calculated from external dimensions and approximate geometric shape. Biomass of carbon was approximated as 0.05 times cell volume.

Primary production was determined by measuring the incorporation of $^{14}\text{CO}_2$ (Vollenwieder 1969) using 4-6 hour in situ incubations during the middle of the solar day. The ^{12}C available was calculated from the pH, temperature and total alkalinity data using the dissociation formulae of Vollenweider (1969). Exactly 25 ml of radio-labelled seston was drawn through a 25 mm Type HA Millipore filter (0.45 μm pore size); the filter was emersed immediately into Brays solution in 5 ml minivials and counted by liquid scintillation spectroscopy, correctioned for quenching by the Channel ratio method.

RESULTS

Effect of Temperature of Crude Oil

The effect of temperature on the weathering of Prudhoe Bay crude oil was studied at two temperatures; 25°C and 5°C. The loss of volatile components of the oil was measured and the rate of loss determined. The negative exponential loss was $k = -0.0049/\text{hr.}$ at 25°C and $k = -0.0041/\text{hr.}$ at 5°C. Thus the temperature related differences in weathering were small.

Effect of Solar Radiation on Crude Oil

Measured quantities of crude oil were placed in plastic petri dishes and exposed to sunlight as described. The effects of sunlight on the total weight of oil after 36 days is seen in Table 1. The closed dishes showed about the same loss, but the open dish lost significantly more total oil after 36 days (ANOVA, NS). Analysis of the class composition of the oil showed no differential loss of a particular fraction (Figure 1), thus the total losses must have come almost equally from each fraction.

Controlled Oil Spill on a Tundra Pond

When measured amounts of crude oil were spilled in core tubes implanted in Pond Omega, the untreated cores lost weight of oil at a negative exponential rate ($k = -0.0308/\text{day}$). By the end of the experiment, a mercury treated core tube (abiotic control) had lost 69% of its oil in 45 days whereas untreated cores lost 75% in the same time. This indicated that about 6% of the loss of oil was not due to weathering, but due to biological factors and/or incomplete extraction of the aged oil by Freon.

Class composition analysis of the oil components from cores over the first 13 days are seen in Figure 2. Within the first day after the spill, the aromatic fraction decreased about 8% resulting in a concomitant increase in the saturate fraction. At 4 days, however, the levels of these two components returned to their original percentage levels and remained there for the remaining 9 days, although a general trend showing a loss of the aromatic fraction may be seen. These data also corroborate the solar radiation experiments in that even though the total weight loss decreased at an exponential rate, the class composition remained relatively unchanged. For comparative purposes, the class composition of the oil remaining from the 1970 oil spill on Pond E showed that even though a great loss of total weight of oil could be expected in the 5 years of exposure, the class composition changes did not vary greatly (Figure 2).

Gas Chromatographic Results of the Saturate Fractions

From the analysis of a 0 day (top profile) and 14 day (bottom profile) cores by gas-liquid chromatography. (Figure 3.) only the n-alkanes less than C_{13} have disappeared. The envelope region of the 14 day chromatogram is much higher than the 0 day control indicating total evaporative losses of the saturate fraction. This further verifies the previous experiments. Chromatograms of saturate fractions from oil which had been isolated from abiotic controls were similar to that of the 0 day sample.

Phytoplankton production

The normal seasonal cycle of primary production in control Pond C began with low rates (dark bottle fixation equal to light bottle fixation) in the post thaw period in mid June (bottom of Figure 4); the rate increased to a maximum in early July, declined in late July through mid August, and increased again after the first freezes have caused death and leaching of nutrients from terrestrial grasses (Hobbie, 1972; Hobbie, In press). The average annual primary production rate in control Pond C, a pond about 20 cm deep was 2.34 ug C/1-hr in 1975. If the daily production is 10 times the daily average over midday period, then the production over the 75 day summer from mid June to early September was about 350 mg C/m²-year. The plankton in these ponds are amongst the least productive in the world, caused by a short growing season and a chronic shortage of phosphorus despite 24 hours of daylight (until early August) (Hobbie, in press; Hobbie et al, 1972; Hobbie, 1973).

Algal biomass ranged from 50 to 400 mg dry wt/m² (Figures 5 and 6). The seasonal maximum occurred in mid August and late June, the latter caused primarily by soil algae washed into the ponds by overland flow due to spring thaw. After the overland flow had ceased by late June, the algae become dominated by the Chryptophyta, especially Rhodomonas minuta (Figure 3) and the Chrysophyta, Chromulina spp. and Chrysococcus. Lynghya sp., became the dominant in late August. In control pond C from 8 to 26 genera of algae (average 17 genera of sample data) were found in each sample counted (minimum 100 organisms).

The application of 240 ml of oil/m or about 1.2 ml/l of fresh Prudhoe crude oil in Pond Omega took place on July 10 at 0240 hrs ADT. The effect on the primary production was a sharp inhibition in the days following the spill. Compared to the control Pond C, the production remained lower for 6 days (Figure 4). By 18 days the production in Pond Omega was substantially higher than in the control pond. Comparing the average ratio of production in Pond C with that in Pond Omega before and after the spill primary production appeared to be 28% lower on the average during 46 days after the spill (Figure 4, top).

In order to examine the sensitivity of primary production by phytoplankton, we dosed a nearby pond, Pond A with 0.6 ml/l (0.120 l/m²) crude oil to compare to Pond C. The constancy of the ratio of primary production in two adjacent ponds showed a range of ratio of 0.6, comparing primary production in Pond Omega to Pond C before the spill (Table 2). Following an experimental spill (0.6 ml/l) on Pond A the ratio of primary production in the experimental pond to control Pond C increased sharply to greater than 1.5 (a change of range of the ratio of 1.8) for 8 hours following the spill and then returned to near normal ratios (Table 2). Thus, at a slightly lower dose rate the immediate effects of the oil were to cause a short term stimulation of phytoplankton production. This stimulation contrasts with inhibition in primary production seen in Pond Omega dosed at 2 times that level.

By July 16, six days after the spill the algal biomass was greater in the oil spill pond ^{Omega} than control Pond C and remained

higher on every later date except one (6 of 7 dates) (Figure 5 vs 6). The biomass in the oil pill pond reached a maximum of 481 mg dry wt/m³ on August 6 (Figure 5), as though the oil had caused a slight stimulation. However, the average density of algal cells in the plankton of ponds C and Omega had the same seasonal pattern. Only the amplitude of the oscillations in density was greater in the control Pond C. The effect on biomass must have been caused by changes in species composition and in average size of cells. The number of genera found in the samples counted was no different before or after the spill (Average 17 genera/sample).

DISCUSSION

Losses of Prudhoe crude oil

From the experiments presented concerning changes in oil composition under summer arctic conditions, there was no great effect of temperature (25° vs 5°C) on the loss of Prudhoe Bay crude oil. Photodecomposition losses also appear to effect the total loss of volatile components in crude oil but not in specific components (Figure 1). However, the total weight loss of oil appeared greater when exposed to the atmosphere than when covered loosely by a plastic cover (Table 1). Under controlled conditions there was no loss of any particular component of the oil at a greater rate than the other components tested (Figure 1). The light exposed oil had a very crusty, plate-like appearance at the end of the experimental period when visually compared to the dark treatment. This could be the result of polymerization of the oil components after extended exposure to light containing ultraviolet, as reported by Klein and Filpel (1974).

Analysis of the saturate fraction of Prudhoe crude oil which had been spilled in a controlled manner (core tubes) on Pond Omega, was done by gas-liquid chromatography. The results indicated that within 14 days, the n-alkanes C_7 to C_{12} had been utilized by the indigenous microflora of the pond. When compared to abiotic (Ug-killed) controls, it was apparent that the biotic component was utilizing the shorter carbon length components of the saturate fraction. These data conform to those of Atlas (1975) for degradation of Prudhoe crude oil. He found the greatest losses the shorter n-alkanes after 42 days. However, his experiments

were run under controlled conditions of temperature (20°C) with shaking and with a marine Pseudomonas sp isolated from an oil spill near Prudhoe Bay.

We found about 24% loss in total weight in 36 days (Table 4) with weathering alone, whereas Atlas (1975) reported a nonbiological loss of about 26% for Prudhoe crude oil in 42 days, incubated with California seawater. Degradation of Prudhoe Crude in natural biological systems was greater than this. We found a 75% loss in 45 days using in situ incubations in Pond Omega; whereas Atlas (1973) found 80% loss in fertilized containers floating in Prudhoe Bay and 60% loss in natural Arctic Ocean water.

The bulk of the experimental work on crude oil effects on arctic freshwater systems has been carried out on lakes in Mackenzie River valley, N.W.T., Canada, where oil development is occurring. The effects on primary producers may be summarized by the following observations from a wide range of dose rates (0.03ml/l to 9.1 ml/l) (Table 3):

- 1) Rapid volatilization causes loss of toxic compounds within hours, with a 30-40% loss of total volume of crude oil in the first day (Snow and Rosenberg, 1975b).
- 2) Primary productivity often shows immediate inhibition (day 0-1) with reduction extending no more than the first season.
- 3) Algal biomass and periphyton biomass increase in oiled sections of N.W.T. lakes.
- 4) Species composition changes as blue-green algae become dominant especially in the periphyton which develops into luxuriant growths.

Similar patterns were not demonstrated by the present study with an experimental spill on Pond Omega or by the spill on Pond E in 1970.

- 1) Volatilization and solution of oil from the pond surface was not nearly so rapid with Prudhoe crude (10% in first day) as compared to the Canadian crude oils (30-40% loss in first day).
- 2) Primary production did decrease following the spills (1.2 ml/l); however, recovery took place between 6-18 days after the spill (1975) (Figure 4).
- 3) There was no significant change in algal density. An increase in algal biomass occurred following the spills (Figures 5 and 6).
- 4) Blue-green algae did not become dominants; however, dominance shifted from the Chrysophyta, Chromulina and Cryptophyta, Rhodomonas to Chlorophyta, Chlamydomonas and Chrysophyta, Uroglena.

The lower loss rates were only in part caused by the low average water temperatures (5.0°C) in Pond Omega after the spill. Increasing the temperature by 20° C only increased the volatilization rate by 20%. Since the solubility of the of fresh Prudhoe crude was only 3%, as measured by fluorescence of the CCl_4 -extractable materials we can assume most of that first day loss was by volatilization. The loss rate of Pembina crude was 34% and of Norman Wells crude about 43% on the first day. Thus the proportion volatilized on the first day must be a function of the type of oil.

Not all the loss of saturate fraction was abiotic in the ponds as previously discussed. Losses from cores incubated in situ were still losing oil residues after 45 days. Although the saturate fraction had lost all compounds less than C_{13} in 13 days when tested, a HgCl killed control had not lost them at all after 7 days. Thus the loss of the compounds in the saturate fraction was largely biological. We did not isolate petroleum degrading bacteria; however, the data of J. Hobbie and C. Sheldon (personal communication) showed that bacterial density was from 3.0 to 5.5×10^5 cells/ml (using acridine-orange epifluorescent counting) higher following the spill compared to the control Pond C (density range $0.8-1.5 \times 10^6$ cells/ml). Further, compared to open water in the pond, bacterial density appeared to be significantly higher in water of oil enriched cores incubated in situ for two days following the addition of oil. Although data are total counts of bacteria and not simply hydrocarbon degrading bacteria, Shindler et al. (1975) found increased colony forming units in a series of oil-closed artificial ponds near the Ottawa River. Atlas (1973) reported increases in bacteria of several orders of magnitude in oil treated fresh waters near Prudhoe Bay.

Unlike the artificial ponds studied by Shindler et al. (1975) or littoral corals studied by Hellbust et al. (1975) the biomass of algae and periphyton in our thaw pond did not increase proportional to the oil dose rate. The experimental spill in 1970 on neighboring Pond E caused virtually identical effects as the spill in 1975, on Pond Omega except that the dosing rate was 45 times greater on Pond E (Alexander and Coulon, 1972, Barsdate and

Prentki, 1973; and Hobbie, In Press). If eutrophication was the mechanism causing the species compositional changes, we would expect a greater effect from the heavier spill (10 liters/m^2). However, after the large spill in 1970 on Pond E no significant increase or decrease could be seen in nutrient levels or in algal biomass. Thus nutrients in the oil released by decomposition or net nutrient accrual stimulated by heterotrophic activity did not have demonstratable effects. However, dissolved phosphate concentration is acutely limiting algal biomass accumulation in these ponds, so that only very large doses of fertilizer cause responses in the attached or suspended algae (Stanley, 1973). The iron-rich, organic bottom material maintains an equilibrium concentration of dissolved reactive phosphate between $1\text{--}3 \text{ ug P/l}$. (Barsdate and Prentki 1975). Thus eutrophication by oil degradation affecting the nutrient levels was not expected in these arctic ponds. Otherwise, in the literature, only Snow and Brunskill (1975) and Snow and Scott (1975) found no algal enrichment when crude oil was added to a subarctic system. They dosed floating limnocorrals on Lake 3, N.W.T. with 5 l/m^2 of Norman Wells Crude. Because the floating oil prevented light penetration, added fertilizer stimulated of algal biomass accumulation much less than expected. Oil alone caused no increase.

What then appears to be acting as an 'on' or 'off' switch causing changes in algal composition in arctic ponds but is not dependent upon the dose rate over a 45-fold difference in initial oil concentrations? Parrow ponds are subject to intense grazing

by zooplankton, clearing the water of seston about once per day in July (Hobbie, In press). The zooplankton species responsible for the bulk of the grazing pressure are killed in 2-4 days by the application of oil. They are, Daphnia middendorffiana and the fairy shrimps, Polyartemiella hazeni and Branchionecta paludosa. Only omnivorous cyclopoid copepods survived the entire summer (J. O'Brien, personal communication). Following the 1970 spill on Pond E these species were eliminated on succeeding summers (1971-1973) (Stross 1974). In fact, the species composition of the phytoplankton did not return to prespill conditions by 1975, because our indicator species, Rhodomonas minuta had not returned. This logic leads us to the tentative conclusion that the change in species composition has been caused and maintained by the severe reduction in density and/or elimination of the large grazing zooplankton.

It was the demise of the zooplankton, even at low dose rates (as low as 0.6 ml/l) with Prudhoe crude oil which in some way allowed species like Uroglena spp. to become common in ponds where it is not normally found. Interestingly, the oil spills with Norman Wells crude oil on Lake 4 and 4C in N.W.T. at 0.03-0.04 ml/l did not kill the zooplankton (Brunskill personal communication). Obviously the role of zooplankton grazing intensity and size selectivity in determining composition of the seston needs more work in these arctic systems. The effect of crude oil is a function of (1) its toxicity to zooplankton (2) its toxicity or stimulation of algae directly and (3) its apparent increase of nutrients where light and, in our case, phosphate is

not acutely limiting. In a Barrow pond, direct inhibition or stimulation of primary production was dose dependent and short lived. Most of the effects in changed algal composition appeared to have been caused by the elimination of the zooplankton.

ACKNOWLEDGEMENTS

The authors would like to thank Thomas Federle, Chris Hurst, and Russell Risma for their field and laboratory work. This research was funded by grants from E.R.D.A. to Dr. John Hobbie, North Carolina State University and to Dr. Vera Alexander, University of Alaska. Support was provided in part by NSF Office of Polar Programs grant 75-12945 to H.C. Miller, University of Cincinnati under auspices of coordinated research of R.A.T.E. (Research on Arctic Tundra Environments). Logistic support was provided through the Naval Arctic Research Laboratory, Barrow, Alaska.

BIBLIOGRAPHY

- A.P.H.A. 1971. Standard Methods for the examination of water and waste water. Am. Pub. Health. Assoc. Inc., New York.
- Alexander, V., R. Clasby and C. Carlon. 1972. Primary productivity and phytoplankton studies in the Barrow tundra ponds, p. 169-173. In Proceedings - 1972 Tundra Biome Symposium, U.S.I.B.P.
- Arhelger, S. and K.K. Button. 1972. Hydrocarbon biodegradation in the Arctic. Baseline data study of the Alaskan arctic aquatic environments. pp. 231, 234. University of Alaska Instit. Marine Sci. No R72-3.
- Atlas, R.M. 1973. Fate and effects of oil pollutants in extremely cold marine environments. Report to ONR, Oct. 1973. NITS AS AD-769, 895, 34p.
- Atlas, R.M. 1975. Effects of temperature and crude oil composition on petroleum biodegradation. Applied Microbiology 30:396-403.
- Barsdate, R.J. and V. Alexander. 1973. Natural oil seeps at Cape Simpson Alaska: Aquatic Effects.
- Barsdate, R.J. and R.T. Prentki. 1973. Nutrient metabolism and water chemistry in lakes and ponds of the arctic coastal tundra. U.S. Tundra Biome Data Report 73-127. 163 p.
- Barsdate, R.J. and R. Prentki, 1975. Nutrient Metabolism and

water chemistry in lakes and ponds of the arctic coastal tundra. U.S. Tundra Biome Data Report 74-140.

Brunskill, G.J., D.M. Rosenberg, N.B. Snow, G.L. Vascotto, R. Wagemann. 1973. Ecological studies of aquatic systems in the MacKenzie Porcupine drainages in relation to proposed pipeline and highway developments. Vol. 1 Environment Canada, Information Canada Cat. No. R72-10073/1-

Button, D.K., P.J. Kinney, D.M. Schell and B.R. Robertson. 1973. Hydrocarbon biodegradation in Alaskan waters. ppl. 171-184 In Proceed Workshop at GA State University Dec. 4-6, 1972/ Louisiana State University Sea Grant Publ. Vol LSU-SG-73-01.

Dickman, 1971. Preliminary notes on changes in algal primary productivity following exposure to crude oil in the Canadian Arctic. Can. Field Naturalist 85:249-251.

Edmondson, W.T. (ed.) 1959. Freshwater Biology, 2nd Edition. John Wiley, NY 1248 p.

Hanna, B.M., J.A. Hellebust and T.C. Hutchinson. 1975 Field studies on the phytotoxicity of crude oil to subarctic aquatic vegetation. Verh. Internat. Verein. Limnol. 19:2165-2171.

Hellebust, J.A., B. Hanna, R.G. Sheath, M. Gergis and T.C. Hutchinson. 1975 Experimental crude oil spills on a small

subarctic lake in the MacKenzie Valley, N.W.T.: Effects on phytoplankton, periphyton and attached aquatic vegetation. p. 509-515. Conference on Prevention and Control of Oil Pollution, Proceed. Amer. Petroleum Inst.

Hobbie, J.E., R.J. Barsdate, V. Alexander, D.W. Stanley, C.P. McRoy, R.G. Stross, D.A. Bierle, R.D. Dillon, M.C. Miller, P.I. Coyne, and J.H. Kelley. 1972. Carbon flux through a tundra pond ecosystem at Barrow, Alaska. U.S. Tundra Biome Report 72-1. 29p.

Hobbie, J.E. 1973. Arctic limnology: a review, p. 127-168. In M.E. Britton (ed.) Alaskan Arctic Tundra. Tech. Paper No. 25 Arctic Institute of North America. Washington, D.C.

Hobbie, J.E. (ed.) In press. Limnology of Arctic Ponds.

Jobson, A. F.D. Cook, D.W.S. Westlake. 1972. Microbial utilization of crude oil. Applied Microbiology 23:1082-1089.

Kinney, P.J., D.K. Button and D.M. Schell. 1969. Kinetics of dissipation and biodegradation of crude oil in Alaska's Cook Inlet. Proceed. Joint Conf. on Prevention and Control of Oil Spills. AM. Pet. Instit. F.W.P.C.A. New York.

Klein, A.E. and N. Pilpel. 1974. The effects of artificial sunlight upon floating oils. Water. Res. 8:79-83.

Moore, S.F., G.R. Chirlin, D.J. Puccia, B.P. Schrader, 1974.

Potential biological effects of hypothetical oil discharges in the Atlantic coast and gulf of Alaska. M.I.T. Sea Grant Report No. MITSG 74-119. Robertson, P., S. Arhelger, R.A.T. Law and D.K. Button 1973. Hydrocarbon biodegradation in Port Valdez. In: Port Valdez Environment Studies. Institute of Marine Science Report. University of Alaska, Fairbanks.

Robertson, B., S. Arhelger, R.A.T. Law and D.K. Button 1973.

Hydrocarbon biodegradation in Port Valdez. In: Port Valdez Environmental Studies. Inst. of Marine Science Report. University of Alaska, Fairbanks.

Roeder, D.R., G.H. Crum, D.M. Rosenberg, and N.B. Snow, 1975.

Effects of Norman Wells crude oil on periphyton in selected lakes and river in the Northwest Territories. Environ. Canada Technical Report. 552, 32 p.

Shindler, D.B., B.F. Scott, and D.B. Carlisle. 1975 Effect of crude oil on populations of bacteria and algae in artificial ponds subject to winter and ice formation. Verh. Internat. Verein. Limnol. 19:2138-2144.

Snow, N.B. and G.J. Brunskill. 1975. Crude oil and nutrient enrichment studies in a MacKenzie Delta lake. Environ. Canada Technical Report. No. 533, 7p.

Snow, N.B. and D.M. Rosenberg. 1975a. Experimental oil spills on MacKenzie Delta Lakes I. Effect of Norman Wells Crude Oil on Lake 4. Environ. Canada, Technical Report No. 548.

44 p.

Snow, N.B. and D.M. Rosenberg. 1975b. Experimental oil spills on MacKenzie Delta Lakes II. Effect of two types of crude oil on Lakes 4C and 8. Environment Canada, Technical Report No. 549. 19 p.

Snow, N.B. and B.F. Scott. 1975. The effect and fate of crude oil spilt on two arctic lakes. Proceed. In conference on Prevention and Control of Oil Pollution. Amer. Petroleum Institute. U.S. E.P.A., U.S. Coast Guard.

Stanley, D.W. 1973 Benthic algal productivity in tundra ponds. U.S. IBP Tundra Biome Data Report. 73-118. 70 p.

Stross, R.G. 1974. Zooplankton Synchrony and productivity in arctic coastal ponds at Barrow, Alaska. U.S. Tundra Biome Data Report. 74-4.

Utermöhl, H. 1958. Zur Vervollkommenung der quantitative. Phytoplankton Methodik. Mitt. int. Verein. Limnol. 9:1-38.

Vollenweider, R.A., 1969. A manual on methods for measuring primary production in aquatic environments. F.A. Daus Comp. Philadelphia, PA.

LIST OF TABLES

- Table 1. Loss of weight of Prudhoe Crude Oil after weathering in darkness and exposed to sunlight for 36 days (1 way ANOVA table).
- Table 2. Changes in ratio of primary production in experimental pond and control Pond C before the oil spill (July 3-5, Pond Omega) and immediately following a spill of 0.6 ml/l on Pond A (July 10-11).
- Table 3. Effect of Northern Crude Oils on primary production, algal composition of arctic or subarctic lakes reported in the literature.

TABLE 1

WEIGHT LOSS OF PRUDHOE CRUDE OIL ± SUNLIGHT EXPOSURE

Treatment	Day	0 g/dish	36 g/dish
Dark-closed		0.914	0.750
		0.969	0.791
	%loss	0.0%	18.2%
Light-closed		0.872	0.710
		0.816	0.657
	%loss	0.0%	19.0%
Light-open		0.938	0.713
		0.950	0.753
		0.936	0.691
	%loss	0.0%	24.1%

ANALYSIS OF VARIANCE FOR WEIGHT LOSS

Source of Variation	df	SS	MS	F
Among	2	52.57	26.29	11.96*
Within	4	8.79	2.20	

Table 2

Comparison of primary production in Pond Omega and Pond C prior to oil spill, and in Pond C and Pond A immediately following a spill.

Time/date	Pond C (ug C fixed/liter-hour	Pond Omega std. dev.)	Omega/C	
July 2 13:48-19:45	3.71 0.90	2.56 $\pm$ 0.45	0.69	
July 3 8:50-13:10	3.92 $\pm$ 1.05	2.30 $\pm$ 0.22	0.59	
13:10-19:00	2.67 $\pm$ 0.11	2.46 $\pm$ 0.49	0.92	
18:55-1:10	1.46 $\pm$ 0.10	1.70 $\pm$ 0.03	1.16	
July 4 1:05-8:55	1.40 $\pm$ 0.61	1.21 $\pm$ 0.03	0.86	
	Pond C	Pond A	Pond A'	Ratio A/C
July 10 Prespill				
11:15-16:00	1.87 $\pm$ 0.16	1.36 $\pm$ 0.32		0.73
Postspill				
11:45-16:00		2.85 $\pm$ 0.13		1.52
16:00-20:30	1.34 $\pm$ 0.34	2.37 $\pm$ 0.70	1.80 $\pm$ 0.49	1.55
20:30-00:15	1.15 $\pm$ 0.30	0.90 $\pm$ 0.035	1.37 $\pm$ 0.04	0.98
July 11				
00:12-4:45	1.23 $\pm$ 0.36	1.03 $\pm$ 0.17	0.77 $\pm$ 0.04	0.73
4:40-8:40	1.70 $\pm$ 0.22	1.55 $\pm$ 0.16	1.40 $\pm$ 0.37	0.87
8:30-14:30	1.24 $\pm$ 0.25	1.14 $\pm$ 0.16	1.13 $\pm$ 0.00	0.92
14:20-24:30	1.55 $\pm$ 0.10	1.84 $\pm$ 0.57	1.46 $\pm$ 0.24	1.06

A and A' refer to two locations in the Pond A, the latter being under a heavy oil film.

TABLE 3

EFFECT OF CRUDE OILS ON PHYTOPLANKTON FROM NORTHERN LAKES

Lake-oil exposure	Dose cc/l (l/m ²)	Crude oil	Change in ¹⁴ C Primary Production	Change in Algal Biomass	Change in Species Composition	Reference
Marsh near Inuvik, N.W.T.-bottles 275a	1.95	MacKenzie Valley crude, aged 2 months	1000% decrease 4 hrs. after addition	n.a.	n.a.	Dickman (1971)
Hanna L. N.W.T.-littoral coral	2.65 (14.5) and 6.2 (35 l)	Norman Wells	32% decrease ave. for 65 days	none density >1 of 6 dates post spill	<i>Oscillatoria</i> spp. increased in relative density	Hanna et al. (1975) Hellebust, J.A. et al 1975.
Ottawa R.-artificial ponds	1.5 (0.44) and 9.1 (2.67)	Norman Wells	n.a. n.a.	increase over controls greatest increase over controls	n.a. n.a.	Shindler et al. (1975).
Lake 4 N.W.T.-whole lake	0.03 (0.06)	Norman Wells	reduced to 0 day 0 recovered by day 1	n.a. periphyton increased 1 season	n.a. periphyton blue greens dominant	Snow and Rosenberg (1975a)
Lake 8 N.W.T.-cylinders with bottoms	2.25 (5.0)	Pembina	n.a.	no increase without added N and P and light	n.a.	Snow and Brunskill (1975) Snow and Scott (1975)
Lake 4C, N.W.T.-littoral coral Lake 8, N.W.T.-littoral coral	0.04 (0.06)	Norman Wells	n.a.	Seston, part. carbon and part. nitrogen increase. ca. 300% Seston, particulate carbon and nitrogen increase ca. 200%	n.a.	Snow and Rosenberg (1975b) Roeder et al. (1975) Snow and Scott (1975)

TABLE 3 (cont.)

Cape Simpson- ponds exposed to natural seeps	"n.a. light to heavy"	Cape Simpson	200%-1000% increase over exposed	increased 10 X in medium exposure decreased 70% in heavy exposure	greens up blue-green cryptophyta down	Barsdate, Alexander, and Benoit (1973)
Pond E, Barrow Alaska- whole pond 1970	50 (10)	Prudhoe Bay	1970 slight increase 1971 50% decrease 1972 170% increase 1975 No Diff.	no diff.	<u>Rhodomonas</u> down <u>Uroglena</u> increase	Barsdate & Prentki (197 Alexander e al. (1972) Miller and Reed (1972) Stanley (19 present stu
Pond Omega, Barrow Alaska- whole pond	1.2 (.24)	Prudhoe Bay	28% decrease relative to control (46 days)	no diff.	<u>Chromulina</u> <u>Rhodomonas</u> down <u>Uroglena</u> & <u>Chlamydomonas</u> up.	present study

LIST OF FIGURES

- Figure 1. Percent class composition of Prudhoe Crude Oil after weathering in darkness and exposed to sunlight for 36 days.
- Figure 2. Changes in percent class composition of Prudhoe Crude Oil degraded in core tubes on Pond Omega for 13 days, compared to oil degraded for five years on Pond E.
- Figure 3. Changes in saturate fraction separated gas chromatographically before (top) and after (bottom) being degraded for 13 days on Pond Omega.
- Figure 4. Primary production ($\mu\text{g C/l}\cdot\text{hr}$) of phytoplankton in Pond C (open circles) and Pond Omega (open triangles) (bottom) and the ratio of production in oil-spill Pond Omega/production in control Pond C (top) over the ice free season.
- Figure 5. Algal biomass ($\mu\text{m}^3/\text{l} \times 10^6$) in control Pond C (top) and percent biomass composition by phylum (bottom) during the ice free season. Key (top to bottom): dots - Euglenophyta, blank₁ -- Chrysophyta, blank₂ - Cryptophyta, horizontal lines -- Pyrrophyta, opaque -- Cyanophyta, diagonal lines -- Bacillariophyta, blank -- Chlorophyta
- Figure 6. Algal biomass ($\mu\text{m}^3/\text{l} \times 10^6$) in oil-spill Pond Omega (top) and percent biomass composition by phylum (bottom) during the ice free period.

Figure 1, Miller, Hater, Vestal

Figure 2, Miller, Hater, and Vestal

Figure 3, Miller, Hater, and Vestal

Figure 4, Miller, Hater and Vestal

Figure 5, Miller, Hater, and Vestal

Figure 6, Miller, Hater and Vestal