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9

Oil Spill Effects

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INTRODUCTION

Oil production at Prudhoe Bay stimulated interest in research on effects of a possible oil spill on ponds. In fact, there are natural oil seeps at Cape Simpson, not very far from Barrow, and a producing gas well is in sight of the ponds. For this reason, NSF funded pond research in 1970 and an experimental oil spill was carried out on Pond E. This pond was sampled during the years of intensive research and then the Department of Energy provided funds for an additional oil spill (Pond Omega in 1975) and follow-up studies from 1975 through 1979. This research allowed additional studies on chironomids, zooplankton, and algae; much of this basic research is included in this book. In addition to the basic research, the oil spills were experimental treatments that produced information on such things as the control of phytoplankton algae by zooplankton and recolonization of ponds by insects.

Most of the research on effects of oil has been carried out on marine species; there are, however, several studies of effects on arctic freshwaters. In Canada, both lake and stream spills have been studied in the Mackenzie Delta (Brunskill et al. 1973, Snow and Rosenberg 1975a, 1975b). In Alaska, a spill was studied in an arctic lake (Jordan et al. 1978, Miller et al. 1978a) and the natural seeps at Cape Simpson have been investigated (Barsdate et al. 1973).

Spill on Pond E, 1970

On 16 July, 1970, 760 liters (4 barrels) of crude oil from Prudhoe Bay (ARCO) were applied to the surface of Pond E (Figure 9-1). Pond E has a surface area of 300 m^2, or 490 m^2 if the surrounding marsh is included, and an approximate volume of 800 m^3. This amount of oil is about 16,000 liters ha^{-1} or 25 times the dose used for the Mackenzie Delta study.

Several hours after the spill on Pond E the oil covered the entire pond; 24 hours later the wind had moved the oil to the west side of the pond where it accumulated in a band 3 to 5 m wide. Throughout August and early September, about half of the applied oil moved back and forth in the

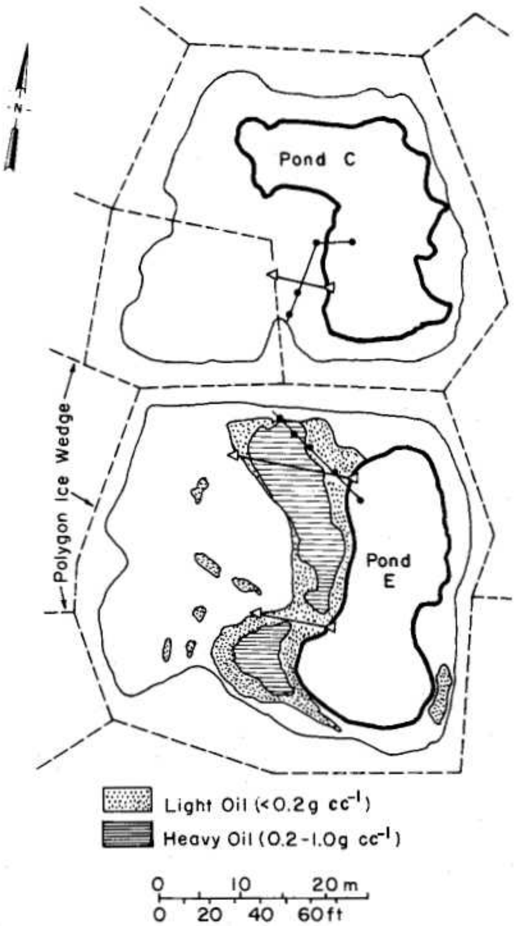

FIGURE 9-1. *Ponds C and E showing location of sampling points for temperature and oxygen in 1970 (solid points), the distribution of oil in July 1971, and the location of the 1971 and 1972 vegetation transect (triangles).*

pond as the wind changed while the rest remained in the emergent-vegetation zone. Some of the lighter fractions of oil evaporated and as the remainder became more viscous, it began to adhere to the stems of the emergent plants (first noticed in mid-August). Only a small amount of oil penetrated into the sediment or into the wet litter. A lighter (rainbow-colored) scum surrounded the margin of the ponds and extended over much of the surface whenever the wind fell. Later, the lighter scum folded into brown floating fans whenever it struck a blade of grass. These fans were easily broken up by wave action and sunk. In September, the floating oil retarded freezing so that the water beneath the oil accumulations did not freeze until the ice was 2 cm thick on the rest of the pond.

The following spring (1971), these same areas of accumulation thawed more rapidly than the rest of the pond. Pond E did overflow during the runoff but little oil moved out of the polygon due to filtering by the snowpack and by the emergent plants. A few small clumps of plant litter soaked with oil were found some 20 m from the polygon. Through late June and early July, 1971, some floating oil was still visible (Figure 9-1) and the oil odor was evident. By mid-July, the thin film of oil surrounding the heavy accumulation along the west side had changed from a typical oil slick to a thin brown scum. At the same time, the thick accumulations began to sink, and became attached to the plant litter in the *Carex* bed.

A rough determination of the quantity of oil remaining in July 1971 revealed that at least half of the oil was still present. This was measured from aerial and ground observations of the area covered by the heavy accumulation of oil, the oil slick, and the light scum. Samples were then taken 0.5 m to either side of the division between the light and the heavy accumulation to obtain an average weight of oil for each area. Approximately 150 m^2 of the total area was covered with oil weighing greater than 2 kg m^{-2} and about 190 m^2 with oil weighing less than this. These values included the oil attached to the vascular plants and litter. This attached oil made collection and extraction of the oil very difficult so there may well be a large error associated with this estimate. Certainly a lot of the oil was still present nearly 1 year after the spill, for a minimum

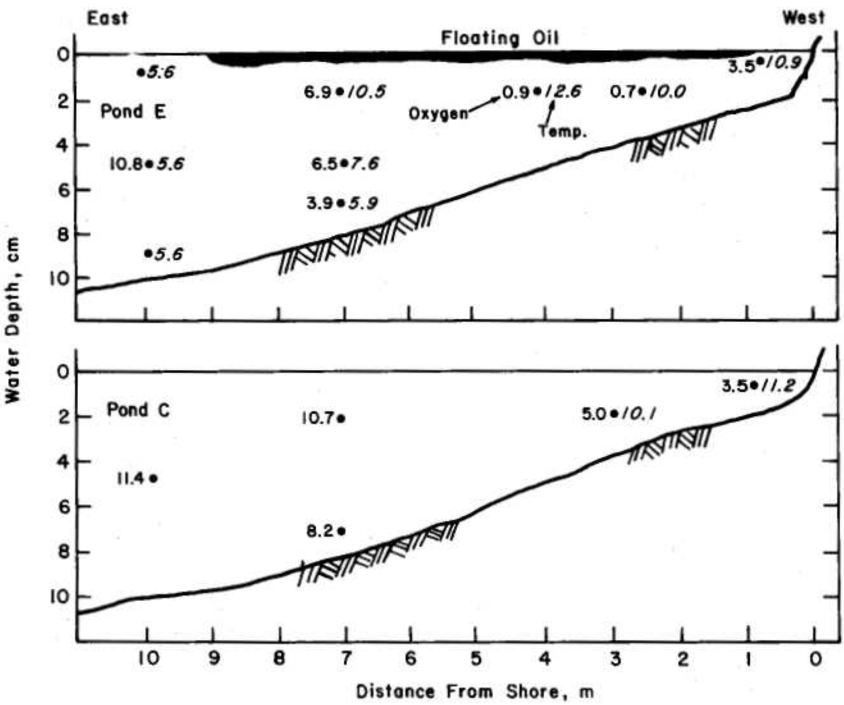

FIGURE 9-2. *Temperature (°C) and oxygen concentrations (mg O_2 liter^{-1}) in Ponds E and C, 23 July 1970.*

estimate of the quantity is 395 kg remaining of the 680 kg added (this is $150 \times 2 + 190 \times 0.5$).

During the remainder of 1971 and in later years, the location and general appearance of the oil did not change and there was no further effect on the timing of the freeze and melt. Occasional oil slicks and small patches of floating oil were seen in 1972 and 1973; and in June, 1975, oil was visible in the *Carex* beds on the west side of the pond as a low ridge several centimeters high in the sediments. Although the surface of the ridge was covered with a brown scum and organic detritus, any mechanical disturbance caused a renewed oil slick to well up from the ridge.

Spill on Pond Omega, 1975

The experimental spill in 1975 was made on Pond Omega, a 260 m^2-pond located several hundred meters from Pond B (see Miller et al. 1978a for exact location). The 0.24 liter m^{-2} dose on 10 July was about one-tenth the amount added to Pond E. The initial movement of the oil slick was controlled by the direction of the wind and within 24 hours after the spill, the oil had collected in the *Carex* beds around the pond. This was similar to the 1970 oil spill.

PHYSICAL AND CHEMICAL MEASUREMENTS

Temperature

There was practically no change in the physical regime of the ponds as a result of the oil spill. The water temperature of Pond E did increase by about 4°C for 3 days after the spill but returned to normal after the oil moved into the pond margin and after this was exactly the same as the temperature in Pond C. As long as the floating oil covered a large area, it is likely that there was a microstratification of temperature both horizontally and vertically. For example, 7 days after the spill the range of temperature beneath the oil was slightly higher than in a similar location in Pond C (Figure 9-2). Evaporation in Pond E was about the same as in the control Pond C as shown by their similar water levels (Figure 9-3). Finally, it was possible that the oil could change the heat budget of the sediment through a decrease in albedo or an increase in heat conduction. Again the similarity of the depth of thaw (Figure 9-3) to that in the control pond indicates that any changes were too slight to measure.

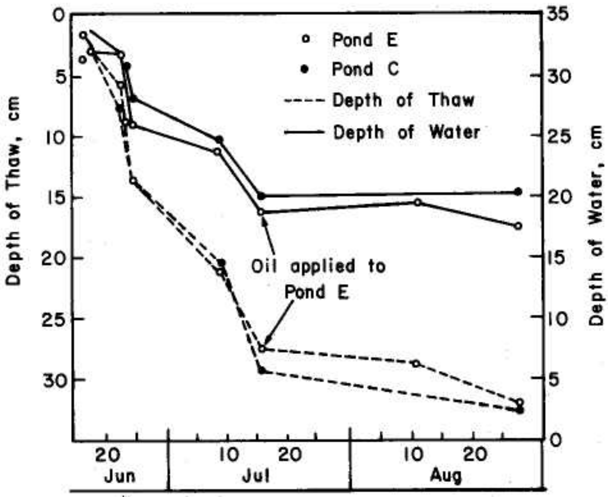

FIGURE 9-3. *Depth of thaw and of the water level in Ponds C and E, 1970.*

Oxygen

The only measured chemical change was in the oxygen concentration. There is normally a decrease in oxygen near the pond margins caused by the high rate of sediment respiration (Chapter 8), by the shallow water containing a small absolute amount of oxygen, and by the restricted circulation and mixing in the shelter of the emergent plants (Pond C in Figure 9-2). This decrease is intensified by the floating oil which not only drastically restricts water movement but also reduces the diffusion of oxygen through the water surface. These data are for a single date and there is every possibility that oxygen could be lowered even further on warm days or at night. If so, then the benthic animals may be affected.

Nutrients and Water Chemistry

There was no detectable change in the inorganic chemistry of the water after the oil spills in 1970 and 1975. We measured pH, alkalinity, Ca, Ha, K, Mg, Fe, and conductivity as well as nutrients (Table 9-1). In fact, the oil itself contains by weight 0.23% N and 0.82% S (Thompson et al. 1971) so the amounts added are large (20 mg N and 70 mg S liter^{-1} of Pond E) . Also, the organic matter added can change the systems as Brunskill et al. (1973) found anaerobic conditions and H_2S beneath the ice of Lake 4 (Mackenzie Delta). However, in Ponds E and Omega the strong reducing conditions did not develop and evidently the N remains tied up in the heavier fractions (Ball 1962).

TABLE 9-1 *Nutrient Concentrations in Control Pond C and Before and After Whole Pond Spills on Pond E and Pond Omega*

Parameter-Pond/Year		1970 prespill	1970 postspill	1971	1972	1975 prespill		1975 postspill
Dissolved reactive phosphate	Pond C	0.066[2] (.042)	0.082[2] (.029)	0.071[2] (.04)	0.064[2] (.01)	0.24[3] (.13)		0.38[3] (.58)
(μg at. PO_4—P liter^{-1})	Pond E	0.052 (0.03)	0.076 (.048)	0.059 (.05)	0.082 (.04)		0.28 (.21)	
	Pond Omega					0.43 (.30)		0.43 (.62)
Ammonium (μg at. NH_3—N liter^{-1})	Pond C	2.9 (1.6)	1.4 (0.4)	2.6 (0.8)		2.4 (2.3)		2.7 (2.0)
	Pond E	2.8 (1.2)	1.2 (0.3)	2.1 (1.9)			1.6 (0.8)	
	Pond Omega					2.8 (1.2)		2.2 (1.5)
Nitrate (μg at. NO_3—N liter^{-1})	Pond C	0.64 (.47)	0.03 (.05)	1.30 (1.1)		1.0 (1.1)		0.88 (.74)
	Pond E	0.57 (.58)	0.27 (0.8)	2.9 (2.6)			2.8 (3.8)	
	Pond Omega					2.6 (1.5)		1.0 (0.7)
Silicate (μg at. SiO_3—Si liter^{-1})	Pond C	4.2 (5.7)	9.4 (7.6)	2.3 (0.9)		3.4 (2.6)		1.5 (1.5)
	Pond E	3.5 (2.4)	8.6 (4.3)	2.9 (1.8)			8.9 (10.3)	
	Pond Omega					1.8 (1.0)		1.6 (0.7)

[1] Data expressed as yearly average (± standard deviation).
[2] 1970-72 DRP was extracted into isobutanol and read in 10 cm cells.
[3] Autoanalyzer, unextracted 1975.
Source: Miller et al (1978a).

The only chemical change noted was a detectable amount of nitrogen fixation in Pond E 3 years after the spill (Miller et al. 1978a). This fixation occurred in only one of three samples; the only other N fixation ever found in the ponds was in an experimental subpond of Pond B which was heavily fertilized with phosphorus. This may be bacterial fixation similar to that found in oiled experimental ponds along the Ottawa River (Shindler et al., 1975).

Some of the oil is lost by volatization and some lost by degradation; the exact amount lost is difficult to measure in the field but at least half of the oil disappeared in the first several months after a spill (details given in Miller et al. 1978b). For example, the initial loss rate of the volatile components of Prudhoe Bay crude oil was 10.3% day^{-1} at 5°C and 12.5%

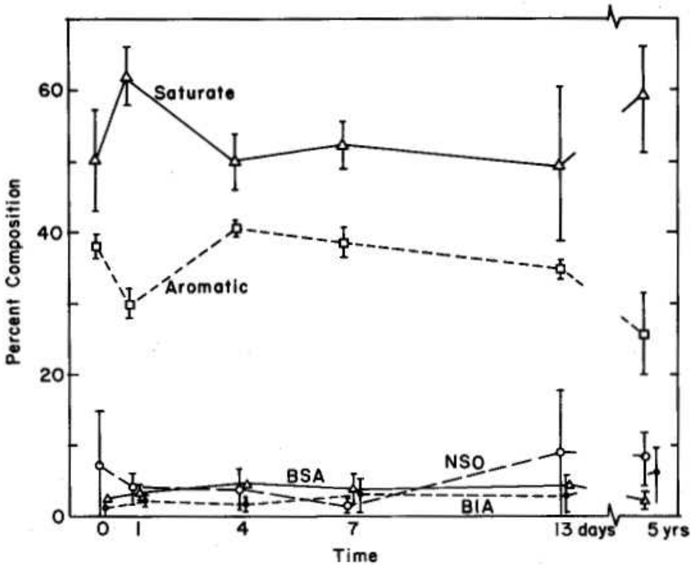

FIGURE 9-4. *Composition of Prudhoe Bay crude oil as a percentage of the total. The classes are benzene-soluble asphaltenes (BSA). benzene-insoluble asphaltenes (BIA), the saturate fraction, the aromatic fraction, and the nitrogen-, sulfur- or oxygen-containing fraction (NSO). (After Miller et al. 1978b.)*

day^{-1} at 25°C in a laboratory hood with moving air. The loss of all fractions of the oil was 18 to 19% in 36 days when the oil was placed in darkened Petri dishes in the field. When clear dishes were placed in the sun, 24% of the oil was lost, so this photo-decomposition could be important in the arctic. The loss was even higher when the oil was placed in plastic tubes containing natural water and sediment and incubated in the pond. After 45 days, 75% of the oil disappeared, which indicates that biotic processing was not too important. Somewhat slower rates were reported by Federle et al. (1979); after 1 year 58% of the oil remained in core tubes.

Despite the rapid loss of oil, the overall composition of the remaining oil does not change appreciably over time (Figure 9-4). The different classes were separated on solid-liquid chromatographic columns as described by Jobson et al. (1972) after separation from the water and sediment by Freon extraction. Even after 5 years in the pond, the composition of the oil is about the same. However, the saturate fraction (pentane soluble) did show some biological degradation, as Miller et al. (1978b) found that in the saturate fraction all of the hydrocarbons with fewer than 13 carbon atoms were lost within 13 days (measured by gas-liquid chromatography).

TABLE 9-2 *Average Bacterial Numbers and Turnover Times for Acetate in the Plankton and Benthic Respiration in Ponds B, C and E*

Pond	Treatment	Bacteria * (10^6 ml^{-1})	Benthic** respiration (dark) (mg C m^{-2} day^{-1})	Turnover* of acetate (hr)
B	Control	1.02	165	224
C	Control	1.90	113	129
E	Oil	1.18	51	110

* 1971
**1972

The loss rate of Prudhoe crude (10% in the first day) is much less than that measured by Snow and Rosenberg (1975a) who found that 34 to 43% of Canadian crude oil was lost in the first day. Our results are similar to those of Atlas (1975) who also worked with Prudhoe crude. Thus it is important to realize that oil from different sources will weather in different ways. Also, the amount of oil that will actually dissolve in water will differ for different sources. Federle et al. (1979) reported that Barrow pond water took up 15 mg oil liter^{-1} after 2 hours irrespective of the amounts of added oil. At 8°C, vigorous shaking resulted in 90 to 125 mg oil liter^{-1} in solution. The water soluble fraction is the most lethal part of the oil.

BIOLOGICAL MEASUREMENTS

Bacteria

One year after the oil spill in Pond E, the bacterial activity in the plankton was higher than that in control ponds but total numbers of bacteria were unchanged. Activity, as measured by the turnover time of ^{14}C-acetate (Wright and Hobbie 1966), was most rapid in Pond E (Table 9-2). Bacterial numbers were within the range of the controls. However, the direct count method enumerates all bacteria and we know that only a small fraction of these are active. These active forms could have increased in Pond E without any measurable change in direct counts.

Two years after the oil spill, the sediment respiration (one date) was less than half that of the controls (Table 9-2).

Bergstein and Vestal (1978) used plate-count techniques to enumerate the types of bacteria in the water and sediment in oiled and unoiled portions of Pond Omega, 2 years after the spill. There were no differences in the numbers of bacteria that could grow on crude oil, nutrient agar, mineral salts agar, or hexadecane between oiled and unoiled areas of the pond. If there was a toxic or stimulatory effect on the microflora after the spill, the microflora were back to the control-pond levels within 2 years.

TABLE 9-3 *Rates of Photosynthesis of the Benthic Algae on 16 August 1971 in Ponds E, C and J*

Pond	Treatment	mg C m^{-2} hr^{-1}	mg C m^{-2} day^{-1}
E	Oil	5	60
C	Control	13	160
J	Control	11	130

Source: D. Stanley (personal communication).

The general results from spills in lakes in arctic Alaska are similar to the pond results. For example, Jordan et al. (1978) found no significant increases in numbers (direct counts) in the water or sediment of a lake one year after the addition of oil (0.25 liters m^{-2} or 0.18 ml $liter^{-1}$). They also found that glucose uptake rates were unaffected by the oil but that the uptake of hexadecane and napthalene increased drastically over controls (but only after 110 hours of incubation). Another study by Horowitz et al. (1978) measured high numbers of hydrocarbon-utilizing organisms in the sediments of a lake near Barrow 7 years after a large gasoline spill. From these and other studies it appears that large numbers of hydrocarbon-utilizing microbes are present only when there are continual additions of oil or gasoline.

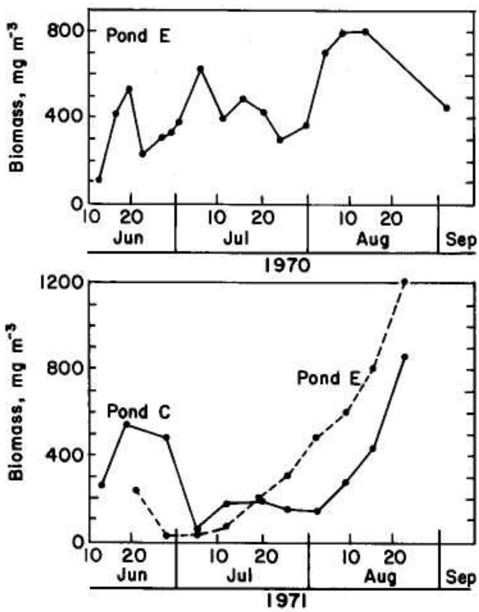

FIGURE 9-5. *Biomass of phytoplankton algae (mg wet weight m^{-3}) in Ponds E and C.*

Algae

One year after the spill on Pond E, the photosynthesis of benthic algae was reduced by more than 50% over the controls (Table 9-3). Only a single measurement was made, however.

The phytoplankton algae were studied in great detail in the oil experiment ponds. The results are clear; there was some increase in primary production and a change in species. However the causes are difficult to separate into direct toxicity effects and indirect effects due to the killing of zooplankton. This death of zooplankton will be documented later; they are extremely sensitive to oil and were eliminated from Pond E.

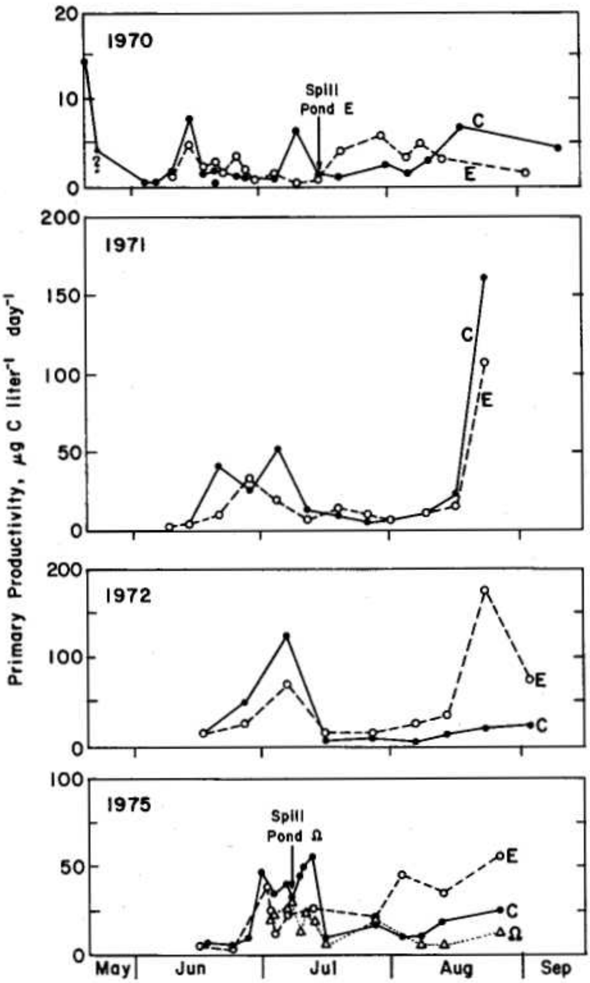

FIGURE 9-6. *Primary productivity in Ponds E, Ω and C. (After Miller et al. 1978a.)*

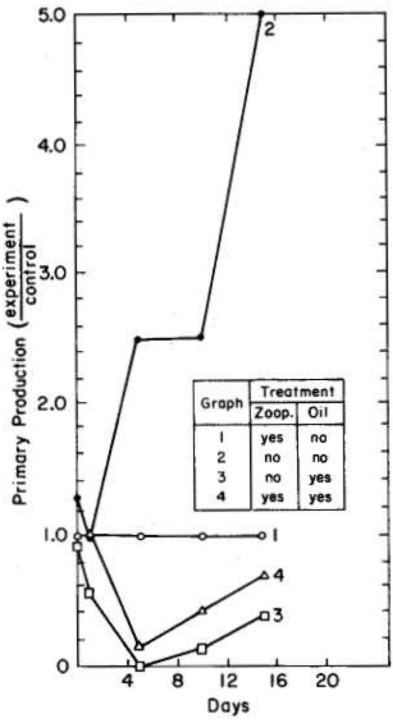

FIGURE 9-7. *Primary production in subponds after various treatments. (After Federle et al. 1979.)*

The quantity of phytoplankton, measured by direct counting with an inverted microscope, changed only a little as a result of the oil spill in Pond E on 16 July 1970 (Figure 9-5). Within 3 weeks of the spill, the amount of algae did double but a similar pattern was seen the following summer. This may be an advancement of the late summer bloom that had been released by removal of the zooplankton. A similar increase, measured as particulate carbon, occurred after the oil addition in the Mackenzie Delta lakes (Snow and Rosenberg 1975b).

The long-term primary productivity of the phytoplankton was not changed appreciably by the oil spills (Figure 9-6). There is enough variability from pond to pond and year to year that the differences between Pond E and Pond C (the control) cannot be attributed to the oil. However, the productivity of Pond E certainly was not lessened by the oil except during the first summer. The same effect, a temporary reduction in primary production, was seen after the 1975 oil spill in Pond Omega (Figure 9-6).

The reduction in primary productivity is directly proportional to the amount of oil added. Federle et al. (1979) found that when various quantities of oil were shaken with Pond C water, the short-term productivity was reduced by 50% (by 15 μl oil liter^{-1}) and stopped completely by 30 μl. Oil layered on top of experimental vessels and not shaken was only half as toxic. Thus, the water-soluble fraction of the oil is inhibitory to the algae.

The inhibition lasts at least several weeks (Figure 9-7) but the algae begin to recover after one week. This inhibition and recovery has also been

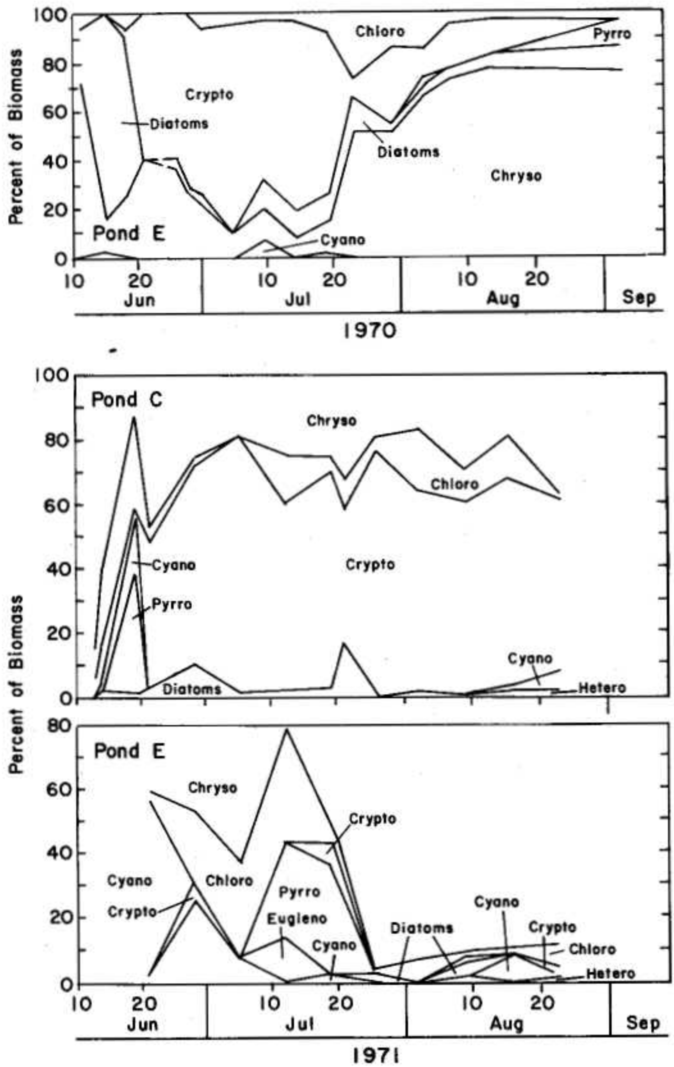

FIGURE 9-8. *Groups of phytoplankton as a percentage of the total wet weight in Ponds C and E.*

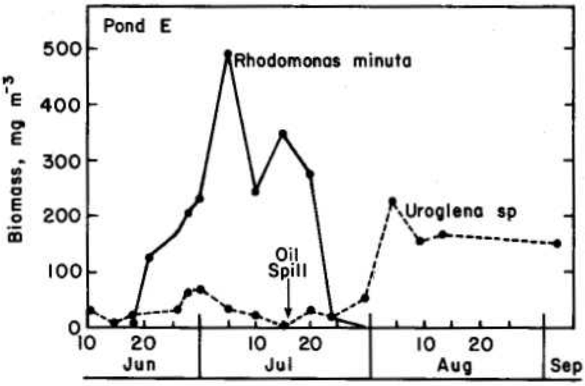

FIGURE 9-9. *Biomass (mg wet weight m^{-3}) of* Uroglena *sp. and* Rhodomonas minuta *in Pond E, 1970.*

found in *Chlamydomonas* cultures (Soto et al. 1975) and was caused by volatile fractions of the oil.

The most dramatic effect of the oil experiment in the subponds (Figure 9-7) was the replacement of the cryptomonad species of algae by chrysophytes (Federle et al. 1979). The same replacement of species occurred in Pond E in 1970 and 1971 (Figure 9-8) and in Pond Omega in 1975 (Miller et al. 1978a). In all the unaltered ponds we studied, the usual seasonal progression of forms was an early chrysophyte domination followed by a cryptophyte peak; a typical pattern is given for Pond C, 1971, in Figure 9-8. One of the obvious changes is a complete replacement of the small flagellate *Rhodomonas minuta* by *Uroglena* (Figure 9-9). This replacement took place in Pond E in 1970 and the *Rhodomonas* did not return to this pond until 1976, the same year that *Daphnia* and fairyshrimp returned in any numbers (Federle et al. 1979). The same replacement occurred in Pond Omega in 1975 (Miller et al. 1978b) and in the oiled experimental subponds (Figure 9-7). Similarly, Barsdate et al. (1973) noted decreased densities of cryptophytes in ponds at the natural oil seeps at Cape Simpson.

It is likely that the *Rhodomonas minuta* are eliminated because the zooplankton are killed rather than because of special sensitivity to oil. This species, a worldwide planktonic form, has never been cultured so we could not test it in the laboratory. We did run experiments in which the only treatment was removal of the zooplankton and concluded that this removal was enough to eliminate the *Rhodomonas* (Figure 9-7, treatment 2). Other workers have also found that zooplankton control the species composition of the phytoplankton (Porter 1973, Weers and Zaret 1975) but the mechanism of this interaction in the arctic ponds remains unknown. It is possible that the grazing pressure and the zooplankton's enhancement of the nutrient cycling rate control the competition among the various algal species.

In other experiments with oil in the Arctic, green and blue-green algae become abundant. For example, Hanna et al. (1975) and Snow and Scott (1975) report that *Oscillatoria* increased after oil spills and some of our experimental subponds followed the same pattern (Federle et al. 1979). This change did not occur in the whole-pond experiments we performed but did occur when experiments were run in subponds without sediment. It is likely that the phosphorus in the natural ponds is kept low and relatively unavailable because of adsorption by the sediment; in lakes and in experimental vessels without sediment the phosphorus becomes more available because of the elimination of zooplankton.

Rooted Plants

No damage to the vascular plants, especially the dominant *Carex aquatilis*, was observed in the ponds during 1970, but growth was affected during following years. Immediately after the spill much of the oil became attached to the stems of this sedge along the shore of the pond. As long as the oil touched only the stem there was no damage; some damage did occur when the oil contacted leaves. In the same manner the new leaves of *Carex* that appeared the next spring (1971) were killed in the area of the pond where they had to actually push through the floating layer of oil. This mechanical effect, therefore, could have been the cause of the low biomass of *Carex* in the areas of heavy oil accumulation (Table 9-4). The area covered with a light accumulation of oil had a lowered *Carex* biomass in 1971 but was back to normal in 1972. There was no evident effect on the rooted plants of the 10-fold smaller spill in 1975 in Pond Omega.

TABLE 9-4 *The Above-water Live Biomass of* Carex aquatilis *in Ponds E and C in 1971 and 1972**

Treatment	8 July 1971	17 July 1972
Heavy oil		
A (north transect, Pond E)**	3 (15)	6 (8)
Light oil		
B (south transect, Pond E)**	18 (9)	34 (8)
Control		
(Pond C transect)**	30 (8)	27 (5)

* Data are expressed in g dry wt m^{-2}; (n) = number of samples.

**Location of transects given in Figure 9-1.

TABLE 9-5 *Sequence of Disappearance of Zooplankton Species from Pond Omega Following the Experimental Oil Spill on 9 July 1975**

Species Observed	Observed presence after spill 7/10	7/11	7/12	7/14	7/16	7/18	7/21	7/23	7/29
Fairyshrimp (both species)	X	O	O	O	O	O	O	O	O
Daphnia middendorffiana	X	X	X	O	O	O	O	O	O
Heterocope septentrionalis	X	X	X	X	X	O	O	O	O
Cyclops spp.	X	X	X	X	X	X	X	X	X

*An "X" indicates that a representative of that species or group of species was found alive on that day. An "O" indicates that no individual of that species or group was found alive on that day.
Source: O'Brien 1978.

TABLE 9-6 *Numbers per Liter of Four Groups of Crustaceans in Ponds C and E June through August 1971*

Pond	Jun 14	Jun 21	Jun 28	Jul 5	Jul 12	Jul 19	Jul 26	Aug 2	Aug 16
Cyclops vernalis									
E	2.3	1.5	1.3	1.6	0.0	0.5	0.2	0.1	0.2
C	0.8	6.7	4.6	4.0	2.3	2.9	1.6	0.6	1.0
Daphnia middendorffiana									
E	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C	0.0	0.1	3.0	1.8	3.6	1.2	3.9	1.4	1.7
Fairyshrimps									
E	0.4	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
C	0.1	4.9	3.0	0.4	0.2	0.2	0.1	0.1	0.1
Calanoid Copepods									
E	0.6	3.4	0.2	0.2	0.1	0.0	0.0	0.0	0.1
C	0.0	93.5	32.4	10.0	10.1	5.4	4.4	2.7	2.7

Source: R. Stross (personal communication).

TABLE 9-7 *Zooplankton Production in Ponds B, C and E in 1971, 1972 and 1973*

Pond	Year 1971	1972	1973	$\overline{X}$
E (Oil)	0.05	0.08	0.04	0.06
B (Control)	0.53	1.07	0.44	0.68
C (Control)	1.40	1.19	0.82	1.14

Source: R. Stross (personal communication).

Zooplankton

The major effect of the oil spills on the ponds was the rapid kill of the zooplankton. O'Brien (1978) studied the animals during the Pond Omega experiment and showed the great sensitivity of the fairyshrimp and *Daphnia* and the lesser sensitivity of the copepods (Table 9-5). In pond E, which received 10 times more oil than Pond Omega, the copepods were eliminated in 1970 but a few were found in 1971 (Table 9-6). Some animals of each species were present at the beginning of every year, presumably due to transfer of animals during the spring flooding of the tundra. These were killed each year by the small amounts of the water-soluble fraction (WSF) released each year from the oil in and near the pond (Figure 9-1). *Daphnia* did not return to Pond E until 1977 (Butler and Keljo personal communication); therefore, production of the zooplankton community was extremely low even though some copepods were present (Table 9-7).

The differential sensitivity of the zooplankton to oil was confirmed in aquarium studies of O'Brien (1978). *Daphnia* were killed at all levels of added oil including 0.2 ml oil liter^{-1} or about 15% of the Pond Omega treatment level. Fairyshrimp were most sensitive, *Daphnia* next, *Heterocope* next, and *Cyclops* least, exactly duplicating the field results of Table 9-5. The toxicity could be eliminated by vigorous aeration.

The results of the pond studies are similar to those from other marine and freshwater studies. For example, Busdosh and Atlas (1977) found that 3.0 ml liter^{-1} of Prudhoe crude oil killed marine amphipods and that it was the WSF that was toxic. A tidepool copepod was killed by 1 ml diesel oil liter^{-1} within 3 days (Barnett and Kontogiannis 1975). Aeration of oil and water dispersions resulted in a loss of 80 to 90% of the WSF within 24 hours (Anderson et al. 1974). Because the aeration did eliminate the toxic effects of small amounts of oil, O'Brien (1978) suggests that aeration might be used in an actual spill.

Aquatic Insects

Insects from the ponds are not killed by oil in aquarium studies. Mozley (1978) added up to 8.4 ml liter^{-1} in 13-liter aquaria and found no change in survival of several kinds of chironomid larvae and eggs, of trichopteran larvae, and of plecopteran nymphs. Unfortunately, up to 50% of the animals in the controls of these experiments died during the 12-day test so that a low level of toxicity would have been missed.

Despite the lack of toxicity of oil in the laboratory, some insects and other invertebrates were eliminated or drastically reduced in numbers in the oiled ponds at Barrow (Mozley and Butler 1978). The *Agabus* (beetles), *Asynarchus* and *Micrasema* (caddisflies), *Nemoura* (stoneflies) and *Physa* (snails) were especially affected while *Libertia* (mites) remained present in all ponds. Most of these animals live only in the plant beds and

TABLE 9-8 *Two-year Mean Densities and Taxonomic Composition of Benthic Macroinvertebrates from Hand-core Samples in Barrow Thaw Ponds**

Measure	Pond J	Pond G	Pond Ω	Pond E
Mean density m^{-2}	26,800	5,380	7,810	14,700
Standard Error	4,800	570	800	3,800
%Chironomini	35.9	63.9	18.3	28.4
%Tanytarsini	51.1	30.0	64.0	9.9
%Tanypodinae	5.8	4.4	6.7	15.0
%Orthocladiinae	0.5	1.8	2.4	20.6
%Oligochaeta	6.8	0	7.9	25.9

*Standard errors are based on variation between mean densities for each sampling date.
Source: Mozley, 1978.

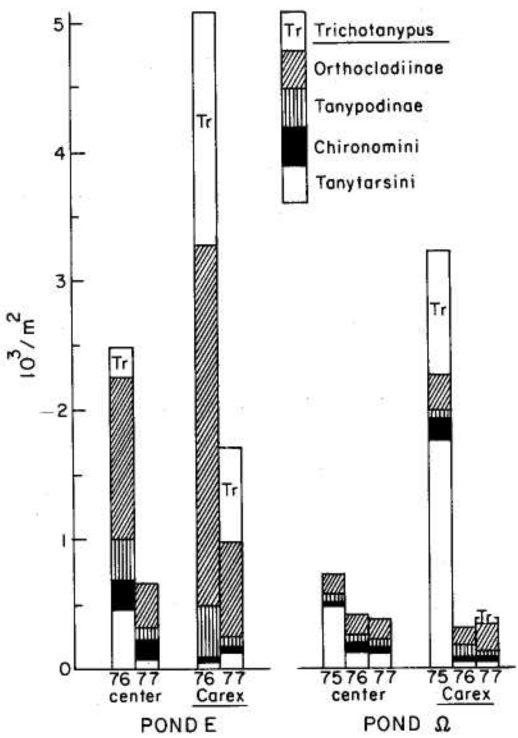

FIGURE 9-10. *Number of emerging chironomid adults per square meter by subfamily in the two ponds treated with oil. Trapping was continuous through the emergence season. (After Mozley and Butler 1978.)*

may have become trapped in the oil on the plant stems and in the floating oil. Snow and Rosenberg (1975a) reported similar entrapment of insects in the surface film of a Mackenzie Delta lake. At Barrow, recovery must take more than 6 years as many of the insects were still absent in Pond E in 1977.

The chironomid larvae were virtually unaffected by the oil spills. The numbers present in the sediments did vary a great deal from pond to pond but the highest and lowest numbers occurred in the control ponds J and G (Table 9-8). Emergence was affected by the oil, however, and the metamorphosis of *Tanytarsus* was strongly reduced after the spill in Pond Omega (Figure 9-10). This genus of filter feeders did not recover in Pond E either and was also strongly affected in Mackenzie Delta Lake 4 (Snow and Rosenberg 1975a).

These observations on the aquatic insects indicate that the oil-induced changes are on the species level and that such measures as secondary production and carbon flux are virtually unchanged. For example, the emerging cohort of *Chironomus* in 1977 presumably hatched in the year of the spill in Pond E and yet its numbers in Pond E were the same as in the control Pond J (Mozley and Butler 1978). These authors conclude that a light spill such as these reported here might best be treated by merely attempting to absorb floating oil onto inert materials and possibly by flooding the ponds to float oil away from the littoral plants.

SUMMARY

Crude oil from Prudhoe Bay was added to Pond E in 1970 (1.6 liter m^{-2}) and to Pond Omega in 1975 (0.24 liter m^{-2}). The wind moved the floating oil to the edge of the ponds and some oil floated for about a month. By the end of the summer all the oil was trapped along the pond edge and much had sunk. No oil left the pond during runoff the next spring but oil was still visible at the edge. After several years, at least half the oil was still present and was covered by debris and organic matter; it still welled up and created a scum when disturbed.

The only physical-chemical change caused by the oil was a slight decrease in the oxygen concentration of the shallow pond margins. This was likely the result of reduced diffusion and water movement. There was no change in the pH, alkalinity, or nutrient concentrations.

At least half of the oil was lost during the first year after the spill, mostly by volatilization and chemical degradation; there was also a small effect of biological degradation. In Pond E, for example, the oil remaining after five years had virtually the same chemical composition, but there was some loss of those hydrocarbon compounds with fewer than 13 carbon atoms (presumably from biological degradation).

The number of bacteria in the plankton was unaffected by the addition of oil but their activity increased during the first year. Two years after the spill in Pond Omega, there were no differences in the types and numbers of bacteria in the oiled and unoiled parts of the pond (plate count technique, nutrient and oil agar). Thus it appears that a single addition of crude oil briefly stimulated microbial activity but the microflora were back to control-pond levels within 2 years.

The effect of oil on benthic algae was only briefly studied; 1 year after the spill the photosynthesis in Pond E was 50% that of a control pond. In contrast, the phytoplankton algae were intensively studied and we found that the water-soluble fraction of the oil strongly reduced photosynthesis for several days. The amount of algae, however, did not change as a result of the spill and productivity reached normal levels within several months.

The added oil drastically changed the species composition of the planktonic algae in both the ponds and in experimental chambers. This change, a rapid replacement of the cryptophyte *Rhodomonas* by the chrysophyte *Uroglena,* continued for 6 years. It is likely that the *Rhodomonas* are eliminated because the zooplankton are killed; experimental removal of the zooplankton caused the same elimination. It is not known whether the algae responded to a release of grazing pressure or to a cessation of the zooplankton's recycling of nutrients.

No damage to the vascular plants was observed in the ponds during the first year, but growth of *Carex aquatilis* was reduced in later years. Much of this reduction was caused when new leaves encountered a barrier of floating oil.

In experiments in the laboratory, the fairyshrimps were most sensitive to oil, *Daphnia* were next, *Heterocope* next, and the *Cyclops* were least sensitive. This sequence duplicates the field results; all the *Daphnia* and fairyshrimps were killed immediately by the whole-pond treatments and did not return for 7 years. The less-sensitive copepods returned within a year.

In laboratory tests, aquatic insects and other invertebrates were not sensitive to oil. In the field, the spill had no major effect on the numbers and production of chironomids, but there were some minor effects on their emergence. One genus, *Tanytarsus,* was nearly eliminated from the ponds. Beetles, caddisflies, stoneflies, and snails were also drastically affected; most of these animals live only in the plant beds and may have become trapped in the oil on plant stems and in the floating oil. These insects were still absent in Pond E 6 years after the spill.

When the oil spills are relatively light, as in these experiments, then the best treatment would be to absorb the floating oil and perhaps to flood the marsh to float oil away from the littoral plants. The biota of ponds will recover within a few years with this simple treatment. More drastic clean-up measures will induce greater changes into the ecology of ponds.