

# EFFECTS OF CRUDE OILS AND THE OIL DISPERSANT COREXIT ON PRIMARY PRODUCTION OF ARCTIC MARINE PHYTOPLANKTON AND SEAWEED

STEPHEN I. C. HSIAO, DOUGLAS W. KITTLE† & MALCOLM G. FOY‡

*Arctic Biological Station, Environment Canada, Fisheries and Marine Service, PO Box 400,  
Ste. Anne de Bellevue, P.Q., Canada*

## ABSTRACT

*Effects of crude oil and Corexit on primary production of arctic marine phytoplankton were studied in situ. The production rate varied with types and concentrations of crude oil, method of preparation of oil-seawater mixtures, environmental conditions and species composition of each sample tested. In samples with the same species composition, inhibition of production generally increased with increasing oil concentration. The crude oil-Corexit mixtures were more toxic than crude oil or Corexit alone.*

*In situ primary production of the seaweeds, Laminaria saccharina (L.) Lamouroux and Phyllophora truncata (P.) Newroth et Taylor was significantly inhibited by all types and concentrations of oil tested.*

## INTRODUCTION

Because of offshore drilling and the transport of large quantities of oil, it is only a matter of time before significant quantities are spilled into the arctic marine environment creating potential hazards for the associated marine and estuarine floras. Toxic effects of oil on marine algae have been noted by many investigators (Clendenning, 1959, 1960; Schramm, 1972; Mommaerts-Billiet, 1973; Pulich *et al.*, 1974; Dunstan *et al.*, 1975; Lacaze & Villedon de Naide, 1976), but few studies have dealt with arctic marine phytoplankton and seaweed (Shiels *et al.*, 1973).

† Present address: National Museum of Natural Sciences, Botany Division, Ottawa, Ontario K1A 0M8, Canada.

‡ Present address: LGL Limited, Environmental Research Associates, Suite 414, 44 Eglinton Ave. West, Toronto, Ontario M4R 1A1, Canada.

After a spill, oil starts to dissipate at sea and is washed on and off the beaches by wind, waves and tidal current. This means that contamination varies continuously and it is impossible to determine accurately the amount of oil to which any one area is exposed. Spilled oils are frequently 'cleaned up' by means of spraying chemical dispersants such as Corexit and BP 1002 in order to minimise the damage to avian and intertidal marine life. The effects of these dispersants on quantity and quality of primary production may be as important as those of oil itself since marine phytoplankton and seaweed are the primary producers in the marine food chains.

The objective of this study was to determine the potential impact of oil and the oil dispersant Corexit on primary production of arctic marine phytoplankton and seaweed. This information may provide a greater awareness of potential indirect effects of oil pollution upon higher trophic levels and fish stocks in the marine environment.

#### MATERIALS AND METHODS

##### *Preparation of oil-seawater dispersions*

Two methods were used to prepare oil-seawater dispersions. (1) Ten and 4000 ppm of each of 4 types of crude oil (Atkinson Point, Norman Wells, Pembina and Venezuela) were added to the water sample containing natural populations of phytoplankton and Millipore prefiltered (0.45  $\mu\text{m}$ ) natural seawater in 300 ml BOD bottles, for phytoplankton and seaweed respectively. They were shaken by hand for 5 min. (2) Three concentrations (0, 50 and 2000 ppm) of 4 types of crude oil were mechanically mixed with Millipore prefiltered natural seawater as described by Percy & Mullin (1975). One hundred ml of each of these oil-seawater dispersions were mixed with 200 ml of seawater containing natural populations of phytoplankton, or with 200 ml of Millipore prefiltered natural seawater for seaweed experiments. The mean final oil concentrations to which the algae were exposed during the experimental period were estimated as shown in Table 1.

TABLE 1

<i>Crude oil</i>	<i>Oil added (ppm)</i>	<i>Final oil concentration in seawater dispersion (ppm)</i>
Atkinson Point (AP)	0	Control
	50	4
	2000	147
Norman Wells (NW)	0	Control
	50	3
	2000	43
Pembina (P)	0	Control
	50	7
	2000	47
Venezuela (V)	0	Control
	50	4
	2000	83

#### *Preparation of Corexit-treated seawater and oil-Corexit mixtures*

Mixtures containing 10 ppm Corexit alone or in combination with 10 ppm of each of the crude oils (Atkinson Point, Norman Wells, Pembina and Venezuela) were prepared in 300 ml BOD bottles using water containing natural populations of phytoplankton.

#### *Preparation of algal materials*

Water samples containing natural populations of phytoplankton were collected with a van Dorn sampler from different depths at various locations in the Beaufort Sea and Eskimo Lakes (Fig. 1), and 200 ml were used for *in situ* toxicity experiments. One hundred and twenty-five ml of each sample was preserved with 5 ml of 40% formaldehyde neutralised with calcium carbonate. Later, the preserved phytoplankton samples were identified and enumerated as described by Foy & Hsiao (1976) for species composition and abundance.

The sporophytes of *Laminaria saccharina* (L.) Lamouroux and *Phyllophora truncata* (P.) Newroth et Taylor were respectively collected from station 560 in Liverpool Bay and station 561 in the Eskimo Lakes (Fig. 1), and were transferred to the field laboratory of the Arctic Biological Station in a seawater bath. Prior to experimentation, thalli were floated at 2 m near the field camp (69°25'N, 131°16'W). Both *Laminaria* and *Phyllophora* blades were cleaned with kimwipes to remove epiphytes. Then discs of *Laminaria* blades were cut from meristematic tissues with a cork borer (12.5 mm diam.). *Phyllophora* blades were cut with a razor blade at the end of the first dichotomy with a length of about 2.0 cm. Eight discs of *Laminaria* or 4 pieces of *Phyllophora* were tested with the oils in 300 ml BOD light and dark bottles filled from a single batch of Millipore prefiltered natural seawater.

#### *Carbon-14 technique*

The method for carbon-14 uptake experiments generally followed procedures described by Strickland & Parsons (1972) for phytoplankton, and by Lobban (1974) for seaweed. One ml of 10  $\mu$ Ci of  $\text{NaH}^{14}\text{CO}_3$  (NEN Canada) was added to each 300 ml BOD light and dark bottle with a phytoplankton sample or seaweed blades of known total carbonate content of seawater. Duplicate bottles were set up, well stoppered and suspended on a line which was anchored by two lead weights and buoyed vertically by a float. The bottles were placed at predetermined sampling depths or in a seawater-cooled water bath on deck for 4 to 8 h under natural sunlight and temperature. Light intensity and temperature were determined at one or two intervals during the incubation. Other environmental parameters such as salinity, pH, nutrients (nitrate, phosphate, silicate), phytoplankton density, chlorophyll *a*, and species composition were also determined. After incubations, photosynthesis of phytoplankton and seaweed was halted by adding 1 ml of 40% formaldehyde neutralised with calcium carbonate.

The labelled phytoplankton samples were filtered through Millipore HA type

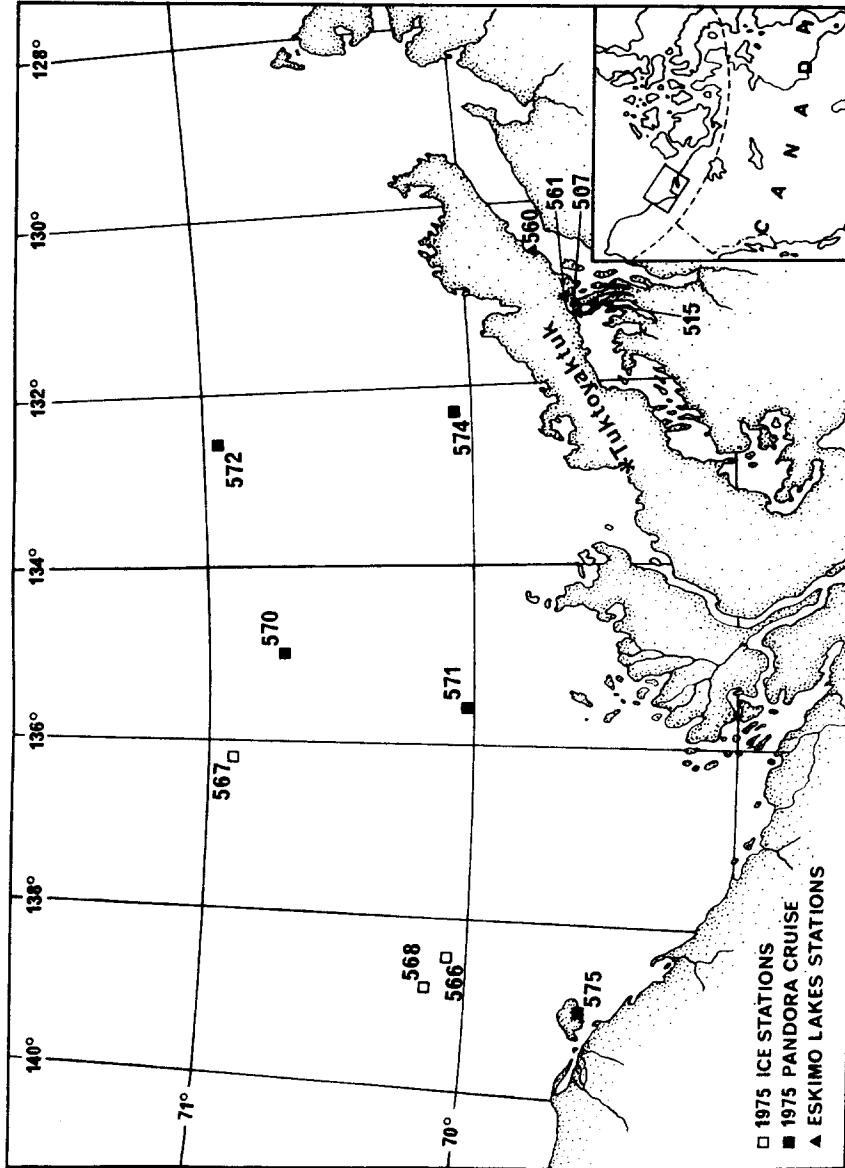


Fig. 1. Beaufort Sea and Eskimo Lakes stations.

47 mm diameter filters under a vacuum of 380 mm Hg, and rinsed with 5 ml of 0.001 N HCl made with prefiltered natural seawater to remove inorganic radioactive bicarbonate solution retained on the filter. The wet filters were transferred to glass scintillation vials containing 15 ml of liquid scintillation cocktail, Aquasol-2, well agitated and then counted for 10 min with a Nuclear Chicago Isocap 300 liquid scintillation system.

All seaweed blades were removed from the bottles, then rinsed with 0.001 N HCl made with Millipore prefiltered natural seawater blotted dry with Whatman filter paper, and then placed on aluminium trays to dry overnight in an oven at a temperature of 70° to 80°C. The dried *Laminaria* and *Phyllophora* thalli were placed in tightly capped vials and stored in a desiccator in a freezer until radioassay. Using a metal spatula, the dried seaweeds were crushed to very fine pieces to facilitate weighing out approximately 20 mg subsamples. To make algal tissue soluble for scintillation counting, Lobban's method (1974) was followed.

All counts were corrected for efficiency by the internal standardisation method of Schindler (1966). The counting efficiency and primary production rate of phytoplankton were calculated as detailed in Hsiao *et al.* (1977). The production rate of seaweed was calculated as follows:

$$P = \frac{(R_L - R_D) \times C_1 \times 1.05}{R \times T}$$

where  $P$  = photosynthetic production, mg C/g/h;  $R$  = absolute activity (dpm) of carbon-14 added to sample;  $R_L$  = uptake carbon-14 in dpm per g dried seaweed from light bottle;  $R_D$  = uptake carbon-14 in dpm per g dried seaweed from dark bottle;  $C_1$  = total carbonate content of seawater in the BOD bottle as mg C; 1.05 = isotope correction factor and  $T$  = time of incubation in hours.

#### RESULTS AND DISCUSSION

In experiments performed *in situ* in the Beaufort Sea the effects of the four oils at a concentration of 10 ppm on primary production of natural populations of phytoplankton ranged from stimulation to inhibition (Fig. 2). A similar variability in response occurred in the Eskimo Lakes at station 507 (Fig. 3), but at station 515 primary production was consistently inhibited (Fig. 4). The results showed clearly that photosynthetic production varied with oil types (Figs. 2 to 4), phytoplankton density, species composition and environmental conditions (Tables 2 to 4). Hsiao (1976) using laboratory cultures under environmentally controlled conditions demonstrated that carbon-14 uptake of 4 species of arctic marine phytoplankton was influenced to varying degrees by the different oils, and suggested that the effects on a given phytoplankton population depend on the species composition of that population. With the same species composition of natural populations of

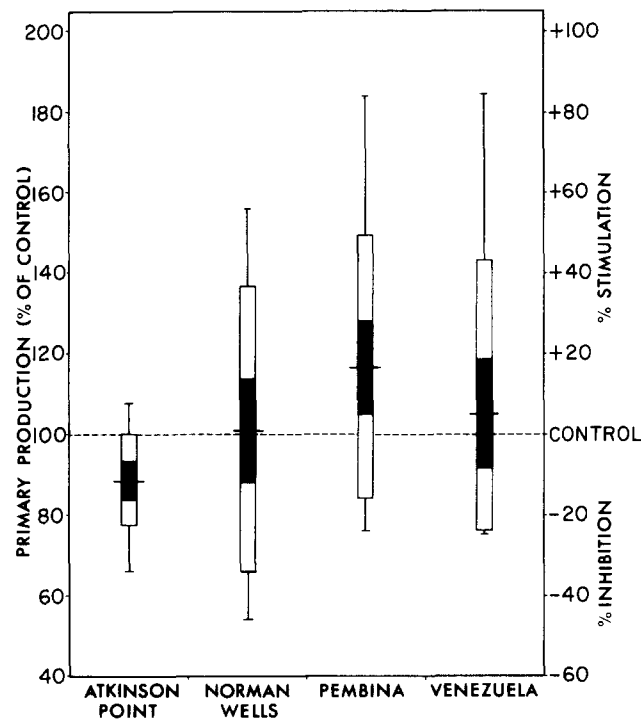


Fig. 2. Effect of crude oils (10 ppm) on the *in situ* gross primary production of phytoplankton at 1 m at various Beaufort Sea stations. Horizontal line on each bar indicates mean, black portion of bar indicates standard error of the mean, open portion of bar indicates standard deviation and vertical line indicates range of observations.

phytoplankton at stations 515 and 507, primary production was inhibited more in samples exposed to higher concentrations (43 to 147 ppm) of oil than by lower concentrations (3 to 4 ppm) (Fig. 5). Gordon & Prouse (1973) showed that Venezuela crude inhibited photosynthesis of natural populations of phytoplankton from Bedford Basin and the northwest Atlantic Ocean between Halifax and Bermuda; but that very low concentrations of the oil stimulated photosynthesis. The mechanism of stimulation of algal photosynthesis at low concentration is unknown. It is perhaps due to the presence of growth-regulating compounds (Gordon & Prouse, 1973) and/or trace metals in the crude oils (Hufford, 1971) acting as micronutrients. Baker (1971) showed that the toxicity of different crude oils was partly dependent on the content of aromatics. Shiels *et al.* (1973) reported that oil toxicity to phytoplankton varied with temperature, and appeared to be most acute at high light intensity. Recently, Lacaze & Villedon de Naide (1976) confirmed that high light intensity enhanced crude oil toxicity and inhibited primary productivity of *Phaeodactylum tricornutum*. Because of different environmental

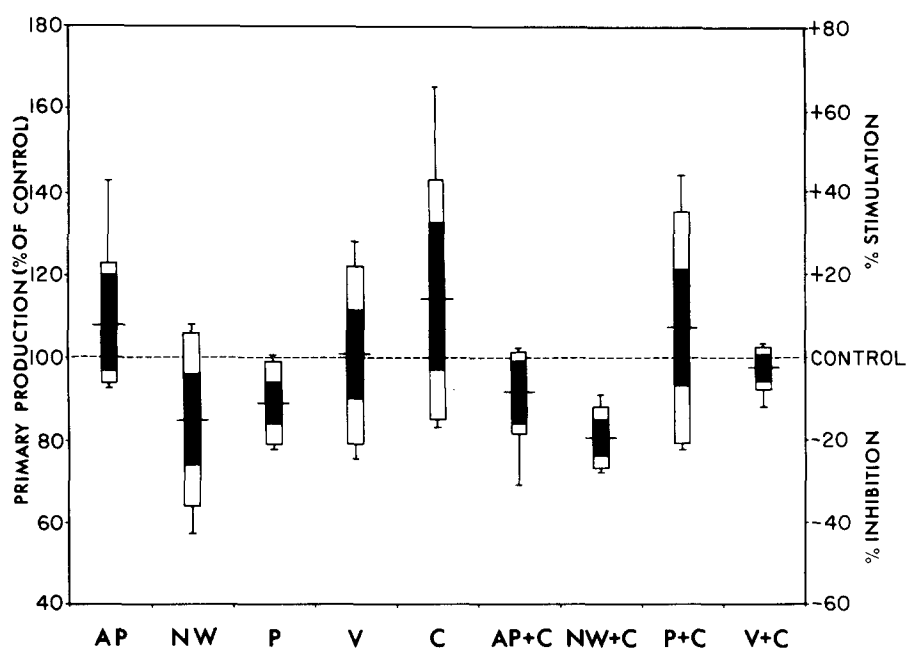


Fig. 3. Effects of crude oils, Corexit and oil-Corexit mixtures (10 ppm each) on the primary production of Eskimo Lakes phytoplankton at 1 m at station 507. See Fig. 2 for explanation of symbols.

conditions, it is difficult to compare our results directly with the studies mentioned above.

Corexit alone at a concentration of 10 ppm generally stimulated phytoplankton photosynthesis (Fig. 3). This could be a result of an increase in carbon dioxide from mineralisation of the dispersant (Mulkins-Phillips & Stewart, 1974). The crude oil-Corexit mixtures (1:1 ratio) caused less stimulation or more inhibition of photosynthesis than did the oils alone (Fig. 3). Perhaps during emulsification, more of the relatively water soluble low boiling and aromatic compounds were released from the oils, thus producing a synergistic increase in the toxicity of the oils.

The photosynthetic capacities of two macrophytes, *Laminaria saccharina* and *Phyllophora truncata*, were consistently inhibited by the presence of all four oils tested. The effects were most pronounced in *Laminaria* (Figs. 6 and 7). Both species were most sensitive to Venezuela crude. Shiels *et al.* (1973) showed that photosynthetic inhibition occurred in *Laminaria saccharina*, *Cladophora stimpsonii* and *Ulva fenestrata* at 7 ppm of Prudhoe Bay crude oil, whereas other species were not significantly affected at this concentration. Clendenning (1959) found that the photosynthetic capacity of *Macrocystis pyrifera* was reduced by 36% after 24 h of exposure to 1% of diesel oil, but it was completely inhibited after 3 days' exposure. He attributed the toxic effects of oil on this alga partly to its action on fatty



TABLE 3  
 PHYSICAL, CHEMICAL AND BIOLOGICAL PARAMETERS AT 1 m AT STATION 515 IN THE ESKIMO LAKES DURING *in situ* EXPERIMENTS IN 1975

Date	15 June	26 June	2 July	9 July	15 July	21 July
Temperature (°C)	0.73	2.95	4.19	10.72	10.85	6.1
Salinity (‰)	8.95	13.26	—	10.60	10.59	13.25
Light intensity, (lux)						
Range	700-1316	504-2030	1148-2450	1162-2240	1050-2170	434-602
Mean	998	1277	2064	1844	1654	504
pH	8.33	7.79	7.74	7.83	7.82	7.58
Nitrate (µg-at/litre)	0.3	1.8	0.9	0.1	0.2	0.7
Phosphate (µg-at/litre)	0.07	0.30	0.30	0	0	0
Silicate (µg-at/litre)	2.9	6.1	3.8	3.8	4.2	4.8
Phytoplankton density ( $\times 10^3$ cells/litre)	784	392	73	172	194	64
Chlorophyll <i>a</i> (mg/m <sup>3</sup> )	1.39	0.76	0.64	0.46	0.58	0.85
Primary productivity (mg C/m <sup>2</sup> /h)	1.16	1.25	2.25	2.26	2.55	1.87
"Dominant phytoplankton	<i>Chaetoceros</i> <i>ceratosporum</i> <i>Goniaulax</i> <i>catenata</i> Unidentified pigmented flagellates	—	<i>Chaetoceros</i> <i>ceratosporum</i>	Unidentified pigmented flagellates	<i>Chaetoceros</i> spp. Unidentified pigmented flagellates	Unidentified pigmented flagellates

"Cell numbers were more than  $10^4$  cells/litre. The actual cell numbers and species composition are reported in Hsiao (1976).

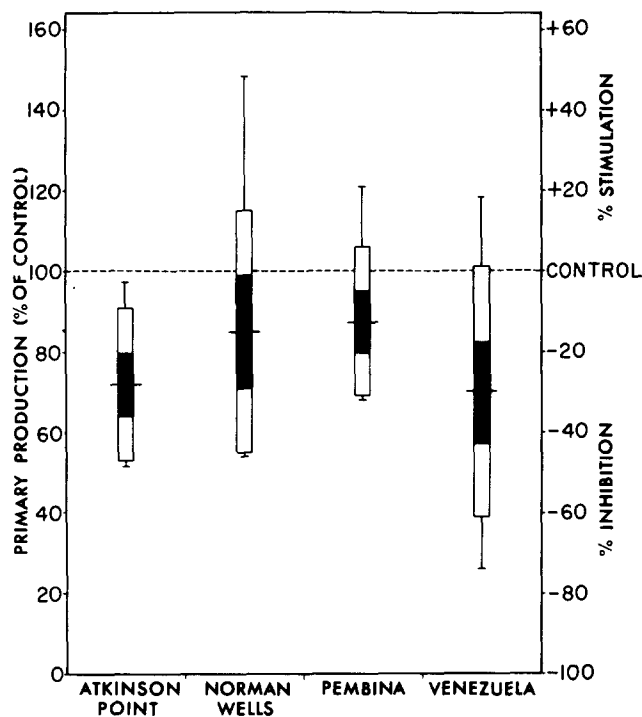


Fig. 4. Effect of crude oils (10 ppm) on the *in situ* gross primary production of phytoplankton at 1 m at station 515 in the Eskimo Lakes. See Fig. 2 for explanation of symbols.

TABLE 4  
PHYSICAL, CHEMICAL AND BIOLOGICAL PARAMETERS AT 1 m AT STATION 507 IN THE ESKIMO LAKES DURING *in situ* EXPERIMENTS IN 1975

	13 August	14 August	15 August
Temperature (°C)	7.5	7.5	8.0
Salinity (‰)	13.33	13.34	13.34
Light intensity, (lux)			
Range	882-1428	868-1400	1148-1820
Mean	1170	1131	1489
pH	7.51	7.56	7.77
Nitrate (μg-at/litre)		0.28	0.32
Phosphate (μg-at/litre)	0	0	0.11
Silicate (μg-at/litre)	2.83	5.29	5.29
Phytoplankton density (× 10 <sup>3</sup> cells/litre)	48	55	54
Primary productivity (mg C/m <sup>3</sup> /h)	2.31	2.09	2.21
<sup>a</sup> Dominant phytoplankton	Unidentified pigmented flagellates	Unidentified pigmented flagellates	Unidentified pigmented flagellates

<sup>a</sup>Cell numbers were more than 10<sup>4</sup> cells/litre. The actual cell numbers and species composition are reported in Hsiao (1976).

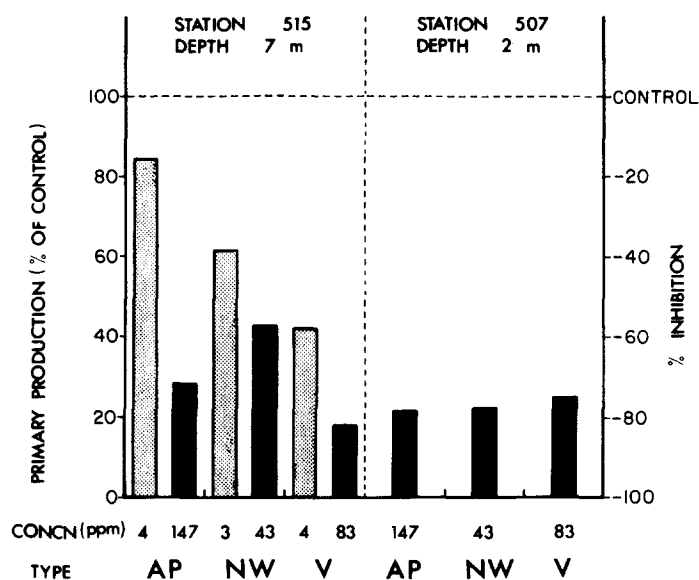


Fig. 5. Effect of concentrations of crude oil-seawater dispersion on primary production of phytoplankton in the Eskimo Lakes during July 1974.

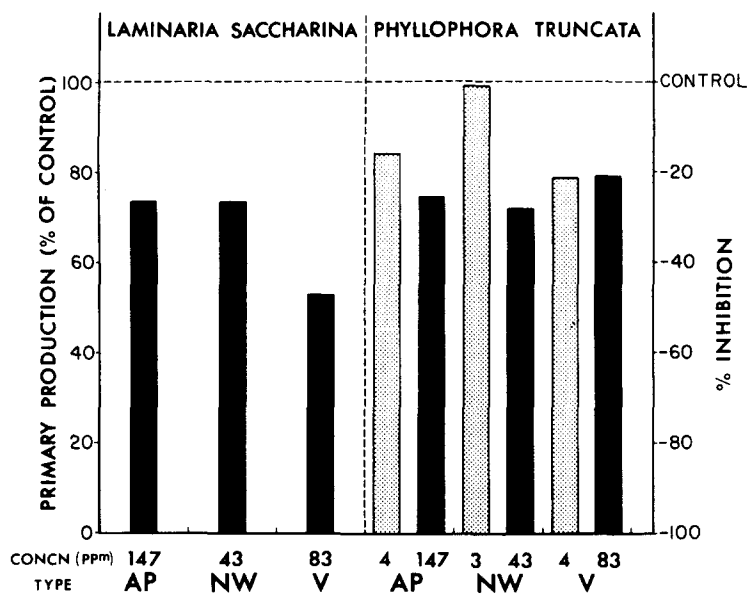


Fig. 6. Effects of concentrations of crude oil-seawater dispersion on primary production of *Laminaria saccharina* and *Phyllophora truncata* at Eskimo Lakes station 507 at 2 m during August 1974.

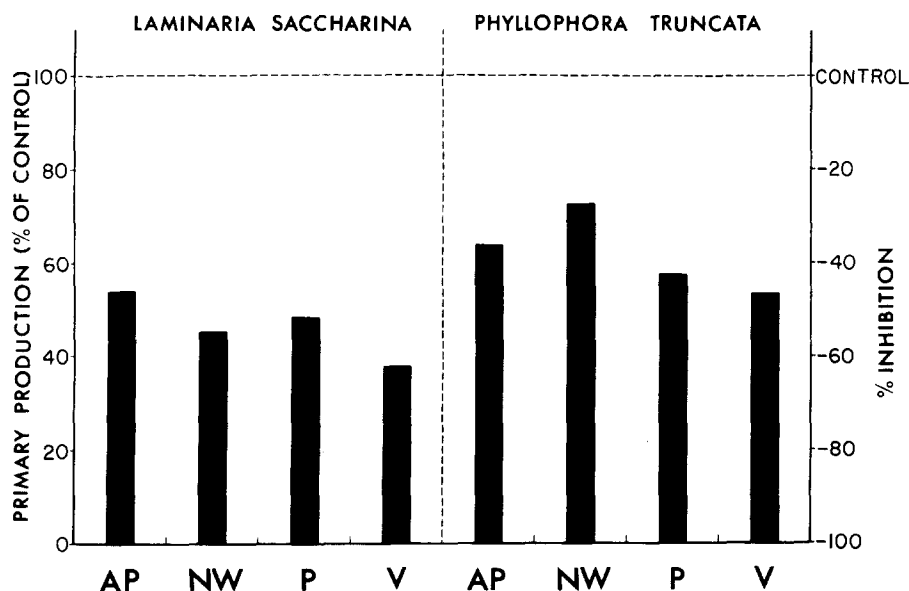


Fig. 7. Effects of crude oil (4000 ppm) on primary production of *Laminaria saccharina* and *Phyllophora truncata* at Eskimo Lakes station 507 at 2m during July 1975.

constituents of the cytoplasmic membrane and partly to its content of toxic cresol and phenol.

It is clear that crude oils can reduce primary production, depending on type and concentration of oil, the method of preparation of oil-seawater mixtures, the duration of exposure, the environmental conditions and the algal species. Crude oils possibly inhibit photosynthesis by impairing cellular permeability (Baker, 1970), chlorophyll destruction (Dallyn, 1953), disruption of chloroplast membranes, accumulation of end-products (Baker, 1970) and blocking gas exchange (Schramm, 1972). Applying the dispersant Corexit to spilled oil results in a mixture that is far more toxic than the oil itself.

#### ACKNOWLEDGEMENT

We thank Dr J. A. Percy and Dr P. A. Bowler for helpful comments on the manuscript.

#### REFERENCES

- BAKER, J. M. (1970). The effects of oils on plants. *Environ. Pollut.*, 1, 27-44.

- BAKER, J. M. (1971). The effects of oils on plant physiology. In *The ecological effects of oil pollution on littoral communities*, ed. by E. B. Cowell, 88–101. London, Petroleum Institute.
- CLENDENNING, K. A. (1959). The effects of water discharges on kelp: fuel oil. *Univ. Calif., Inst. Mar. Resources*, **59-4**, 13 p.
- CLENDENNING, K. A. (1960). The effects of waste discharges on kelp: phenol and cresols. *Univ. Calif., Inst. Mar. Resources*, **60**, 45–7.
- DALLYN, S. (1953). Herbicidal action of oils. *Mem. Cornell Univ. agric. Exp. Stn.*, **316**, 43 p.
- DUNSTAN, W. M., ATKINSON, L. P. & NATOLI, J. (1975). Stimulation and inhibition of phytoplankton growth by low molecular weight hydrocarbons. *Mar. Biol.*, **31**, 305–10.
- FOY, M. G. & HSIAO, S. I. C. (1976). Phytoplankton data from the Beaufort Sea, 1973 to 1975. *Environ. Can. Fish. Mar. Serv. Res. Dev. Tech. Rep.*, **617**, 44 p.
- GORDON, D. C. JR. & PROUSE, N. J. (1973). The effects of three oils on marine phytoplankton photosynthesis. *Mar. Biol.*, **22**, 329–33.
- HSIAO, S. I. C. (1976). Biological productivity of the southern Beaufort Sea: phytoplankton and seaweed studies. *Beaufort Sea Project Tech. Rep. No. 12c*. Victoria, BC, Environment Canada.
- HSIAO, S. I. C., FOY, M. G. & KITTLE, D. W. (1977). Standing stock, community structure, species composition, distribution and primary production of natural populations of phytoplankton in the southern Beaufort Sea. *Can. J. Bot.*, **55**, 685–94.
- HUFFORD, G. L. (1971). *The biological response of oil in the marine environment, a review. Background Report*. Washington, DC, US Coast Guard Oceanographic Unit, Office of Research and Development, US Coast Guard Headquarters.
- LACAZE, J. C. & VILLEDON DE NAIDE, O. (1976). Influence of illumination on phytotoxicity of crude oil. *Mar. Pollut. Bull.*, **7**, 73–6.
- LOBBAN, C. S. (1974). A simple, rapid method of solubilizing algal tissue for scintillation counting. *Limnol. Oceanogr.*, **19**, 356–9.
- MOMMAERTS-BILLIET, F. (1973). Growth and toxicity tests on the marine nanoplanktonic alga *Platymonas tetrathele* G. S. West in the presence of crude oil and emulsifiers. *Environ. Pollut.*, **4**, 261–82.
- MULKINS-PHILLIPS, G. J. & STEWART, J. E. (1974). Effect of four dispersants on biodegradation and growth of bacteria on crude oil. *Appl. Microbiol.*, **28**, 547–52.
- PERCY, J. A. & MULLIN, T. C. (1975). Effects of crude oils on Arctic marine invertebrates. *Beaufort Sea Project Tech. Rep.*, No. 11. Victoria, BC, Environment Canada.
- PULICH, W. M. JR., WINTERS, K. & VAN BAALEN, C. (1974). The effects of a No. 2 fuel oil and two crude oils on the growth and photosynthesis of microalgae. *Mar. Biol.*, **28**, 87–94.
- SCHINDLER, D. W. (1966). A liquid scintillation method for measuring carbon-14 uptake in photosynthesis. *Nature, Lond.*, **211**, 844–5.
- SCHRAMM, W. (1972). The effects of oil pollution on gas exchange in *Porphyra umbilicalis* when exposed to air. *Proc. Int. Seaweed Symp.*, 7th, Sapporo, Japan, 8–12 August 1971, 309–15.
- SHIELS, W. E., GOERING, J. J. & HOOD, D. W. (1973). Crude oil phytotoxicity studies. In *Environmental studies of Port Valdez*, ed. by D. W. Hood, W. E. Shiels and E. J. Kelley. *Inst. Mar. Sci., Univ. Alaska, Fairbanks, Occasional Publ.*, No. 3, 413–46.
- STRICKLAND, J. D. H. & PARSONS, T. R. (1972). A practical handbook of seawater analysis. *Bull. Fish. Res. Bd Can.*, **167**, 310 p.