Effects of the Water-Soluble Fraction of a Coal-Derived Oil on Pond Microcosms

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Abstract. Two 80-L pond microcosms (laboratory model ecosystems) were treated with the water-soluble fraction of a crude coal liquefaction product and responses were monitored for nine weeks. A large portion of the dominant macrophyte community was destroyed by the treatment, as were filamentous algae and benthic diatoms. Snails emigrated from the systems, and zooplankton disappeared. Primary production and respiration declined for two weeks, remained low for two more weeks, then gradually returned to pre-treatment levels. Changes occurred in pH, alkalinity, conductivity, dissolved oxygen, dissolved organic carbon, and dissolved inorganic nitrogen. The microcosms recovered by the end of the experiment, but community composition and some chemical variables differed from the pre-treatment conditions.

If the development of a commercial coal liquefaction industry continues, transportation of coal-derived synthetic oils by barge and rail may become commonplace during the next 25 to 50 years. Methods for handling and transporting coal liquids will probably be adapted from the petroleum industry, and statistics on petroleum spills can be used to estimate the probability of spills of liquefaction products. Such calculations indicate that spillage of up to 150,000 barrels (25,850 m³) of synthetic oil annually could be expected from a commercial liquefaction industry producing 500,000 barrels (79,000 m³) per day (Leggett et al. 1980). Although accidental releases of liquefaction products are likely, hazard assessments have generally assumed that the environmental impacts of syncrude spills will be similar to those of petroleum spills. Recent evidence suggests that crude coal liquids are in fact considerably more hazardous than petroleum (Giddings and Washington 1981; Giddings et al. 1980; Strand and Vaughan 1981; Walton et al., in press). It appears that the physical and chemical differences between natural and synthetic oils, differences that may be of minor importance to refining or product use, could have a significant influence on the environmental fate and effects of spilled products.

This paper describes some effects of a synthetic crude oil on complex aquatic model ecosystems, or microcosms. These systems allow the environmental behavior of contaminants to be examined in the context of a whole ecosystem under controlled conditions; they thereby bridge the gap between laboratory experiments and field studies. Previous research has shown that pond microcosms are ecologically similar to the natural ecosystems from which they are derived (Giddings and Eddlemon 1980). The objectives of the present experiment were:

1. to measure the effects of a liquefaction product on a wide range of aquatic organisms under near-natural conditions, and
2. to determine the direct and indirect effects of the product on the ecosystem as a whole.

Materials and Methods

Microcosms: Approximately 250 L of water, 100 L of sediment, and a portion of the biotic community were collected on June 29, 1978, from a 0.04-ha pond dominated by the macrophyte Elodea canadensis. The materials were brought to an environmental chamber in the laboratory and transferred to four 80-L glass aquaria as follows: Sediment was apportioned equally into all aquaria, with frequent stirring to ensure uniformity.
When the aquaria contained about 7 cm of sediment, an interstitial water sampler (described below) was placed in each microcosm. The interstitial samplers were covered with additional sediment to a total depth of 10 cm. Opaque plastic tape around the lower portion of each aquarium prevented light from reaching the sediment from the side. Fifty L of pond water were siphoned into each aquarium through a simple diffusion device that allowed the water to flow in without disturbing the sediment. The next day, 100 g (drained wet wt) of Elodea and associated flora and fauna were placed in each aquarium; a few shoots were pushed into the sediment to anchor the mass. About 500 mL of the water drained from the Elodea was also added to each microcosm as a source of microbiota. The microcosms were covered with 0.3-cm-thick Plexiglas to retard evaporation. A bank of cool-white fluorescent and incandescent lights provided 180 μE m⁻² s⁻¹ PAR (400-700 nm) on a 12-hr-light: 12-hr-dark cycle.

**Sampling and Analysis:** Water samples were taken from each microcosm by lowering a glass tube through the water column, closing off the upper end, removing the tube and its core of water, and releasing the water into a clean polyethylene bottle. Samples were analyzed for pH (Corning 7 pH meter) and alkalinity (Hach digital titrator with methyl orange-bromcresol green indicator). A portion of each sample was frozen in Whirlpak bags and stored for nutrient analyses. At the end of the experiment, the samples were thawed and analyzed for NH₄-N, NO₃-N, total P, and dissolved organic carbon (DOC). Conductivity and temperature were measured directly in each microcosm with a YSI Model 33 conductivity meter.

Sediment interstitial water was collected through sampling devices buried in the sediment as the microcosms were assembled. Each sampler consisted of six Amicon H1X50 hollow fibers (Amicon Corporation) glued into a frame of glass tubing and glass rods (Figure 1). The noncellulosic 0.2-mm i.d. fibers had a nominal molecular weight cut-off of 50,000 daltons (8.2 × 10⁻⁵ g). One end of a length of Tygon tubing was attached to the outlet of each sampler; the other end projected out of the microcosm. A vacuum pump was used to draw interstitial water into the hollow fibers and through the glass and Tygon tubing into a 40-mL vial. The first 10 mL of each collection were discarded and the next 20 to 30 mL were frozen for nutrient analyses.

Net daytime primary production and nighttime respiration were estimated from diurnal changes in dissolved oxygen (DO) concentrations (McConnell 1962; Giddings and Eddlemon 1978). An automated DO monitoring system incorporating a Yellow Springs Instruments 54AR DO meter and YSI 5720 self-stirring DO probes recorded DO concentrations in each microcosm every 30 min. A switching mechanism started the stirrer on each probe 2.5 min before the DO reading from the probe was recorded. Thus, the water in each microcosm was stirred for 2.5 min every half hour; the stirring was sufficient to distribute DO uniformly throughout the microcosm (as determined by independent measurements with another probe) but did not damage the biota.

Net daytime primary production (P) and nighttime respiration (R) were calculated using the following equations:

\[
P = A - D;
\]
\[
R = B + D
\]

in which A = net DO increase during the day, B = net DO decrease during the night, and D = net diffusion of oxygen into the water from the air. All variables were expressed as mg L⁻¹ 12 hr⁻¹. Diffusion was calculated from the percent saturation (S) at the average DO concentration during each 12-hr period (i.e., the mean of the maximum and minimum) using an empirical relationship derived in an earlier experiment with similar microcosms in the same environmental chamber (Giddings and Eddlemon 1980):

\[
D = 2.97 - 0.0277 S.
\]

The small size of the microcosms precluded quantification of the biota before the end of the experiment, but the general structure of the ecosystems could be discerned by close visual inspection. The occurrence, relative abundance, and appearance of the macroscopic biota were noted. Samples of the microbenthos were obtained by placing glass slides on the sediment surface for 3 to 5 days and then examining them microscopically. Dominant species were determined subjectively. At the end of the experiment, snails and macrophytes were harvested from each microcosm, dried at 100°C for 5 days, and weighed.

**Test Material:** The coal liquefaction product used in this experiment came from the Fossil Fuels Research Materials Facility at