ARCTIC
VOL. 31, NO. 3 (SEPT. 1978), P. 408-411

Summary Of The Workshop On Ecological Effects of Hydrocarbon Spills In Alaska

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In any study of the effects of the introduction of an organic compound, such as oil, into a particular environment, such as the Arctic we should, at the outset separate two basic responses: the responses of those organisms (largely bacteria and fungi) to whom the oil is a nutrient to be attacked and eventually decomposed, from the responses of those organisms (largely plants and animals) to whom the oil is a physical and chemical agent of potential toxicity to be tolerated with varying degrees of success. Because individual species of higher organisms are readily identified taxonomically we have tended to focus on the effects of oil spills on individual species (e.g. the fairy shrimp or the black spruce) while the decomposers are usually treated as a mixed population, that shifts continuously in response to environmental factors, and within which the fate of a single species is simply not determined. In fact both groups really function as mixed populations that exhibit dynamic responses to environmental changes, such as oil spills, but our perception of the effects of these changes is largely population-oriented in the decomposers and species-oriented among higher organisms. This emphasis on species among the higher forms produces poignant tales of death and deprivation among the fairy shrimp of Barrow, or among the snail-darters of Tennessee, while environmental shifts wipe out hundreds of species of bacteria and fungi from mixed populations without notice or lamentation.

This dichotomy is shown in the studies included in this workshop in which oil spills produced an initial decrease in microbial biomass and activity, in both aquatic and terrestrial environments, and then stimulated a marked resurgence of the microbial population led by those bacteria and fungi that can use hydrocarbons as nutrients. The fate of individual species is of little interest but the workers seek to identify limiting nutrients so that the activity of the whole population can be accelerated (perhaps by the application of fertilizer) and the decomposition of the oil thus facilitated. Studies of plants and of benthic animals have emphasized the fate of individual species (O'Brien this volume) to a large extent but a very commendable effort has been made to examine whole mixed populations and to report the responses of these populations in terms of biomass and activity.

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OIL DECOMPOSITION

The actual removal of oil from the Arctic environment depends on a combination of physical weathering and microbial decomposition and this consensus appears to have been accepted at the outset in this workshop and some authors concluded that weathering was the predominant process in this system (Jenkins *et al.*). The application of hydrocarbons produced an initial decrease and a subsequent increase in general bacterial biomass in some systems (Sparrow *et al.*) while others reported no change (Jordan *et al.*) and fungal biomass was similarly affected (Miller, *et al.*). Significantly, oil treatment stimulated the development of larger populations of oil-degrading bacteria in aquatic sediments (Jordan *et al.;* Horowitz *et al.*) and in soil (Sparrow *et al.*) and higher rates of hydrocarbon degradation were measured in these oil-treated systems (Sexstone *et al.*) accompanied by high rates of aryl hydrocarbon hydroxylase activity (Linkins *et al.*). In some cases the general respiration of soil populations was increased (Linkins *et al.*) as were populations of proteolytic, cellulolytic and denitrifying bacteria (Sparrow *et al.*) and this stimulation of the growth of the decomposers could be enchanced by the administration of oleophilic phosphate fertilizers whose hydrocarbon component stimulated the growth of oil-degrading bacteria (Bergstein and Vestal). Population composition shifts were also seen in mycorrhizal fungi in oil-treated soil (Antibus and Linkins). Thus a general principle of microbial ecology is sustained here in that the addition of an organic material to a system stimulates the development of a specific microbial population capable of using that material as a nutrient. The rate of this decompositon process is of maximum importance and it obviously depends on the robustness of the initial microbial population and on nutrient limitation. Clearly the application of fertilizers (Bergstein and Vestal; Horowitz *et al.;* Mitchell *et al.*,) and tillage of the soil can accelerate hydrocarbon breakdown in soils (Mitchell *et al.*) and we should examine all arctic ecosystems, including the marine system under ice, for their unaided and fertilizer-aided capacities to decompose hydrocarbons to form an intelligent base for management policies concerning oil exploration and oil spills. One of the special problems of the Arctic is the very slow rate at which these decomposer populations develop significant activities (Sexstone *et al.*; Horowitz *et al.;* Sexstone *et al.*#2), and accessory nutrient supplementations may be required to achieve acceptable rates of hydrocarbon decomposition.

A very important facet of oil degradation is the relative rates at which the different components of oil are broken down by bacteria and fungi. Westlake's conclusion that bacteria first degrade the straight-chain alkanes and then proceed to the more complex aromatic compounds was challenged by Horowitz and by Vestal who contend that each class of hydrocarbon components has a decomposer population, with some overlap, and that the decomposition of each class of compounds proceeds at an independent rate. The determination of the rates at which representative hydrocarbon molecules are removed from the environment, as determined by "following" a C_{14} label introduced into these compounds, has been used to good effect by Hobbie's and Altas' groups and offers considerable promise in the prediction of the persistence of various types of hydrocarbon in various Arctic environments.

OIL TOXICITY

There are many reasons why oil may be toxic to animals, ranging from its readily-understandable effects on surface breathing aquatic insects (whose control is often based on hydrocarbon toxicity), to subtle chemical effects of minor components that may only be revealed by detailed physiological studies (as in the physiological effects of sulphur compounds). In the workshop we have an elegant study (O'Brien) in which oil is seen to cause fairy shrimp and other zooplankton to vacate their niches, with a consequent release of grazing pressure on algal biomass (Miller *et al.*). Meanwhile the benthic insects lost certain species but retained pre-spill levels of insect biomass (Mozley and Butler) and this study underlines the value of the assessment both of the effects on individual species and on the biomass and activity of the entire population.

Oil appears to constitute a fairly general "contact herbicide" whose direct application is most often toxic to plants. This toxicity is so dependent on contact that soil moisture-based differences in penetrability to the root system may influence toxicity (Walker *et al.*) and plants may be protected by a high water table. Of course, plants vary in their sensitivity to this "contact herbicide" and sensitivity mapping (Walker *et al.*) and bioassays of the sensitivity of specific plants under field conditions are very valuable. In general trees (birch and black spruce) appear to be very sensitive to the toxic effects of oil (Jenkins *et al.*), while sedges and grasses are more resistant, and mosses are sensitive but recover quickly especially if supported by phosphorus treatment (McKendrick and Mitchell). The more subtle toxic effects of oil may express themselves as "winter kill" when physiological damage precludes a plant's survival during adverse conditions (Linkins and Antibus). The direct effects of oil on soil center on differences in wetability based on the introduction of hydrophobic residues into the soil (Everett).

Thus it is clear that oil exerts direct and immediate toxic effects on certain plants and animals, in both aquatic and terrestrial systems, and that more subtle toxic effects are often detected only with the passage of time. Whole populations react in the expected manner in that oil-resistant forms proliferate and then lead the recolonization of the system as the toxic hydrocarbons are removed by weathering or by microbial decomposition. The extent of severe ecological damage from oil spills is, therefore, a function both of the oil-sensitivity of the plant and animal populations and of the rates at which oil is removed by human intervention, weathering or microbial decomposition.

FURTHER STUDIES

As these studies were presented in the same forum it became obvious that pedestrian matters of standardization have become important. Simulated spray or pond spills used in these studies varied between 5 and 40 l/m^2 — a level of perhaps 10 l/m^2 should be agreed on for all future studies to facilitate comparison. Crude oils vary considerably in composition and it is imperative that workers in this area should report the exact origin of their sample and its general chemical characteristics. Most of the reports to this workshop concern spills made in the brief summer season and, in view of the distinct physical differences between summer and winter spills noted by Jenkins *et al.*, more investigations on winter spills may be in order.

In the decomposition studies perhaps the most promising development is the advent of rate studies which should be extended to cover the major classes of oil constituents and a very wide variety of ecological systems. The use of field based toxicity studies of particular species and communities is very useful but they should be accompanied by an analysis of population shifts, under stress and during recovery, and of changes in total biomass of the particular system under investigation.

SPILL MANAGEMENT SEQUELAE

These studies are now in an excellent position to contribute directly to the development of suitable spill managment policies because they have developed and proved the technology required to assess rates of decomposition and specific and community toxicity. Thus the various clean-up strategies can be evaluated against a background of specific toxic levels and unaided decomposition rates. In many cases it is clear that microbial decomposition, aided by fertilizer application (McKendrick and Mitchell) (especially oleophilic fertilizers — Bergstein and Vestal), will reduce the level of hydrocarbons below the toxic level for the indigenous plants and animals at a satisfactory rate. It may be very important to induce oil to sink into the sediment in aquatic systems because a stronger decomposer population can be developed in this part of the aquatic system (Horowitz *et al.*). The possible toxic effects of dispersants should be evaluated in aquatic systems because it is distinctly possible that natural processes may sink the oil satisfactorily without damaging the bacterial decomposer population that awaits it in the sediment. Similarly, burning involves a balance of beneficial oil removal and detrimental effects on soil biota (McKendrick and Mitchell, #2) and, in instances where it is feasible, these effects should be assessed and balanced in further studies. This entire program, with its emphasis on rates of microbial decomposition and on differential sensitivity of both species and populations of higher organisms, is basically well designed and offers a scientific basis for the development or rational oil spill clean-up policies in the sensitive Alaskan ecosystem.