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The Long-Term Effect of Oil Pollution on Marine Populations, Communities and Ecosystems: Some Questions

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The long-term effect of oil pollution on marine populations, communities and ecosystems: some questions

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An evaluation of the consequences of environmental contamination requires an understanding of the extent to which it is responsible for changes in populations of organisms in the affected area. Population change is not solely related to mortality which may be observed, but depends also on the population dynamics, stock size and survival strategy of the species affected. Population changes affecting species of commercial or sentimental importance or whose diminution is followed by major community adjustment, are regarded more seriously than those of other species. Community adjustment to stress by contaminants may be subtle, difficult to detect and still more so to evaluate. In some instances it is possible to unravel the causative agents, but studies of community response to stress have lagged behind those at lower organizational levels of the individual, tissue or cell. The succeeding papers address questions arising from these considerations.

Introduction

Oil is only one of many substances discharged into, or otherwise reaching the sea. It is more complicated in its constitution than most, though not more so than urban sewage, but in one respect it is unique. It is the one pollutant of coastal waters that is familiar to every member of the general public: to many at first hand because they have encountered it on amenity beaches, and to all at second hand from television or news pictures whenever there is a major tanker accident or oiled seabirds are rescued from the shore. Public concern, whether justified or not, has been sufficiently vocal that oil pollution has received great attention in recent years. Indeed, the Royal Commission on Environmental Pollution (1981) reported in mid-October the results of 2 years' investigation of the subject, and the U.S. National Academy of Sciences held a Workshop in early November to review again the impact of oil pollution in the marine environment and to update its earlier report (National Academy of Sciences 1975). In the last decade there have been innumerable other conferences, discussions and reviews of the subject. It has hardly suffered neglect.

Oil in the sea may be damaging in a variety of ways: through its physical properties when floating as a slick or stranded on the seashore, by the toxic properties of many of its constituents, and because even low concentrations in marine food organisms cause tainting and inflict commercial damage. Spilled oil also makes a great mess. All of this is well known. Nevertheless, although this Discussion Meeting addresses itself to the particular circumstances of oil pollution with all its complexities, the problem of assessing its environmental impact raises a number of issues, both scientific and technical, which have general application to studies of environmental pollution. In this respect, oil may be regarded as a model pollutant of the sea.

A Discussion Meeting of the Royal Society, held in 1978, was concerned with a cognate subject: the sublethal effects of pollution in the sea (Cole (ed.) 1979). Oil, like other polluting

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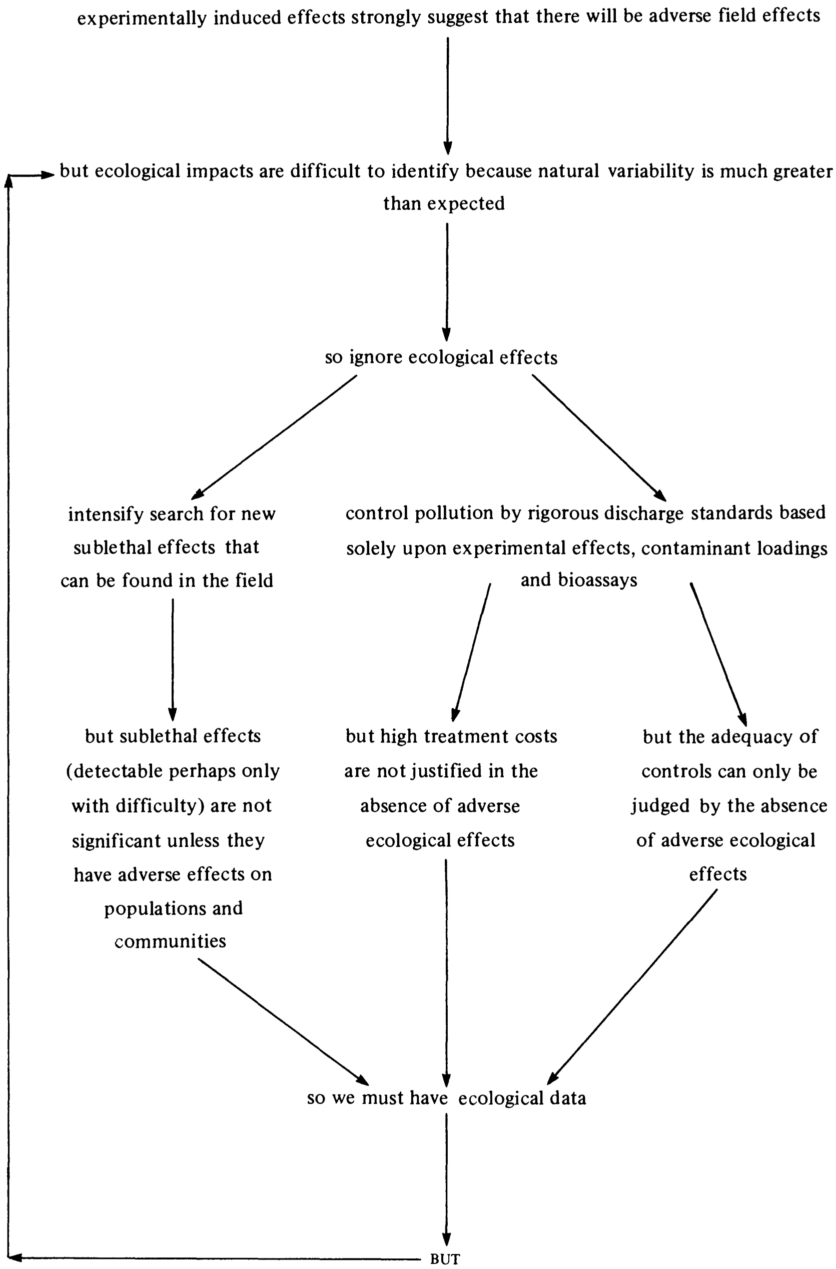
Table 1. Considerations regarding environmental evaluation (Lewis 1980)



substances at low concentrations, can cause sublethal disturbances of physiology and behaviour in many organisms, as well as developmental and growth abnormalities. The lethal effects of oil pollution are much more obvious, but it is generally assumed and sometimes explicitly stated that, since disadvantaged organisms rarely survive long in the natural environment, direct casualties of oil pollution represent only a fraction of the total mortality and must be augmented by delayed, indirect casualties, which are the consequence of sublethal damage to organisms. It is rarely possible to form more than a very rough estimate of the losses caused directly by an oil spill. It is quite impossible to extrapolate from laboratory studies of sublethal effects of petroleum hydrocarbons on selected organisms to mortality in the natural environment. But even if it were possible to estimate the actual mortality following an oil spill, this would still not permit any real assessment to be made of the environmental impact of the pollution, for that depends not on the mortality but on the numbers and fate of the survivors.

Practical strategy for assessing the impact of a pollutant only too often follows the circular arguments illustrated by Lewis (1980), and all lead back to the natural environment (table 1). It hardly needs repeating that, if the possible environmental consequences of pollution are a matter for concern, realistic assessment of how far that concern is justified can only come from a study of the natural environment. Experimentation in the laboratory – to discover the toxicity of pollutants to particular organisms, or the mechanisms by which the toxins interfere with metabolic processes or the structural integrity of tissues or cells, or with the behaviour of animals – is an essential part of pollution research. It may give early warning of unforeseen hazards, and the results of such research are often the basis for concern about possible pollution impact. It sometimes yields results of fundamental scientific interest and occasionally of value in suggesting techniques for monitoring the health of the environment. It is not a substitute for that monitoring, however, and here the problems begin, for monitoring changes in the natural environment is time-consuming and beset with difficulties (McIntyre & Pearce 1980).

Community effects

'In most monitoring programmes, contamination is measured in terms of chemistry and chemical analysis of material from various compartments of the environment can provide a sensitive indication of the concentrations of substances selected for study' (Gesamp 1980). There are often technical difficulties in chemical monitoring: of sampling, of analysis, of the variability of marine organisms, and of distinguishing contamination from natural sources from anthropogenic inputs. Human ingenuity has resolved many of these problems and may be expected to resolve more. The sensitivity of chemical analysis is now so great that there must be doubt if there is any such thing as a pristine environment, if, indeed, there ever was!

Chemical monitoring measures the extent of environmental contamination. Pollution, in the definition adopted at the outset of its deliberations by Gesamp (1969) and by most other bodies, implies that a particular level of contamination has deleterious effects. They may take the form of hazards to human health, interference with human activities, reduction of human amenities, or harmful effects on living resources. We are here concerned only with the last of these. Unlike considerations of human health hazards, in assessing harmful effects on living resources it is, from a strictly biological point of view, the population and not the individual that is important. McIntyre *et al.* (1978) argue that unless an effect has consequences at the population level, it is insignificant, and that seems incontestable. Even if the population of a species is locally reduced by pollution, it is still necessary to assess the significance of the decline for the species in question and for its role in the community of which it is part.

It is not unexpected that a change in the physical or chemical nature of the environment, whether occasioned by the addition of a substance that was not present before or was present in smaller concentrations, or by natural events, should be accompanied by some change in the organisms living there. If the change takes the form of the destruction of an entire community or the disappearance of a species of commercial importance from the affected area, there can be little argument that the change has been deleterious. It is not quite so evident that the change

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is deleterious when the balance of the abundance of different species of small benthic polychaetes alters, though without the disappearance of any, and apparently without any loss of diversity, as has been observed in the neighbourhood of oil platforms in the North Sea (Addy *et al.* 1978); nor when one genotype of a species is replaced by another (Battaglia *et al.* 1980); nor when some physiological response is shown by an organism to the presence of a contaminant.

Some responses are little more than the adaptive responses of an organism to environmental change, and far from such responses necessarily being harmful, fishery enhancement activities often subject the early stages of the fish to as many as possible of the stresses it is likely to encounter in nature (Waldichuk 1979). Adaptive physiological response may be distinguished from harmful physiological response if it contributes to the survival, growth and reproduction of the species. That distinction is not always easy to make, though perhaps the development of techniques directly aimed at measuring 'scope for growth' (Bayne *et al.* 1973) in stressed organisms is an important contribution to that problem.

At the higher organizational level of the community, it may be possible to detect adaptive responses to changed circumstances. The difficulty of monitoring population or community responses to pollution is certainly great (McIntyre *et al.* 1978) but a variety of techniques are available to measure ecological change (Gray *et al.* 1980) and in a few instances it has been possible to gain some understanding of the mechanisms by which the response is brought about. The assessment of its significance is a different matter. The adjustment of the benthic community in the neighbourhood of oil platforms in the North Sea (Addy *et al.* 1978) appears little different from that detected by Buchanan *et al.* (1978) in benthic deposits off the Northumberland coast from natural causes. Here some species became more abundant and others less abundant, but there was no loss of diversity or production, the energy simply being channelled through a different suite of species. No species disappeared from the community and presumably under appropriate circumstances there would be no obstacle to a return to the former community structure.

The measurement of community response to environmental change or stress at present lacks the precision and sophistication of the measurement of response at lower organizational levels of individuals, tissues or cells. The reasons for this are obvious: the analysis of community behaviour requires a greater investment of effort and time than physiological studies of individual or cellular performance. There is a mismatch between our knowledge of response to stress at different organizational levels (Clark 1979) and despite the reasonableness of the GESAMP (1969) stipulation that pollution involves a deleterious effect of a contaminant, it is not easy to apply it in practice, particularly in detecting and still more evaluating community responses to the low levels of contamination that it is now possible to detect.

POPULATION EFFECTS

Much of the concern about pollution in the sea relates less to the changes that it may cause in ecological communities than to the effect that it may have on the populations of selected species within the community. A very large proportion of the published literature on the impact of acute pollution incidents, in fact focuses attention on the mortality of particular plants and animals at the time of the pollution. Much less attention is paid to the population dynamics of the species in question or to the state of the initial standing stock of it in the area, though both have profound consequences for the effect that the observed mortality has on the standing population (Cushing 1979). Considerations such as these should perhaps inform discussions of the different impacts that repeated and heavy mortalities of seabirds, particularly auks, have had on the size and health of their colonies in different parts of the British Isles (N.E.R.C. 1977).

Preoccupation with mortality is in part a reflection of the main thrust of comparative physiological research. This has given considerable insight into homoeostatic mechanisms and, in its ecological connotations, into the limiting conditions for the survival of individual organisms. Many marine invertebrates lack a wide physiological regulatory ability or tolerance, and their strategy for success in a changing environment is not individual survival but some other mechanism. There is some evidence that genetic variability with the local selection of successful genotypes is an adaptation to unpredictably variable environments (Grassle & Grassle 1978; Mann & Clark 1978). This mechanism underlies the success of opportunistic species such as *Capitella capitata* (Grassle & Grassle 1974; Gray 1979), but it is not yet possible to evaluate the significance of the genetic variability that has been detected in a wide variety of other marine organisms (Valentine 1976; Valentine & Ayala 1978). Species with wide-ranging, mobile adults or with widely dispersed juvenile stages available for recolonization also have quite different strategies for the maintenance of populations that may be subject to heavy losses from locally changed conditions, from long-lived static species with a high regulatory ability.

It is evident that in practical studies of pollution impact, some species are more equal than others. First among the more equal species are those of particular interest to humans. A community adjustment that almost eliminates the small polychaete *Myriochele* without affecting the benthic productivity of the area is of little interest to anyone. An adjustment that almost eliminates the herring or sprat, or for somewhat different reasons, the puffins that feed on young herring and sprat, would be viewed quite differently. At the level of populations, the definition of pollution as a 'deleterious effect' of contamination is not entirely objective but reflects human values. The discharge of micaceous china clay waste into St Austell Bay in Cornwall converted a hard substratum into a soft one. Crabs and lobsters were displaced and a benthic fauna dominated by polychaetes and bivalves developed, accompanied by predatory flatfish (Howell & Shelton 1970). This certainly proved to be financially deleterious because of the greater commercial value of crustaceans than flatfish. It is not clear on any other criteria if the exchange of flatfish for crustaceans was deleterious, although it was clearly due to the longstanding discharge in the bay.

A second category of 'more equal' species has a rather stronger scientific basis. It includes those that have a dominant role in determining the character of the community they inhabit. These are most conspicuously dominant herbivores such as the limpet *Patella* or sea urchins. In some circumstances they may be carnivores such as asteroids or the gastropod *Nucella*. The selective loss of these, whether from natural causes or pollution, may be followed by a fundamental change in community structure. Here, too, some consideration is needed before it can be decided, except by human subjective preferences, whether or not the change is deleterious.

Recovery period

The most important consideration in assessing environmental impact is neither the immediate mortality nor the perturbation that this may cause to the population of a particular species or the community of which it is part. Once a damaging or perturbing influence has been removed, marine ecosystems begin to return to something similar or equivalent to their former condition. A community change that is restored within a few months is regarded quite differently from one that persists for several years. It is by now well established that in temperate waters, massive acute oil pollution damage is substantially restored in about 2 years (Mann & Clark 1978), but more detailed and sensitive investigations reveal subtle changes persisting for at least a decade (Sanders *et al.* 1980; Southward & Southward 1979). The timescale for recovery may be very different in tropical or polar environments and special ecosystems, such as coral reefs, may present special problems, but recovery from damage is much less well documented for these ecosystems than for temperate marine ecosystems.

Important theoretical and practical considerations arise from studies of the recovery of damaged ecosystems and have implications for ecosystem monitoring in general.

At what point can recovery be declared complete? An isolated, fringe population of a species that lacks a dispersive phase in its life history may take many years or a lucky chance to become re-established, and may not be re-established at all after a catastrophic accident. Arctic marine invertebrates commonly lack a dispersive phase and this is a contributory factor in supposing that recovery of Arctic ecosystems from damage will be slow. The British Isles, lying at the southern fringe of distribution of a number of Arctic species and the northern fringe of southerly species, has many isolated and precarious populations on its shores and in coastal waters, and on that account is particularly vulnerable to protracted damage from oil, or any other sort of pollution. Such rare, isolated populations have little ecological significance, though they often have considerable scientific interest, and their presence or absence at any particular site depends upon their local success and is unpredictable.

A balanced age structure in the population of a species that lives some 20 years may take that long to become re-established. Is this needed before recovery can be regarded as complete? Some species show regular recruitment and an actuarial population structure, but there is growing evidence that for a number of marine invertebrates, recruitment is highly erratic and within 2 or 3 years one species may virtually replace another related species at a particular site. This has been well documented for the replacement of *Nephtys hombergi* by *N. caeca* on a beach near the mouth of the River Tyne because of the failure of the former to spawn for 2 years in succession (Olive *et al.* 1981), and similar recruitment failures have been recorded in benthic species in offshore deposits in that area (Buchanan 1967).

Both the detection of perturbations and the judgement that recovery is complete depends on a knowledge of the norm. The norm at the population or community level may fluctuate widely, and the difficulty of detecting a faint signal against such a noisy background is a recurrent concern in advisory reports on environmental monitoring (McIntyre *et al.* 1978; GESAMP 1980). Natural fluctuations caused by the recruitment failure of a key species (Lewis 1972) or by a severe winter (Crisp 1964) cause at least as great a change as any caused by major pollution damage. These are extreme examples, where there is a reasonable possibility of distinguishing natural fluctuations from other disturbances. The problem is much more intractable when the perturbation is subtle and the influencing factors undramatic. The problems of detecting a faint pollution-induced signal against such a noisy background has driven most advisory reviews to fall back on a variety of monitoring procedures at the dependable chemical, biochemical and physiological levels, admittedly refined to take account of the natural environment and not stay solely in the laboratory. But little of this provides an answer to the question posed in this meeting: what is the long-term effect of oil pollution at the level of the population and the community?

Conclusion

Pollution research has a primarily utilitarian objective: to identify and preferably predict the consequences of anthropogenic additions to the natural environment and to evaluate the consequences as a basis for decisions whether, on balance, the consequences are acceptable or not. This research has yielded some discoveries of fundamental scientific interest and has stimulated new departures in physiological and ecological research. These then have their own justification whether or not they contribute directly to pollution research, but, in fact, by leading to a better understanding of the functioning of individual organisms, populations and ecosystems, make an important contribution to pollution studies.

A Royal Society Discussion Meeting is naturally concerned with the scientific aspects of pollution research, but it is as well to be aware of the utilitarian objectives underlying much of it. It is possible, sometimes with difficulty, to detect population or community change in response to oil pollution. How best can that change be detected? The natural environment is in any case in a state of flux. Are population changes caused by oil pollution greater or less than natural fluctuations, and are they additional to or contained within them? Are some ecosystems more vulnerable than others? What can we learn from case-history studies of oil spills, natural seeps or chronic oil pollution? While it is not a task of this meeting to take into account the political and economic considerations that will balance oil pollution against puffins, or flatfish against lobsters, such decisions will be based at least in part on an evaluation in biological terms of the seriousness of environmental changes caused by oil pollution. It would therefore be as well if these practical matters were borne in mind.

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