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The Impact of Oil Pollution on Marine Populations, Communities and Ecosystems: A Summing Up

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The impact of oil pollution on marine populations, communities and ecosystems: a summing up

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The Discussion Meeting revealed a considerable divergence of views. Present evidence suggests that oil pollution may have serious local and temporary consequences, but they are no greater, and generally less than natural fluctuations. There are a number of areas of ignorance or uncertainty, which accounts for the different attitudes taken at the meeting. The principal need is to gain a better understanding of the functional performance of ecosystems and their response to disturbance, whether caused by natural events or pollution.

Introduction

The purpose of this Discussion Meeting has been to consider the effects of oil pollution on marine populations, communities and ecosystems. This delimitation of the subject stems from the view of international bodies such as Gesamp (1969) and I.C.E.S. (McIntyre *et al.* 1978) that in strictly biological terms, contamination becomes pollution only when it has a deleterious effect on populations. Different considerations may, of course, apply if the contamination endangers human health or interferes with human activities or amenities. It may be noted that no criteria are offered for what is or is not a 'deleterious effect', and this aspect of the impact requires separate evaluation.

The emphasis on population effects rather than on sublethal changes in individual organisms, or even their mortality, takes into account the realities of population dynamics and is, in theory, unexceptionable. The acknowledged difficulty of measuring population change that may be induced by a low level of contamination against a background of often large natural fluctuations (McIntyre & Pearse 1980), however, leads some scientists to question the usefulness of this criterion of pollution. Nevertheless, it is of the greatest importance and cannot be neglected because of the difficulty of measuring the actual consequences of contamination of the natural environment.

One objective of pollution science should be to predict effects and, at least from the point of view of drawing attention to potential hazards, it is incontestable that the accumulation of contaminants in the natural environment or, more particularly, in organisms is a matter of concern. If the contaminants are known to be toxic or are observed to impair or kill organisms in other ways, the concern must be correspondingly greater. The urgent task is then to discover how far that concern is justified, or, more, properly, to quantify the impact of pollution on natural populations and communities. With that information, the basis is set for an evaluation of the consequences of the pollution and of the cost-effectiveness of abating it.

While the papers given at this meeting and the discussion that followed them addressed these questions, they also extended over a wider field. The problems of measuring population change have been re-examined and techniques by which the difficulties might be overcome or circumvented considered. Attention has also been drawn to a number of possible threats that still require evaluation. The major part of the meeting was, however, devoted to an assessment of the impact of a variety of chronic inputs of oil-derived materials and to the effects of acute spillages of oil. Consensus exists on some matters, but there remains a surprising divergence of views about the assessment of the impact of oil pollution, about an appropriate research strategy for measuring the impact, and also about presumed contamination that has not yet been measured, still less evaluated.

Disagreement among scientists implies either a lack of essential information or else a lack of focus about the objectives of an enquiry. This summing-up is principally an attempt to identify the areas of consensus and disagreement and the reasons for the latter, rather than to summarize the papers presented at the meeting.

Pathways and fates of oil in the sea

Dr Whittle and his colleagues drew attention to the very great complexity of 'oil' and its variable constitution at source, both during the life of a single oil well and at different oil reservoirs, and with time once it is released into the natural environment, depending on temperature, sea conditions, weather and other factors. These facts are well enough known but are worth repeating because, except among petroleum chemists, there is a strong tendency to gloss over the great variety of contaminants and their properties embraced in the term 'oil pollution'.

What is less appreciated is that despite the sensitivity and sophistication of modern analytical techniques, it is still possible and practicable to sample only a small spectrum of compounds included in 'oil' and this is particularly true of non-hydrocarbon components, which may constitute as much as 25 % of a crude oil. It is possible to measure the changing proportions of some classes of compound during the degradation of spilled 'oil' or to focus attention on a specific class of compound of particular interest, but we are far from knowing in detail the physical and chemical fate of crude oils or refined products once they are released into the sea.

Two important consequences follow. First, the great sensitivity of modern analytical techniques reveals contamination of much lower concentration than was formerly detectable. Contamination of sediments and marine organisms by petroleum-derived compounds (as well as by other materials) therefore now appears to pervade almost the whole natural environment. This is a matter for uncritical concern by those who fail to notice that the newly discovered contamination is several orders of magnitude less than that which was known previously. That we cannot quantify that concern, however, remains disturbing and is a matter that was discussed in various ways at the meeting.

Second, as Dr Vandermeulen pointed out, the very small range of petroleum-derived compounds that it is possible to monitor by chemical analysis throws confusion on studies of the depuration of marine organisms that have been exposed to contamination. A major contaminant may appear to decrease in concentration, but generally it is not known if this is because it is being eliminated or metabolized. When, as usually happens, the metabolites are unknown, they are not monitored but may accumulate in the organism with effects that are imponderable. The seriousness of this lack of understanding, like that of widespread low-level contamination, cannot be evaluated.

A number of attempts have been made to estimate the global or regional input of petroleum hydrocarbons to the marine environment. Some inputs, such as those contributed by refinery

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or municipal effluents can be gauged with reasonable accuracy, but river-borne or atmospheric contributions, which in aggregate may be much more significant, can be estimated with far less confidence. While such large-scale budgets are of value in providing a perspective of oil pollution against natural hydrocarbon production, or of one region against another, there appears to be little point in striving to achieve a more accurate estimate of the global input of petroleum to the sea. The contaminants are in great variety and far from uniformly distributed in the oceans; moreover, interest in the consequences of this contamination is essentially local and related to whatever resource may be at risk there. Given a specific target in a specific area, such as clam beds in Southampton water, it is possible to draw up a more realistic budget for the local sources of contamination, to identify principal sources and, if necessary, take remedial action. Even with such a limited and practical objective, however, as Dr Whittle showed, the task is still difficult.

The considerable areas of ignorance surrounding the fate of 'oil' released into the sea pose a dilemma for future research strategy. Ignorance is naturally a challenge to scientists, but even where the subject has sufficient fundamental scientific interest to justify its pursuit, it is clearly not practicable to determine all the physical, chemical and biochemical processes that determine the fates of the wide variety of components, both hydrocarbons and non-hydrocarbons, contained in crude oils and refined products, in the enormously greater variety of organisms in the sea. Research priorities, particularly if the investigation is to be directed to practical ends, are best determined by observations of harmful effects of pollution, which require elucidation. This turns attention to the impact of oil pollution at higher organizational levels than the molecular.

Ecological measures of pollution impact

In considering the impact of oil pollution in the sea, the meeting was mainly concerned with its effects on populations and communities. Since many marine organisms are mobile and local populations of all species are subject to losses by natural mortality and gains by recruitment of young, a population is a dynamic entity and the determination of population change is not easy. Estimates of population density are perforce based on samples, but organisms are rarely uniformly distributed even in a homogeneous habitat, which is itself a rarity, and the population estimate must therefore be subject to a number of statistical controls. Estimation of population change is an even more uncertain process but a variety of statistical techniques have been devised to measure population change or community adjustment to disturbance, and although all have shortcomings they are widely used in pollution studies.

Discussion of ecological techniques for measuring the impact of oil pollution revealed a divergence of views. On the one hand, there was a reluctance to accept what was regarded as a simplistic approach of reducing a complex community response to a single statistic that, for all its apparent precision, conceals more than it reveals. Equally, however, there is a strong view that some of the more recently developed indices of change or disturbance reflect biological reality, and, provided that this proves to be true, they have the great advantage of presenting to politicians and administrators a manageable quantification of the seriousness of pollution instead of leaving them with the impossible task of evaluating complicated biological statements.

Dr Southward showed that a Cornish shore, damaged during the clean-up after the wreck of the *Torrey Canyon*, which he had studied continuously since before the event to the present day, had still not returned to the luxuriance of fauna and flora it had enjoyed before 1967.

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If a naturalist of Dr Southward's great experience claims that the shore has not yet fully recovered, we can only accept his judgement. But not all investigators have his wealth of experience and not all ecosystems are as well known as the rocky shores of southwest England Furthermore, if Dr Southward's judgement is correct, there should be some way of quantifying differences between the community that existed before 1967 and that in 1981. Formal methods of quantification, whatever their failings, appear to be essential, if only for practical purposes.

Professor Crisp pointed out that Dr Southward enjoyed the advantage of being able to see the rocky shore environment, unlike those working on the subtidal benthos who had necessarily to rely on sampling and elaborate statistics. It may well follow that measurement of ecological disturbance in such habitats is less sensitive than that which is possible on rocky shores. It may also be that rocky shore environments present a 'most favourable' view of the impact of oil pollution. They are high-energy beaches that are, for the most part, rapidly cleared of contaminating oil by natural processes, and recovery may be set in train sooner than in low-energy environments where residual contaminations may persist. The more favourable circumstances for studying community response to oil pollution in the intertidal zone of rocky beaches than in the sublittoral benthos is, of course, no excuse for neglecting the latter. Indeed, since the sublittoral benthic fauna may often be of greater economic significance than that of rocky shores, there is likely to be the greater pressure to quantify and understand impacts of pollution on it.

Dr Sharp and Dr Appan gave a virtuoso display of the use of a wide variety of indices and other statistical measures of community changes in their study of the benthic fauna in parts of the Gulf of Mexico. This environment has been subject to the influences of oil exploration and extraction for several decades as well as of major discharges of crude oil such as the Ixtoc I blow-out in Campeche Bay in 1979–80. No single index of comminity change is reliable in itself, but the battery of indices used in the studies in the Gulf of Mexico give a reasonably consistent result and reveal no impact of any consequence on the benthic fauna. It may be argued by those convinced that the activity of the oil industry in the area must have had some impact, that the indices are too insensitive to detect any but the grossest changes, though this argument tends to be forgotten when subtle impacts are claimed to have been detected by the same methods. An unanswerable comment on this debate was made by Mr Howe in another context: 'How long do you go on looking for an effect that you cannot detect?'

From the papers and discussions it was evident that despite a certain scepticism about the value of diversity indices and other statistical measures of community change in response to contamination, such indices remain an essential tool in ecological studies. Professor Gray argued persuasively that departure from a log-normal distribution gives evidence of community disturbance, though since this index is influenced by seasonal mortality and recruitment it must be used with discretion. It has the advantage over other techniques of concentrating on major components of the fauna and so reduces the demand for taxonomic expertise, which is often not readily available. As with any other recently introduced technique, it remains to be seen how widely Professor Gray's approach will prove to be applicable. At least for the present, slavish reliance on a single statistic is likely to lead to the simplistic measure of pollution impact, which was condemned by some speakers at the meeting. Measurement of community change is sufficiently difficult that all available information must be assessed.

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Measurement of water quality

Dissatisfaction with the uncertainties of assessing pollution impact by ecological means has led to the alternative, or better, complementary approach of measuring water quality. At one extreme, techniques exist for the chemical or biochemical analysis of the concentration of a contaminant in the water, but this makes no contribution to the assessment of its actual impact. Dr Bayne's approach of measuring the 'scope for growth' of the mussel *Mytilus* in contaminated waters has the advantage of providing a functional link with the population and community. It is also valuable in integrating all environmental stresses to which the animal is exposed in its natural habitat. While this does not allow the particular effects of oil pollution to be separately identified, it provides a realism lacking in most other experimental studies.

The limitation of this approach is the difficulty of extrapolating from the response of *Mytilus* to that of the other components of the community. As Dr Lewis observed in his paper, it is a difficult and unpredictable species to deal with ecologically. Furthermore there are certainly individual differences in response within a single population of *Mytilus*. When under stress, *Mytilus* has its own strategy for survival. Dr Bayne has made the interesting observation that the population living under a variety of pollution stresses in the Cattewater at Plymouth continues to grow normally, but this is at the expense of reproduction. *Mytilus* has an extended pelagic larval life and the non-breeding Cattewater population is replenished by recruits from other, healthy populations. This is a common tactic for e.g. the polychaete *Nereis diversicolor* living in the upper reaches of estuaries where the salinity régime prohibits successful breeding. Other resilient species have quite different survival strategies from *Mytilus* or *Nereis diversicolor*. This is conspicuously true of 'opportunisitc' species, which are characterized by a short life span and repetitive breeding throughout much of the year. They experience a large population turnover and colonizing individuals are available at most times to fill gaps created in the community by loss of their own numbers or of other species subject to local pollution stress. Many, perhaps the great majority, of marine organisms are neither so resilient nor have reproductive strategies that allow losses to be made good rapidly. They are most likely to be severely damaged by pollution stress.

Biological measurement of water quality by the 'scope for growth' of *Mytilus*, provided that the technique is used judiciously, has great advantages over the less sophisticated measurement of the concentration of a particular contaminant in the water. Nevertheless, it is still necessary to relate the response of *Mytilus* to that of other members of the local community, more particularly the vulnerable species and those that have a key role in determining the community. For that to be possible, a knowledge is needed of the structure and functioning of the local ecosystem.

Natural population fluctuations

Despite the difficulties of estimating the size of local populations, it has long been known that some marine organisms undergo very large, long-term fluctuations in abundance for reasons that are primarily climatic or hydrographic. This natural and erratic ecosystem variability creates serious problems for measuring anything but the largest disturbances caused by pollution unless an obvious source is known (and not always then), for measuring the recovery of an ecosystem from disturbance, and particularly for assessing the significance of community of ecosystem change, however induced.

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The most detailed information about natural fluctuations, and the longest time series, relate to the abundance of some commercial fish species. Dr Jones presented reconstructions, from historical records of catches, of the varying fortunes of the Hokkaido herring and the Norwegian spring spawning herring since the fifteenth century. Time series extending over several centuries can also be reconstructed for a number of other fish stocks. The fluctuations refer to recorded catches and take no account of possible fluctuations in fishing effort, but the changes in apparent abundance can be correlated with known climatic change and are too great, and sometimes too rapid, to be due to anything but natural causes. With hindsight, it is possible to see that a fisheries biologist, lacking knowledge of the long-term range of fluctuation, might well discover a progressive and apparently catastrophic decline in a fishery if observation started at the beginning of a downturn. In the present climate of opinion, it would no doubt be suspected that pollution, overfishing or some other human agency was the most probable cause.

Large population fluctuations occur in other marine organisms, though inevitably they are less well documented than fluctuations in commercial fish stocks. While the underlying causes may be climatic or hydrographic, as Dr Lewis demonstrated in his paper, subsequent biological interactions are of great importance and sometimes result in repercussions throughout the whole ecosystem. The dense growth of fucoid algae with an associated fauna on intertidal rocky shores after the loss of a dominant herbivore such as *Patella* is well known. Less dramatic but comparable ecosystem adjustments after the decline of an important member of the local community have been detected in the sublittoral benthos and are probably continuing but erratic events in all marine environments. The nature of the interactions between members of a community vary widely from grazing or predation to simply excluding others by occupying space.

Most marine organisms include a distributive phase in their life history, often in the form of a pelagic larva. Recruitment to a local population, which is crucial to its maintenance, therefore does not depend on its reproductive success but on the influx of young settlers. Depending on the duration of the distributive phase of the species, the recruits may have been derived from near or distant populations. The success of recruitment is also determined by the survival of the young recruits: some species settle in the adult habitat and are adapted to high mortality, others are not so profligate. Fluctuations and sometimes failure of recruitment or survival are commonplace and it is becoming increasingly evident that most marine ecosystems are far from stable but are in an erratic, chance state of adjustment on a large or small scale Indeed, apparently stable ecosystems may sometimes be no more than in a pause between periods of change.

The evidence of erratic change from both fisheries and marine ecological studies emphasizes the need for extended studies of communities if sudden change is to be properly interpreted. Dr Lewis also emphasized the need for such long-term studies to have an adequate geographical range. The failure of recruitment of the intertidal gastropods *Gibbula* and *Monodonta* for several years in succession at Milford Haven might be attributed to the activities of the oil industry there, but for the fact that the same recruitment failure affected these gastropods on the whole western coast of Britain to the northward limit of their range. Most studies of the response of ecosystems to pollution lack both the temporal and geographic dimensions that are evidently needed to gain a proper understanding of pollution impact and to separate that from climatic, hydrographic and other naturally induced change.

Assessment of pollution impact depends as much, perhaps more, on the duration of damage

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as on the immediate losses. Given the state of erratic flux in which many marine ecosystems exist, it is difficult to state in explicit terms what is the norm and it is correspondingly uncertain when recovery from damage is complete. While Dr Southward may be correct in saying that Cornish beaches damaged in 1967 after the wreck of the *Torrey Canyon* had still not returned to the conditions they enjoyed before 1967, it is impossible to say what the abundance of the fauna and flora would have been in the absence of the damage, nor can any account be taken of the effects of occasional severe winters in the period 1967–81 or of local recruitment failures from natural causes from time to time.

Dr Lewis pointed out that we are faced with a paradox. Severe or chronic pollution from an identified source causes damage that can be identified and assessed with reasonable certainty. Low-level and pervasive contamination might well cause insidious effects that are both more worrying and more difficult to detect.

Impact of chronic and acute oil pollution on populations, communities and ecosystems

Examination of the difficulty of measuring the impact of oil pollution in the marine environment revealed a number of areas of uncertainty and disagreement. This lack of consensus was responsible for a similar divergence of views in the assessment of the actual long-term effects of oil pollution, which occupied the greater part of the meeting.

The immediate impact of large oil spills on the intertidal flora and fauna, and to a lesser extent the inshore subtidal benthic fauna, is well known and has been thoroughly documented in many oil spills in different parts of the world. In far fewer of them has there been any serious attempt to monitor the recovery processes and their time scale. Beaches damaged after the wreck of the *Torrey Canyon* have been studied longer than any other and Dr Southward referred to the subtle differences that he could still detect more than a decade later. Dr Vandermeulen reviewed the aftermath of a number of more recent major oil spills in various parts of the world, and Dr Conan the effect of the largest oil spillage of all, resulting from the wreck of the *Amoco Cadiz* on the Brittany coast in 1978.

An important factor delaying recovery, particularly when low-energy environments are contaminated, is secondary contamination. This has been apparent in Brittany where oil from the *Amoco Cadiz* trapped in sediments and the inner reaches of the Abers was subsequently released and inflicted further damage. Weathered oil is still trapped in sediments and an oil sheen is sometimes visible when the oil leaches out on a rising tide. This, however, has now lost its toxic components and is not expected to have any further biological effect. Similar protracted damage has been claimed for the benthos of Buzzard's Bay, Massachusetts, after the wreck of the barge *Florida*, though in this instance the affected area was enlarged by the movement of contaminated sediments. In cold environments there is the likelihood that oil trapped under sea ice has its main impact after it has been released by the spring thaw.

Protraction of recovery is also caused by the apparent delay before some animals succumb to the pollution. In sandy and muddy habitats on the Brittany coast, delayed mortality is claimed to have been 1.4 times as great as the immediate effects. On one beach, the bivalve *Tellina fabula* began to disappear only several months after the spillage, and is now restricted to subtidal deposits. Reduced growth, recruitment failure and other effects have been detected in Brittany in the seasons after the wreck of the *Amoco Cadiz*. Not all species have been equally affected; some indeed have benefited, it is thought through reduced predation. While this prolonged effect may well be a response to oil contamination, these investigations lack a broader geographical dimension and so, following Dr Lewis's argument, this cannot be certain.

Recontamination, delayed mortality and possible subsequent adverse effects on the survivors of an oil spill all delay recovery, and even after the primary cause of damage has disappeared there are further reverberations in the ecosystem from biological interactions. Those who have studied the impact of oil spills are clearly of the opinion that they are extremely damaging and cause a prolonged disturbance in the affected ecosystem. It is also evident, however, that our knowledge of recovery processes is still vague. Professor Gray, in fact, complained that almost identical observations were made after each large oil spill and little advantage was taken of the opportunity to learn more of the functioning of marine ecosystems in response to a major disturbance, which may as well be caused by natural phenomena as by oil pollution.

In view of the concern expressed about the impact of acute oil pollution, it is surprising that far less evidence of damage can be shown to result from chronic pollution. Dr Dicks and Dr Hartley discussed the effects of refinery effluents which provided that the concentration of petroleum fractions is below 25 mg l^{-1}, as is possible in more modern refineries, the well known environmental deterioration around the outfall is slight and extremely localized. Around offshore platforms in the North Sea, some change in the benthic community has been detected, but this may often be due to disturbance as much as to petroleum hydrocarbons, though oil-based drill fluids have recently come under suspicion. Dr Sharp and Dr Appan could detect remarkably little effect on benthic communities in the Gulf of Mexico, which have been exposed to the effects of oil exploration and extraction for several decades.

Benthic communities on parts of the Californian coast have been exposed to oil from natural seeps for centuries if not millennia. Although they have been studied in recent years, as Dr Straughan showed in her paper it is difficult to draw many firm conclusions from these investigations because of the complexity of the situation. Since most parts of the southern Californian coast are subject to natural oil contamination, control sites against which areas affected by oil may be compared are necessarily far distant. Oil seeps from the substratum erratically and is subject to weathering from the time of its release. The area around the seeps at Coal Oil Point is subject to considerable sediment movement. Many of the animals living there are mobile and most have pelagic larvae, so that recruitment of the local fauna is not dependent on its reproductive success. While some halo effect can be detected around active seeps, it is of very limited extent and elsewhere the effects of the oil are extremely patchy in both time and space. Some areas are faunistically impoverished but others are enriched by the increased trophic input, and, overall, there appears to be a general enrichment over a large area of Coal Oil Point.

None of the studies of the effects of chronic petroleum contamination are as complete and detailed as might be wished, and the difficulty of measuring community change in benthic habitats is acknowledged. Nevertheless, it is evident that the impact of chronic contamination is, except in the intertidal zone of the shore, generally confined to very small areas and elsewhere is too small or too subtle to be measured by the ecological techniques at present available. This, presumably, is a reflection of very low levels of contamination.

The final papers were devoted to examining whether or not mortality from oil pollution can be related to population changes in plankton, commercial fishes or seabirds. Plankton near the surface of the sea is exposed to the highest concentration of toxic water-soluble constituents

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of oil from a slick. The eggs and larvae of many commercial fish species are also planktonic, but more importantly, recruitment, the size of fish stocks, and catches are routinely monitored and may in a general way provide some indication of the health of the marine environment. The heavy mortality of some species of seabirds from floating oil attracts much public attention and since these birds have a low reproductive rate, which may preclude the rapid recovery of damaged populations, it may be expected that these animals, if any, would reveal an impact of oil pollution at the level of the population.

Studies of the effect of oil on plankton are conspicuous for their discrepant results. A variety of petroleum hydrocarbons certainly kill or inflict sublethal damage on planktonic organisms in laboratory experiments, but generally at unrealistically high concentrations. Studies of the effect of adding oil to planktonic communities in artificial enclosures or in shallow pools have revealed a variety of community adjustments, though not consistently so. Field investigations of the actual response of planktonic communities to oil spills are sparse, but these too show little consistency. In most investigations there has been evidence of trophic enhancement with an increase in planktonic bacterial and yeast populations. Sometimes the zooplankton biomass has been observed to be drastically reduced (copepods appear to be particularly vulnerable), but it is not known if this is a consequence of the toxic effect of the oil or of avoidance of the area by the organisms. In short, little of general application can be concluded from studies of the impact of oil pollution on planktonic communities. Only the neuston, living in the top few centimetres of the sea, is likely to be exposed to high concentrations of petroleum hydrocarbons under a fresh oil slick, but these organisms have been little studied. Other areas of ignorance relating to planktonic ecosystems in boreal and some tropical environments are, for that reason, also matters of concern. Dr Davenport concluded that on present evidence, however, there is nothing to suggest that oil pollution has a dramatic or widespread impact on plankton.

Despite the very large amount of information that exists about the size of fish stocks, Dr McIntyre could find little evidence that oil pollution has a serious impact on populations. A reduction in growth and a high incidence of fin erosion was noted in the heavily contaminated waters of the Brittany coast after the wreck of the *Amoco Cadiz*, but that appears to have been a transient effect. The most significant commercial impact of oil pollution is tainting of the catch, or fear that the catch may be tainted, but natural population fluctuations, or the effects of commercial fishing practices, or the insensitivity of the estimates of recruitment and stock size, mask any impact that losses from oil pollution may have. Dr Sindermann found that even fin erosion and other pathological conditions observed in flat fish from polluted waters appear not to be particularly related to petroleum. There remain fears. Mr Beverton pointed out that heavy contamination of the shallows off the Dutch coast, which are the principal nursery grounds for North Sea flatfish, would have a catastrophic impact on recruitment of the year class of the affected species. Dr Southward was also concerned that pollution losses in combination with overfishing could well drive populations of some fish species into a dramatic decline.

As with other organisms, the assessment of the population dynamics of seabirds is difficult, and all parameters are subject to substantial errors. From Professor Dunnet's cautious analysis, the surprising fact emerges that despite the low natural annual mortality of long-lived species, the large losses from oil pollution are small in comparison with the total expected annual mortality. The breeding populations of all British species of seabird are increasing although colonies near the southern extreme of the geographical range are generally in decline. The cause of this change is unknown, but the mechanism of the increase must implicate the young, non-breeding population, which is differently distributed at sea from the breeding birds. Factors that influence their early recruitment to the breeding colonies may be social rather than physiological. While fears may be expressed about circumstances in which this buoyant situation might be reversed, since the underlying cause of the increase in breeding populations is unknown they remain entirely speculative.

Assessment

Assessments of the impact of oil pollution on marine communities vary widely. At one extreme, the view is held that an oil spillage that reaches shallow water and the shore causes great immediate damage, recovery from which is still not complete more than a decade later, while the apparent lack of impact of more diffuse but chronic inputs is merely a reflection of the insensitivity of the methods used to measure change in marine communities. At the other extreme is the view that while a coastal oil spill causes substantial loss of life, this is made good within 2–3 years and subsequent changes, like the impact of small chronic contamination, are minuscule if detectable at all.

These conflicting interpretations are unlikely to have been resolved as a result of the discussion at this meeting. Since assessment of the seriousness of oil pollution involves judgement of matters that are not wholly scientific, there is room for disagreement among scientists. Nevertheless, scientists are asked to advise governments and there are clear dangers in leaving the final evaluation of largely scientific information to non-scientists. During the discussion of indices of various kinds to measure population or community change, Lady White made a plea, on behalf of politicians, for scientists to give simple, clear answers. If the situation is complicated, as it often is in evaluating pollution effects, it is difficult and perhaps meaningless to formulate a conclusion in terms of a single index. Damage, in any case, is in the eye of the beholder and an impact that in one area is harmful to a particular important interest, such as a fishery, may have no such consequences elsewhere.

It is at least possible to summarize what is at present known about the effect of oil pollution of various kinds on marine populations, communities and ecosystems from information presented at this meeting, acknowledging that there remain many areas of ignorance and uncertainty. Chronic contamination of the foreshore may be expected to cause local environmental impoverishment with a severe reduction or even total elimination of the macrofauna and flora. The spatial extent of this effect depends upon the concentration of noxious material in the discharge, its volume and local water movements. Chronic discharges below tidal limits, even of such long standing as from natural seeps, may cause very localized impoverishment, but outside this area or with low levels of contamination, such community adjustment as occurs is hard to detect and in some cases appears no different from community changes which are the result of natural causes. They generally do not seem to be of great consequence.

The most dramatic changes in the ecosystem follow heavy acute pollution of the shore, as occasioned by a substantial oil spill. The ecological succession that follows is by now well known and there is substantial restoration of something like the former flora and fauna within a few years. Subsequent community adjustments are subtle and prolonged, but there is a divergence of views about how they should be evaluated. Marine communities are not stable but are in a continual, erratic state of flux. Events following heavy pollution damage are, once the source of contamination is removed, identical with those following natural catastrophe, whether it be failure of recruitment of a key species, the effect of a severe winter, storms, or other events.

It is difficult to regard damage caused by oil pollution, confined as it is to small areas, as momentous or of very great significance, except where some vital human interest is adversely affected. Commercial fisheries are one such interest, but hitherto the greatest damage inflicted by oil pollution has been by tainting or exclusion of fishermen from fishing grounds and not by depressed recruitment caused by the mortality of eggs or fry. Great public concern has been expressed about the impact of the losses of seabirds on the size of breeding colonies, but happily this proves to be unfounded: most colonies are increasing in size and the decline of southern colonies appears to be largely from natural causes.

If present evidence leads to a more reassuring assessment of the impact of oil pollution than was possible a few years ago, areas of ignorance or uncertainty are a source of concern to pessimists. Heavy contamination of fish nursery grounds might have catastrophic consequences for the recruitment of a whole year class for some species of commercial fish. Changing fishery practices might deplete the food supply to seabirds and losses to them from oil pollution then become critically significant. Any assessment must be based on current circumstances and information. If either change, then a new assessment must be made and may lead to different conclusions, but at present oil pollution cannot be regarded as a serious threat to marine ecosystems or human interests except on a local scale, which in most cases is very circumscribed.

This was also the conclusion reached by the Royal Commission on Environmental Pollution in its recent report (1981), but from a political point of view, oil pollution is an emotive issue and the Commission recommended ways of reducing avoidable spillages and discharges, at least in British waters. So long as oil remains a vital fuel source, however, and is transported around the world, it is likely to be released, deliberately or accidentally, into the sea with some impact on the marine environment. Economists will undoubtedly ask that some equation be made between the damage that is caused and the cost of avoiding it. That equation has a biological component that biologists at present have some difficulty in supplying. We are far from being able to evaluate the productivity of, for example, a damaged benthic community at various stages in its progress from a near monoculture of opportunistic species to a diverse fauna. In providing answers to practical questions, scientists are faced with a challenge that reveals important gaps in their understanding of ecosystem function. A great deal is known about ecosystem structure, much less about the partition of energy flow in communities and their functional performance. For both practical and scientific reasons, the need is to gain a better understanding of how an ecosystem functions and how it responds to disturbance.

I am indebted to a number of speakers at the meeting and particularly to Dr Bayne, Dr Lewis, Dr McIntyre, Dr Southward and Dr Whittle for their comments on my assessment of the discussions, though none is likely to be in complete agreement with all the conclusions I have drawn in this paper.

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