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Summary and Conclusions: Environmental Effects of North Sea Oil and Gas Developments

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Summary and conclusions: environmental effects of North Sea oil and gas developments

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This Royal Society Discussion Meeting has examined the total environmental impact of a whole industry in a single geographical area. Land-based developments related to the exploitation of the North Sea oilfields and their social consequences have been substantial, although neither the worst fears nor the best hopes have been realized. An accommodation has been reached with the fishing industry in the affected area.

Offshore platforms are a source of chronic pollution from production water, but in recent years there has been a marked increase in the use of oil-based drilling muds and it is estimated that 20 Mt per year of petroleum hydrocarbons are added to the sea in oil-contaminated drill cuttings. The effect of these additions has been studied in the laboratory, in mesocosms and in field surveys which, together, yield a consistent picture. Within a radius of a few hundred metres of a platform there is impoverishment of the benthic fauna. Close to the platform the production of anoxic conditions through smothering and the activity of sulphide-producing bacteria is probably more significant than the toxic effect of the oil-based muds. Outside this immediate zone of impact, the oil results in organic enrichment and enhanced populations of some of the fauna. The total area affected is, in the context of the North Sea, minuscule. There is no evidence that plankton is materially affected and the success of commercial fisheries dependent upon the plankton crop is more influenced by fishery practices than by any other factor.

Seabird populations, about which there was formerly much concern, have not so far been affected by oil pollution in the North Sea. There is wide fluctuation in recruitment success, but populations of species thought most vulnerable to oil pollution are generally increasing.

Although marine pollution research has yielded valuable insights into the responses of individuals, populations and communities to perturbation, natural as well as man-made, it is not likely that future problems associated with oil extraction from the sea will be as stimulating to fundamental research. Different problems relating to environmental pollution should now be addressed by marine scientists.

Introduction

Marine pollution did not suddenly break upon the world with the wreck of the *Torrey Canyon* in 1967, but it stimulated widespread concern about oil pollution and resulted in a large research effort into the consequences of all discharges to the marine environment, whether accidental or deliberate.

Nineteen years later, marine pollution studies have come of age and during that time there have been innumerable conferences on almost all conceivable aspects of marine or any other kind of pollution. This Discussion Meeting has been a little different from its predecessors because it was concerned with the total environmental impact of a whole industry in a particular geographical area – the North Sea.

The development of oil and gas extraction in the North Sea, described by Larminie, has been extensive and surprisingly rapid. Gas extraction started in 1965 and the first oil production platforms were installed in 1969. A chain of oilfields down the centre of the northern half of the North Sea has been exploited and now there is the prospect of other oilfields closer inshore and to the west of Scotland coming into production. All of this has taken place in a most hostile environment and unprecedented water depths, and has demanded new technology for it to have been possible. It is a testimony to the skill and science of the operators that it has been accomplished with so few accidents.

These developments have taken place during a period when there was alarm and a good deal of ignorance about the consequences of marine pollution, and the oil industry was under pressure to severely limit, if it could not completely avoid, environmental damage. Meeting the public demand for 'clean' technology has resulted in the development of a range of monitoring techniques of increasing sensitivity and subtlety to measure environmental change as well as techniques to contain and deal with spilled oil that minimize environmental damage.

The development of sophisticated measures of environmental change has been the work of those hostile to industrial activity in the sea as much as those involved in it, and as much in relation to other pollutants as to oil. Apart from its immediate and utilitarian purpose, this development has been of general benefit to marine ecological research. It has led to a study and better understanding of natural change in marine ecosystems, which proves to be a very noisy background against which to detect a faint pollution-induced signal. Whether or not it is necessary to have such an acute early warning system for pollution effects is a matter I shall not discuss here, but the striving for greater sensitivity in monitoring techniques has resulted in a better understanding of the responses of marine organisms and marine ecosystems to stresses of all kinds, natural as well as man-made. It is notable, too, that natural change can be as great as, and of a similar nature to, pollution-induced change and this has helped set marine pollution into perspective.

Interactions with human affairs

The North Sea is a multipurpose resource. In addition to oil- and gasfields, it has exploitable sand and gravel beds, supports one of the most productive fisheries in the world, and in the south includes some of the most heavily trafficked sea-lanes in the world. It receives the wastes of the largely urbanized and industrialized populations of 31 million people living around it, together with the large influx of summer visitors to the coast, particularly on its eastern side, and a substantial input from the major rivers entering it (Clark 1986). As Eisma showed, it has complex water movements and is far from being a homogeneous body of water. There are equally complicated seasonal movements of fish and of seabirds for breeding and winter feeding. The various human activities, commercial, domestic and recreational, interact with each other and also with these biological events.

It is in this web of interacting forces that the development of North Sea gas and oilfields has taken place. But as Johnston reminded the meeting, its inevitable environmental impact has not been simply at sea and around offshore platforms. A small fleet is required to supply the platforms; the oil has to be brought ashore mainly by pipelines which have been laid on or trenched into the seabed; and ashore there is the need for oil terminals, refineries, harbour facilities, construction yards for the platforms, housing and the rest of a widespread infrastructure.

It is, of course, impossible for a major industrial development to take place without an impact on the human and natural environment, and the impact may take unexpected forms. One of the major preoccupations of the Zetland County Council is the economic boom in the Shetland Islands resulting from the construction of the Sullom Voe oil terminal and the damage this may do to the traditional way of life in the islands, particularly when the boom passes. On the whole, though, it can be claimed that the land-based operations connected with the offshore developments of the industry have been accomplished without undue friction and without the worst fears or some of the hopes being realized.

Offshore, the chief interaction has been with the fishing industry, and here too, it can be claimed that an accommodation between the two has been reached. The scope for interaction between the oil industry and other users of the sea will be much increased if or when oil extraction moves into shallower inshore water, and a very sensitive approach will be needed if such developments are to proceed harmoniously.

Inputs

The concern of the Discussion Meeting has been much more with the impact on the natural environment of oil and petroleum hydrocarbons. Estimates in 1982–83 put the annual oil input to the North Sea between 100 and 170 Mt (Bedborough *et al.*) and the sources are the atmosphere, rivers, land run-off and general shipping as well as activities of the oil industry itself. By far the greatest input of petroleum hydrocarbons in the sea is from rivers, land run-off and the atmosphere, but these are diffuse inputs, whereas those from oil industry operations are for the most part at fixed sites where the input is chronic and therefore more likely to cause local environmental deterioration.

At one time, the chief concern was about oil pollution from tanker operations, but recently attention has focused on offshore drilling activities, and these now represent a major input of petroleum hydrocarbons to the North Sea. With the increased use of oil-based drilling muds, the input from this source has risen to about 20 Mt per year and until low toxicity oils were phased in after 1982, this was largely in the form of diesel with its greater potential to cause environmental damage.

Sublethal signals

It is, of course, an advantage to have early warning of potentially damaging situations, and for this an array of toxicity tests and studies of the sublethal effects of xenobiotics on a range of animals has been developed.

In the early days of marine pollution research, the approach was naïve and undue faith was placed in the LD_{50} test and the existence of pollution indicator species. Both were crudely misapplied and had little predictive value for the natural environment outside the laboratory. But these studies have now reached a new level of sophistication, not least through the work of M. N. Moore and his colleagues at the Institute for Marine Environmental Research.

Their research on molluscs has shown that changes in response to exposure to petroleum hydrocarbons can be detected at the molecular, subcellular and tissue levels. There is induction of the detoxication mechanisms involving the cytochrome P-450 monooxygenase system, destabilization of the lysosome system and, at the tissue level, atrophy of the epithelium of the

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digestive tubules. These changes have been confirmed in realistic laboratory experiments, in mesocosms, and in the field following actual oil spills. The relevance of these sublethal phenomena to pollution (in the strict sense of that term that the effects are damaging) is firmly established because the metabolic demand of these responses is reflected in a reduced scope for growth and in reduced fecundity with possible implications for recruitment and ultimate population size.

Studies of the sublethal effects of xenobiotics have now matured to the point that they can give early warning of pollution damage and a measure of the recovery of individual organisms from it. Beyond this utilitarian value, the whole field of investigation has proved to be of exceptional scientific interest in giving an insight into the defensive physiological machinery of marine invertebrates to environmental perturbations. It is one of the fairly rare instances in which applied research has had a tremendous scientific spin-off.

Experimental ecology

As a bridge between laboratory and field studies, mesocosms are attractive because they offer greater realism than can be achieved in the laboratory and greater control than is possible in field investigations. The earliest use of mesocosms was in large enclosures for the study of plankton. In their application to pollution research it appeared that while these experiments were very informative about what happened in 'big bags', they were not very relevant to the real environment. Mesocosm experiments involving benthic communities appear to be somewhat more informative, particularly when interpreted in conjunction with the results of field investigations.

Two such studies were reported to the Discussion Meeting. One by Leaver *et al.* was concerned with the impact of drill cuttings and oil-based drilling muds on meiofauna, the other by Gray on the effect of water-accommodated fractions of diesel on a hard substratum intertidal community and a soft bottom subtidal community. Both investigations are long-term; Leaver's experiments have continued for 15 months and Gray's for over 2 years. Both include impact and recovery phases of the ecosystem response.

In the Leaver *et al.* mesocosms, there was a steady decline in meiofaunal abundance even in the control mesocosm. It is not known if this was a consequence of the experimental conditions inherent in the use of enclosures or to natural seasonal fluctuations in the abundance of elements in the meiofaunal community. If the latter, it presents a serious problem in the design of any long-term experiments. At the very least, it represents an important uncontrollable variable which needs to be understood, but seasonal studies of the meiofauna on the Grangemouth intertidal mudflats by C. G. Moore *et al.* begin to give some insight into this.

Next, it is not clear, even when congenial physical and chemical conditions are restored after disturbance, if recovery of the meiofauna is dependent upon recolonization from outside the affected area. This may be a feature of the natural environment but is clearly impossible in mesocosms. Furthermore, in these experiments it is not certain if some of the erratic peaks in recovery of the nematode populations are due to a comprehensive recovery of the community or to the increase in numbers of a single species at a peak time of reproduction.

Gray also had some difficulty in providing satisfactory controls for his rocky intertidal mesocosms, but that is because no rocky shore community is homogeneous and exact replication in each experiment is impossible. Because his mesocosms are not entirely closed, recruitment from unaffected areas is possible for at least some species, and he was able to quantify this for *Littorina*. On the whole, these experiments with macrofauna and flora appear not to have suffered unduly from the uncertainties usually associated with mesocosms, and this may be because attention is focused on a group of species whose biology and interactions are much better known than those of meiofaunal and planktonic communities.

Having noted these problems and uncertainties, the mesocosm experiments do allow some conclusions to be drawn. Deposition of drill cuttings an oil-based drilling muds, whether diesel-based or of the low-toxicity oils that have replaced diesel, have a number of effects which can be separated.

The deposition of drill cuttings, whether oil-contaminated or not, smother the seabed, cut off the substratum from water exchange, reduce the redox potential and increase the soluble sulphide level. The important role of micro-organisms in this sequence of events is explained in the report of Sanders & Tibbetts. This is associated with a substantial fall in the nematode population and the elimination of burrowing copepods, although epibenthic copepods appear able to survive this smothering. If the cuttings are contaminated with diesel or high concentrations of low-toxicity oil, the nematode population continues to decline over the year following deposition of the cuttings, but at low concentrations of low-toxicity oil, shows an erratic recovery. In these circumstances, epibenthic copepods show an enhanced population, perhaps because of organic enrichment by the low toxicity oil. There is also confirmatory evidence of this from field studies in the Beryl field (C. G. Moore *et al.*).

Gray's mesocosms also reveal varied responses of the communities exposed, this time, to high or low dosages of diesel. Attached algae showed little response except, ominously a reduced growth rate of *Laminaria* and *Ascophyllum* during their second year of exposure. This has obvious implications for the alginate industry which harvests these seaweeds. The green algae *Chondrus* and *Ulva*, on the other hand, show enhanced growth.

Of the animals on the rocky substratum, *Littorina* suffered increased mortality at the higher concentration of diesel and *Mytilus* failed to secrete byssus threads, became detached from the rocks and were eaten by crabs. This leads to the intriguing suggestion that a steady dribble of oil from offshore platforms might be beneficial in inhibiting marine growth on the platform legs.

In the soft-bottom mesocosms, mobile species such as amphipods and ophiuroids become less abundant, as do filter-feeders and carnivores. Surface and subsurface deposit feeders on the other hand appear to be less affected, although Leaver *et al.* observed a heavy immediate mortality of the bivalve *Tellina* when drill cuttings contaminated with diesel or a high concentration of low-toxicity oil were added to their mesocosms.

Proof of the pudding

In many ways, it has always seemed preferable to study pollution effects in the real environment than to extrapolate from the apparently more precise results of toxicity tests and microcosm or mesocosm experiments. They can never reflect the compensatory mechanisms that exist in populations and communities in the natural environment. But although there has been no shortage of monitoring programmes of oil pollution effects, they have revealed the familiar problems that beset measuring change in marine ecosystems and relating it to man-made influence. If the pollution is major and from a known source, such as the wreck of an oil tanker on the coast, it is hardly necessary to mount an expensive monitoring exercise to measure damage and assign the cause, even though that is not as certain as might appear at first sight. When the pollution is small, the effects it may have are hard to identify with certainty because of the complexity of the natural environment. Hence the attraction of controlled experiments.

Most, if not all, marine environments show temporal and spatial inhomogeneity and the sampling protocol must be suitably designed to take account of it. This is expensive and time-consuming and in the past, few monitoring programmes have been on sufficient geographical or time scale to distinguish natural from man-made events. In the 4–5 years after the opening of the five refineries around the Milford Haven oil terminal, there was no successful recruitment there of the shore gastropods *Gibbula* and *Monodonta*. As clear a case of cause and effect as one might wish for, except that there was poor or no recruitment of these species in those years on the entire west coast of Britain to the northern limit of their geographical range (Lewis 1982). Few monitoring programmes look so far afield.

Over the past 15 years, considerable effort has been devoted to studying the effects of oil pollution in the natural environment in most situations and forms in which it occurs. At this meeting, attention has been directed chiefly to the offshore platforms in the North Sea.

C. G. Moore *et al.* have examined the meiofauna around the Beryl A platform and also in intertidal mudflats near the Grangemouth refinery, and their results need to be read in conjunction with the mesocosm experiments of Leaver *et al.* Sanders & Tibbetts have studied the effects of drill cuttings on microbial populations at two unnamed offshore installations, and Kingston has taken a comprehensive view of the impact of drill cuttings and the oil-based drilling muds with which they are contaminated on the benthic macrofauna at a variety of North Sea oilfields.

It is difficult from these observations to separate the toxic effects of the oil-based drilling muds from those of the activity of sulphur-reducing bacteria, leading to the production of sulphides, in areas where the seabed is blanketed by drill cuttings and organically enriched by the presence of oil-based muds whether these contain diesel or various formulations of low-toxicity oils.

Close to the platform where the greatest depth of cuttings accumulates, blanketing of the seabed is severe, but a short distance away (50–250 m) where cuttings are 10 cm deep, there is the greatest activity of sulphur-reducing bacteria and production of sulphides. Around the Beryl A platform, meiofauna is impoverished for a distance of 800 m (C. G. Moore *et al.*) and, viewing North Sea oilfields generally, the distance from the platform over which there is an impact on the benthic macrofauna is about 500 m (Kingston). It is anticipated that the impacted area would be smaller around platforms where there are strong bottom currents and dispersion of the cuttings contaminated with oil-based muds would be greater, as in the southern North Sea.

Degradation of the oil in drilling muds results in organic enrichment of the substratum. Moore & Murison reported an enhanced population of epibenthic copepods around the Beryl A platform in 1985, although not in 1984, and they attributed this to the degradation of diesel in the oil-based muds used there until 1982 after which low toxicity muds were employed. No such enhancement of nematode populations has occurred and biodegradation and release is presumably faster at the surface of the substratum than in the less oxygenated layers below, so that surface dwelling animals (epibenthic copepods) might be expected to benefit earlier than animals living deeper in the substratum (nematodes).

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The rate at which diesel and low-toxicity muds degrade is uncertain. From the microbiological studies of Sanders & Tibbetts, it appears that diesel is degraded faster than low-toxicity oils with a high boiling point, but slower than low-toxicity oils with a low boiling point. From Kingston's study of a large number of North Sea oilfields it appears, surprisingly, that Statfjord A and Brent which have used diesel-based drilling muds show more enhancement of the opportunistic benthic macrofauna than at Beatrice which has used low-toxicity muds.

An important finding of Kingston's survey was the extreme patchiness of drill cuttings around platforms. This has obvious implications for any sampling programme and accounts for extraordinarily high and anomalous levels of contamination found in some surveys around platforms. If routine monitoring of contamination levels is required by law, the objectives of the monitoring programme should be explicit and the monitoring schedule designed appropriate to satisfy those objectives (Segar & Stamman 1986). Current legal requirements do not meet this need.

Oil discharges do not affect only animals living in the seabed, but are particularly likely to affect the plankton living in surface waters. Variations in the standing crop of plankton in the North Sea are exceptionally well known thanks to the continuous plankton survey carried out over many years by the Institute for Marine Environmental Research. Attempts have been made to correlate these with climatic and natural water quality changes. As Reid showed, there is nothing to implicate petroleum hydrocarbons with these fluctuations. Although, of course, there remain uncertainties and it is possible to conceive of circumstances in which oil might have some consequence for plankton production, this does not seem a serious risk.

Interest in plankton is primarily because the success of commercial fisheries depends critically on the abundance of plankton. Fisheries have not been seriously discussed, apart from the exclusion of fishermen around platforms and the damage trawls may cause to exposed pipelines, or vice versa (Johnston). It has long been known that the success of a fishery depends more on the practices of the fishermen themselves than on any other human activity.

For many years, the chief concern about oil pollution was its impact on seabirds. It has a very visual impact through the press and television and it produces a strong public emotional reaction. By now, as Dunnet showed, we know that the recruitment of seabirds, like most other maritime organisms, is erratic. Many seabird populations have increased in recent years for unknown reasons and despite losses from oil pollution. Ornithologists are more concerned about the impact of intensive fishing on the food supply of seabirds than the losses from oil pollution, which distressing though they may be in the public eye, are biologically insignificant.

The development of the Beatrice oilfield in the Moray Firth generated considerable alarm because it was the closest to shore of any of the North Sea oilfields. It is close to internationally important seabird colonies and winter feeding grounds, and within the area of economic fisheries. Because of the sensitivity of the area, comprehensive monitoring programmes have been established there (Addy). This survey has revealed the seasonal movements of seabirds in the Moray Firth and may show the interaction of economic fisheries with seabird populations, but happily has not shown any impact of the development of this inshore oilfield except in the immediate vicinity of the platforms. It has, however, done much to reassure local public opinion about the oil industry operations in the Moray Firth, which appears to have been the main purpose of the exercise.

It is scarcely an exaggeration to suggest that seabirds have caused more problems for the oil industry than any other factor. It was the picture of oiled guillemots coming ashore on the

Cornish coast after the wreck of the *Torrey Canyon* that did most to arouse public opinion to the effects of oil pollution and this impression has been reinforced by television and the press at every oil spillage since then.

Tanis & Mörzer-Bruijns (1962) estimated that between 250000 and 750000 birds per year, mainly guillemots, were lost in the northeast Atlantic and North Sea from oil pollution. That may be an order of magnitude too high, but is still an impressive figure. It was thought that these seabirds with their very low reproductive rate could not sustain such continuing losses, and the decline of the breeding colonies in Brittany, France, and southwest England appeared to confirm these fears.

With the development of the North Sea oilfields and the increased traffic of oil by sea, northern seabird colonies were expected to be under greater threat. There was also concern that migratory landbirds crossing the North Sea would be attracted to gas flares and killed in them. Happily, neither of these fears proved justified. Censuses of breeding colonies of guillemot and razorbill around British coasts in 1969 and again in 1974 showed that while fringe colonies at the southern end of their geographical range in Brittany, Cornwall and southwest Wales were certainly declining, those in Scotland were, in many cases, increasing in size (N.E.R.C. 1977).

The underlying reason for this change is probably climatic, but as Dunnet has shown, the extent of seabird population fluctuations and their immediate causes are certainly complex. Public concern about seabirds has led the oil industry to be particularly wary of inflicting damage on them, but development of the North Sea oilfields has had no discernible impact; the development of industrial fishery practices has probably had more by depleting the food resources of the birds.

Conclusions

The past 20 years have seen a large number of meetings, symposia and conferences on matters relating to oil pollution. There have been many alarms and excursions, but they have faded from sight or fallen into perspective. To a great extent we now have the measure of oil pollution. Refinery waste discharged across the foreshore or into shallow water causes progressive environmental deterioration in that area. A tanker wrecked on the coast causes immense local damage, but restoration is more a logistical one of disposing of oily waste than a biological one. The operation of offshore platforms results in a disturbance of the benthic fauna, but only within a few hundred metres and in the context of the North Sea the total area affected is minuscule. Oil pollution has had no significant impact on fisheries or seabird populations.

In this case, it is easy to be complacent and suggest that it is hardly worth investigating oil pollution any further. But technology does not stand still and new developments in the industry will always need fresh evaluation if their environmental impact is to be contained. Dispersants in use 20 years ago were more toxic than the oil they were meant to disperse; once this fact had been explored, it proved possible to introduce equally effective low-toxicity dispersants. In the same way, the rapid increase in the use of oil-based drilling muds in North Sea oilfields led to an evaluation of their impact on the environment, and this has been reduced by the introduction of low-toxicity oil-based muds. No doubt as oil extraction moves closer inshore, further environmental problems will be revealed and it will be necessary to investigate them and reduce them.

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The sort of investigation required to satisfy this need will generally be *ad hoc*, target-oriented and narrow in scope. What place has fundamental science in this? The final session of the United States National Academy of Sciences review of oil in the sea, in 1981, was devoted to the identification of future research needs. It is fairly easy to list areas of incomplete understanding and gaps in our knowledge if the objective is to account for the transport, degradation and fate of all the components of a crude oil, and of all the degradation products; to account for the passage and metabolism of these substances in marine food webs, their sublethal effects on plants and animals, and the responses of marine populations and ecosystems to these sublethal as well as lethal effects of petroleum hydrocarbons. The list is unending. Much of the work would be of trivial scientific interest and for the most part would have no practical significance for the activities of the oil industry.

Papers presented at this meeting have contributed much new information but few surprises. If anything, they have confirmed the earlier view that oil pollution has a detectable but very localized impact, and that the impact can be contained within acceptable limits; or if not acceptable, that the technology exists to reduce the impact – at a price. Perhaps we should conclude that oil pollution research is no longer justified and that it can no longer give useful direction to fundamental marine research. There are more important challenges for fundamental marine science to address, and if it is felt necessary to respond to pressures to do 'useful' rather than 'pure' science, there are more urgent pollution problems which cannot be solved without considerable advances in fundamental scientific understanding, such as acid precipitation or carbon dioxide and the 'greenhouse effect', both of which may well have an important but unquantified marine dimension.

One argument that has not been seriously addressed at this meeting is the awkward one advanced in some quarters that 'no detectable effect' of an input to the sea cannot be equated with 'no effect'. The dispersion and dilution of pollutants may avoid local damage or reduce it to a trivial level, but the waste has nevertheless been added to the North Sea, causing, it is claimed, a widespread if less conspicuous debilitation of marine ecosystems. It is difficult to answer this claim on scientific grounds, but it reflects an attitude which underlies proposed European Community directives and requries consideration if not an answer. In practical terms, that may prove a more intractable problem for marine scientists than any we have discussed at this meeting.

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