FOREWORD

Marine contamination by petroleum, whether by natural seepage or by spills from ships at sea, by accidents in harbour or at offshore installations or by atmospheric or terrigenous input is by no means a new or rare phenomenon. In recent years however, the problems have been highlighted not only by the increased utilisation and marine transport of oil but also by a number of spectacular accidents which have raised questions about possible effects on the ecosystem. A number of detailed studies have been carried out in an attempt to answer these questions. The demands for such knowledge have been further increased by the various questions raised as a result of expansion of offshore exploration and exploitation for oil, particularly in environments hostile to these operations, in regions as far apart as the northern North Sea and the coast of Alaska.

Consequently, diverse aspects of the problem are being studied in several parts of the world by chemists and biologists who are often asking the same questions but using different approaches and sometimes producing conflicting views. Against this background, it seemed timely therefore to bring together a group of scientists from university, industry and government, actively engaged in such work, to examine and discuss common problems relevant to petroleum hydrocarbon contamination of the marine ecosystem and so a Workshop was sponsored by the International Council for the Exploration of the Sea, and held in Scotland at Aberdeen in September 1975.

The Workshop considered methodology, occurrence and fate in the environment, and effects on the ecosystem of petroleum hydrocarbons in the sea. Most of the papers presented and updated where necessary, are brought together in the present volume together with an edited version of the recorded discussion that followed each session. Of necessity, the reportage of the discussion is very brief although the proportion of time available for discussion compared favourably with that set aside for formal presentation of the papers. In preparing the discussion reports, the editors were assisted in particular by Dr R. Hardy, Dr R. Johnston, Mr P. R. Mackie and Dr I. C. White, and by comments from several contributors.

No attempt was made to produce specific recommendations but a study of the papers in this volume does give a clear indication of several lines of research which must be followed up before an adequate understanding can be reached of the effects of petroleum in the sea and it is evident that widespread monitoring operations will be fully effective only when the basis of our knowledge has been thus extended.

A list of participants to the workshop may be found in Appendix I.

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K. J. Whittle

Rapp. P.-v. Réun, Cons. int. Explor. Mer, 171: 196–201. 1977.

ECOLOGICAL EFFECTS OF MARINE OIL POLLUTION

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Field surveys in the intertidal zone provided information on the effects of oil spills, cleaning treatments, and refinery effluents. More precise results for rocky shores, saltmarshes and lugworm beds were obtained by field experiments. The survey and experimental methods are briefly described, and results for the different biological communities summarised. Effects of oils and effluents vary considerably according to type and quantity of oil, cleaning treatment (if any), effluent characteristics, and hydrography and biology of the area affected.

Related laboratory work concerns the toxicity ranking of oils, dispersants, effluents and effluent constituents; and behavioural responses of some organisms to sub-lethal doses of pollutants.

Offshore surveys in Milford Haven, and the Celtic and North Seas, were initiated and are briefly referred to.

INTRODUCTION

During the past few years the Oil Pollution Research Unit has carried out a number of shore surveys and field experiments with the aim of finding the effects of oil spills, cleaning methods and refinery effluents on the distribution and abundance of intertidal flora and fauna.

Related laboratory work concerns the toxicity ranking of oils, dispersants, effluents and effluent constituents, and behavioural responses of some organisms to sub-lethal doses of pollutants. The purpose of the laboratory work is to help in the explanation, interpretation and prediction of effects in the field.

Offshore surveys in Milford Haven, Southampton Water and the Celtic and North Seas have been initiated with the aim of describing, analysing and measuring change in the macrobenthos of areas of oil industry activity.

This paper summarises and updates previously published work and briefly describes work in progress.

EFFECTS ON INTERTIDAL COMMUNITIES

ROCKY SHORES

Long term changes in rocky shore flora and fauna are monitored in Milford Haven, Britain's largest oil port.

Moyse and Nelson-Smith (1963), and Nelson-Smith (1964, 1967) described the distribution of littoral plants and animals in Milford Haven, basing their studies on a series of rocky shore transects. These results, dating from the earliest stages of the industrialization of Milford Haven, form a baseline for all subsequent rocky shore surveys. The transects were re-surveyed by Crapp during 1968—1970 and results are discussed in full in his thesis (Crapp, 1970), and subsequent papers (Crapp, 1971). He concluded that no general impoverishment of the rocky shore fauna and flora had occurred during Milford Haven's first decade as an oil port. There had been, however, a marked change in the barnacle populations, attributable to climatic changes, a decline in the abundance of the topshell *Monodonta lineata* possibly attributable to climatic changes and an unexplained decline in the numbers of *Littorina saxatilis tenebrosa*. Localised effects attributable to the oil industry were observed in the case of Little Wick Bay near a refinery effluent and on Hazelbeach following oiling and dispersant treatment.

Using Crapp's methods, a further survey of some of the Milford Haven transects was carried out during 1973 and 1974. These included areas of particular interest, namely, a shore at West Angle Bay affected by the "Thuntank" fuel oil in 1971, Lindsway Bay affected by the "Dona Marika" petrol in 1973, and the refinery effluent discharge area in Little Wick Bay (Fig. 115). It was concluded that there is some evidence of an unexplained increase of *Enteromorpha* over the areas of Milford Haven re-surveyed during 1974. This will have to be further investigated through complete re-survey. Oil spillages, and in particular the "Dona Marika" pet-

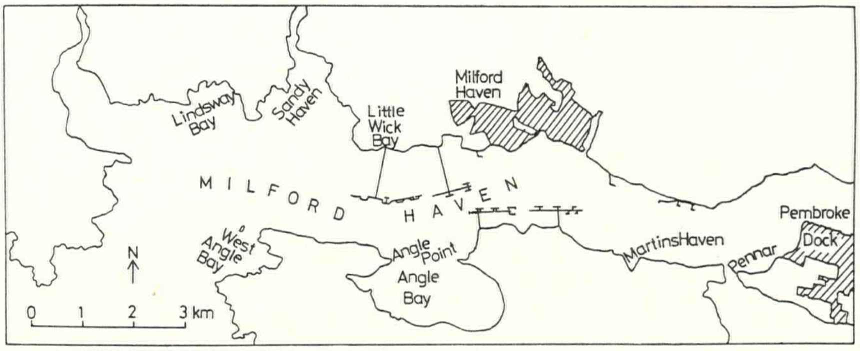

Figure 115. Milford Haven, showing sites mentioned in the text.

rol spillage, caused short-term localized changes, mainly involving gastropod molluscs and the limpet/seaweed ratio. About one mile of coastline was badly affected by the "Dona Marika" petrol in 1973, the most spectacular effect being algal growth following limpet "drop-off", but recolonisation by young limpets occurred during 1974. These effects are described in more detail by Baker (1976a).

In the region of the Little Wick refinery effluent, the numbers and distribution of some gastropod molluscs corresponded closely with the data of Crapp (1971), i.e. *Littorina neritoides, L. saxatilis neglecta, Monodonta lineata* and *Gibbula umbilicalis* are still absent or rare on the transects nearest the discharge.

Limpet densities measured at mid-tide level at 15 sites show that densities are lowest near the effluent and measurements of size show that the largest limpets occur where densities are lowest. A possible hypothesis explaining these observations is that for several years, settlement of new limpets has been prevented by the effluent. The limpets on this particular shore settled and became established there before 1960 (the year the discharge started). The age of the limpets, perhaps in association with the abundant food, explains their size. It is worth noting here that very little is known about the ages attained by shore organisms, but 16 years is considered feasible for a limpet. It is also worth noting that the settlement of another species, the barnacle *Balanus balanoides* is known to be reduced by this effluent as described subsequently.

More detail on effluent effects is given by Baker (1976b).

Field experiments were carried out on rocky shores by Crapp (1971). He used Kuwait crude oil, Kuwait atmospheric residue, and the dispersant B. P. 1002 and concluded that experimental oiling did not damage the flora and fauna except where the application of thick atmospheric residue brought about physical dislodgement of periwinkles and topshells. The application of B. P. 1002 caused substantial mortalities among many species but the main effect was the development of an algal forest following the destruction of limpets.

SALTMARSHES

Observations following oil spills and results of field experiments are described by Baker (1971). A single oil spillage does not usually cause long term damage to marsh vegetation. Short term effects are death of oiled shoots, followed by new growth from plant bases. During the recovery period there may be reduced germination and flowering, a reduced population of annuals and growth stimulation of some species. Cleaning methods (dispersants, burning or cutting) did not reduce oil pollution damage in experimental plots, and in some cases increased it.

Experimental successive oil sprayings indicate that in general recovery from up to four oilings is good, but more than this results in a rapid decline of the vegetation. Species vary considerably in their tolerance of successive spillages and a tentative grouping is given, from the very susceptible annuals *Suaeda maritima* and *Salicornia* spp., through grasses and rosette perennials, to the very tolerant Umbellifer *Oenanthe lachenalii.*

The Martinshaven saltmarsh in Milford Haven, comparatively near oil company installations, has been oiled on a number of occasions and oil dating from the "Chryssi P. Goulandris" spillage of January, 1967. is still present in mud at the seaward end of the marsh; it is present down as far as 50 cm where it was carried by dispersants. Degradation is presumably slow because the mud is anaerobic. Refinery effluent has been discharged down the saltmarsh creek on two occasions, during power crises. The most interesting recent change in the salt marsh vegetation is the death of a large patch of *Spartina* at the seaward end of the marsh. Signs of this were noticed during 1973 and the dead patch became well defined during 1974. Death has not been obviously associated with any one oiling incident or the effluent discharges, so the cause is debatable. It

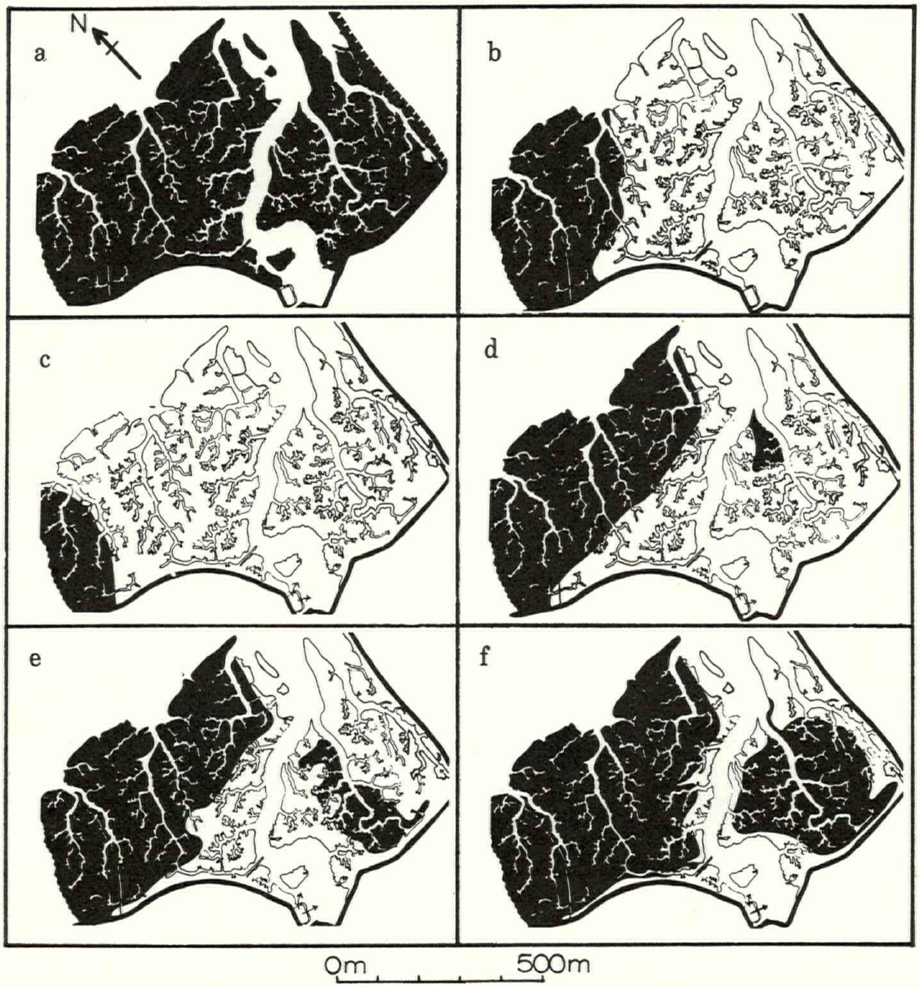

Figure 116. A series of maps summarising the changes in areas containing living marsh plants at Fawley from 1950 to July 1974. a, 1950; b, 1966; c, 1970; d, 1972; e, 1973; f, 1974. Areas containing living marsh plants shaded black.

could be a chronic pollution effect or it could be a natural die-back. There is some evidence that *Spartina anglica* can eventually succumb to waterlogged reducing conditions (which the plant may help to bring upon itself by trapping fine silt). Goodman and Williams (1961) decided that *Spartina* "die-back" was caused by a toxic reduced ion, possibly sulphide, in the substrate. The Martinshaven effect does not, however, entirely fit this picture because some of the dead plants are in relatively well drained stony mud and in other parts of the marsh *Spartina* is flourishing in more badly drained conditions. The dead patch is, on the other hand, in the position where small oil films land from time to time, where the short-lived effluent discharges fanned out, and where oil is still, in places, present in the mud. The evidence suggests, therefore, that it is a chronic pollution effect.

The effects of a continuous refinery discharge have been studied in Southampton Water. An area of *Spartina* marsh which died over the period 1951–1970 has been mapped and reasons for death investigated. Soil pH, soil oil content, sulphides, outfall water temperature and pH do not in general reach prohibitive levels over the affected marsh, and it was concluded that plants died as a result of oil films from the discharge and elsewhere which were stranded on the plants following high spring tides. The saltmarsh has been re-surveyed twice each year since 1972 to monitor any changes in the distribution of plant species in association with an effluent improvement programme initiated by the refinery. The results are described in detail by Dicks (1976a). Recolonisation of some parts of the previously denuded areas has taken place (Fig. 116) and this appears to be associated with the effluent improvements although other factors may well be important (e.g. the recent mild winters and the virtual absence of acute oiling incidents since 1970).

The most widespread of the recolonising plants is *Salicornia*. If recovery continues, the sequence in which the plants are recolonising the denuded areas could result in a saltmarsh dominated by species other than *Spartina anglica*.

SAND AND MUD FLATS

Field experiments on the lugworm *Arenicola marina* are described by Levell (1976). Plots were set up in dense *Arenicola* beds in an area of muddy sand (Sandyhaven, Milford Haven). Pollutants used in the experiments were fresh Kuwait crude oil, B. P. 1100X dispersant, and mixtures of 1:1 and 5:1 oil: dispersant. *Arenicola* densities were estimated by counting casts; the relationship of cast numbers to animal number was determined as 1:1.

Simulated single spillages result in a rapid decline of cast production and then, over the following month, a gradual increase in feeding activity reaching a constant level of 50—75 % of the original *Arenicola* density. Animals extracted from the substrate twenty-four hours after pollution all seemed moribund and flaccid although no dead animals were found. During the following week it appears that the majority of these animals recover and continue to feed, and the rest either die and decompose or leave the substrate. It was noted that the burrows of all the animals found dead within the substrate were lined with a thick layer of oil even though the substrate surface showed only traces of an oil film after two or three days of tidal submergence.

Simulated repeated spillages at two monthly intervals caused progressive reduction of the *Arenicola* density. Four successive spillages resulted in eradication of the original population of 20—25/0·25 m^2.

Recolonisation of plots by juvenile *Arenicola* is being monitored. The recolonisation of recently polluted substrates is inhibited but it is not yet known whether settlement is selective or non-selective. There may be a complete non-selective settlement of juveniles in the area, survival occurring only where the substrate was unpolluted.

Experiments carried out at a badly drained site and in an area where there was standing surface water following heavy rainfall show that Kuwait crude oil does not appreciably penetrate a waterlogged substrate. In these plots there was no significant reduction of cast numbers following oiling.

TOXICITY TESTING

COMPARATIVE TOXICITIES OF POLLUTANTS

Work has been published on the comparative toxicities of oils and dispersants. With saltmarsh plants tested by spraying and assessing recovery over three months (Baker, 1971), the low-boiling fractions are the most toxic and fresh crude oils are more toxic than weathered oils. Undiluted B.P. 1002 and B.P. 1100 dispersants were both more toxic to plants than fresh Kuwait crude oil, but neither caused permanent damage at concentrations of less than 10 %.

Ottway (1971) using 1 hour exposure times and 5 day recovery periods, tested twenty different crude oils on the winkle *Littorina littoralis* and found a wide range of toxicities with the translucent thin brown oils being the most toxic. Further work by Ottway (1976) showed that oil products with low boiling points appeared to be more toxic than the heavier fuel oils. Ottway found that there appeared to be no simple relationship between, on the one hand the toxicity of oil and dispersant mixtures and on the other the toxicity of oil or dispersants alone. In some cases the oil and dispersant mixture was more toxic than either the crude oil or the dispersant.

Comparison of the toxicities of refinery effluent samples may be used to help trace sources of toxicity and preliminary experiments were carried out at the Kent refinery during August, 1974. Winkle activity was used as an indicator. Test winkles (*Littorina littorea*) were used to assay effluent samples collected over 24 hour periods from different effluent streams. Effluent samples were all kept in a refrigerator until needed, then raised to test room temperature before being tested simultaneously on tanks of winkles. (It is not valid to test different sets of samples at different times of day, because winkles have a diurnal rhythm of activity).

In the case of cooling water from the main plant and the lubricating oil plant, winkle activity was not depressed significantly below that of the controls; however, there was a depression in the case of the process water. Further process water tests, using samples taken from the weirs of the two separators, confirmed this result and also indicated a considerable difference between the two separators. One had a very variable pH and salinity, and had a general depressing effect on winkle activity. The other had less variable pH and salinity, and a less depressing effect on activity: however, there appeared to be an inverse relationship between pH and activity. Since the lowest activity was at the two values closest to the pH of sea water, it is unlikely that pH alone is the causal factor, but it may reflect other effluent characteristics that were not analysed.

Although these results do not go very far in elucidating the problem of effluent toxicity, they do illustrate the possible use of bioassays for this purpose. Work on developing and using a more sensitive test than *Littorina* retraction is being carried out by S. Hainsworth. Preliminary results indicate that different test species can give significantly different toxicity rankings of samples from effluent streams.

TOLERANCE RANKINGS

Tolerance ranking of species from rocky shores and saltmarshes has been worked out for some oils and dispersants. The tolerance of saltmarsh plants to Kuwait crude oil (Baker, 1971) varies from the sensitive annuals to highly resistant rosette perennials. The tolerance of littoral molluscs (Crapp, 1971) to B. P. 1002 varies from the sensitive limpet (*Patella vulgata*) to the very resistant topshell *Monodonta lineata* and winkle *Littorina littorea.* More casual observations following oil spills indicate that these tolerance rankings hold good for pollutants which were not systematically tested.

BEHAVIOURAL RESPONSES

Common types of laboratory toxicity test use death of the test animal as the criterion for toxicity. This is sometimes not a useful criterion for tests, e.g. those involving effluents, because some pollutants are not acutely toxic and death of test organisms may not occur for days or weeks if it occurs at all. As Cowell (1974) has pointed out, the long term continuous flow experiments necessary for this type of test suffer from almost insuperable problems of differential absorption of hydrocarbons onto tubing and tank sides and stripping of volatile compounds through aeration. Easily observed short term behavioural responses are more promising as a basis for bioassay or toxicity ranking tests.

Responses which have been used so far are:

Non-activity of barnacle nauplii;
Retraction of winkles into their shells (Parsons, 1972);
Escape reaction of ragworms from their burrows;
Limpet detachment.

Work on behavioural responses is described by Dicks (1976b). He concluded that:

a) rhythm in an animal's activity can substantially influence its susceptibility to pollutants, and that this should be taken into account during toxicity testing for comparative purposes;
b) mortality tests may produce misleading results for making ecological predictions as sub-lethal doses can result in mortality on the shore by inducing an unfavourable behavioural response;
c) tests using behavioural responses are more suitable than mortality tests for making ecological predictions because they take into account criteria of importance to organisms in their environment;
d) the low salinity of a refinery effluent was at least as important as other effluent characteristics in producing a response in barnacle nauplii, and this response has resulted in a reduced population density of adult barnacles in the immediate area of the effluent outfall.

OFFSHORE SURVEYS

Offshore surveys in Milford Haven, Southampton Water, the Celtic and North Seas have been initiated with the following aims:

a) description and analysis of macrobenthos in areas of oil industry activity;
b) detection of natural and oil industry-related changes.

The aims and requirements of a biological survey are rather different from those of a monitoring programme. The usual approach in a little known offshore area is an initial large-scale survey followed by choice of restricted areas for more detailed work. The sampling method most commonly used is grabbing, using a Day grab which samples $0{\cdot}1\ m^2$ to a depth of about 10 cm. Samples are sieved on board ship, usually using a 1 mm mesh sieve and everything retained by the sieve is stored in 4 % hexamine buffered formalin in sea water and stained with eosin to facilitate sorting in the laboratory.

Base-line survey results for Milford Haven (Addy, 1976) and for the Ekofisk oilfield in the North Sea (Dicks, 1976c) have been published. Work is in progress on a follow-up Milford Haven survey, surveys in Southampton Water and the Forties Field (North Sea) and a wide-ranging semi-quantitative survey of the Celtic Sea. Quantitative work carried out in the Ekofisk oilfield in 1973 (10 grab samples per site at 24 sites) did not pick up any gradients in distribution and abundance of macrobenthos that could be related to oilfield installations.

Monitoring results as opposed to original surveys will not be available for some time, so we are not yet in a position to say anything about natural or other changes from year to year, or from season to season. However, a point worth making with regard to accurate monitoring concerns numbers of grab samples per sampling area. With the relatively homogeneous bottom of the Ekofisk field, it was found that eight to ten grab samples per sampling area was the minimum required for acceptable standard errors and confidence limits. With less than this number, the confidence limits are so large that monitoring would pick up only very large changes in the fauna. More than ten grabs per site are necessary for more variable areas.

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