PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Summing-Up: Deficiencies and Future Needs

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Summing-up: deficiencies and future needs

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Introduction

Although there are a great many experimental studies of particular pollutants and their effects, and some critical examination has been made of the mechanisms involved, there is great difficulty in determining whether such effects, if they are sublethal, occur in the sea. There is even more difficulty in deciding whether they produce significant harm in loss of organic production affecting, for example, the living resources of the sea: the stocks of fish and shellfish. Extrapolation from the results of laboratory experiments to the situation in the sea is hazardous because of the simplicity of experimental conditions in comparison with the complexity of the marine environment.

The theme of the Discussion Meeting was the need to bridge this formidable gap between the laboratory and the real world of the sea. A review of the scope and limitations of techniques available to measure sublethal effects in the laboratory was developed through an examination of the use of test animals planted in the sea and the use of simulated ecosystems in large floating enclosures, to a consideration of the application of the results to the control of substances established as likely causes of pollution. Procedures (borrowed in the main from radioecology) for the assessment of effects, especially those resulting in hazards to human health or damage to particular living resources, were described but examples of their application to particular substances outside this field are few – perhaps mercury is the best example – and their undeniable success in limiting risks due to radioactive waste discharge has so far made little impact in a wider marine pollution context.

Although the scientific papers in this volume show clearly that there is no lack of original ideas for the measurement of pollutant effects, the apparent precision of some of the techniques described is seriously weakened by lack of knowledge of the chemical state in which potential pollutants occur in both experiments and the sea and, especially, by the elimination from most trials of many environmental variables which may profoundly modify the effects produced. In addition to chemical speciation, already referred to, it is clear that the extent of the association of potentially polluting substances with particulate matter, and the effect of this upon their availability, is of major importance. Thus laboratory and tank-scale trials can usually do no more than provide a first indication of the potential for harm of a particular substance and although enhancement of effects in the sea by combined action with other substances may occur, there is probably greater likelihood of reduced consequences owing to complexing, adsorption, precipitation and other physical and chemical processes.

Some new avenues of possible advancement were revealed during the discussion and these are summarized in the concluding section of this paper, together with the principal conclusions regarding future research needs derived from consideration of the individual contributions.

Review of contributed papers

The Discussion Meeting was carefully structured so as to begin with a review of the problems associated with the assessment of sublethal effects of polluting substances in the sea and to proceed by way of an examination of examples of the different methods available for use in the laboratory, in large enclosures or in the sea, to an appreciation of the difficulties in separating such effects from natural variability in populations and the problems of developing standards and criteria which could provide a sound basis for control.

Dr Waldichuk, in his initial review, stressed changes in reproductive capability as the most important of sublethal effects. He reminded us that for the sea we are concerned with populations rather than with individuals (in contrast to the situation in human affairs) and that no examples can be quoted of populations of marine fish or invertebrates which have been reduced by pollution (this is perhaps not true of certain seabirds). Dr Waldichuk quoted, however, examples from fresh water and mentioned also the seals of the Baltic which seem to be suffering in their reproductive capability because of polychlorinated biphenyls and DDT and this may have reduced the population. All other types of sublethal effects are of less importance, since, unless they can be shown to influence reproductive success, they are not significant at the population level.

Dr Waldichuk concluded by pointing out where, in his view, additional research is required. He stressed the need to take physiologists into the environment to make observations directly so that the artificial simplification of laboratory experiments can be avoided or reduced. He mentioned also the value of taking animals to the suspected pollutants by using, for example, caged fish, molluscs or crustaceans, or by exposing plates carrying settled populations of benthic invertebrates, an approach demonstrated very clearly by Dr Stebbing in a subsequent paper.

The limitations of laboratory bioassays (toxicity tests) were also examined by Dr Waldichuk but he did not refer to the absence of suspended particulate matter in most laboratory experiments, a difference from conditions in the majority of coastal waters that profoundly influences the effects of many pollutants, including some of the most potentially harmful, as was made abundantly clear by Dr Burton in a later contribution. It is evident that we must begin to look upon standard l.d._{50} results, even those obtained in running seawater over 96 h, as only the very beginning of the assessment of the possible effects of particular substances.

This approach was further developed by Dr Perkins who argued for bioassays of sublethal pollutants realistically related in duration to the life-span of the species concerned. Although good reasons were adduced for this view, the high cost in money and man-hours in running precise experiments for long periods seemed to be largely ignored. It is generally known, for example, that in the assessment of potential carcinogenicity, quick tests, based largely on effects on bacteria, are being very extensively used for initial screening of new chemicals, because of the expense of long-term experiments with laboratory mammals. In other respects, however, Dr Perkins was essentially practical and realistic and very much aware of the deficiencies of much work on toxicity. He mentioned the importance of including the examination of recovery processes; the possibility that recovery may occur following damage by pollutants is often ignored and rarely precisely assessed. There was a reference in Dr Perkins' paper to beneficial effects of some substances normally classed as pollutants and further examples were provided by other speakers.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

A discussion took place here, which was extended later, on the choice of animals for bioassays and strongly divergent views were expressed. Personally, I deprecate the search for more and more sensitive organisms or life-history stages, believing firmly that animals (or, in certain circumstances, plants) should be chosen for bioassay that are of high economic importance and are readily available at the various stages in their life cycle, preferably with a wide geographical distribution so that results from different laboratories can be realistically compared (see F.A.O. 1977). The subject of comparability of techniques in pollution work was not considered during the Discussion Meeting but the efforts made by I.C.E.S. (1974, 1977*a*, *b*) and other international bodies in this field have shown that continued work is very much needed.

Dr Burton, in describing physico-chemical limitations of laboratory experiments, dealt mainly with chemical speciation, making it abundantly clear that the problems of duplicating conditions in the sea in laboratory tests are formidable and will be resolved only with great difficulty. In view of the very limited research in this field, and its confinement to only a few substances (not always those of greatest significance as pollutants in the sea), his plea for closer cooperation between marine chemists and biologists is very timely. Dr Burton also directed attention to the problems associated with pollutants, particularly metals, which exist in both dissolved and particulate states in the sea. The relative proportions may, it seems, differ so widely between experimental vessels and, say, turbid coastal waters, as to render extrapolation from the laboratory to the sea virtually impossible. Although the biological implications of Dr Burton's thought-provoking paper were not examined in any detail, they are clearly profound and should be sufficiently obvious to provide a brake on the use of bioassay tests, as usually performed at present, for regulatory purposes. It is, however, generally known that such 'standard toxicity tests', carried out over periods of 48–96 h, not always in running seawater, figure very largely in evidence presented to international regulatory bodies regarding the potential harm that particular contaminants may cause.

The incidence of skeletal abnormalities in fish, and their possible connection with polluted conditions, were described by Dr Bengtsson, backed by experimental work with freshwater fish in which a high proportion of individuals showed abnormalities. In natural populations of both freshwater and seawater fish, abnormalities are not usually present in more than about 10 % of the population, often much less, and no evidence of lethal effects in seawater fish has so far been found. Mortalities might, however, pass unnoticed in wild populations, if they occur during the young stages. The list of causative factors for such abnormalities is extensive and embraces many conditions already recognized as potentially harmful. Deformed fish are considered to be vulnerable to predation but their presence, and loss, seem unlikely to have a significant effect at population level in the sea. Such affected fish may, however, have value as indicators of unsatisfactory environmental conditions.

Dr Stebbing described the use of a clone of the common colonial hydroid, *Campanularia flexuosa*, for the assessment of water quality. It was noted that the initial response was to divert energy from growth of hydranths to the production of gonozoids, so increasing reproductive capability. This seems to be the development by natural selection, in response to adverse conditions, of characteristics having survival value, and other examples were quoted later, such as the storage of mercury as mercuric selenide by black marlin and the accumulation of metals in granules by various invertebrates. These detoxification and protective mechanisms undoubtedly warrant further study.

Although the use of *Campanularia flexuosa* was initially to assess water quality, the technique is being developed to measure responses to particular groups of pollutants. It can also be used for general field surveys of allegedly polluted areas and for the detection and quantification of cyclic and seasonal changes. It may have value as an early warning technique which could be used by local authorities, such as Regional Water Authorities in the United Kingdom, with responsibility for pollution control. Similar techniques, perhaps employing quite different organisms (animals or plants), may help to facilitate an area-by-area study of marine pollution which has much to commend it as an alternative to the blanket application of emission standards and environmental quality criteria.

Dr Bryan gave extensive factual data to provide a basis for an understanding of bioaccumulation and also examined the extent of the occurrence of biomagnification at the higher trophic levels. The subject was shown to be substantially more complex than is generally appreciated and the folly of generalizations was clearly demonstrated. Bioaccumulation is an important subject in relation to the deliberations of both national and international regulatory bodies; the word is frequently used, generally in the context of anticipated serious harm to living resources, without a full understanding of the processes involved. In particular, it is not appreciated that substances taken in by an animal may also be quickly 'lost' by natural processes of metabolism and excretion or may be stored out of harm's way.

Dr Bryan showed that the ability to regulate metal content existed to differing degrees in various classes of marine animals and the influence of age, size, stage of maturity and other physiological parameters was briefly examined. The existence in the wild of strains of common benthic animals acclimatized to very high levels of copper, zinc and other metals was recorded: the fauna of Restronguet Creek, River Fal, with bottom sediments containing very large amounts indeed of metals, appear normal and the estuary to which the creek discharges has been a productive oyster fishery for at least 100 years.

Dr Bryan mentioned that the bulk of many contaminating substances discharged to the sea, including most of those considered to be potentially harmful, is to be found in the sediments, particularly those containing much fine material and with a substantial content of organic matter. The mechanisms and dynamics of uptake and release of pollutants from sediments and their transfer to biota, although not strictly perhaps within the remit of this Discussion Meeting, can clearly be identified as a subject deserving much increased attention. One aspect of some importance is that heavily contaminated sediments, e.g. in industrialized estuaries and in the vicinity of large outfalls (including those discharging sewage), may continue as potent sources of pollution of marine biota long after the recognized polluting discharges from land have been controlled. A good example is provided by the sediments contaminated with mercury lost from chlor-alkali plants now converted to eliminate most of the mercury discharge.

Behavioural responses and their use in the assessment of sublethal effects of pollution were reviewed by Dr Eisler who noted that the bulk of the research in this field has been published within the last decade. No regulatory body at present relies upon behavioural effects in controlling pollution but a few schemes employing live freshwater fish in automatically operated early warning systems have been described. Particular responses, e.g. in swimming performance or shoaling behaviour, could trigger alarms or, if sufficient confidence in the method is developed, operate shut-off or flow diversion mechanisms so avoiding costly damage. Such systems might be very useful to provide protection against losses due to unplanned releases of potentially highly damaging mixed effluents. Ultimately they would be replaced by detectors based upon the identification and measurement of the particular substances deemed to be of critical importance. We are, however, some way from identifying these substances, particularly in organic effluents.

Professor Gray was concerned to analyse the ways in which benthic populations reacted to heavy pollution by organic wastes, e.g. sewage and pulp mill effluents and also oil. He showed that initially the result is increased dominance by a small number of species, for example the worms *Capitella*, *Polydora*, *Scolelepis* and *Heteromastix*, which may become enormously abundant. These he described as opportunist species able to adapt their reproductive strategy to take quick advantage of a new situation. Deeper analysis showed, however, that worms previously considered as single species in fact comprise complexes of several species differing in reproductive systems, and these differences enable the mixed populations to respond quickly to a range of changed situations. In the situations examined there are also what Professor Gray called 'middle level species' which do not possess these adaptive characteristics and are recommended as more sensitive indicators of organic pollution. He concluded that life history adaptation is more important than tolerance (as usually measured by bioassays) in dealing with pollution. The capacity to respond quickly to organic pollution is evident in a wide range of species.

The paper by Dr Bayne was concerned mainly with integrated physiological and biological measurements, particularly 'scope for growth', as an indication of ecological fitness in *Mytilus edulis*. Although marked changes in scope for growth in mussels can be produced by several natural disturbances in the environment, as for example exceptionally hot summers, storms and severe winters, evidence was produced of differences between mussels from the River Lynher, King's Dock, Swansea, and the River Swale which were probably related to the different levels of gross input of sewage and industrial wastes. Differences in scope for growth could be related to differences in fecundity and probably in egg quality. In this way effects on individuals can be extended to potential effects on populations.

In the studies reported use was made, in the analysis of the results, of a standard mussel of 1 g dry mass (a conception worthy of wider adoption) and the physiologists were taken to the animals in the way recommended by Dr Waldichuk.

The joint paper by Dr Davies and Dr Gamble and that given by Dr Steele were closely related and can be considered together. This work in large floating plastic bags has created wide interest, in part because it is a conscious effort to bridge the gap between laboratory investigations and the situation in the sea. It would, I think, be fair to say that although this objective has not been realized to the extent anticipated – conditions in the bags are still to a substantial extent artificial – this type of work is now moving forward to fields which may be more productive than the heavy metals initially studied, e.g. oil hydrocarbons and sewage. I was particularly pleased to hear of the projected work on sewage dumping because sewage disposal is a major continuing world problem which will grow in size rather than diminish and the cost: effectiveness ratio of the earlier lines of work with these expensive containers might not appeal to research managers with a keen economic sense.

Dr Cushing's paper (presented at the meeting by Mr D. J. Garrod) illustrated the degree of variability from year to year in recruitment to commercial fish stocks, established as the result of the analysis of a long time series of data, and the consequent difficulty in distinguishing any effects of artificial stresses such as pollution from natural variability. Dr Cushing could equally have used data relating to molluscan shellfish populations although they are much less abundant. The year-to-year variation in year-class strength and recruitment to the exploitable stocks is enormous. Dr Cushing continued by giving examples of the scale of population changes (declines) resulting from heavy exploitation by man. He quoted exploitation rates killing 40–50 % of stocks of fish per year without providing convincing evidence of any detectable effect on recruitment because of the protective effect of very heavy egg production. This very large egg production is an adaptive mechanism cushioning the stock against severely damaging environmental circumstances. Dr Cushing showed that, in fish larvae, increased death due to pollution is likely to result in compensating *decreased* density-dependent losses. During the discussion it appeared that the one situation in which pollution might conceivably have a large effect on fish stocks would be by massive kills at localized spawning grounds. The lesson is clearly to manage each stock so that other major causes of loss, particularly exploitation, do not reduce abundance to such a low level that the relatively small additional stress due to pollution can have a serious effect.

The last paper by Mr Preston was concerned with the description of procedures, largely borrowed from the field of radioecology, which could give a more rational system of both assessing the *significant* effects of pollution and of controlling their discharge to maintain risks to man and the living resources at an acceptable and safe level. These procedures are based on what is called the 'critical path' approach. It seems necessary to emphasize that, despite what may have been said at the recent Windscale enquiry (1977), there has been successful control of the disposal of radioactive waste in the United Kingdom based on the application of these methods. The results have been fully published and are freely available for examination. Published data (see, for example, Mitchell 1977) confirm that levels of exposure are well below the dose limit recommended by the International Commission on Radiological Protection. The methods employed are those described by Mr Preston and he has explained how they could be adapted for the control of other kinds of pollution of the sea. If we are to avoid an approach based upon uniform emission standards for industrial discharges (imposed primarily for trade equilization purposes within the E.E.C. (see Portmann 1978)) and blanket application of water quality criteria, without any reference to the differing influence of varying environmental factors from area to area, we really must pay more attention to the methods adopted by the radioecologists. They have been proved in practice and I have no doubt that they are capable of wider application but, as Mr Preston notes, much new observational and experimental work is required. It is high time that the development of this approach was taken in hand.

Deficiencies and research needs

A major deficiency revealed by the Discussion Meeting was the lack of knowledge of the chemical state of polluting substances in both laboratory experiments and the sea. Because of this the results of much of the work on the bioassay of particular substances must be treated with great reserve. Information regarding the state of the substances when added may not indicate the form in which the supposed pollutant reached the test animal or the condition in which it commonly occurs in the sea. It is clear that the processes of complexing, adsorption and precipitation have a major influence on the availability of potentially polluting substances added to the sea, perhaps especially of metallic residues. These processes may be responsible, especially in turbid estuarine waters, for removal of many substances from the water column and their accumulation in sediments. There they may become available to benthic animals and the extent to which they are recycled by passage through the benthos and thence to their

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

predators needs urgent examination. This subject lends itself to experimental investigation in laboratory vessels, as Jernelöv (1970) showed in his research on mercury. With the aid of appropriate radionuclides some very precise work would be possible. The general problem of the exchange of contaminants between the water column, sediments and biota, and the influence of environmental variables upon the rate of these processes, is a broad field of study which has so far received far too little attention. As indicated earlier, it is highly relevant to pollution control because potentially harmful metals and complex organic substances resistant to biological breakdown may accumulate in such sediments, often in shallow coastal waters very close to the point of discharge of wastes.

Another major deficiency in the attack on marine pollution is the failure to take advantage of the precise work done by the radiobiologists in developing the critical path approach (Preston 1974) to the control of the discharges of radioactive waste. It is claimed that the situation is simpler in dealing with radioactivity because there is a single target organism – man – and other elements in the marine ecosystem are protected, if human health is safeguarded, because of their lower sensitivity to radiation damage. However, there is no doubt that the approach can be modified so that, for example, possible damage to commercially important marine fish stocks could be assessed and limits to discharges fixed to provide satisfactory margins of safety. Such a precise approach to major discharges of potentially polluting substances, which takes account of local circumstances, seems to be substantially more rational and scientific than reliance upon uniform emission or water quality standards for particular substances which, although soundly based in one area and set of circumstances, may be either too lax or unnecessarily restrictive in quite different environmental conditions.

The importance of establishing the significance (in the strictly quantitative sense) of different types of sublethal effects in affecting population levels rather than individuals was stressed in the first contribution to the Discussion Meeting, but it is not yet generally realized that sublethal effects, for example on enzyme systems, must be related to some loss of reproductive capability if they are to have an effect at population level. Unfortunately, reproductive performance is difficult to assess unless animals can be reared in the laboratory and even diminished fecundity or embryonic defects may not be significant if, as in most fish, there is excess production of eggs with 99.9 % or more of larvae going to waste.

The penetrating studies reported on *Mytilus edulis* show, however, that there is hope of finding easily measurable effects which can be correlated with reproductive capacity. Mussels are already being used to monitor environmental variables (a subject closely allied to the measurement of sublethal effects) but have one great disadvantage as test animals: their ability to close the shells and cease filtration, so protecting themselves against objectionable substances in the ambient seawater. The development of a similar integrated approach to environmental stresses (including pollution) with other common widespread shore animals of commercial value (e.g. crustaceans) could have particularly valuable results. The practice of relating the results to a 'standard mussel' is one borrowed from work with radioactivity and should be more generally adopted in bioassays and other work on the effects of marine pollutants.

A different approach to the monitoring of water quality, by using standardized elements of the benthic fauna, was well demonstrated by the work on *Campanularia flexuosa*. Other species have been recommended and used and the choice will vary with circumstances, area, and latitude: there is little doubt, however, that from the applied angle this approach has much to commend it since it can provide a quick demonstration of adverse conditions. It will be

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

important to select animals (or plants in some circumstances) whose responses can be quantified with reasonable precision.

Several novel approaches to the assessment of water quality were suggested during the discussion: the most interesting was perhaps the effect of environmental contaminants on the number and range of parasites, e.g. of fish, and this seems worthy of further investigation. There was also a suggestion that the newly hatched larvae of certain helminths could be used as test organisms in the laboratory, since the eggs can be stored for long periods and would still remain fully capable of releasing viable larvae under standardized conditions.

Much doubt was cast on the value of standard laboratory bioassays (the so-called toxicity tests) for reasons explained above: the discussion included consideration of the choice of test animals which revealed widely divergent views. Because we are concerned with the management of coastal waters and the sea for the benefit of man, rather than with the preservation unchanged of the marine environment, it is rational to relate the testing of potential pollutants to species of economic value. They should clearly be readily available at the different life-history stages and have a wide geographical distribution. It would be an advantage if they had previously been closely studied so that not only the pattern of population changes was understood but also their physiology, histology and biochemistry. If techniques for their artificial rearing in the laboratory had been developed this would be a further advantage. One hesitates to use the adjective 'normal' in referring to, for example, physiology because it seems best to regard pollution as one of a number of environmental factors to which the organism has to respond. Many of these, e.g. dissolved oxygen, turbidity, salinity and temperature, may at times put the organism under severe stress so that it is virtually impossible to establish where normality resides. Moreover, as was mentioned during the Discussion Meeting, some substances labelled as pollutants (and therefore harmful according to accepted international usage of the word) may have a beneficial effect at particular concentrations. These beneficial effects warrant further examination because they seem to represent an initial reaction to pollution similar to the response to adverse naturally produced environmental conditions. It would be interesting to know whether such initial beneficial effects have been observed with synthetic substances which do not occur naturally in the sea.

Detoxification processes in marine animals must clearly be of widespread occurrence, particularly those associated with naturally occurring substances. Storage within particular tissues or organs is a form of detoxification and new examples (see Walker 1977) are steadily coming to light. Further research in this area is likely to be profitable and would help to provide a better understanding of bioaccumulation, a term which has come into general use, particularly in discussions in international regulatory bodies, without anything approaching a full understanding of the complexity of the processes of uptake, metabolism, storage and excretion involved. The need for more precise statements regarding this subject, and for a better understanding of the effects of environmental factors upon the rates of accumulation and discharge of potentially harmful substances, hardly needs stressing. Once again the application of the methods of the radiobiologists could make an important contribution.

Several examples have come to light in recent years of acclimatization by benthic invertebrates to raised levels of certain metals. It is suggested that relatively short-term natural selection may have occurred so that strains able to withstand very high concentrations have been established. There are some obvious difficulties in accepting such an explanation and further search for such tolerant forms might be worthwhile so that other possible mechanisms

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

of adaptation could be explored. If such adaptation, e.g. to metals, were widespread it would certainly raise doubts about the use of benthic organisms as pollution indicators. The whole concept of indicator organisms clearly needs rethinking in the light of the discovery that several worms known to flourish in situations subject to heavy organic contamination exist as complexes of closely related (but not interbreeding) species, some members of which are able to take quick advantage of a locally changed environment. It seems unlikely that these species complexes exist only within a particular group of worms.

We need to have clearly in our minds the objectives of marine pollution control. These are best defined, I believe, by reference to the definition of marine pollution developed by the United Nations Joint Group of Experts on the Scientific Aspects of Marine Pollution (Gesamp) and now generally accepted. This refers to 'such deleterious effects as harm to living resources, hazards to human health, hindrance to maritime activities or reduction of amenities'. We are not seeking to preserve the marine environment unchanged but to conserve its resources, including those elements in the marine ecosystem upon which the resources depend. All these objectives are man-orientated and this is right: the marine environment must be managed for the benefit of mankind and not merely preserved. Management implies change and dynamic equilibria rather than a static condition. A certain amount of change due to pollution may be acceptable, just as we accept change due to exploitation of fish or shellfish stocks or the extraction of oil or gas. It is always the degree of acceptable risk that we seek to determine and the economic aspects of pollution prevention cannot be ignored.

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