*ECOTOXICOLOGICAL TESTING FOR THE MARINE ENVIRONMENT. 1984.
G. Persoone, E. Jaspers, and C. Claus (Eds). State Univ. Ghent
and Inst. Mar. Scient. Res., Bredene, Belgium. Vol. 1. 798 p.*

MARINE ECOTOXICOLOGICAL TESTING IN CANADA - A PERSONAL ASSESSMENT

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ABSTRACT

Canadian studies in marine ecotoxicology focus on three main types of problems : those arising from the impact on the marine environment of (a) ocean dumping, (b) offshore hydrocarbon development, and (c) discharge of industrial effluents to marine receiving waters. Activities range from the regulation of dumping and discharges, which is required by various items of legislation, to long-term research into processes affecting the interaction of chemical contaminants with marine ecosystems.

The regulation of materials introduced to the sea is usually based on a combination of chemical analysis for known or suspected pollutants (defined by appropriate legislation), and short-term acute toxicity tests using marine organisms of local significance. These studies are usually directed to defining the acceptability of dredge spoils, industrial effluents and materials used in offshore drilling.

Research programmes address the need to understand the impact of increasing industrial use of marine resources. Studies of contaminant distribution therefore deal not only with current or local contaminant levels, but also with physical, chemical, geological, and biological processes which may affect contaminant distribution, and from which spatial or temporal trends in contaminant distribution may be inferred. Toxicological studies focus on several levels of biological organization or complexity, ranging from single enzyme systems to populations or communities. With increasing biological complexity, sensitivity to pollutant stress may decrease, but "relevance" increases. A single index of ecosystem "health" is unlikely to be satisfactory, and it seems more promising to develop a suite of indices, applicable at various levels of complexity and sensitivity. These could include highly sensitive but specialised indices of enzyme inhibition and induction or more general, but less sensitive, measures such as those of species diversity.

KEYWORDS

Marine ecotoxicology, Hazard assessment, Bioassays, Legislation, Canada, Review.

INTRODUCTION

Canadian ecotoxicological studies reflect several concerns, which can be summarized as :

(a) the routine or deliberate introduction of wastes or industrial products into the sea ;

(b) the impact of offshore mineral development, especially of hydrocarbons ;

(c) background or diffuse-source marine pollution problems.

This classification is somewhat artificial : some examples of marine pollution may fall into more than one of these categories, but for the purposes of this paper, it will be a convenient framework within which to discuss various problems.

Some general observations on the legislative and political background to marine environmental studies may be useful. Marine pollution studies in Canada are mainly a federal responsibility, although some provincial governments are expressing increasing interest in those aspects of the subject related to offshore development. The federal Acts most usually involved are the Fisheries Act (part of which states essentially that substances which have a deleterious effect on fisheries shall not be introduced to the environment), the Ocean Dumping Control Act (which embodies regulations developed as a result of Canada's joining the London Dumping Convention), and (to a minor extent) the Environmental Contaminants Act (which is concerned mostly with industrial effluents). In addition, sections of certain other Acts may bear on specific problems : Section XX of the Canada Shipping Act, for example, controls certain discharges from shipping. Some legislation may refer to specific places, an example being the Arctic Waters Pollution Prevention Act. In practice, however, most work in the field of interest to this meeting derives from the Fisheries and the Ocean Dumping Control Acts.

Two federal policies also have some impact on what work is done in this area, and on how it is done. The policy that the proponent of a development scheme usually should describe its environmental impact results in certain industries - especially the offshore oil industry - stimulating certain kinds of monitoring and research work. Although the proponent may be required to make an Environmental Impact Statement, the federal Government usually has the right and responsibility to review it. The policy of "contracting out" government-sponsored studies to the private sector has resulted in the development of several environmental surveying and consulting companies which undertake various kinds of environmental monitoring and toxicological testing. The outcome of these policies and legislative requirements is that marine pollution studies - in their broadest sense - are done mainly by the federal Government (usually, but not exclusively, by the Departments of Fisheries and Oceans and of the Environment), and by various private and semiprivate sector contractors, who may be under contract either to the federal Government or major industries.

DETAILED PROBLEM STATEMENT

SHORE-BASED INDUSTRIAL POLLUTION

Fig. 1 summarizes some of the major sources of coastal industrial pollution. On the east coast, various industries including those related to mining, pulp and paper, and (occasionally) chemicals, have produced effluents or products which may be accidentally or deliberately discharged to the sea. In many instances, these have been close to inshore fishing grounds which support important fisheries such as that for lobster (e.g., Uthe and Zitko, 1980) or herring (Hodder et al., 1972). In addition, the risk exists that discharges from these shore-based activities may affect more distant fishing grounds such as the productive shelf areas (e.g., the Grand banks of Newfoundland) or the Gulf of St Lawrence fisheries. On the west coast, similar coastal industries (again related to mining and to pulp and paper) may produce discharges which may affect marine fish (Waldichuk, 1979). In the Arctic, the development of two base metal mines on northern Baffin Island and on Cornwallis Island have some local impact in terms of coastal metal pollution (Bohn and Fallis, 1978 ; Fallis, 1982). Although there are few commercial-scale fisheries in the Arctic, the subsistence fisheries in the region are important to the native people of the area.

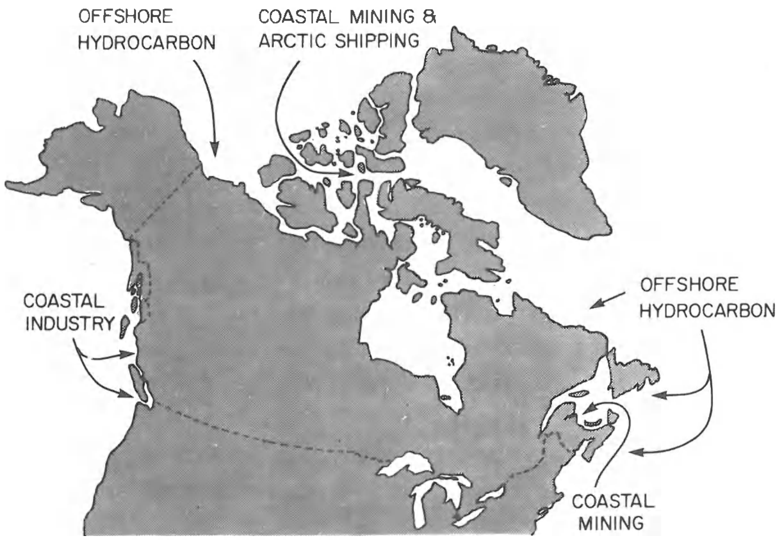

Fig. 1. Map of Canadian coastal waters showing areas and sources of concern with respect to marine pollution.

OCEAN DUMPING

The Ocean Dumping Control Act regulates "batch" disposal of materials to the sea, as opposed to continuous discharges (e.g. from factory effluents) which would be regulated under the Fisheries or the Environmental Contaminants Acts. The Ocean Dumping Control Act is applied (at least on the east coast) most usually to dredge spoils. On the west coast, it is applied also to cases of dumping of chemical and industrial products. The Act is also intended to cover disposal of objects such as wrecked ships, but usually these do not present a specific pollution hazard except in cases such as the deliberate sinking of a wrecked crude oil tanker (Vandermeulen, 1980).

Within this general subject of "deliberate discharge" I have mainly considered industrial chemical wastes and related materials. In addition to this, large amounts of domestic waste such as sewage are introduced to the marine environment. However, in most locations around Canada's coast, the impact of these discharges is minor : treatment plants at various levels of sophistication, the capacity of the sea to accept inputs of biodegradable material at some rate, and a generally fairly dynamic oceanographic regimes, combine to make local eutrophication a minor problem. There are instances of it, especially in estuaries which are inadequately flushed, but these are the exception rather than the rule.

OFFSHORE HYDROCARBON DEVELOPMENT

Exploitable reserves of hydrocarbons have been found on Canada's east coast and in the Arctic, and exploration for them is continuing in these areas and is likely to begin on the west coast within the next decade. On the east coast, commercially significant reserves of natural gas exist in the Sable Island area of the Scotian Shelf. Oil reserves exist in the Grand Banks area, and natural gas exists in possibly exploitable amounts along the Labrador shelf. The time-table for development of these reserves will be determined by political and economic factors which are at present unpredictable, but the Sable Island gas and Grand Banks oil reserves could be developed within the next five to ten years. Both these areas are important as fishing grounds or as nursery and spawning grounds, and so a major question is how to achieve the coexistence of hydrocarbon development and major fisheries especially in the light of two large oil spills which have taken place in the east coast within the last 15 years (Anon., 1970 ; Vandermeulen, 1980). The Labrador shelf also appears to be an important spawning, nursery, and fishing ground, so development of the gas reserves there will raise similar questions.

In the Artic, there are significant reserves of oil in the Beaufort Sea and of natural gas in the High Arctic Islands. Although the development of these reserves may be further distant than those of the east coast, two major problems are already being considered seriously : these are the possible impact of oil development on a possibly sensitive and fragile ecosystem, and the effects of routine hydrocarbon transport through Arctic waters. Apart from the "spill" threat posed by the latter, we must consider whether year-round traffic by ice-breaking tankers will disturb the normal migratory patterns of Arctic mammals, and whether the noise caused by tankers will affect the behaviour of mammals or birds.

As well as hydrocarbon development offshore, the possibility exists that other mineral resources will be exploited. On the east coast, there is already offshore mining of high quality sand, and on the west coast, the potential exists for mineral nodule recovery ; however, this latter activity is still very much in the exploratory stage.

DIFFUSE-SOURCE POLLUTION PROBLEMS

Many of Canada's marine ecosystems and fisheries are contaminated to some extent by pollutants which come from no readily identifiable source. As an example, I shall consider pollution by organochlorine compounds such as the DDT group of insecticides and the polychlorinated biphenyls (PCBs). The east coast fisheries are contaminated by both these materials. While the DDT residues present may have arisen partially from the massive DDT spray programmes carried out in the 1950s and the early 1960s to protect the New Brunswick forest industry from the spruce budworm (Kerswill, 1967), no such large scale use of PCBs occurred in eastern Canada. The most probable source of these materials is via atmospheric transport from the industrial northeastern United States (Ware and Addison, 1973). Arctic ecosystems are also contaminated by these materials, though to a lesser extent than those on the east coast, and while there has been some insecticide use in the Mackenzie river communities (e.g. Addison and Brodie, 1973), it seems likely that much of this contamination again arises from atmospheric transport from distant sources.

In a similar way ecosystems can be contaminated by "background" levels of certain metals (Ray et al., 1984), and by certain radionuclides, which are usually fallout products from atmospheric nuclear weapons tests carried out during the 1950s (Smith, 1984).

MARINE ECOTOXICOLOGICAL TESTING IN RESPONSE TO THESE PROBLEMS

These problems are addressed using various approaches, which we can summarize as follows :

(a) short-term acute toxicity tests ;
(b) analytical chemical approaches ;
(c) development of sensitive sublethal effects monitoring techniques.

Of these approaches, acute toxicity tests have rather limited applications, as I shall discuss below. Chemical analyses may not be strictly "ecotoxicological testing", but the two topics are so closely related, and since chemical approaches complement and are often used as substitutes for biological tests, I have no hesitation in including them here. Finally, the development of sublethal tests probably represents the bulk of Canadian research effort in marine ecotoxicology at present.

ACUTE TOXICITY TESTS

Acute toxicity tests are used principally for regulatory purposes (as required by the Fisheries Act or the Ocean Dumping Control Act), or for comparative purposes (to allow the selection of less toxic materials to be used in marine environments).

There are at present no standardized acute toxicity tests using marine biota. Presumably this reflects the variety of environments and biota which have to be tested. Most acute toxicity tests are carried out to respond to specific local problems, and any local marine organism which is readily available, easy to maintain under laboratory conditions and which could reasonably be expected to be exposed to the materials under test will be used. Exposures in such tests are usually of the conventional 96 h static type.

Two problems arise in such tests. The first group is purely technical, and arises particularly in tests of dredge spoils, etc., carried out under the Ocean Dumping Control Act. These involve questions of whether to test a whole sample, or to use an elutriate test ; whether to use a pelagic or a benthic test organism, whether to continuously suspend the sample, or to let it settle, etc. In the face of these technical problems, the regulatory agencies responsible for implementing the ODCA prefer to translate the bioassay criteria recommended in the Act into analytical chemical criteria

(Swiss et al., 1980). It is recognized, of course, that a criterion of acceptability expressed in biological terms is in principle better than one defined in chemical terms. However, at present the practicalities of marine bioassays are such that chemical analyses are easier to carry out and to interpret than are biological assays.

The second group of problems arises in interpreting the results of acute toxicity tests : most drilling muds (for example) or dredge spoils are toxic to some extent, and the question of whether some localized lethality is acceptable becomes a value judgement between the convenience and commercial value of using muds or dumping spoils, and the damage (usually localized) to some component of marine systems. This value judgement is the same, in the long run, as most others between the exploitation of marine resources and the potential damage that such exploitation may cause. There is no general solution to this problem, and each case must be considered on its own merits.

CHEMICAL STUDIES

Chemical studies related to ecotoxicology have several objectives. These may be summarized as :

(a) distribution studies to detect temporal or spatial changes in marine environmental quality and for regulatory purposes ;

(b) process studies to allow prediction and understanding of the behaviour of contaminants, especially as they relate to bioassays.

There is considerable activity, particularly under the auspices of international bodies such as ICES or OECD, in making large-scale spatial comparisons of pollution in the Canadian marine environment with that elsewhere. The general conclusion from such studies is that industrial pollution in eastern and western Canada is still relatively minor, at least in comparison with the obviously heavily industrialized and polluted areas of western Europe or the US (e.g. ICES, 1977) ; The Arctic is still relatively pristine, and in general, pollutant levels in certain environmental reservoirs seem to be declining (e.g. OECD, 1980 ; Zitko, 1981). To support this kind of study, various groups are devising monitoring programmes based on using marine organisms as accumulators of contaminants and devising specific studies such as mussel watches (e.g., Popham and D'Auria, 1983).

There is considerable interest in studying the speciation and distribution of chemicals in waste or effluent samples, with the view to understanding the factors which control biological availability. The underlying rationale to this is that by understanding the chemical processes, we can more reliably interpret chemical analyses, and so eliminate the need for bioassays of particularly difficult sample types such as the dredge spoils discussed above. This approach is exemplified by the work of McLeese et al. (1982) and of McGreer et al. (1981) on the uptake of metals and organochlorines by benthic biota.

SUBLETHAL EFFECTS MONITORING METHODS

It has become clear during the past 15 years that the most common pollution problems arise not from catastrophic events such as major chemical spills (e.g., Jangaard, 1972) or major oil spills (e.g. Anon., 1970 ; Vandermeulen, 1980), but from routine or frequent discharge of relatively small amounts of pollutants. These may often accumulate in commercially important species and may result in (temporary) fishery closure while the impact on public health is assessed. As a result our ecosystems are pervaded by rather low levels of various chemicals, which are not lethal individually or synergistically. The question arises, however, as to whether these low contaminant burdens have any general effect on the "health" of ecosystems.

The choice of an index of environmental "health" involves a compromise of the sort shown in Fig. 2 : very roughly, a response to a particular chemical is likely to decrease in sensitivity but increase in "realism" as the biological complexity of the response increases. For example, a single enzyme system (relatively low biological complexity) is likely to give a sensitive response to pollutants, but this response will be difficult to interpret in terms of changes in the whole organism, the population, or the community. On the other hand, pollution-induced changes at the community level (i.e. high biological complexity) are likely to have major effects at all trophic levels in terms of species abundance and diversity. Ideally, this is what we would prefer to measure, but such changes are not likely to be detected as an early warning of pollution, and by the time that they are seen, they may be irreversible. In other words, when we look for pollution-induced changes, we are looking for deviations from the normal state. It is easier to define the normal state (and so detect deviations from it) in a simple system than it is in a complex one. To further compound the problem, in temperate shelf ecosystems spatial and temporal variation may characterize the "normal" state - so how do we detect deviations from that ?

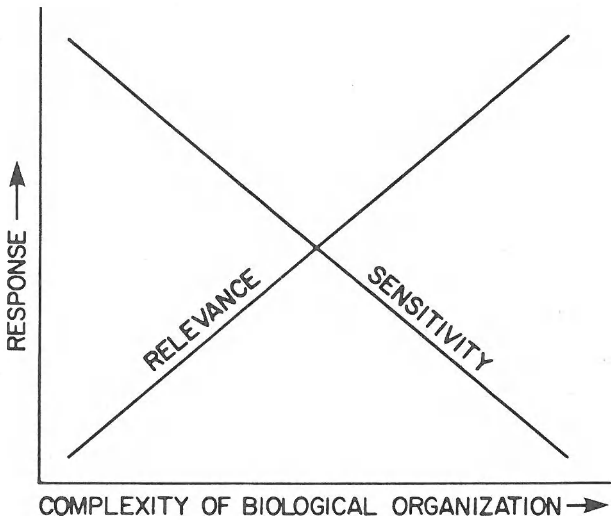

Fig. 2. Schematic representation of the applicability of sublethal responses at various levels of biological complexity.

Canada is now devoting considerable effort to developing indices of stress which focus on simple, rather than complex, biological indicators on the assumption that an early warning of the effects of pollution will allow rapid and effective control. Such indicators include those proposed by ICES (1980) and others. Induction of mixed-function oxidase enzymes is being actively studied as a field indicator of the sublethal effects of oil (e.g., Payne, 1976). Histological responses are being examined in Mytilus as a possible response to metal pollution as well as to organic pollutants, and various other enzymatic or biochemical responses have been assessed in specific pollution events (Haya et al., 1980). It is recognized, of course, that such indices cannot be applied indiscriminately, and that considerable care must be taken to eliminate the possible impact of natural factors such as age, sex, and condition on these indices. Nevertheless, they appear to be potentially useful as early warning indicators of the presence and effects of pollution of various sorts. Although by themselves they are probably no more useful as an indicator of environmental health than is a single clinical test an index of human health, such tests may be useful when taken together with other observations such as chemical distribution studies.

There is interest in other indices of the effects of pollution at higher levels of biological organization. Much of the classical work on the toxic effects of pulp effluent on fish has dealt with sublethal effects on respiration and whole- organism biochemical processes in salmonids, and some of these biochemical or physiological tests could be applied to early warning systems of biological effects (Davis, 1976). Although these tests are described in freshwater systems, they are applied to anadromous fish. At the population or community level, there seems to be less chance of detecting an early warning of the impact of pollution (e.g., Hargrave and Thiel, 1983) : this is not to say that an early warning does not occur, but simply that it will be difficult to detect that signal against the natural "noise" of the system. A similar situation occurs in the particular case of the potential impact of a major oil spill on marine ecosystems : the consensus seems to be that while such a spill might well impact larval fish and so affect future year class strength, this effect would be difficult to isolate from other normal factors which could bring about a similar result (Longhurst, 1982).

One programme in which this ecosystem approach to the detection of the effects of pollution is chosen has been started at the Bedford Institute of Oceanography. This adresses the problem of disposal of high-level radioactive waste in the deep sea. Although Canada does not dispose of radioactive waste in this way, and probably will not, other countries are tentatively considering doing so. To provide information about the potential impact of such activities, Canada has developed a programme to study the physical, geochemical, and biological processes which occur in the deep sea, and which could contribute to the dispersal or to the environmental impact of these wastes.

CONCLUSIONS

Canadian activities in marine ecotoxicology involve three main approaches :

a) acute toxicity tests (usually 96 h static LC50 tests) using locally appropriate organisms, usually for regulatory purposes ;

b) chemical distribution and process studies to allow (amongst other things) some assessment of temporal and spatial trends in environmental contamination, and for regulatory purposes ;

c) development and increasing use of sensitive, sublethal indices of early warnings of the deleterious effects of contaminants.

Any, or all, of these approaches may be used in addressing specific problems. However, some trends in the use of these approaches are clear :

a) Acute toxicity tests are used mainly for regulatory purposes. In certain fields, their use is declining, as discussed above.

b) At present, most effort in marine ecotoxicological studies goes into analytical chemistry, either in the form of monitoring or survey operations (for contaminant trend analyses and for regulation), or into research into the processes of chemical distribution and behaviour. To some extent, this arises from the fact that analytical chemistry is, at present, simpler, more reliable, and more informative than is analytical toxicology. However, since a purely "chemical" approach to pollution ignores the biological effects of chemicals, we can expect a gradual shift towards "effects monitoring" as methods for the latter become more developed.

c) There is increasing interest in the development and application of sublethal indices of environmental stress, usually those which may be used as an early warning of the effects of pollution. This reflects the reality that most of Canada's pollution problems arise not from catastrophic incidents, but from a chronic, low level pervasion of contaminants throughout the environment. This emphasis also reflects Canada's current interest in the development of offshore hydrocarbon reserves, where the application of sublethal stress indices may allow early control of any deleterous releases from such operations.

ACKNOWLEDGEMENTS

I thank my colleagues in the Departments of Fisheries and Oceans and of the Environment and in various other organizations for providing information on which to base this paper.

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