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How Can We Best Test The Effects Of Pollutants And Changes On The Animals And Plants Of Chesapeake Bay?

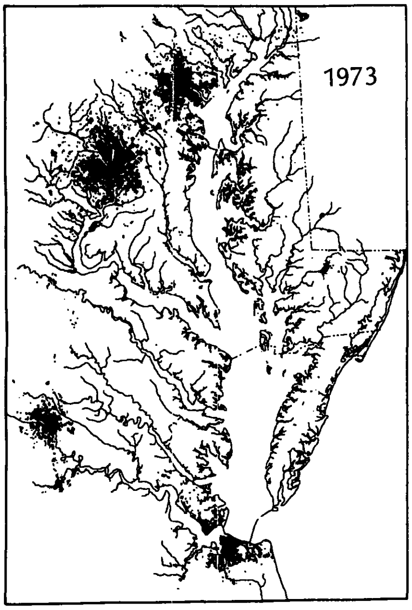
L. Eugene Cronin

Morris H. Roberts Jr.
Virginia Institute of Marine Science

TEN CRITICAL QUESTIONS FOR CHESAPEAKE BAY

IN RESEARCH AND RELATED MATTERS

PEOPLE AND INDUSTRY



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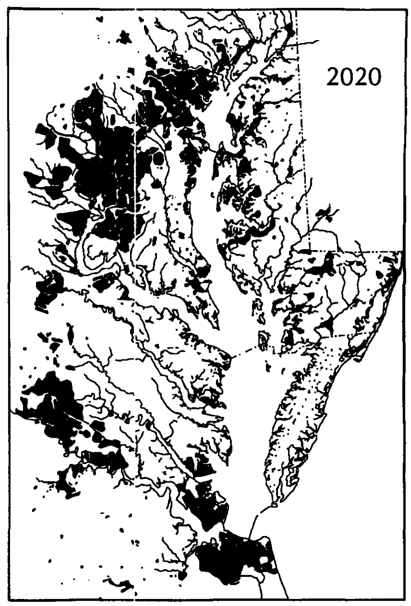

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CHESAPEAKE RESEARCH CONSORTIUM

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CRC

TEN CRITICAL QUESTIONS FOR CHESAPEAKE BAY IN RESEARCH AND RELATED MATTERS

L. Eugene Cronin, Editor

CHESAPEAKE RESEARCH CONSORTIUM
4800 Atwell Road
Shady Side, Maryland 20764

Comprising
The Johns Hopkins University
University of Maryland
Smithsonian Institution
Virginia Institute of Marine Science - The College of William & Mary

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CRC Coordinating Committee

L. Eugene Cronin, CRC

Lawrence C. Kohlenstein, JHU

J. Kevin Sullivan, SI

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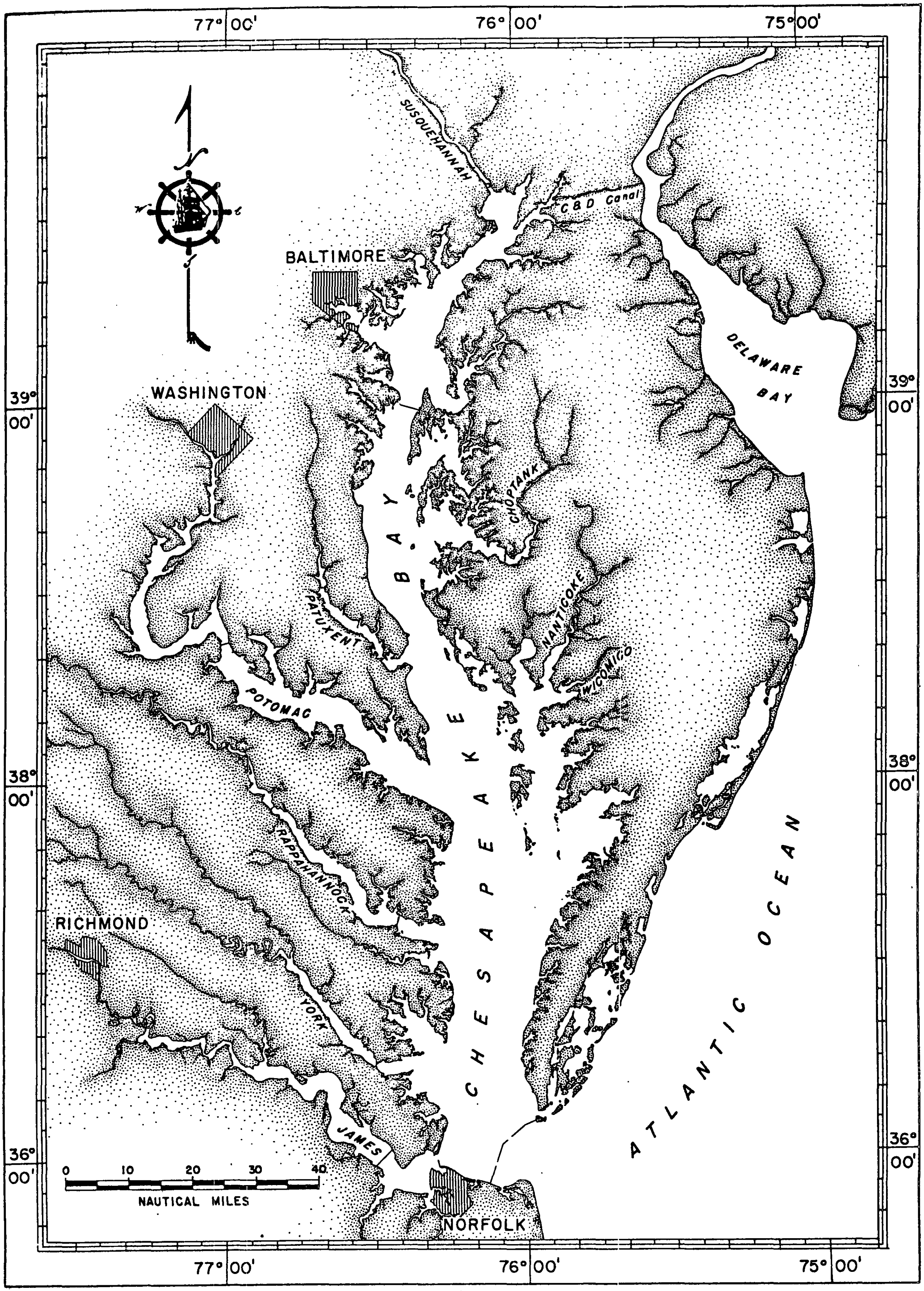

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L. EUGENE CRONIN
MORRIS H. ROBERTS, JR.

Chesapeake Research Consortium
4800 Atwell Road
Shady Side, Maryland 20764

Virginia Institute of Marine Science
Gloucester Point, Virginia 23062

INTRODUCTION

The animals and plants of the Bay, and the processes in which they are involved, are the basis for almost every use and desirable quality of the Bay. They provide both commercial and recreational fisheries, assimilate some quantities of wastes, contribute to esthetic quality, provide a favorable environment for many birds and mammals and feed all of the species which are used by man. However, the biota are directly or indirectly affected by many human activities - by maritime transport, recreational activities, agricultural production, waste discharges, domestic development, engineering activity, and other land-based activities.

Therefore, the ultimate and most important question to be considered in evaluating any new pollutant or proposed environmental modification is - What effect will it have on the biota? The answer to this question is essential for any decision to prohibit or allow the release of a new chemical in the Bay, for selection of criteria and standards for all pollutants, for evaluation of the effects of physical changes and chemical additions and for the selection of specific goals in improving the biological quality of the Bay.

We cannot now answer this question with useful accuracy, and there are compelling reasons for developing that ability. The living resources of this system, which is only slowly flushed and accumulates most of the chemicals it receives, are vulnerable to serious damage unless we can predict effects and use this knowledge to minimize impacts.

Chemical pollutants and changes in such attributes as fresh-water input, temperature, salinity and water depth can have many kinds of significant biological effects. They include reduction in photosynthesis, excessive growth stimulated by nutrient addition, acute mortality, crippling as with oil on ducks, interference with reproduction, reduction of species diversity or many other impacts (Goldberg 1979). Some of these effects impinge on only a few individuals, but many also change whole communities and the larger biological system. Many species effects are direct and acute, as the killing of a sensitive life stage (eggs or larvae), but others have indirect, often long-term, effects. Indirect long-term effects might result from the removal of a microscopic species necessary in the food web or interference with successful migration of spawning fish, or might involve the cumulative response to a variety of pollutants, each in itself not obviously damaging at the ambient concentrations but together having a significant adverse effect.

Techniques for assessment of some effects of pollution and environmental changes have been developed. Laboratory toxicity experiments have been conducted on a variety of species and for many different chemicals and conditions. In a few cases, experiments have been conducted in large tanks or enclosures which partially simulate the complex natural aquatic system, and in even rarer cases studies have been conducted in open waters where the real impacts occur. Such tests and studies all contribute to the development of criteria and standards for pollutants such as sediments, pesticides, and toxic chemicals, as well as factors such as temperature, salinity, and dissolved oxygen. Methods for effective planning and design of programs for reiterative and interacting sequential studies have been designed and should be modified and utilized for the Bay. These include the use of an "Adaptive Environmental Assessment" technique developed in Austria and British Columbia (Auble et al. 1982) and other tiered approaches discussed by Duke (in press).

Available data regarding pollutant effects are, however, insufficient for protection of the Chesapeake Bay and other rich coastal and estuarine systems. The present body of pertinent knowledge as it relates to estuaries like the Chesapeake Bay has been summarized in a report from the National Academy of Sciences and National Academy of Engineering (1970), in the establishment of Water Quality Criteria (1972), in a review of Chesapeake Bay Biota (Schwartz 1972), in the Synthesis Report of the EPA Chesapeake Bay Program (EPA 1982), and by a recent panel of the National Research Council (Panel on Estuarine Research Perspectives 1983). Recognized deficiencies include:

- Toxic levels have been established for fresh-water species and transferred to estuaries without recognition that the environment and biota are fundamentally different.
- The toxic effects which have been determined for estuarine organisms too often ignore the substantial effects of salinity on an organism's response, either because of effects on bioavailability of the toxicant or because of salinity stress on the test organisms.
- EPA has recently noted that toxicity data on the 125 "priority pollutants" are completely lacking for at least half of the most important fish species

of Chesapeake Bay.

- Results of single species tests fail to take into account community interactions such as food supply, predation, sensory disruption, etc., and therefore community and ecosystem effects cannot be accurately predicted in the affected area - the open Bay.
- Of the array of chemicals which have already reached the Bay, including several hundred organic components and scores of inorganic materials, only a small number, perhaps 10%, have been tested against any Bay biota.
- Probably fewer than 2% of the species of the Bay have been used in tests of pollutant effects.

There are three compelling reasons for employing biological tests of pollutant impacts. First among these is the vital importance of the health of Bay biota to decisions affecting the uses of the Bay system. Second, we are presently unable to predict accurately the effects of pollutants and environmental changes on the Bay biota. Finally, we recognize that pollutants introduced into the Bay system will increase in number and quantity. Therefore, biological tests must be selected or developed which best predict overall ecosystem responses to pollutants and environmental changes. Application of such tests will contribute significantly to estuarine science and to rational use and protection of estuaries around the United States and the world.

RESEARCH PLAN

PROJECT 1. Development of new or improved toxicology test procedures for important species and groups in the Chesapeake Bay.

Objective:

1. To develop capability for testing of representative species and stages from important ecosystem compartments.
2. To develop multispecies test procedures, using as an example a benthic community toxicity test protocol.
3. To improve testing for chronic sub-lethal toxicity by developing full life-cycle culture of additional estuarine species.

Approach:

In order to predict the biological impacts of a toxic substance or environmental change, it is essential to evaluate by test the potential effects on species and groups representing all relevant components of the complex estuarine system. There are over 2700 species in the Chesapeake (Wass 1972), of which 126 have been identified as being "important" for economic or ecological reasons (Pfitzenmeyer 1977). At present only 10-15% of the species known to be important can be used in toxicity tests, and most of them only for short-term tests. Substantial improvements in pre-decision testing is essential.

The three objectives stated should be approached by simultaneous and interactive sub-projects. We suggest the following research efforts:

A. Improved laboratory testing of species.

It is not feasible or necessary to test all stages of all species in the "important" list, but the selection of species must be rational. An invited workshop or interlaboratory discussions, involving knowledgeable persons from Chesapeake Bay academic institutions and agencies and from EPA laboratories, should be held for the purpose of selecting:

1. From the "important" list, those species which can now be employed in tests for acute and chronic effects and for which adequate protocols exist.
2. From the full list, those additional species which should be employed in testing by virtue of their ecological or commercial roles.
3. For each species, the life history stage or stages which might provide the most useful data (frequently the larvae or other sensitive stages).

This species selection should provide representatives of all major components of the food web, of the principal taxonomic groups in the Bay, of the abundant and ecologically significant species, and of the species of direct economic value to human interests.

There are many published references on biotoxicity, but few of them consider the distinctive features and inherent complexity of the estuary. A program of specific collaborative research must be developed on the basis of workshops or inter-laboratory discussions. It should include:

1. Evaluation of recommended stages or forms of various species as test organisms.
2. Development of practical, cost-effective and statistically valid methods for acute and chronic toxicity tests.
3. Comparative interspecies testing to identify any sub-set of species which reliably predicts the biotic effects of pollutants or environmental changes in Chesapeake Bay.
4. Development of improved protocols, when needed, for species now used in testing.

B. Benthic community tests as an example.

Most available test protocols are for single species and for animals of the water column. There is urgent need for tests which involve realistic mixtures of interactive species, and the benthic community provides an exceptionally valuable example. While a start has been made to such testing (Rubenstein 1978, Schwartz et al. 1979, Hansen and Tagatz 1980, Tatum 1980, Rubenstein et al. 1980), it is necessary to evaluate the applicability of these procedures to the Bay system and expand or modify them as may be appropriate.

The exceptional importance of test procedures for benthic organisms is supported by at least three considerations. The benthos is energetically closely coupled with the water column in estuaries, not only deriving energy by feeding but also providing food for many pelagic forms. Second, the bottom sediments are the ultimate sink for virtually all toxic substances introduced into the aquatic milieu. Toxic substances are very often rapidly sorbed to sediments and deposited, "detoxifying" the water column and adding to the accumulation in the sediments - the immediate environment of the benthic species (see Nichols, p. 71 of this volume). Such materials may have a prolonged residence in the biologically active upper sedimentary layers. The third reason is the exceptional value of benthic species as signal species or groups because many species are sessile or sedentary in post-larval stages and benthic species frequently demonstrate bioaccumulation to exceptionally high levels.

Effects of sediment-accommodated materials may be manifest in two different ways:

- by killing or impairing those organisms residing in a previously "clean" substrate
- by inhibiting recruitment of planktonic larvae into a contaminated sediment

Test procedures which are applicable independent of season are needed to evaluate both recruitment and survivorship effects.

Research is also needed to develop adequate procedures to evaluate the toxic effects of exposure of benthic fishes (e.g. flatfishes and sciaenids) and motile invertebrates (e.g. blue crabs) to contaminated sediments. Initial attempts at this type of exposure by one of us (Roberts, unpublished) have revealed the need to cage such species as spot 1) to prevent them from resuspending sediment in a tank, or burying themselves in the sediment if alarmed, 2) to reduce the oxygen demand attendant with resuspension of anoxic sediments, and 3) to facilitate observation of the fish during the test. Procedures are also needed to discriminate between effects resulting from direct contact with sediment and those resulting from toxicants redissolved in the overlying water.

A basic question of design for tests involving sediment relates to the selection of sediments contaminated to different concentrations versus the mixture of contaminated and uncontaminated sediments to provide a dose series. The mixing process obviously modifies the sediment characteristics with regard to oxygenation, water content, compaction, etc., all of which may modify the chemical state of toxicants and hence bioavailability. On the other hand, when selecting sediments from different sites to provide a concentration gradient of one pollutant, one may well introduce other toxicants, knowingly or unknowingly, which confound interpretation of results.

Laboratory tests can, and sometimes should, simultaneously include several species or a community. In testing benthic infauna such community testing is inherent both for recruitment tests and survivorship tests. In addition, multispecies test procedures are necessary to evaluate effects which result from benthic boundary layer interactions. Such evaluations can be accomplished through simplified food chain experiments designed to evaluate the transfer of contaminants from sediments back into the water column.

Multispecies test procedures to evaluate transfers across the benthic boundary layer must be accompanied by careful evaluation of purely physiochemical transfers, and will therefore require the cooperative research of chemists, geochemists and perhaps others with the toxicologists to unravel this compartment of the ecosystem. Analytical geochemical problems may slow progress unless a parallel commitment is made to this line of research.

Multispecies benthic testing can provide new procedures within five years which can be applied routinely to priority pollutants or proposed new compounds at a rate of at least five to ten per year.

C. Improved chronic or sub-lethal toxicity testing

Assessment of the long-term effects of detrimental changes is notoriously difficult, but potentially much more valuable than short-term acute results. They may involve subtle impairment of sensory organs, mobility, reproduction, feeding mechanisms or behavior. In laboratory tests, such effects may not be apparent in adult individuals but become detectable in specific stages of the life cycle or only in succeeding generations. Only a few species have been effectively utilized in testing for such effects, and experience with estuarine animals and plants is exceptionally rare.

The principal tool required for such chronic toxicity testing is the availability of an appropriate set of species which can be reliably cultured through the full life history over a series of generations. The only estuarine species now available for routine testing are Cyprinodon variegatus (Hanson and Parrish 1977, Hansel et al. 1978) and Mysidopsis bahia (Nimmo et al. 1977 and Nimmo et al. 1978).

In selecting candidates for development of chronic test procedures, criteria should be ruthlessly applied to insure that procedures are cost-effective, reliable and relevant to the Chesapeake Bay. These criteria must include the following:

- Complete life cycle culture methods are, or will be, available to at least two researchers.
- The candidate species is of ecological significance in the Bay system.
- The life cycle is of relatively short duration.
- The species is known to be acutely sensitive to toxicants in general.

As species are examined, the most efficient and effective protocols for such testing should be developed and circulated to colleagues for verification and improvement. Standard toxicants should be used for round-robin testing by participating researchers and the results of these tests, along with complete documentation of the finalized test protocol, should be published.

Such research should be conducted at several laboratories around the Bay, selected to provide access to differing sites, to appropriate Bay species and to resident expertise. The program of studies should be highly interactive among those institutions and with experts outside of the Bay community.

The development of testing for chronic effects will depend upon the interest and availability of specialists on the species involved as well as upon appropriate funding and facilities. Protocols for at least five species of Bay biota can be matured within five years.

Schedule and constraints:

Rapid progress will require the full-time attention of several senior scientists and their associates. It will also depend upon the availability of appropriate laboratory facilities, where suitable conditions of salinity, temperature, and other environmental circumstances are available and where appropriate concentrations of toxicants can be presented to the species and groups employed. Analytical facilities and staff are a necessary adjunct so that identification and measurement can be made of initial and subsequent chemical burdens in the environment and in the biota. Strong institutional interest and commitment are essential.

Feasibility:

Several laboratories already exist around the Chesapeake Bay which are conducting or are capable of conducting the research outlined. Additional support is necessary to implement the research in a timely fashion, to provide for more frequent and detailed interactions between researchers, and ultimately to allow interlaboratory testing of procedures.

Substantial benefit can be drawn from research which has been conducted at many laboratories on acute toxicity, mutagenic effects, teratogenic effects, behavioral responses, pathological effects, bioaccumulation and other related topics. Advantage can also be drawn from the extensive, albeit incomplete, knowledge of Chesapeake Bay Biota (for example - McErlean, Kerby and Wass, 1972, Baltimore District U.S. Army Corps of Engineers, 1977, Shea et al. 1980, Lippson et al. 1980).

Related research is in progress at the Virginia Institute of Marine Science, the University of Maryland, the Smithsonian Institution, The Johns Hopkins University, various consulting companies and others. These existing research efforts provide a strong base on which to build this research.

PROJECT 2. Develop cost-effective field procedures for assessment of lethal and sub-lethal effects of chemical and physical changes.

Objectives:

1. To predict, with useful accuracy, the effects in the Bay system of pollutants or environmental changes.
2. To establish standard but flexible protocols for cost-effective reliable testing of the field effects of new, possibly toxic chemicals and potentially damaging alterations.

Approach:

Experience has proven that prediction of community responses is one of the most difficult problems in estuarine science, or in any ecological system. (Committee to Review Methods of Ecotoxicology 1981). The estuary is notoriously complex and variable, but we are urgently in need of a capability to predict community responses to challengers.

There have been several previous studies of experimental ecosystems and of open-water impacts which have attempted to make such predictions possible. Existing experimental systems designed for testing ecosystem or community responses, ranging in volume up to 1700 cubic meters, have been employed. In each case, the approach is to challenge confined communities of various scales as surrogates of the real world and therefrom to extrapolate to estimate the impacts. Results of these studies, only partially reported, indicate that each system has been instructive but troublesome to operate over the long periods of time necessary to establish community equilibria and to measure the full response to any change or challenge.

Small tanks, including trash barrels, have value but are often too limited in scale to yield adequate results. Fresh analysis of the special needs and the appropriate scale for estuarine experiments will be required.

Further research to develop holestuarine multi-community model systems for testing will be expensive and time consuming. The inherent problems in balancing all energy/material flows in such a complex system suggest that the limited multispecies protocols proposed in project 1 have higher potential for producing useful results in the near term, although extensive model systems must be aggressively studied.

A second possible approach to prediction of effects from field data is open water testing involving deliberate intoxification of a defined portion of the ecosystem (which differs from inadvertent intoxification as with the release of Kepone to the James River or PAH's to the Elizabeth and Patapsco Rivers). In such an open Bay experiment, various difficulties must be overcome. The forces of tidal currents and wind, variations in light, temperature, salinity, suspended sediments and other ecosystem components often threaten to overwhelm experimental plots and controlled additions of materials. Further, public policy rarely permits dedication of any portion of the Bay system to experimental use in this manner. Yet, a case must be developed for small scale field studies at least for the limited purpose of validating laboratory ecotoxicity test protocols. The number and conduct of such tests must be carefully regulated to insure maximum utility of results with minimal cost or long-term damage to the ecosystem.

A third approach is the opportunistic utilization of events - - accidental spills and regulated discharges. Full advantage must be taken of such opportunities for research on field effects. Stand-by plans for rapid initial response to such events should include staff, facilities, and general design for observations which permit estimation and partial understanding of the biological effects. A general protocol for rapid development and implementation of an extended research plan tailored to the specific event should be developed.

The great limitations to this approach are funding and resources of staff and facilities. One cannot justify establishing a staff and facility solely to investigate infrequent and unpredictable pollutional events. On the other hand, it is inherently difficult for professionals to set aside on-going projects with all the consequent costs to careers, and often real dollar costs in lost experiments and supplies, to accommodate the study of a random event, however interesting or important.

Managers and funding agencies need to explore how best to redirect monies and manpower to the study of events such as the Kepone incident expeditiously yet with minimal disruption of on-going important research projects.

Scale:

Large-scale multispecies ecosystem model research should continue with modest expansion. In recognition of previous difficulties, proposals for research along these lines must be scrutinized carefully to determine the probability of generating useful results in a timely fashion.

Research involving field experimentation to the extent needed to validate multispecies laboratory tests should be performed at two or three estuarine sites in the spectrum of salinity within the Bay. It may be prudent to restrict initial studies to one or perhaps two habitat types. Tests should be of limited spatial extent and involve mass loadings which are small compared to the overall system.

Extensive study of one opportunistic field dosing experiment of any size could effectively engage all of the manpower pool assignable to such a project. Perhaps two or three such studies could be accommodated within a decade.

Feasibility:

Several large laboratories around the Bay are technically capable of assembling or developing ecosystem-effect teams and providing them with the back-up analytical and data management systems required. Cooperative plans can and should be developed for opportunistic study of pollution events of large magnitude. If these institutions have the will to so direct their effort, adequate funding becomes the most severe constraint.

PROJECT 3. Apply laboratory and field test protocols to important present and potential environmental problems

Objectives:

1. To obtain acute and chronic toxicological data for significant pollutants for which data do not now exist.
2. To test proposed new chemicals or environmental changes projected to result from man's activities affecting the biota of the Bay system.

Approach:

Existing and new test protocols should be applied to the testing of the defined priority pollutants as well as to complex pollutants such as sewage treatment plant effluents or industrial wastes of immediate concern. Attention should be focused first on those compounds of greatest concern within the Bay system, which the Workshop review * demonstrated to include:

- Chlorine and the most abundant organo-halogens
- The most abundant of the polynuclear aromatic (PNA) compounds
- Specific components of sewage wastes
- Various fractions of petroleum
- The more abundant organometallic compounds
- Specific components of the wastes from coal mining activities
- Sediments, in the various physical arrangements which enter the Bay from erosion and dredging

Other materials should be thoroughly assayed when they become potential problems, prior to regulated release or prohibition.

Existing laboratory tests, while generally quite reproduceable at minimal cost, are oversimplified. Nevertheless they do serve well the purpose of assessing relative toxicity to help us focus our attention on truly serious problem compounds as we apply the more complex sophisticated and expensive tests to be developed in projects 1 and 2.

In the application of existing and new testing protocols, attention must be given to incorporation of salinity, temperature, and possibly other environmental parameters as variables in the tests, since there are known interactive effects with some pollutants. These interactions may be of a physical-chemical nature, affecting bioavailability, or of a biological nature, related to the organism's adaptive response to the environmental parameter.

This project will initially be research, since hypothesis development and testing is an essential part of the implementation process. The experience gained will permit affirmation of reasonably standardized protocols, which can then be routinely utilized. The project will gradually become routine testing, but we foresee that valid research questions will be generated through the testing process, especially as new test protocols are applied.

*See BACKGROUND PAPERS ON CHESAPEAKE BAY NEEDS IN RESEARCH AND RELATED MATTERS. Maryland Sea Grant Publ. No. UM-SG-TS-83-02 and Chesapeake Research Consortium Publ. No. 111. 1983. 138 pages.

Scale:

The first rigorous application of a variety of new tests will be slow and expensive. Experience will improve efficiency somewhat, but this task will require substantial involvement of personnel, equipment and supporting facilities. These studies can, to some extent, proceed today and can be coordinated with protocol development as part of Projects 1 and 2. A laboratory dedicated to this program should be able to provide reliable results for 5-10 compounds for 3 or 4 species/year. Five years of effort by one or more laboratories would provide substantial improvement in available information.

Feasibility:

University and government laboratories already exist around the Bay with the knowledge and experience to apply existing protocols as well as new protocols as these become available. For routine testing, there are also several consulting firms with appropriate expertise.

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