Oceanus

1, Spring 1981

The Oceans as Waste Space?

Oceanus®

The International Magazine of Marine Science

Volume 24, Number 1, Spring 1981

William H. MacLeish, *Editor*
Paul R. Ryan, *Managing Editor*
Deborah Annan, *Assistant Editor*

Editorial Advisory Board

Edward D. Goldberg, *Professor of Chemistry, Scripps Institution of Oceanography*
Charles D. Hollister, *Dean of Graduate Studies, Woods Hole Oceanographic Institution*
Holger W. Jannasch, *Senior Scientist, Department of Biology, Woods Hole Oceanographic Institution*
Judith T. Kildow, *Associate Professor of Ocean Policy, Department of Ocean Engineering, Massachusetts Institute of Technology*
John A. Knauss, *Dean of the Graduate School of Oceanography, University of Rhode Island*
Robert W. Morse, *Senior Scientist, Department of Ocean Engineering, Woods Hole Oceanographic Institution*
Ned A. Ostenso, *Deputy Assistant Administrator for Research and Development; and Director, Office of Sea Grant, at the National Oceanic and Atmospheric Administration*
Allan R. Robinson, *Gordon McKay Professor of Geophysical Fluid Dynamics, Harvard University*
David A. Ross, *Senior Scientist, Department of Geology and Geophysics; Sea Grant Coordinator; and Director of the Marine Policy and Ocean Management Program, Woods Hole Oceanographic Institution*
Derek W. Spencer, *Associate Director for Research, Woods Hole Oceanographic Institution*
Allyn C. Vine, *Senior Scientist Emeritus, Department of Geology and Geophysics, Woods Hole Oceanographic Institution*

Published by Woods Hole Oceanographic Institution

Charles F. Adams, *Chairman, Board of Trustees*
Paul M. Fye, *President of the Corporation*
Townsend Hornor, *President of the Associates*

John H. Steele, *Director of the Institution*

The views expressed in *Oceanus* are those of the authors and do not necessarily reflect those of Woods Hole Oceanographic Institution.

Editorial correspondence: *Oceanus*, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543. Telephone (617) 548-1400.

Subscription correspondence: All subscriptions, single copy orders, and change-of-address information should be addressed to *Oceanus* Subscription Department, 1172 Commonwealth Avenue, Boston, Mass. 02134. Urgent subscription matters should be referred to our editorial office, listed above. Please make checks payable to Woods Hole Oceanographic Institution. Subscription rate: $15 for one year. Subscribers outside the U.S. or Canada please add $2 *per year* handling charge; checks accompanying foreign orders must be payable in U.S. currency and drawn on a U.S. bank. Current copy price, $3.75; forty percent discount on current copy orders of five or more. When sending change of address, please include mailing label. Claims for missing numbers will not be honored later than 3 months after publication; foreign claims, 5 months. For information on back issues, see page 68.

Postmaster: Please send Form 3579 to *Oceanus*, Woods Hole, Massachusetts 02543.

COVER: Waste pipe from chemical plant on Minamata Bay, Japan (see page 34). Photo by W. Eugene Smith, Magnum; BACK COVER: Sketch by E. Kevin King of pollution sources.

Oceanus (ISSN 0029-8182) is published quarterly by Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543. Second-class postage paid at Falmouth, Massachusetts, and additional mailing points.

Oceanus®

The International Magazine of Marine Science

Volume 24, Number 1, Spring 1981

William H. MacLeish, *Editor*
Paul R. Ryan, *Managing Editor*
Deborah Annan, *Assistant Editor*

Editorial Advisory Board

Edward D. Goldberg, *Professor of Chemistry, Scripps Institution of Oceanogr*
Charles D. Hollister, *Dean of Graduate Studies, Woods Hole Oceanographic*
Holger W. Jannasch, *Senior Scientist, Department of Biology, Woods Hole O*
Judith T. Kildow, *Associate Professor of Ocean Policy, Department of Ocean l*
Massachusetts Institute of Technology
John A. Knauss, *Dean of the Graduate School of Oceanography, University o*
Robert W. Morse, *Senior Scientist, Department of Ocean Engineering, Wood*
Ned A. Ostenso, *Deputy Assistant Administrator for Research and Developm*
at the National Oceanic and Atmospheric Administration
Allan R. Robinson, *Gordon McKay Professor of Geophysical Fluid Dynamics,*
David A. Ross, *Senior Scientist, Department of Geology and Geophysics; Sea*
Policy and Ocean Management Program, Woods Hole Oceanographic Institu
Derek W. Spencer, *Associate Director for Research, Woods Hole Oceanogra*
Allyn C. Vine, *Senior Scientist Emeritus, Department of Geology and Geophy*

Published by Woods Hole Oceanographic Institution

Charles F. Adams, *Chairman, Board of Trustees*
Paul M. Fye, *President of the Corporation*
Townsend Hornor, *President of the Associates*

John H. Steele, *Director of the Institution*

The views expressed in *Oceanus* are those of the authors and do not necessarily reflect those of Woods Hole Oceanographic Institution.

Editorial correspondence: *Oceanus*, Woods Hole Oceanographic Institution
Massachusetts 02543. Telephone (617) 548-1400.

Subscription correspondence: All subscriptions, single copy orders, and change-of-address information should be addressed to *Oceanus* Subscription Department, 1172 Commonwealth Avenue, Boston, Mass. 02134. Urgent subscription matters should be referred to our editorial office, listed above. Please make checks payable to Woods Hole Oceanographic Institution. Subscription rate: $15 for one year. Subscribers outside the U.S. or Canada please add $2 *per year* handling charge; checks accompanying foreign orders must be payable in U.S. currency and drawn on a U.S. bank. Current copy price, $3.75; forty percent discount on current copy orders of five or more. When sending change of address, please include mailing label. Claims for missing numbers will not be honored later than 3 months after publication; foreign claims, 5 months. For information on back issues, see page 68.

Postmaster: Please send Form 3579 to *Oceanus*, Woods Hole, Massachusetts 02543.

HAVE THE SUBSCRIPTION COUPONS BEEN DETACHED?

If someone else has made use of the coupons attached to this card, you can still subscribe. Just send a check — $20 for one year (four issues), $35 for two, $50 for three* — to this address:

Woods Hole
Oceanographic
Institution
Woods Hole, Mass.
02543

Please make check payable to Woods Hole Oceanographic Institution

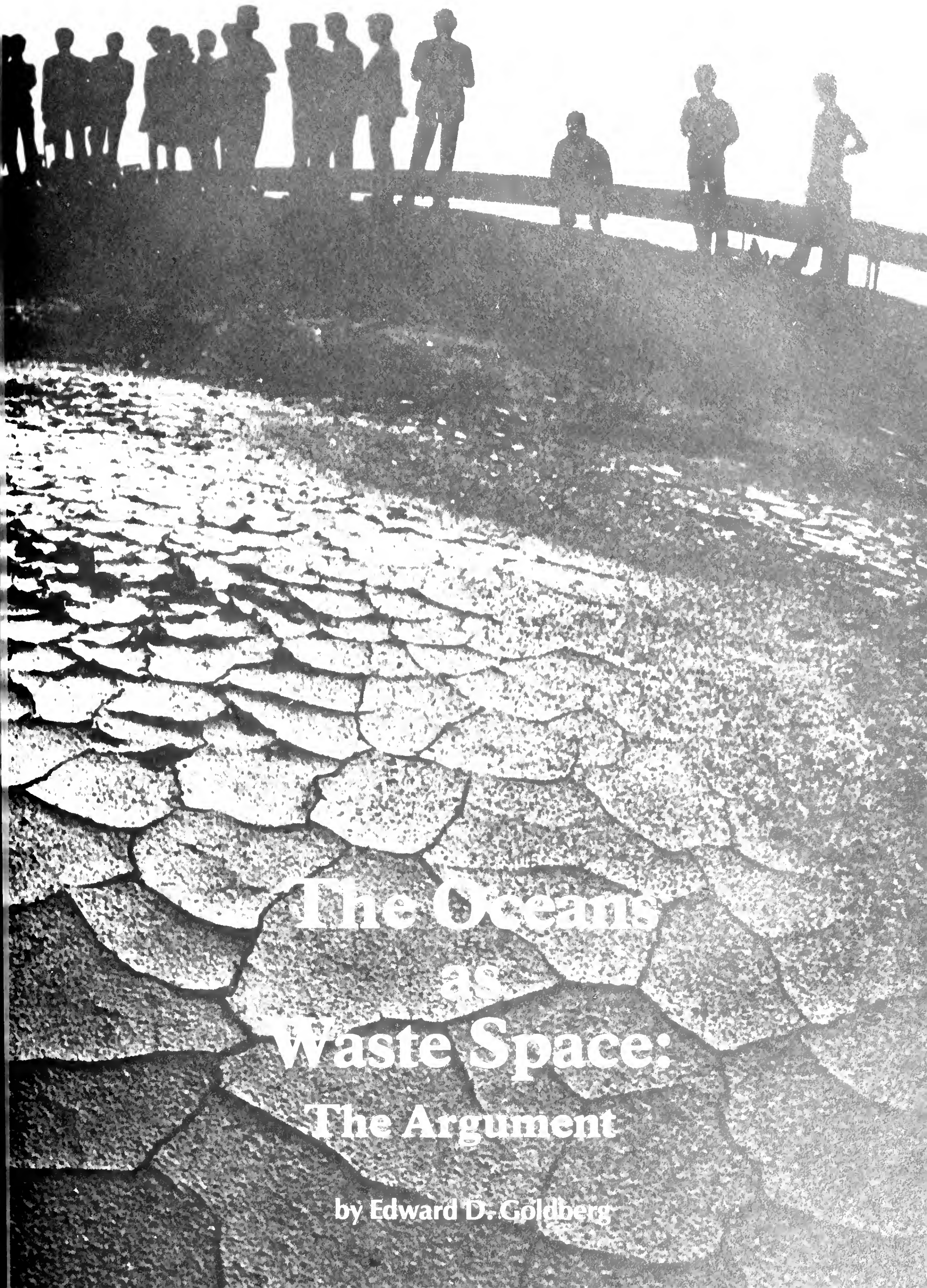
*Outside U.S. rates are $23 for one year, $41 for two, $59 for three. Checks for foreign orders must be payable in U.S. dollars and drawn on a U.S. bank.

Contents

COVER: Waste pipe from chemical plant on Minamata Bay, Japan (see page 34). Photo by W. Eugene Smith, Magnum; BACK COVER: Sketch by E. Kevin King of pollution sources.

Oceanus (ISSN 0029-8182) is published quarterly by Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543. Second-class postage paid at Falmouth, Massachusetts, and additional mailing points.

Once a "holding pond" for a chemical plant's waste, seepage from this place poisoned people living near the mouth of the Minamata River, Japan. (Photo by W. Eugene Smith, Magnum)



The Oceans as Waste Space:

The Argument

by Edward D. Goldberg

The use of the oceans as waste space for the discards of society can be viewed as either sacred or profane. Recently, a mood has developed in countries of the Northern Hemisphere that the oceans are sacrosanct and that any entry of polluting substances is undesirable. The argument is that the integrity of marine ecosystems is jeopardized by the stresses caused by alien materials in the environment of plants and animals. Although the impacts of the contaminants may not be measurable for years or decades after the initial inputs, if at all, it is accepted that changes other than natural variations will occur.

On the other hand, many marine scientists and engineers submit that the oceans do have a finite capacity to receive some societal wastes. Compelling propositions can be formulated to show that marine disposal can in some instances offer economic, social, and scientific advantages over the other two options — atmospheric and land disposal. I shall consider the information base, developed during the last three decades from investigations in marine pollution, for the profane position. For the most part, these studies have attempted mainly to protect public health, but the importance of maintaining viable communities of marine organisms has not been unrecognized. Perhaps there are greater areas of common ground among the involved scientists than may be evident from initial assessments of their positions. All aim to preserve the renewable resources of the oceans and to maintain public health. Their positions may not be unlike those of the atheist and the fundamentalist minister whose discordant views are complemented by a wide area of agreement. Both accept the proposition that there have been perhaps a million or so gods worshipped by different social groups during the history of mankind. The atheist denies the existence of all gods. The minister claims the existence of but one. Thus, it is the instance of one part in a million that separates them (see Warren and Matson, 1978).

The Problem

Each year world society utilizes 3 or so billion tons of mineral, food, and forest products, and produces about 20 billion tons of carbon dioxide from the combustion of oil, coal, and other fossil fuels. The latter is dispersed to the atmosphere. The former, composing a cube about a kilometer on edge, largely passes through society, only a small part being maintained for periods longer than a year or so. Most of the wastes are discharged to land sites; some by combustion to the atmosphere; and some to the oceans. An increasing world population and an increasing use of materials will add to the amounts of wastes in the future.

Only during the last 30 years or so has concern developed about the continued use of the oceans as a repository for some of these discards. This concern came about through the recognition that promiscuous release to the atmosphere or to the oceans of artificially produced radionuclides in the nuclear fuel cycle could imperil human health through direct exposure or through the consumption of food products from the sea. Scientists in a number of countries developed protocols for the releases of radionuclides to the environment in amounts that would not endanger public health. Also, a series of catastrophic events alerted scientists to the limited capacity of coastal waters to accommodate some toxic substances. The Minamata Bay incident in Japan (see page 34) showed that the unrestricted discharge of organic mercurials and mercury to a semi-enclosed basin resulted in tragic mortalities and morbidities for many citizens. The release of Kepone and associated wastes into the James River caused the indigenous fish to carry unacceptable levels of this powerful biocide. The fishery has been closed, resulting in losses of hundreds of millions of dollars. The soiling of coastal waters and beaches by oil spillages from ships and offshore drilling rigs is offensive and has created concern about the careless and often inappropriate exploitation of ocean resources.

Management of Toxic Wastes

The regulation of the amounts of radioactive wastes discharged from nuclear facilities to the sea perhaps provides the textbook example of the effective use of the oceans as waste space. The largest disposal during the last decade was from the Windscale facilities in Britain. The British strategy is worthy of consideration (see page 60). The goals have been to release radionuclides to the Irish Sea without posing an unacceptable risk to those who would suffer the greatest exposures — that is, those who consume the most seafood from the Irish Sea and those exposed directly to the highest levels of radioactivity accumulated in beach areas.

The British have been protected through models, which take into account the pathways of potentially dangerous radionuclides to the population, and through effective monitoring systems. Continuing assessments of the monitoring procedures and of the criteria for acceptable discharges are made on the basis of conventional wisdom. The data are published annually (see Hunt, 1980). In 1978, more than 200,000 curies of radioactivity were discharged from the Windscale facility. The critical populations, which are estimated to receive the highest recommended exposures based on the International Commission on Radiological Protection guidelines, are the local fishing community (25 percent), and the commercial fishing community (19 percent). It must be emphasized that these figures are based on highly conservative assumptions introduced into the models to minimize risk. The important lesson to be learned from these British activities is that effective schemes can be devised for the introduction of highly toxic substances to the marine environment without endangering public health.

The Liberian-flag tanker Argo Merchant *aground and spilling oil off the coast of Nantucket. Above, Navy seaman after dive to film conditions in seas near the tanker. (Photos courtesy U.S. Navy)*

DDT and the Integrity of Ecosystems

Although there was an early recognition (Cottam and Higgins, 1946) that the impact of powerful biocides on nontarget organisms could have disastrous results, it was not until the early 1970s that countries in the Northern Hemisphere restricted the general use of DDT and other chlorinated hydrocarbon pesticides. The marine ecosystems suffered damage. For example, there was the decimation of the brown pelican population on Anacapa Island, off the California coast. This disaster is attributed to the uptake of DDT wastes, introduced into the ocean waters from a chemical plant, by fish which were the bird's food. There is continuing concern about the hazards of radioactive wastes in marine and freshwater environments to the indigenous plants and animals (Egami, 1980). Recent laboratory studies are employing exposure levels that are environmentally relevant (see page 60). Fecundity and mutagenic effects of pollutants are being emphasized. The crucial lesson from such work is an awareness of the importance of living systems to our society.

Brown pelicans in summer plumage. Pelican populations in the Channel Islands are increasing following a decline in the 1960s apparently caused by DDT toxicity and a second decline in the mid-1970s caused by a reduced availability of forage fish. (Photo by Alan Mearns)

Societal Reaction Times

How long does it take a governmental organization to react to an unacceptable situation with respect to the marine discharge of a toxic substance? An equally important question is the time period it takes for scientists to reach an understanding of a critical pollution problem. Obviously, there is no single answer to such questions, but we can gain some sense of the times from recent pollution problems.

From the initial warnings of Cottam and Higgins in 1946 and of Rachel Carson in the 1950s to those of ecologists in the 1960s concerning the hazards of DDT, it took a bit more than two decades for the recognition of a serious environmental problem and its resolution through governmental action. Similarly, in the case of the Minimata Bay poisoning episode through methyl mercury, the problem became evident in 1953. Mercury was involved as the element of concern in 1960, and later the exact form of mercury, methyl mercury, was identified as the culprit. In the 1970s, the Swedish National Institute of Public Health, in conjunction with the Swedish Board of Health and the Swedish National Veterinary Board, assessed the general problem of methyl mercury poisoning and provided guidance to governments to protect the exposed populations from the disease. A level of 0.5 parts per million of mercury in fish, where the mercury exists nearly completely as methyl mercury, was proposed for the Swedish population and this number, or modifications of it, has been adopted by many other countries.

The important lessons are that scientists can reach an understanding of a critical pollution problem and can propose remedial actions within decades. It took slightly more than two decades for the Japanese government to halt the discharge of mercury into the coastal zone. The levels of mercury in fish from the Baltic sea were markedly reduced when the Swedish government, acting on the advice of its scientists, banned the discharge of this element from chemical plants.

The Toxic Substances

During the last three decades, many polluting substances have been identified as entering the marine environment: synthetic organic chemicals, such as DDT, and the polychlorinated biphenyls; the oxidation products from the chlorination and ozonation of waste and cooling waters, such as chloroform and chlorophenols; artificial radionuclides; biostimulants, such as phosphate and nitrate which can lead to the eutrophication of waters; microorganisms that are the agents of human and faunal disease; trace metals, such as cadmium, copper, mercury, and lead; fossil fuel compounds; litter, which encompasses those anthropogenic or natural solid products that are out of place in the marine environment; dredged materials, which can contain any of the pollutants previously listed; and large-volume wastes, such as sewage sludges and industrial discards (NOAA, 1979a).

Surveillance Tactics

Most pollutant analyses are expensive. The ability to assay accurately for most pollutants, especially those in extremely small concentrations, taxes the resources of even the best analytical facilities. Still, successful monitoring activities have been mounted, usually tailored to the concerns of specific marine localities. A. V. Holden (1973) directed an international cooperative study of organochlorine residues in wildlife, utilizing mussels, herring, pike, and eel as the sentinel organisms as well as the eggs of heron, eider, tern, and pelican. Twenty-six laboratories from 12 countries participated. Perhaps the most ambitious program involved the use of bivalves to monitor the environmental levels of halogenated hydrocarbons, petroleum hydrocarbons, artificial radionuclides, and heavy metals in coastal waters of the United States, the so-called Mussel Watch (Goldberg and others, 1978).

Marine Science

During the last 30 years in which the major problems in marine pollution have been identified, there has been a dramatic increase in our knowledge about the oceans. A part of this new information has arisen from pollution studies. For instance, the atmospheric transport of DDT and the PCBs from the continents to the oceans emphasized the movement of naturally occurring organic materials. The significance of methylation reactions in influencing the speciation of some metals and metalloids in ocean waters can be traced directly to the studies arising from the Minimata Bay episode.

But there are other developments that bear directly on marine pollution and on the assimilative capacities of coastal waters. It is only in the last five years or so that accurate analyses of such metals as copper, zinc, cobalt, and nickel in seawater have been carried out. Previous problems with contamination during sampling and inadequate or insensitive assay methods precluded reliable results. There has evolved an extensive literature on bioaccumulation, the ability of organisms to enrich themselves with certain dissolved materials in seawater. Some species have the unique ability of extracting from their environment substances that affect their own health or the health of the organisms that consume them, including human beings. The speciation and the state (solid, liquid, gaseous, or colloidal) of many elements have been determined, information essential for the understanding of bioaccumulation. Finally, there is an increased understanding of the uptake, metabolism, and effects of pollutants in the marine biosphere resulting in a better basis on which to assess potential effects and to formulate control measures. New definitions of toxicity have evolved and field measurements for toxic effects on some organisms are now possible.

The Springboard

The information base established during the last 30 years in marine pollution studies provides a springboard for the preparation of models to determine the assimilative capacity of coastal waters. The ability to introduce toxic wastes to marine waters without having a detrimental effect on public health or ecosystems has been established (see page 44). The identification of pollutant problems and the formulation of remedial actions can be accomplished in time periods of decades or less. There is a knowledge of what is toxic to life in the marine environment and an ever-increasing knowledge about life processes in the sea. This information can be employed to consider the assimilative capacities of coastal waters.

The Titration and Its Endpoints

The assimilative capacity of a body of seawater may be defined as the amount of a given material that can be contained within it without producing an unacceptable impact on living organisms or nonliving resources. This amount, essentially determined by a titration* of the polluting substances in the discharged material with the water body, becomes evident at an endpoint. In marine pollution studies, an extensive set of endpoints has been developed for individual substances. For example, the level of cesium-137 in commercially consumed fish caught off Windscale constitutes an endpoint to maintain human health. The 0.5 parts per million level of mercury in fish gives an endpoint that protects populations heavily reliant on fish for food. The discharge of industrial, domestic, and agricultural wastes, however, can often provide a more difficult problem since these wastes contain a variety, and often an unidentified group, of toxic substances.

Preliminary models which use existing data and are based on the titration concept have been constructed so that the assimilative capacities of various marine waters can be ascertained (NOAA, 1979b). Although such models can be refined with additional data, their construction emphasizes that there can be a scientific basis for regulating the discharge of wastes to coastal waters.

The 1979 Crystal Mountain Workshop in Washington (NOAA, 1979b) examined four sites and concluded that the assimilative capacities of U.S. coastal waters are not being fully utilized. For example, the largest U.S. industrial dumpsite (Site 106 off the coast of New Jersey) receives about 800,000 cubic meters per year of titanium dioxide production wastes, organic chemical wastes, and water treatment materials. Using an endpoint that is defined as an unacceptable disturbance to the community of marine organisms at the dumpsite, scientists determined that it has not reached its total capacity. The waters of the Southern California Bight have successfully accommodated the wastes discharged from a highly industrialized society of 11 million people for the last 20 years without unacceptable effects as determined by studies on the marine plant and animal communities. The most important sources of pollutants are five large municipal outfalls (see page 44). Increased amounts of metals and biostimulants are evident in the Bight waters as well as in the sediments. Organic particulates also have become more abundant as a result of sewage discharges. These organic phases appear to be incorporated, without impact, into the planktonic food web.

There is tenuous evidence that the assimilative capacities of the two other areas, Puget Sound and the New York Bight, may have been reached or exceeded. Some 20 million people live in the lands adjacent to the New York Bight. In the late 1880s, its assimilative capacity for dumped excavation dirt and construction debris was exceeded when shoaling of the channels interfered with shipping.

Four pollutants were examined for potential impacts on the Bight: microorganisms, nitrogen-containing biostimulants, polychlorinated biphenyls, and cadmium. Of these, only cadmium appeared to achieve undesirable levels. For this metal, an endpoint of 5.00 parts per billion in marine waters has been proposed on the basis that, at this concentration, some oysters accumulate enough of the metal to nauseate human consumers. The highest estimates of cadmium now present in the waters are substantially lower than this amount. Nevertheless, a model using reasonable uptake parameters by the shellfish from the suspended sediments indicates that cadmium contents in organisms growing in heavily contaminated dredge spoils might exceed safe limits.

Puget Sound receives about 25 percent of the waste water from the municipal treatment plant (METRO). The recent toxic dinoflagellate blooms in the central basin may be related to these discharges as may be one incident of oyster larvae mortality. There is as yet no compelling evidence for establishing causal relationships between discharge and these events.

Determining the Assimilative Capacity

There is quite a difference between marine pollution studies and those of assimilative capacity.

---

*A method or the process of determining the concentration of a substance in solution in terms of the smallest amount of a reagent of known concentration required to bring about a given effect in reaction with a known volume of the test solution.

Whereas in most pollution work the prime consideration is given to the protection of public health, in assimilative capacity studies, the main emphasis is on unacceptable disturbances to ecosystems. In most pollution work, the foci of interest can be narrowed to a small number of polluting substances. In determining the assimilative capacity of a particular body of water, one must consider not only benign substances, such as dredge spoils that can impede the movement of vessels and mine tailings which can interfere with primary productivity through the reduction of light intensity in the photic zone, but also many toxicants, some of which are unknown. A goal in assimilative capacity pursuits will include the identification of the endpoints (most probably measurable) and unacceptable reactions of marine organisms.

At the present time there is a great deal of work aimed at determining the impacts of pollutants upon members of the marine biosphere. The number of such investigations is great, but much of the work is incomplete.

Future Needs

Our reservoir of knowledge from marine pollution studies is clearly applicable to the calculation of assimilative capacities. For any given material awaiting disposal, there are three options: placement in the oceans, on land, or in the atmosphere. Each has its advantages and disadvantages based on scientific, social, and economic considerations. The burning of toxic halogenated hydrocarbons, such as polychlorinated biphenyls or nerve gases and the consequent discharge of the water, carbon dioxide, and hydrochloric acid to the atmosphere appears to be a rational option. The marine environment has accommodated domestic and industrial wastes in the past. With increasing affluence in many countries and with an increasing world population, the disposal needs for societal wastes will also increase. What additional information do we need to consider oceanic discharge with the caveat that we maintain oceanic resources in renewable states? The simplest answer is increased knowledge about the chemistry, physics, biology, and geology of the sea.

But there are a host of other problems awaiting resolution. Can we propose endpoints, simply measurable in the field, to give us an acceptable effect upon the health of marine communities? Both general and specific stress indicators are available, such as those for metals and petroleum components. There still remains the need to identify specific indices responsive to individual or classes of pollutants, say the low molecular weight halocarbons or the chlorophenols. What are the long-term effects of the very low levels of pollutants in the sea? What are the synergistic and antagonistic effects of collectives of pollutants or individual pollutants?

But there is another set of queries relating to man's activities. What are the amounts and the compositions of discharged wastes entering the environment today? What are the anticipated amounts for the near future? There will be great difficulties in obtaining answers to such questions. First of all, the answers themselves have economic value and could jeopardize the well-being of industries that produce wastes. Second, a data base would require information from all nations of the world, a vast undertaking for an international organization.

The determination of an assimilative capacity is a scientific judgment based on the available, but sometimes incomplete, wisdom of the day. Perfect knowledge is simply unattainable. Ocean disposal becomes acceptable when land or atmospheric dissemination of wastes becomes scientifically, economically, or socially unjustifiable. On land the possibility that we may jeopardize subterranean water supplies is perhaps the most common concern besides that of public health. We can argue that our knowledge of terrestrial plumbing is inferior to that of the oceanic environment. Most probably we can predict the fact of wastes entering the oceans better than we can predict the fate of wastes introduced on land. One of the uses of the oceans is that of a receptacle for wastes. If used properly, it should serve as a renewable resource.

Edward D. Goldberg is a Professor of Chemistry in the Geological Research Division of the Scripps Institution of Oceanography, La Jolla, California.

References

Bayne, B. et al. 1980. Mussel health. In *The International mussel watch.* December, 1978. U.S. National Academy of Sciences.

Cottam, C., and E. Higgins. 1946. DDT: Its effect on fish and wildlife. U.S. Dept. of the Interior, Fish and Wildlife Service, Circ. 11.

Egami, N. 1980. Radiation effects on aquatic organisms. Papers from a symposium, Zushi Beach, Kanagawa, Japan, May 1979. Tokyo: Japan Scientific Societies Press.

Goldberg, E. D. et. al. 1978. The Mussel Watch. *Environmental Conservation* 5: 101-125.

Holden, A. V. 1973. International cooperative study of organochlorine and mercury residues in wildlife, 1969 – 71. *Pesticides Monitoring Bulletin* 7: 35-52.

Hunt, G. J. 1980. Radioactivity in surface and coastal waters of the British Isles, 1978. Ministry of Agriculture, Fisheries and Food. Directorate of Fisheries Research. Aquatic Environment Monitoring Report No. 4.

Jeffries, H. P. 1972. A stress syndrome in the hard clam, *Mercenaria mercenaria. J. Invert. Pathol.* 20: 242-51.

Lowe, D. M., and M. N. Moore. 1979. The cytochemical distribution of zinc (Zn II) and iron (Fe III) in the common mussell, *Mytilus edulis,* and their relationship with lysosomes. *J. Mar. Biol. Assoc. U.K.* 59: 851-58.

National Oceanic and Atmospheric Administration. 1979a. Proceedings of a Workshop on Scientific Problems Relating to Ocean Pollution, E. Goldberg, ed. Estes Park, Colorado, July 10-14, 1978. NOAA/ERL, Boulder, Colorado.

———.1979b. Assimilative Capacity of U.S. Coastal Waters for Pollutants. Proceedings of a Workshop at Crystal Mountain, Washington, July 29–August 4, 1979.

Warren, T. B., and W. I. Matson. 1978. The Warren-Matson Debate on the existence of God. Jonesboro, Arkansas. National Christian Press.

The Oceans as Waste Space:

The Rebuttal

by Kenneth S. Kamlet

Ed Goldberg makes the unobjectionable points that "marine [waste] disposal can in some instances offer economic, social, and scientific advantages over the other two options — atmospheric and land disposal" and that, if the ocean's capacity to receive wastes is used properly, it should serve as a renewable resource. More debatable are Goldberg's assertions that "ocean disposal becomes acceptable when land or atmospheric dissemination of wastes becomes scientifically, economically, or socially unjustifiable" and that "most probably we can predict the fate of wastes entering the oceans better than we can predict the fate of wastes introduced on land."

This article will address these premises, as well as Goldberg's contention that it is not only possible but demonstrable "that effective schemes can be devised for the introduction of highly toxic substances to the marine environment without endangering public health" or ecosystems.

I will offer another perspective for viewing marine waste disposal and will seek to establish the following propositions:

- *The ocean, as a commonly owned (or unowned) resource, is not protected by marketplace and political forces; consequently, ocean disposal should not be permitted for persistent, toxic materials unless disposal in other media has at least marginally greater environmental impacts.*
- *The ocean, as the prototypical dispersal medium, is an inappropriate place to dispose of persistent, toxic materials; the land, which if properly managed is the exemplary containment medium, is, in general, a sounder choice for the management of such wastes.*
- *No waste management strategy can be totally free of risk to health or the environment; management decisions should be based on multimedium comparisons and risk minimization.*

- *In view of the rudimentary ability of marine science to detect, much less correct, problems associated with waste disposal, we cannot prudently rely on a permissive approach based on crude assimilative capacity models in the hope that after-the-fact monitoring and a decades-long response time will ensure that health and the environment are protected.*

The Ocean as a Common Resource

Goldberg argues that ocean disposal is acceptable when disposal in other media "becomes scientifically, economically, or socially unjustifiable." He correctly implies both that the ocean should be viewed as a last rather than first option and that, to the extent disposal in other media becomes more risky, disposal in the ocean becomes easier to justify. I must disagree, however, with the proposition that any discards that are not wanted on land or are deemed too expensive to manage on land should be treated as candidates for ocean disposal. There are good reasons for not treating the ocean as a fall-back waste heap for any material deemed too toxic or too controversial to dump on the land.

One reason is that the ocean, unlike the land, is not protected by the marketplace and political forces that protect private property. If someone proposes to dump toxic wastes on land, those who live or work nearby can be expected to protest. And elected officials can generally be counted on to listen to and support their constituents. The ocean, on the other hand — once one gets beyond nearshore coastal areas — is nobody's backyard, and fish do not vote. So, if we make our ocean disposal decisions on the basis of the sociopolitical acceptability of land-based alternatives, the ocean will always be the disposal medium of choice. Also, would-be land-disposers must purchase and maintain the desired disposal site. Ocean-disposers, on the other hand, have no capital or maintenance costs. Indeed, the U.S. Army Corps of Engineers formally perpetuates and expands this disparity by requiring local proponents of federal navigation projects to furnish all necessary land-based dredged material disposal facilities and to be responsible for needed operation and maintenance. However, where the dredged material is to be ocean-dumped, the local sponsors get a "free ride" — not only out to the disposal site but in unrestricted free use of the site. It is not hard to predict which option will usually be chosen.

The distinction between private and public (or common) property has long been recognized. It was popularized in the late 1960s by Garrett Hardin, a geneticist, who coined the phrase "tragedy of the commons" to describe the phenomenon. Hardin gives the example of a pasture open to all (directly analogous to the ocean). Each rational herdsman can be expected to try to maximize his own gain by keeping as many cattle as possible on the commons. Since each herdsman receives all the proceeds from the sale of an additional animal, the positive utility

(Photo by Jan Hahn, WHOI)

to the herdsman of adding an additional animal is nearly +1. On the other hand, the negative implications of the overgrazing created by one more animal are shared by all the herdsmen. So, the negative utility for any particular decisionmaking herdsman is only a fraction of −1. In Hardin's words:

> *Adding together the component partial utilities, the rational herdsman concludes that the only sensible course for him to pursue is to add another animal to his herd. And another; and another. . . . But this is the conclusion reached by each and every rational herdsman sharing a commons. Therein is the tragedy. Each man is locked into a system that compels him to increase his herd without limit – in a world that is limited. . . . Freedom in a commons brings ruin to all.*

The ocean is the paradigm of a global commons.

To the extent individuals (or nations) make waste disposal decisions involving the ocean based on individual perceptions of self-interest, ocean disposal will inexorably increase — until the "assimilative capacity" of the world ocean is ultimately exceeded.

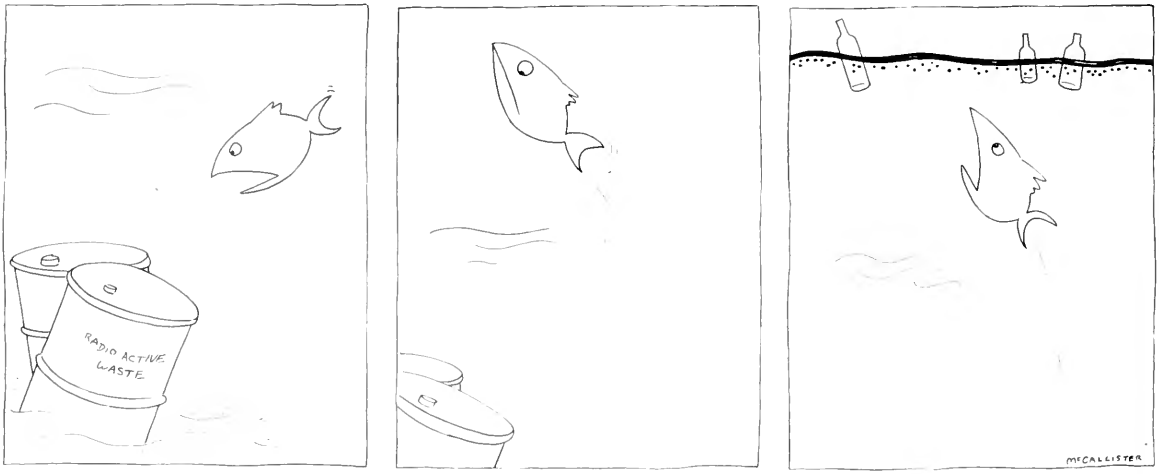
Needler and Templeton (see page 60) recognize this problem. They point out — in the context of sea disposal of radioactive wastes — that "it is certainly not clear that by considering radioactive waste releases only on a case-by-case basis that one is providing the essential protection for the global population." They make the further perceptive observation that:

> *Strictly political decisions also may influence the choice of disposal options. One must hope that the decision to use the marine environment will not be influenced by the fact that the hazard to the producing nation is reduced by marine disposal or that the population is against local disposal, even though the potential hazard to other populations may be much larger. . . .*
>
> *If one assumes that the land areas of nations with favorable geological formations will not be made available to others, some nations on the basis of the optimization requirement may have no choice but to use the marine environment. . . .*

Goldberg, by contrast, points to regulation of radioactive waste discharges to the sea as perhaps providing "the textbook example of the effective use of the oceans as waste space." The Windscale facilities in Britain, and the associated marine modeling and monitoring strategies developed by the British, are cited as a successful example of a marine waste disposal scheme that has been demonstrated as not endangering public health — at least that of the British citizenry. Goldberg then uses the "successful" British experience with assimilative capacities for marine disposal of radioactive wastes as a springboard for urging more general reliance on the assimilative capacity approach.

The success of the Windscale program is a matter of scientific debate. Beyond this, however, any effort to assess assimilative capacities for persistent toxicants on a case-by-case basis (whether directed toward a particular pollutant, waste disposer, or coastal area) is likely to safeguard individual interests at the expense of the world ocean.

The U.S. Congress has, elsewhere, recognized that unless public property is given special protection, it will receive special attention from developers and despoilers. Thus, under the Federal Aid Highway Act, Congress has specified that highways may not be constructed through public parks (and wildlife refuges) unless a) there is



no "feasible and prudent" alternative, and then, only if b) the project includes all possible planning to minimize harm to the park (or refuge). Congress realized that without this extra measure of protection highway builders would preferentially invade public property. Absent of statutory restrictions, such a preference would clearly be in the developer's best interests. No protests from displaced businessmen and residents. No private property to condemn and purchase. No relocation assistance necessary for dispossessed homeowners. Nothing to offset the cost-savings and convenience to the developer of building roads through parks. Nothing except the eventual obliteration of all parks in the vicinity of highway projects.

I would argue that persistent toxic wastes should not be disposed of in the ocean unless there is evidence that there are no "feasible and prudent" land-based alternatives. This should entail, among other things, evidence that the adverse *environmental* impacts of land- or atmosphere-based disposal are at least marginally greater than the environmental impacts of ocean disposal.

The Ocean As a Dispersal Medium

The ocean and inland waters are dispersal media. So is the atmosphere. The land, to the extent pollutants can be kept out of ground and surface waters, is a containment medium.

Is it better to put a persistent toxic material in a dispersal medium or in a containment medium? For persistent synthetic chemicals, such as PCBs, Kepone, DDT, and the like, the answer is clear. The material should be isolated and contained to the fullest possible extent (assuming it cannot be entirely destroyed). For persistent, naturally occurring materials, such as heavy metals and petroleum hydrocarbons, which have natural background levels in the environment, the answer is slightly less clear. A reasonable argument might be made that dispersal-oriented disposal, aimed at diluting these pollutants down to background levels, is a sensible management philosophy. However, large or continuous additions of even such materials can produce harmful departures from background levels, particularly on a localized basis; in such cases, dispersal-oriented approaches seem less plausible.

At the opposite extreme — nontoxic or readily biodegradable materials — the answer is also clear. In such cases, the ocean's assimilative capacity may be enormous. Acids, alkalis, sanitary wastes, and nutrients exemplify this class of materials. A management philosophy aimed at maximizing dispersal of such materials (while avoiding disruption of local ecological systems) will often make the most sense.

Before an assimilative capacity can properly be computed for a particular waste discharged into the ocean — the preeminent dispersal medium — I think it necessary to first determine whether dispersal rather than containment is the preferable management option.

Goldberg acknowledges that for toxic halogenated hydrocarbons, burning and the consequent discharge of combustion products to the atmosphere appears to be "a rational option" (although, apparently not necessarily the *most* rational option in his view). On the other hand, the ocean would be an appropriate disposal medium for "domestic and industrial wastes" which the marine environment "has accommodated. . . in the past."

Need For Multimedium Management

I agree with Goldberg that:

> *For any given material awaiting disposal, there are three options: placement in the oceans, on land, or in the atmosphere. Each has its advantages and disadvantages based on scientific, social, and economic considerations.*

I also agree with the conclusion of the Panel on Marine Waste Disposal (in which Dr. Goldberg and I participated) at the Marine Pollution Policy Workshop (held by the University of Rhode Island Center for Ocean Management Studies, June 25-27, 1980) that:

> *An assessment of assimilative capacity for a portion of the marine environment should be accompanied by a similar assessment for other environmental systems which represent alternative sites for the disposal of a particular waste.*

There is no risk-free way to dispose of persistent toxic pollutants. Management strategies should be designed to minimize risks to health and the environment. This can only be achieved by a multimedium evaluation and comparison of environmental risks and benefits.

The Commission on Natural Resources of the National Academy of Sciences recommended in a 1977 report that the Environmental Protection Agency (EPA) review and revise current sludge disposal policies "in order to recognize the multimedium nature of environmental impacts and to ensure that the relative merits of available options, environmental and economic, are judiciously weighed."

A 1980 draft report of the National Advisory Committee on Oceans and Atmosphere also urges the EPA to "adopt an integrated approach to waste management," and recommends that "wastes should be disposed of in the manner and medium which minimizes risk to human health and the environment, at a price that this Nation is prepared to pay."

Although I endorse the need for a multimedium approach, I believe that the initial comparison should be of the *environmental* merits of the various options. Once the medium of choice is identified from this standpoint, other relevant factors — including economics, technological feasibility, and so on — should be considered. This second-stage analysis should focus on whether the environmentally preferred option can be implemented at *reasonable incremental cost* relative to other options. The approach should *not* be to first decide which option is cheapest or least controversial, and then to decide if and how *that* option can be implemented without unacceptable environmental impacts.

What I find objectionable in Goldberg's formulation is the implication that any waste material that passes muster under an assimilative capacity analysis should be deemed suitable for ocean disposal.

Predictive Abilities of Marine Science

Goldberg relies heavily in his support for the assimilative capacity approach on what he views as the great advances in our knowledge about the oceans during the last 30 years — the ability to determine levels of exposures of organisms to contaminants in the environment, and the capacity of scientists to understand critical pollution problems and propose remedial measures in terms of decades. In any event, as Goldberg sees it, "perfect knowledge is simply unattainable," so we need to do the best we can. Determining an assimilative capacity based on the available, albeit incomplete, wisdom of the day is, in this view, a perfectly defensible and necessary approach.

I must dissent from this view. I submit that our ignorance so far exceeds our understanding in the areas of predicting the fate and effects of marine pollutants, and of successfully remedying problems once they arise, that it would be irresponsible to presumptively permit ocean disposal of persistent toxic pollutants based on available crude assimilative capacity models. Prudence dictates that any presumption must operate in the other direction — at least for persistent toxic pollutants that present a nontrivial short- or long-term hazard potential.

It is foolhardy and wrong to assume that what we do not know cannot hurt us, or that, if unanticipated problems arise, science will be able to remedy them. It is equally wrong to endorse ocean disposal merely because it is cheap and convenient and because an assimilative capacity model does *not* prove it to be obviously hazardous, without also evaluating other disposal alternatives and seeking to *minimize* risk.

Goldberg acknowledges that we need increased knowledge about the chemistry, physics, biology, and geology of the sea before we can be sure that marine waste disposal is consistent with maintaining oceanic resources in a renewable state. He also identifies many problems requiring resolution:

- *finding endpoints measurable in the field;*
- *identifying specific indices responsive to individual or classes of pollutants;*
- *assessing long-term effects of very low levels of pollutants in the sea;*
- *understanding synergistic and antagonistic effects of collectives of pollutants or individual pollutants; and*
- *determining amounts and compositions of discharged wastes going to the oceans today and in the near future.*

In the Crystal Mountain proceedings, Goldberg listed an additional knowledge gap: "following the fate of discharged materials in the coastal environment."

Although we might confidently rely on an assimilative capacity approach were an appropriate and sufficiently sensitive endpoint used, and were the data base reliable, we are far from such a state of grace. As Goldberg's own statement about the gaps demonstrates, what we don't know is almost everything.

Goldberg briefly discusses the four coastal sites and assimilative capacity models discussed at Crystal Mountain. He uses this to support two propositions: 1) that "the assimilative capacities of U.S. coastal waters are not being fully utilized," and 2) that the Crystal Mountain exercise demonstrates that assimilative capacity models are in fact "a scientific basis for regulating the discharge of wastes to coastal waters."

I believe the Crystal Mountain proceedings themselves belie these contentions — at least for the foreseeable future. Let me take the New York Bight panel, in which I participated, as an example.

Of the four contaminants and endpoints selected for evaluation, the panel concluded that no assimilative capacity could be estimated for the human health effects of pathogens in the New York Bight because the existing data base is inadequate. And, although the panel did reach conclusions for the other three, it significantly qualified the results in each case.

Thus, although the panel concluded that present PCB inputs to the Bight could safely (without adverse human health impacts) increase in the future (but definitely not by an order of magnitude), it emphasized that the analysis did not address the fact that other animals of the Bight apex ecosystem, such as bivalves, raptorial birds, and finfish, would require much lower levels of PCBs to be fully protected.

Similarly, although the panel concluded that urban nitrogen loads are at worst no more than 10 to

25 percent of the assimilative capacity of the Bight apex in terms of producing anoxia, it cautioned that an endpoint of higher oxygen content might, in practice, represent a better choice. With such an endpoint the apex would assimilate a smaller additional nitrogen load.

Finally, the panel concluded that cadmium levels in Bight sediments could currently be approaching or exceeding safe limits for shellfish in parts of the Bight. However, the panel found that existing data did not permit "rigorous development of a carrying capacity algorithm based on [cadmium] concentrations in marketable shellfish," which forced it to consider a range of "possible" partition coefficients between shellfish and sediments (varying by a factor of 25) in order to do an assimilative capacity calculation.

More generally, both the Crystal Mountain participants and the URI Workshop concluded that assimilative capacity analyses could be misleading unless a number of factors were taken into account:

- *The quantity of a pollutant that an ocean segment can accept without a particular undesirable impact depends on the effect one chooses to consider.*
- *An area's assimilative capacity for a given pollutant will be smaller if one considers effects on sensitive rather than hardy organisms and more important rather than less important routes of exposure, and if one includes significant impacts that we cannot yet measure because of their long time scale, the insensitivity of our measuring techniques, or their subtlety in relation to natural fluctuations (for example, we have not yet identified the causal agent of finrot disease).*
- *One cannot assume that undesirable impacts will be avoided unless assimilative capacities are separately determined for each important uniform subdivision of the area being considered (for example, Hudson River discharges could have an insignificant impact on the New York Bight, yet have a devastating impact on the Hudson River estuary).*
- *Assimilative capacities must be established for the most sensitive or critical portions of the system being considered.*
- *Management decisions based on assimilative capacities of individual contaminants must recognize that combinations of contaminants can and do have cumulative effects.*
- *The marine environment's assimilative capacity is dependent on the rates of natural processes and must consider time and space scales.*
- *Assimilative capacity approaches are not a substitute for an initial screening of a waste for acceptability prior to marine disposal.*
- *There is inadequate information in most regions of the United States on the chemical constituents, sources, and mass balance of pollutants discharged into the marine environment.*

In short, although I agree that "perfect knowledge is simply unattainable" and that we must make waste management decisions on the basis of available scientific wisdom, I do not think we can justify permissive decisions about ocean disposal on the basis of the crude and misleading assimilative capacity models presently accessible. (Such models may, however, be useful — despite their limitations — in helping to assess the need for restricting ocean disposal of certain pollutants.)

Limitations of Monitoring

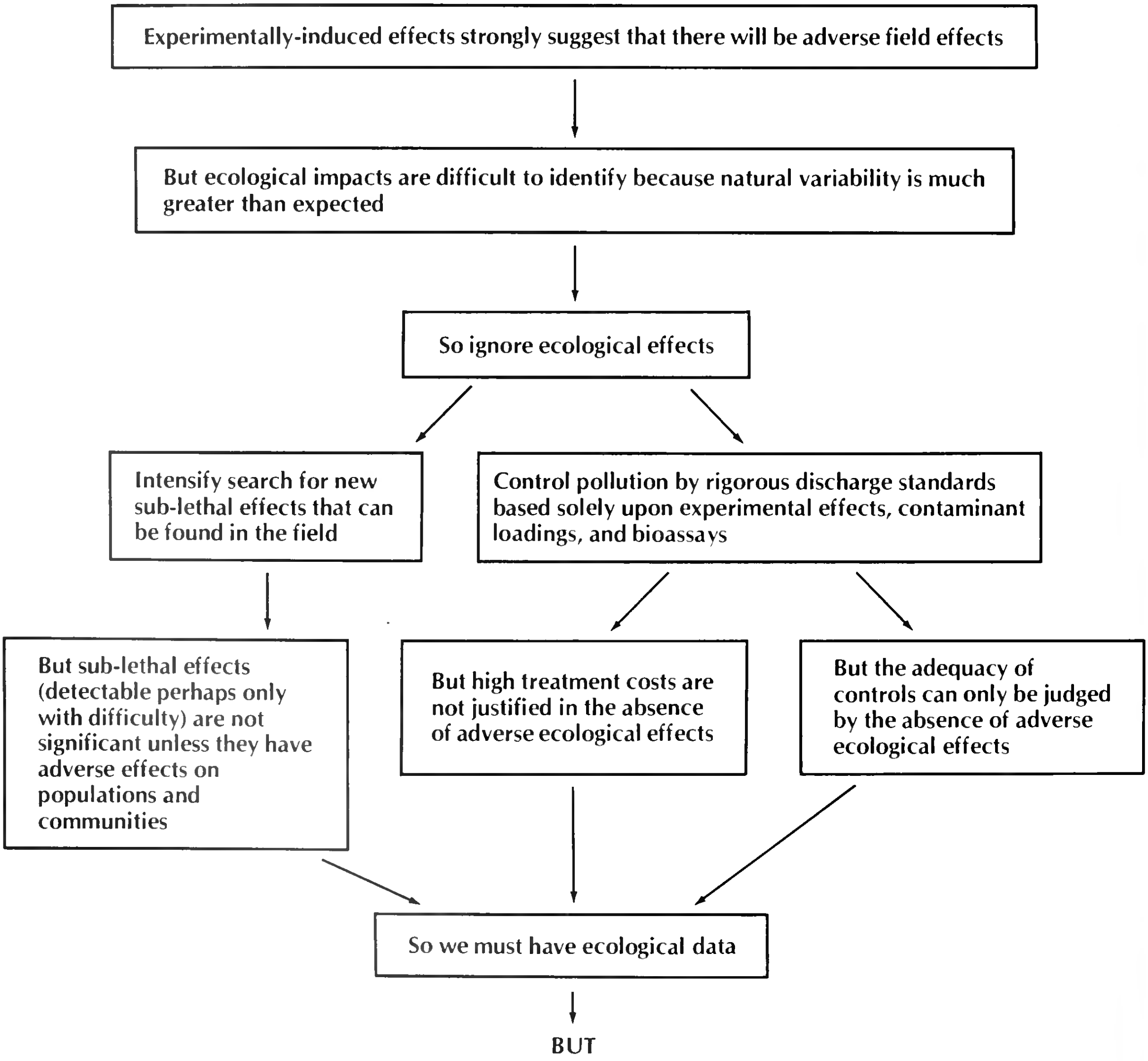
Goldberg finds encouraging the fact that scientists can reach an understanding of a critical pollution problem and can propose remedial actions in terms of decades and that "successful" monitoring activities, such as Mussel Watch, have been mounted that enable marine scientists to follow pollutant exposures of marine organisms. Presumably, this suggests to him that even imperfect assimilative capacity models can be safely used without a serious risk of catastrophic, irreversible harm to health and the environment — even if the models understate the potential for environmental impact.

Again, this is a debatable proposition. Although it may take decades to identify and rectify a problem once a persistent toxic chemical enters the environment, it may take only months or years for the problem to reach crisis proportions. (During this period irreversible or irreparable damage can be done.) For example, in the case of Kepone, within two years of the commencement of its inadequately controlled production at a converted service station, Kepone workers had experienced serious health problems and river sediments had been contaminated to the point that a multimillion dollar seafood industry had to be virtually closed down.

And, although it took a number of years for DDT and PCBs to accumulate in the environment to the point that serious ecological damage became evident, several species of predatory birds were brought to the brink of extinction before the decision was made to ban the production of these chemicals. Since we are still far from being able to routinely monitor the reproductive effects of toxic chemicals (for example, via effects on steroid metabolism), it seems entirely possible that the next time we are forced to deal with an organohalogen or like compound released into the environment, we will be too late to save sensitive species (possibly including man, someday) from extinction.

Our knowledge of the deep ocean has been likened to what we would learn about Washington, D.C., by taking grab samples of trees, buildings, and alleycats from a high-flying helicopter.

Table 1. Considerations regarding environmental evaluation. (Lewis, 1980)



Experimentally-induced effects strongly suggest that there will be adverse field effects

But ecological impacts are difficult to identify because natural variability is much greater than expected

So ignore ecological effects

Intensify search for new sub-lethal effects that can be found in the field

Control pollution by rigorous discharge standards based solely upon experimental effects, contaminant loadings, and bioassays

But sub-lethal effects (detectable perhaps only with difficulty) are not significant unless they have adverse effects on populations and communities

But high treatment costs are not justified in the absence of adverse ecological effects

But the adequacy of controls can only be judged by the absence of adverse ecological effects

So we must have ecological data

BUT

A British scientist, John Gray, has pointed out that marine biological monitoring efforts are of questionable value since the ecological models on which they are based are unable to detect subtle, naturally occurring changes and neglect the majority of the living components of marine ecosystems. For example, Gray notes that the number of samples taken in a biological survey is usually governed by the manpower and facilities available, and the types of organisms collected depend on the available expertise. Usually, only the common species of macrofauna are identified. The small meiofauna that pass through a 0.5-millimeter sieve, and which are usually disregarded, are roughly two orders of magnitude more abundant than the macrofauna. Similarly, most surveys tend to overlook rare species. In doing so, they ignore one of the intrinsic ecological properties of biological samples: the majority of animal species are rare in nature.

Another British scientist, J. R. Lewis, has convincingly argued (see Table 1) that the two prevailing strategies for controlling environmental impacts both suffer from the same inherent shortcoming: in the absence of demonstrable adverse ecological effects (which are difficult to identify because of greater-than-expected natural variability), it is hard to show the significance of observed effects, to justify high treatment costs, or to judge the adequacy of control measures. The two strategies are: increased field testing of sublethal effects, and rigorous control of discharges based on contaminant loadings and bioassays. Lewis proposes that more effort be expended between the two extremes of laboratory effects and community ecology "where the expected effect seems to be lost."

The most relevant future research perhaps should be aimed, as Lewis suggests, at understanding pollutant pathways, immobilization, degradation, and the like; "linking effects studies, contaminant loadings, bioassays and ecology"; and concentrating effects and accumulation work on "those species which have a key ecological role in particular communities" and the loss of which could have considerable community consequences, rather than focusing merely on good accumulator species of high tolerance.

Conclusions

As Lewis puts it, "It is . . . becoming disconcertingly apparent that broadscale field effects [of marine pollution] are less convincingly demonstrable than was expected." The challenge facing the marine science community is to find out why. Is it because chronic effects on communities are negligible and only acute pollution matters? Or, is it because we are measuring the wrong things, unable or unwilling to measure the right things, or otherwise going about the task in the wrong way?

I think the effort to develop new and more reliable field tests of chronic effects is a step in the right direction. But I also believe that, at least where persistent toxic substances are involved, we must adopt a cautious, preventive approach. This means setting regulatory standards based on projections from laboratory experiments and mass balance models. If it turns out we are being more protective than necessary, posterity will forgive us. In the meantime, we must strive to bridge the gap between alarming laboratory results and elusive field measurements.

The assimilative capacity construct is most useful as an organizing principle. To the extent it helps to focus research and monitoring on relevant questions, it is beneficial. It also can be valuable in defining the *lower* limit of needed regulation. However, to the extent that Goldberg would hold out assimilative capacity assessments, now or any time soon, as a sufficient basis for predicting the hazard potential of persistent toxicants in the marine environment, I must dissent.

Kenneth S. Kamlet, a biologist and lawyer, is Assistant Director for Pollution and Toxic Substances at the National Wildlife Federation, Washington, D.C.

References

Alexander, M. 1981. Biodegradation of chemicals of environmental concern. *Science* 211: 132-211.

Atlas, E., and C. S. Giam. 1981. Global transport of organic pollutants: Ambient concentrations in the remote marine atmosphere. *Science* 211: 163-65.

Gray, J. 1976. Are marine base-line surveys worthwhile? *New Scientist* 81: 219-21.

Hardin, G. 1968. The tragedy of the commons. *Science* 162: 1243-48.

Jellinek, S. D. 1980. On the inevitability of being wrong. Remarks before the New York Academy of Sciences, Workshop on Management of Assessed Risk for Carcinogens, in New York, N.Y., March 17, 1980.

Kamlet, K. S. 1978. An environmental lawyer's uncertain quest for legal and scientific certainty. In *Estuarine interactions*, ed. M. L. Wiley, pp. 17-29. New York, N.Y.: Academic Press.

———. 1979. Helping politicians to make the best decisions [concerning management of sewage sludge]. *Compost Science/Land Utilization* 20: 30-32.

Lewis, J. R. 1980. Options and problems in environmental management and evaluation. *Helgoländer Meeresunters*. 33: 452-66.

National Academy of Sciences. 1977. *Multimedium management of municipal sludge*. A report of the Committee on a Multimedium Approach to Municipal Sludge Management. Washington, D.C.: National Academy of Sciences.

National Advisory Committee on Oceans and Atmosphere. 1980. *The role of the ocean in a waste management strategy*. A Special Report to the President and the Congress. Staff Draft, Dec. 29, 1980.

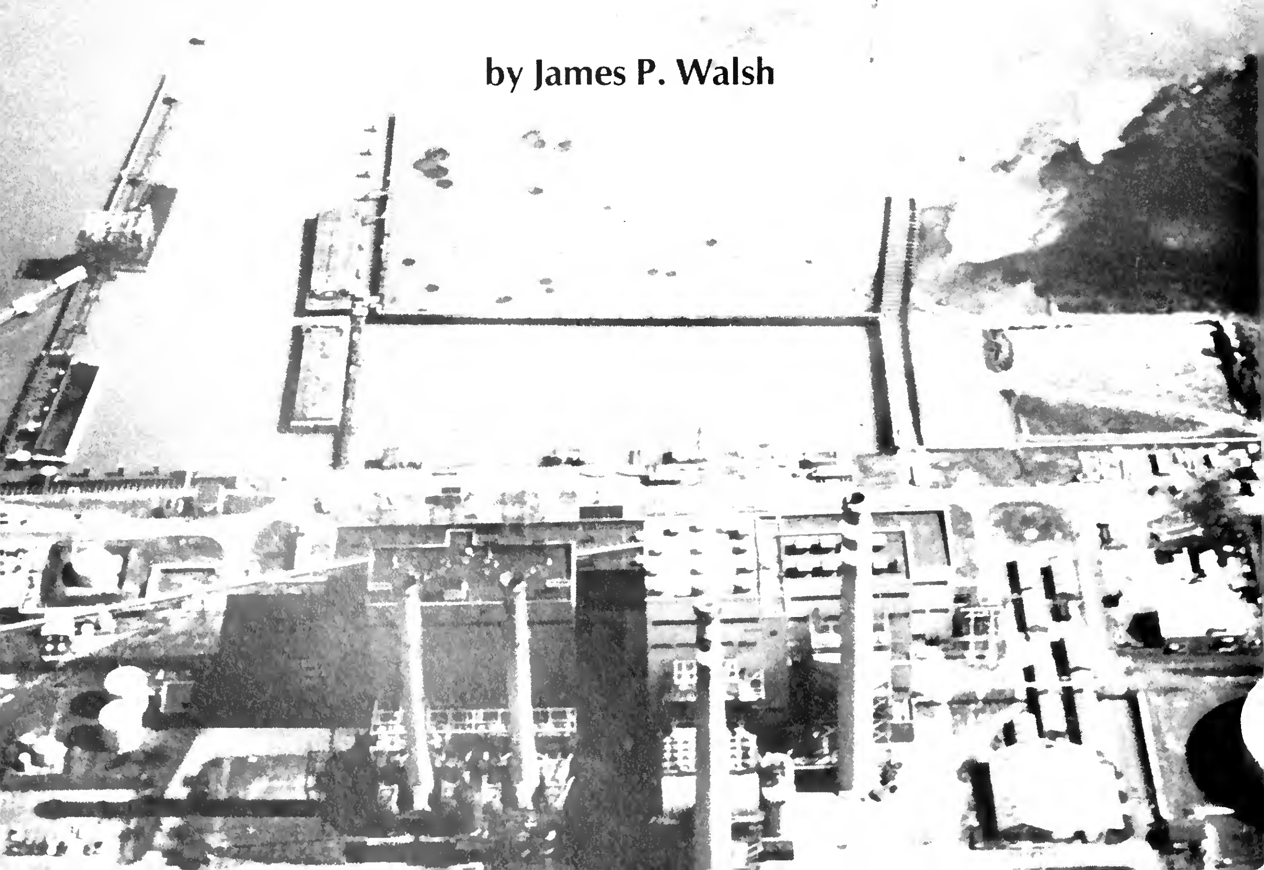
National Oceanic and Atmospheric Administration. 1979. *Assimilative capacity of U.S. coastal waters for pollutants*. Proceedings of Workshop at Crystal Mountain, Washington, July 29 – Aug. 4, 1979.

University of Rhode Island, Center for Ocean Management Studies. 1980. *Towards a national marine pollution policy*. Proceedings of the Marine Pollution Policy Workshop at Galilee, R.I., June 25 – 27, 1980.

U.S. Policy on Marine Pollution:

Changes Ahead

by James P. Walsh



Raw sewage outlet in the sea off Beverly, Massachusetts. (Photo by Laurence Lowry, PR) Page opposite, industrial plant at Sparrows Point, Chesapeake Bay. (Photo by G. Carleton Ray, PR)

The United States has long been a leader in establishing laws to protect the marine environment. U.S. laws are perhaps the strictest of any industrialized nation in the world. A policy prohibiting waste discharge into the marine environment was first set forth in federal law in 1899, when the Rivers and Harbors Act was enacted. In straightforward language, Section 13 of that act prohibits the discharge of "any refuse matter of any kind" into the navigable waters of the United States.

The federal law of ocean pollution control evolved into a long list of statutes that address various sources of pollution. There are two major statutes that shape U.S. policy on marine pollution. One is the Marine Protection, Research, and Sanctuaries Act, commonly called the Ocean Dumping Act, enacted in 1972. It contains the following congressional policy:

> *Sec. 2 (a) Unregulated dumping of material into ocean waters endangers human health, welfare, and amenities, and the marine environment, ecological systems, and economic potentialities.*
>
> *(b) The Congress declares that it is the policy of the United States to regulate the dumping of all types of material into ocean waters and prevent or strictly limit the dumping into ocean waters of any material which would adversely affect human health, welfare, or amenities, or the marine environment, ecological systems, or economic potentialities.*

The other statute is the Clean Water Act of 1977, which amended the Federal Water Pollution Control Act of 1948 and extended the discharge prohibition and liability provisions of Section 311 of the latter law to 200 nautical miles off U.S. shores. The congressional policy statement reads as follows:

> *Sec. 311. . .(b) (1) The Congress hereby declares that it is the policy of the United States that there should be no discharges of oil or hazardous substances into or upon the navigable waters of the United States, adjoining shorelines, or into or upon the waters of the contiguous zone, or in connection with activities under the Outer Continental Shelf Lands Act or the Deepwater Port Act of 1974, or which may affect natural resources belonging to, or pertaining to, or under the exclusive management authority of the United States (including resources under the Fishery Conservation and Management Act of 1976).*

Other portions of the Clean Water Act, most notably Section 403, which includes criteria for ocean discharge permits, deal with the control of ocean pollution in much the same way. The water areas covered include U.S. internal waters, the territorial sea (generally out to 3 miles), the waters of the contiguous zone (out to 12 miles), and the ocean (out to 200 miles in most cases).

The theme established by these two major laws is that there be either no discharges or strict limits on discharges of any "pollutants" or "materials" into marine waters. In both statutes, the definition of prohibited or controlled pollutants or material is quite broad. Categories of serious pollutants, about which there is little debate over harmfulness, such as toxic chemicals or high-level nuclear wastes, are subject to an ocean-dumping ban. Other materials can be dumped only if certain protective criteria are satisfied. Obviously, these laws are complex and exceptions do exist, but these will not be discussed here.

Perhaps the most striking feature of these laws is the implicit assumption that ocean disposal is the least preferable alternative to other methods of dealing with pollutants, such as land disposal. The effects of certain toxic pollutants on public health are well known, hence the ban on human consumption of PCB-contaminated fish from the Hudson River. But the philosophy that all discharges into the ocean are inherently bad goes beyond what scientists know for certain about the fates and effects of many contaminants found in the marine environment.

Section 403 of the Clean Water Act contains the most explicit statement of this philosophy. It specifies special criteria for issuing permits to discharge into coastal and ocean waters. The last clause states that if the effects of any pollutants are not known, or if a reasonable judgment of such effects cannot be made, then no permit may be issued.

The Ocean Dumping Act has a comparable list of criteria and requires that a dumping-permit applicant demonstrate, to the satisfaction of the Environmental Protection Agency (EPA), that the dumping "will not unreasonably degrade or endanger human health, welfare, or amenities, or the marine environment, ecological systems, or economic potentialities." Because of our limited knowledge about the fate and effects of many pollutants, particularly effects of chronic, low-level exposure, demonstrating the absence of deleterious effects is a tough order indeed.

In short, Congress has framed an ocean dumping policy that can be stated rather simply: "If you don't know, don't dump." A 1977 amendment to the Ocean Dumping Act requires the cessation of all ocean dumping of municipal sewage sludge by December 31, 1981. The deadline has remained part of the law despite doubts about whether cities in the New York area are capable of managing, through land disposal, a growing inventory of sewage sludge from new sewage treatment facilities required by

Major U.S. Marine Pollution Control Laws

Title	Date of Enactment	Coverage
The Rivers and Harbors Act of 1899	March 3, 1899	Any refuse material
The Fish and Wildlife Coordination Act (as amended)	March 10,1934	Protection of fish and wildlife habitat
The Federal Water Pollution Control Act (as amended) (common name — Clean Water Act)	June 30, 1948	Point sources of industrial and municipal wastes; oil and hazardous material spills
The Outer Continental Shelf Lands Act (as amended)	August 7, 1953	Oil and gas leasing and operations on the U.S. Continental shelf
The Ports and Waterways Safety Act (as amended)	July 10, 1972	Tanker and other vessel construction and operations
The Marine Protection, Research and Sanctuaries Act of 1972 (common name — Ocean Dumping Act)	October 23, 1972	Dumping of wastes at sea; research; creation of marine sanctuaries

the Clean Water Act. Just last year, Congress amended the law to require that the dumping of industrial wastes also be ended by December 31, 1981.

Congress has sought to tightly control known point sources of pollutants through the Clean Water Act, the Ocean Dumping Act, and other laws. The emphasis has been more on effluent standards and control technology and less on receiving water quality, although both concepts are reflected in the nation's water pollution laws. This emphasis further highlights the strong bias for strict limits on discharges into U.S. waters. Uncertainty is clearly to be resolved in favor of protecting the marine environment.

Signs of Change

One good indicator of changing social views is the manner in which our public institutions, Congress, the executive branch, and the courts, approach the question of managing uncertainty and risk. After many years of laissez-faire regulating, the government got tough in the 1960s and 1970s and policy trends shifted away from free use of the environment. Through environmental laws, uncertainty and risk were shifted away from society at large to producers and consumers. The cost and value of the new environmental requirements, and the process by which government determines those requirements, are now being vigorously tested.

During the debates on the 1977 amendments to the Federal Water Pollution Control Act, the basic approach to ocean pollution just outlined was challenged in connection with secondary treatment of municipal wastes discharged into marine waters. According to Section 301 of the act as it existed prior to the amendments, publicly owned municipal treatment facilities were to achieve "secondary treatment" by July 1, 1977. Not all did, but the requirement still stands. The cost of complying with all the requirements of the law was estimated in 1978 to be $106.2 billion. This enormous cost and the alleged ability of certain coastal areas to assimilate wastes (the Pacific Coast was used as an example) led Congress to adopt in 1977 a special provision, Section 301(h) of the amended law, for waiving the secondary treatment requirement on a case-by-case basis.

The 301(h) waiver authority represents a departure from the effluent-control philosophy of the rest of the act. It applies only to existing municipal waste discharge systems emptying into "marine" waters. The underlying assumption of the provision is that "deep waters of the territorial sea" and beyond, and inshore "saline estuarine waters where there is strong tidal movement," are capable

The Port Retriever, a new vessel in Port of Baltimore to scoop up waste and debris from water's surface. (Photo Researchers)

of diluting primarily-treated municipal wastes without threatening acceptable water quality.

Rumblings of change can be heard in other broader policy debates that would impact on ocean pollution policy. The most significant of these involves a procedural rule in lawsuits challenging federal agency actions. Under existing law, rules issued by federal agencies are presumed to be valid unless shown to be otherwise by the challenging party. Senator Bumpers of Arkansas sponsored an amendment in 1980 that would limit this presumption of validity and shift the burden of proving the soundness of a rule to the agency before it would become effective. The amendment has been strongly opposed by the Department of Justice but is supported by pro-business organizations, such as the Business Roundtable. If adopted, the burden of eliminating uncertainty would shift to the regulating agency, and fewer regulations would probably result.

In an area as fraught with uncertainty as ocean pollution, a change in the basic legal assumption of validity could slow the application of the tight restraints that U.S. pollution control laws now impose on pollutant discharges. Although the Bumpers amendment has not been adopted, the fact that it was even considered and embraced in the Senate has shaken many of those concerned about pollution control. It also is a sign of possible change, a change that could limit the ability of government institutions to aggressively enforce current laws.

The courts also have signaled change. In a recent case involving an oil lease sale in the Beaufort Sea off Alaska, the judges refused to halt the proposed sale even though a risk to the endangered bowhead whale existed. Development was allowed to continue even in the face of uncertainty, if harmful actions were not yet irretrievably taken and the government could take preventive action later. This represents a change in attitude from previous decisions that took a go-slow attitude toward environmental risks.

Finally, the recent national election has created the strong belief that environmental laws and regulations will be closely scrutinized and perhaps changed by the new President and a more conservative 97th Congress. Today economic considerations appear to be the top priority for the American people. Consequently, since many environmental laws make environmental concerns paramount to economic concerns in many cases, legislators and government executives have announced plans to review U.S. pollution control laws.

These, and other more general expressions of dissatisfaction with existing policies, point to impending reexamination and reassessment of marine pollution policy. Do marine pollution laws go too far in some cases? Is the decision process too slow? Are the laws in line with scientific knowledge? Is assimilative capacity the better approach to discharges? What are the most dangerous aspects of pollution and do our regulations focus on these? Are the present controls too costly and without clear benefits? Both sides in the debate have an obligation to explore these issues thoroughly and honestly.

Is There a Problem?

Not everything that man deposits in the ocean is a pollutant, except in the most literal sense. Ecosystems are adaptable, but stress that is deemed unacceptable can occur — that is, determined to be so through some societal decisionmaking process. Both fact and subjective judgment — scientific, political, and social — play a role in this process, and both may change over time either because greater knowledge is acquired or because public values change.

The Clean Water Act seeks as a national goal the attainment of "fishable and swimmable" waters by 1983. Under that expression of national values, a marine pollution problem most certainly exists. In various parts of our coastal waters, shellfishing is prohibited because pollutants accumulated by shellfish pose a health threat. The waters of the New York Bight, for example, are considered to be quite stressed, thus there are difficulties with dumping sewage sludge or dredge spill in those waters.

Over the last two years, pursuant to the National Ocean Pollution Planning Act of 1978, the federal government has been working to inventory national needs and problems in marine pollution and marine pollution research. This has been an open process, involving knowledgeable individuals from state and local governments, universities, private enterprise, and environmental groups. From this effort, a better understanding should emerge about pollution and research priorities.

Several regional committees have completed a review of U.S. pollution issues, which identifies several major ocean-dumping problems that must be managed in the months to come:

Dredge Spoil. Maintenance dredging of existing port capacity and potential dredging of new capacity for such commodities as coal involves tremendous amounts of material that must be disposed of in coastal areas. Between 1973 and 1978, an average of 52.4 million cubic meters of dredge spoil was dumped each year into U.S. ocean waters. On the basis of volume alone, dredged sediment is a major problem that is likely to become more troublesome. The sources of the pollution problem come not, however, from the sediments themselves but the many toxic contaminants that have come to reside in harbor sediments in major industrial ports. The dredging up and dumping of these sediments resuspend the toxic substances (cadmium, PCBs, and others) in the water, posing a threat to marine organisms and possibly to human health.

Municipal Wastes. By the year 2000, a one-third increase in the number of municipal wastewater treatment plants is expected, from the 1,800 or so now on line to 2,400. Unless a 301(h) waiver is obtained, each of these publicly owned facilities will be required to achieve secondary treatment, which means that more sewage sludge will be generated. Since sewage sludge dumping in the ocean is banned, land disposal is the remaining option, yet it is very expensive and likely to be more so by the year 2000.

Loss of Habitat. Alteration of the natural systems that support life in estuaries is a continuing source of great environmental and economic concern. The shellfish industry can be particularly hurt by disease-causing bacteria, viruses, toxic chemicals, and other contaminants that invade estuarine habitats. A steady and irreversible loss of habitat is being documented each year because of pollution or physical alteration. The National Shellfish Register, maintained by the EPA and the Food and Drug Administration, shows that in 1974, 25 percent of previously productive shellfish waters were closed for health reasons. Some are fearful that fish larvae exposed on a regular basis to a combination of pollutants even at low levels could threaten our finfish stocks as well.

These and other waste disposal problems are not insignificant. Those who rely on water quality for their livelihood, such as fishermen, are becoming more and more worried about other ocean and coastal uses threatening them (hence, the fight over oil and gas leasing off Georges Bank).

Suggested Directions of Change

The real threat to humans and natural resources by toxic chemicals, the complexity of the coastal environment, the potential of enormous pollution-control costs, and broad policies and standards born in a time of activism all combine to argue convincingly that continual reassessment of both knowledge and values is the only intelligent course. This is a good time to take stock and bring about constructive change.

1. We should assess, based on presently available information, the state of pollution in U.S. coastal and ocean waters. Bits and pieces of information from years of study by various scientific disciplines have not to date been adequately evaluated and synthesized in a comprehensive manner. Such an effort should then be institutionalized and kept current.

2. Present standards and permitting criteria, such as those just established (October 3, 1980) in Section 403 of the Clean Water Act, should be more precisely defined in terms of specific pollutants and regional water bodies. One of the great difficulties of the pollution regulatory process is the lack of certainty. Recently, the EPA published criteria in the *Federal Register* for determining water quality in connection with 65 toxic pollutants. The criteria assess what is known about the effects of these toxic contaminants on human health, aquatic life, and aesthetics, and identify the threshold quantities of such contaminants that would be acceptable to maintain protection of these values. Effects in both fresh and saltwater environments are listed. This entire process should be accelerated for coastal waters.

3. An information system should be developed to routinely report what has been learned either about particular pollutants or the conditions of coastal waters so that government decisionmakers and the public are better informed. Technical research reports should be condensed and made more readable.

4. Pollution research by all institutions must be better disciplined to ensure the best use of limited research funds. Of particular importance is the study of chronic, low-level exposure to pollutants in coastal areas.

Sewage treatment canal at New York Sewage Treatment Center. (Photo by Burk Uzzle, Magnum)

5. A cost-effective network of coastal water-quality monitoring should be conceived and implemented, focusing on both stressed and nonstressed waters. We need to gain more information about what is happening in the real environment, even if that information is imperfect. This monitoring system should not focus just on regulatory or research needs, but should include both objectives.

6. Regulatory procedures must be simplified. Parties often prolong decisionmaking, especially if they might lose in the process. Somehow a way must be found to achieve the best decision possible, using the best information available, in the shortest time feasible.

7. Water-quality standards should be continuously evaluated and reevaluated by a body set up to do so. The National Commission on Water Quality has been useful, but its work has not focused adequately on coastal pollution problems. An independent, top-quality scientific consensus should be sought on questions relating to the sources, fates, and effects of marine pollutants.

In sum, the process of sifting through the layers of uncertainty in the field of marine pollution should be accelerated. Science, law, economics, and technology should be integrated in a major effort to sort out the known from the unknown, the problem from the nonproblem. Pollution that is a serious threat to human health or valuable resources should be dealt with decisively. Finally, greater levels of basic and applied research should be funded to keep up with the complexity of it all. Ignorance in this field can lead to both a waste of financial resources if we focus on the wrong pollutant and a threat to health if we fail to recognize a Kepone or PCB problem until after it is with us.

Conclusion

Given that certain pollutants in marine waters are a risk, how then will public policy be altered to respond to change? Obviously, it will be difficult to rewrite existing marine pollution laws overnight or to eliminate the primary policy goals of those laws. What is more likely to occur is: 1) a change of pace in achieving presently established goals; 2) the factoring in of economic costs in certain situations, such as where the effects of a pollutant are not known to be clearly severe; 3) the balancing of risk between loss of economic activity and loss of environmental amenities; and 4) the development of more expeditious decision processes.

The larger unanswerable question is whether the nation, in particular the federal government, will invest additional funds in research and development aimed at eliminating uncertainty. Whether the nation's science and technology community can keep pace with the expanding list of things we do not know about pollution is a further quandary. An observation that appears in the National Academy of Sciences' recent publication on the five-year outlook for science and technology is sobering:

> *A final observation relates to ignorance and to the limits of science. Scientific knowledge is systematic, enormous in its extent, powerful; but it is slight compared to what is not known. Thus, science has contributed precise knowledge on such seemingly esoteric matters as the electronic structure of atoms, knowledge that has been used to create new technologies and indeed new industries. However, we remain uncertain about seemingly common-sense questions, such as the effects of different air pollutants on human health. These uncertainties simply indicate questions whose answers are not yet part of the core of agreed-on science. That core will expand, but it will always be smaller than needed to answer unambiguously all questions asked by society.*

James P. Walsh is Acting Administrator of the National Oceanic and Atmospheric Administration. He also has served as General Counsel of the U.S. Senate Committee on Commerce, Science, and Transportation, and as Director of the Senate National Ocean Policy Study.

References

Environmental Quality; 1979. The Tenth Annual Report of the Council on Environmental Quality. U.S. Government Printing Office. Chapter 7.

Federal Plan for Ocean Pollution Research, Development, and Monitoring. 1979. Federal Coordinating Committee for Science, Engineering, and Technology.

Goldberg, E., ed. 1979. Proceedings of a Workshop on Assimilative Capacity of U.S. Coastal Waters for Pollutants. Crystal Mountain, Washington, July 29-August 4.

Lawrence, W. W. 1979. *Of acceptable risk: Science and the determination of safety.* Los Altos, Cal.: William Kaufman, Inc.

Rodgers, W. H. 1977. *Environmental law.* St. Paul, Minn.: West Publishing Co. Chapter 4.

Science and technology: A five-year outlook. 1980. National Academy of Sciences.

Predicting Pollution Effects in the Marine Environment

by Judith M. Capuzzo

Predicting the overall impact of pollutant discharges in the marine environment requires an understanding of the responses of both individual organisms and whole populations, as well as the adaptive nature of such responses. The impact of pollutants on marine life has been traditionally assessed using standard laboratory bioassay techniques. In these assays, the major criterion used to determine an organism's response to a toxicant stress is the measurement of an LC_{50} value — that is, the concentration of a pollutant that results in 50 percent mortality of the test organisms during a designated exposure period. Bioassay results are used by regulatory agencies, such as the Environmental Protection Agency (EPA), to establish maximum allowable concentrations of pollutants in discharged effluents. These data on lethal exposure are useful in detecting the sensitivity of an organism to a particular pollutant, in comparing the relative toxicities of various pollutants, and in establishing potential effluent guidelines. However, important physiological, behavioral, and ecological changes that may occur with sublethal exposure are not measured in the standard bioassay.

In addition to bioassays, responses of pollutants can be determined at five levels of biological organization: biochemical and cellular responses; organismal responses, including the integration of physiological and behavioral changes; community responses under simulated controlled conditions; alterations in population dynamics under natural conditions; and alterations in community dynamics and structure under natural conditions (Table 1). Environmental management of pollutants in marine ecosystems should require an evaluation of effects at each of these five levels.

Biochemical Cellular Responses

The use of biochemical techniques to monitor pollution stress could provide a rapid index of stress conditions resulting from environmental contamination. Two types of responses can be considered for evaluation: specific, induced by a certain group of chemicals; and general, induced by a wide range of environmental conditions, including pollution and nutritive stress.

Two specific responses observed in marine animals are the induction of mixed function oxygenases (MFO) with exposure to certain organic pollutants, such as petroleum hydrocarbons and PCBs, and the binding of certain heavy metals to metallothionein proteins. Mixed function oxygenase reactions, mediated by cytochrome P-450, have been implicated in the metabolism and subsequent effects of several pollutant compounds, as well as the metabolism of many naturally occurring organic compounds. Induction of MFO activity has been demonstrated in several species of marine fish and several groups of invertebrates with exposure to organic pollutants, but is also influenced by other environmental and biological conditions, such as temperature, sex differences, reproductive season, and diet. Monitoring field populations for MFO activity has been shown to be useful in examining both

Table 1. Response levels to pollutants in marine ecosystems. (Adapted from NAS, 1971)

Level	Biological organization	Time required for study
I	Biochemical-cellular	Minutes-hours
II	Organism	Hours-months
III	Simulated community	Days-years
IV	Population dynamics	Months-decades
V	Community dynamics and structure	Years-decades

chronically and acutely oil-polluted environments. Further elucidation of the limitations of MFO response and its modifying factors is needed before its predictive value can be fully exploited.

The detoxification of some heavy metals by binding with metallothionein proteins has been investigated in many species of marine fish, molluscs, and crustaceans. The detoxifying process is related to the binding capacity of the metallothionein. The removal of toxic metals, such as cadmium and mercury, from the cellular enzyme pool prevents interference with essential metals (for example, copper and zinc). When the binding capacity is exceeded, toxic effects of these metals become evident. For example, exposure of salmon to 5 micrograms of mercury per liter of seawater resulted in a significant increase in mercury concentration associated with the enzyme-protein pool and a simultaneous decrease in growth. No effects were observed with exposure to 1 microgram of mercury, presumably because of the binding capacity of metallothionein. Only some heavy metals, however, can be detoxified by metallothionein proteins. Because of the presence of metal-binding proteins, determination of metal concentrations in tissues of marine animals is not always correlated with toxic effects. Detection of metallothioneins in animals from contaminated ecosystems has had only limited application as a monitoring tool but further investigation of its usefulness is warranted.

General biochemical responses to pollutant stress include responses related to energy metabolism and membrane function. One such response is the destabilization of lysosomal membranes. (Lysosomes are cellular structures involved in intracellular digestion and transport.) With a variety of stress conditions such as thermal stress, hypoxia, and exposure to pollutants, the lysosomal membrane (generally impermeable to many substrates) increases its permeability, resulting in the activation of degradative lysosomal enzymes and disruption of cellular systems (Figure 1). The extent of destabilization is correlated with the degree of stress and other physiological indices and thus it would appear to be useful in evaluating the condition of an animal from a contaminated ecosystem.

Measurement of the adenylate energy charge (AEC) provides an index of the metabolic energy available to an organism from the adenine nucleotide pool (ATP, ADP, AMP)*:

$$\mathrm{AEC} = \frac{\mathrm{ATP} + 1/2\ \mathrm{ADP}}{\mathrm{ATP} + \mathrm{ADP} + \mathrm{AMP}}$$

Values for AEC have been correlated with the physiological condition of a wide variety of animals and it appears to be useful as an index of stress conditions. Values range from 0.8 to 0.9 for healthy, growing organisms; 0.5 to 0.75 for organisms in a limiting environment; and less than 0.5 for organisms that are severely and sometimes irreversibly stressed. For pollutants such as chlorinated hydrocarbons or PCBs that may cause inhibition of the electron transport system, the adenylate energy charge may be a particularly useful indicator.

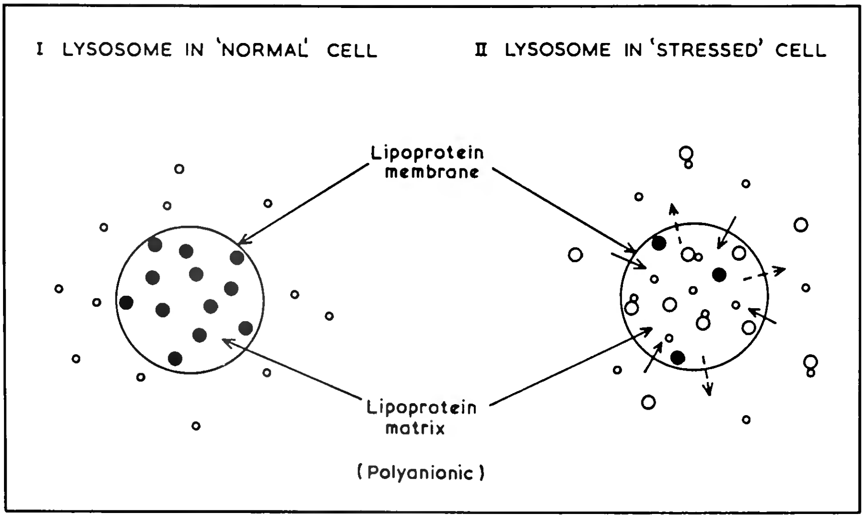


Figure 1. In normal cells, lysosomes are impermeable to many substrates and the lysosomal enzymes are mainly inactive; under stress the lysosomal (lipoprotein) membrane destabilizes, increasing permeability and activating enzymes, resulting in the degradation of cellular systems. Small, clear circles – substrates; filled circles – inactive lysosomal enzymes; large, clear circles – active lysosomal enzymes. (Adapted from Moore, 1980)

---

*The energy of cellular reactions is conserved in the compound adenosine triphosphate (ATP). ATP is the carrier of chemical energy provided through the digestion of food. Adenosine monophosphate (AMP) and adenosine diphosphate (ADP) are intermediary compounds involved in the production of the high energy containing ATP.

Organismal Responses

The responses of an organism to pollutant stress may be manifested in physiological and behavioral changes; increased susceptibility to other environmental stresses, such as disease; and alterations in reproduction and development.

The most important physiological changes to consider are those that may adversely affect an organism's growth and survival, and thus its potential ability to contribute to the population gene pool. In the energy budget of an animal, the energy consumed as food (Q_c) is partitioned into waste energy (Q_w) and energy for metabolism, growth, and reproduction (Q_r and Q_g; Figure 2). Alterations in the energy budget may take place as a result of changes in feeding behavior, respiratory metabolism, or digestive efficiencies with pollution stress. The term *scope for growth* was coined as an index of the energy available for growth after other energy demands are satisfied and, although this may vary seasonally and with the stage of development of a species, it has been shown to be a useful index of pollution stress in both laboratory and field studies. Adequate background information on the energy budgets of organisms in uncontaminated ecosystems, however, is necessary before the effects of pollutants on energy budgets can be evaluated.

Energy utilization for metabolic processes results in the breakdown of proteins, lipids, and carbohydrates. The O:N ratio (atomic ratio of oxygen consumed through respiration to ammonia nitrogen excreted from protein catabolism) is an index of the catabolic balance between the three substrates: low O:N ratios (about 7) reflect complete dependence on protein catabolism for energy utilization, whereas higher ratios indicate increased dependence on lipid and/or carbohydrate catabolism. Alterations in the O:N ratios of an organism under stress have been demonstrated in laboratory and field studies and suggest possible biochemical explanations for energetic changes.

Behavioral responses of an organism to pollutant stress may serve as a mechanism for detection of adverse pollutant concentrations, followed by the triggering of adaptive mechanisms, such as altering feeding behavior or inducing an avoidance response. At an extreme level of stress, the adaptive behaviors are overridden, and an organism's ability to respond to environmental stimuli may become impaired temporarily until the stress is removed, or permanently if chemosensory mechanisms are irreversibly damaged. Behavioral responses that may be expected with pollution stress are presented in Table 2; however, their use as a monitoring tool has had only limited application and should be considered more extensively in correlation with the physiological and biochemical techniques previously discussed.

Pathological responses of marine animals to pollutant stress include tissue inflammation and/or

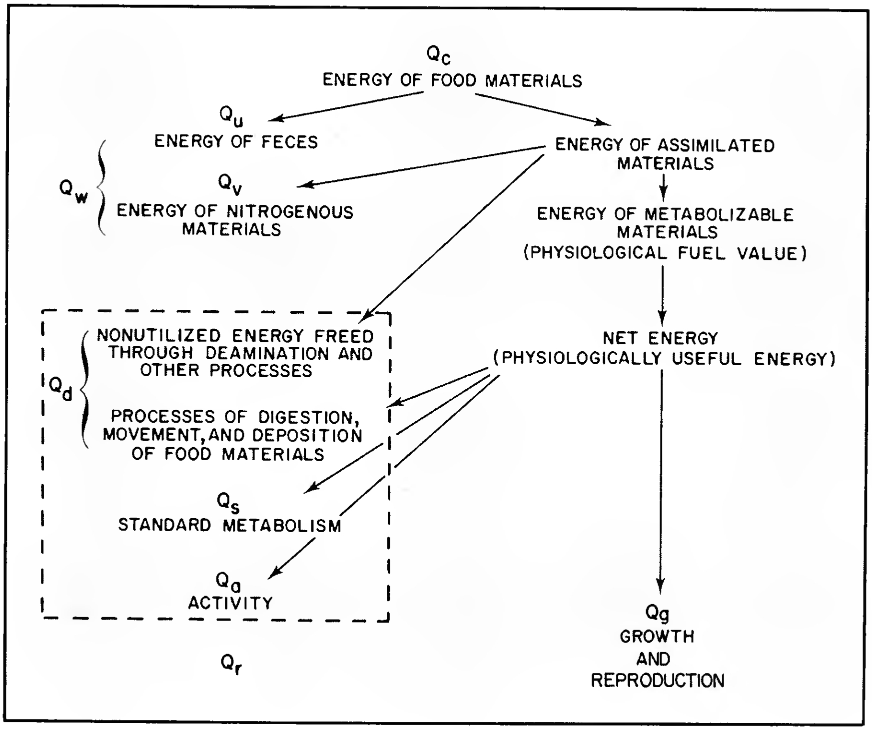


Figure 2. Energy budget of an organism. (Adapted from Warren and Davis, 1967)

Table 2. Behavioral responses of organisms to stress and other stimuli. (Adapted from Miller, 1980; Olla, 1974)

Individual Responses	
Locomotor responses:	
a. Undirected locomotion (no experimental stimuli)	**Rate Pattern of movement Activity rhythms**
b. Directed locomotion	**Sign Rate Pattern of movement Response threshold**
Test stimuli:	
a. Light	**Response threshold**
b. Temperature	**Motor endurance**
c. Chemical	
(1) pheromone	
(2) food	
(3) salinity	
(4) pollutant	
d. Currents	
Other responses:	
a. Learning	
b. Motivation	
c. Shelter building/ Shelter seeking	
d. Physiological rate related activities	**Feeding Ventilation Heart rate**
Inter-individual Responses	
Predation efficiency/vulnerability	
Social interactions:	
a. Aggregation	
b. Aggression	
c. Territoriality	
d. Courtship	
e. Parental care	

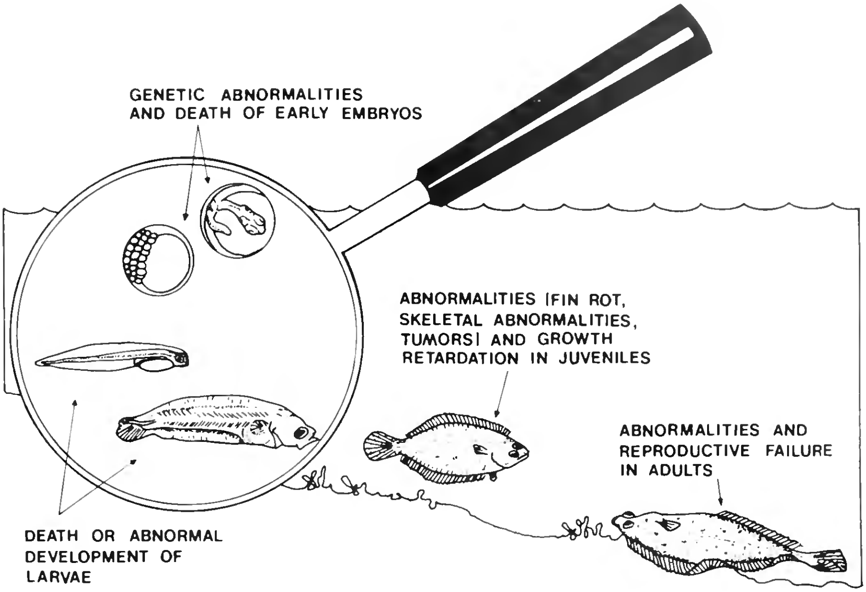
degeneration, repair and regeneration of damaged tissue, the formation of neoplasms, and genetic derangement, including chromosomal damage resulting in morphological abnormalities. Although these changes may be induced by other environmental conditions, the increased incidence of pollution-related diseases and abnormalities has become apparent in recent years. Fin erosion in fish and shell disease in crustaceans are among the most important conditions thought to be induced by the combined effect of pollutant stress and the invasion of damaged tissues by pathogenic organisms. Additional pathological conditions of fish and shellfish that may normally occur in a latent state may be activated by environmental stress.

Morphological abnormalities that are the result of environmental stress include skeletal damage of fish, the occurrence of tumors in some fish and shellfish, and chromosomal aberrations in fish eggs and larvae. Potential effects of pollutants on various stages in the life cycle of the winter flounder (*Pseudopleuronectes americanus)* are presented in Figure 3. A pilot monitoring program in severely polluted areas would provide a more extensive baseline of the correlation of pathological conditions with pollution stress.

Sedentary organisms, such as the blue mussel *Mytilus edulis,* may act as a living monitor of pollution conditions by concentrating various pollutants from seawater. In 1976, the *Mussel Watch* program was initiated in U.S. coastal waters and used the mussel and other bivalves as integrators of pollution conditions by measuring the accumulation of trace metals, petroleum hydrocarbons, chlorinated hydrocarbons, and radionuclides at selected stations on the Atlantic and Pacific coasts. By comparing concentrations of the various pollutants in bivalves from contaminated and uncontaminated stations, one can designate areas of significant environmental concern. The program was coordinated by the Scripps Institution of Oceanography, University of California at San Diego, and funded by the Environmental Protection Agency (EPA). Analyses of the various pollutants were conducted at five institutions in the United States, including the Woods Hole Oceanographic Institution. During the three-year program, both baseline data of background levels and data suggesting a variety of pollution problems from elevated levels of pollutants in bivalve tissues were identified.

An extension of the Mussel Watch program is the Coastal Environmental Assessment Stations program (CEAS) conducted by the EPA. The objective of the program is to correlate accumulation of contaminants with physiological responses; essential to the program are the combined efforts of laboratory and field studies. Mussels collected from an uncontaminated area are placed in cages at selected stations along a pollution gradient and uptake of contaminants and scope for growth determinations are made at each station. In Narragansett Bay, Rhode Island, stations were selected along a pollution gradient from a severely stressed environment in the Providence River to a relatively unstressed area in the lower bay; reductions in the scope for growth index were correlated with high body-burden levels of metals and hydrocarbons.

Figure 3. *Some possible effects of pollutants on the life cycle of the winter flounder. (Adapted from Sindermann, 1980)*



Another ongoing monitoring program is the *Ocean Pulse* program conducted by the National Marine Fisheries Service of the National Oceanic and Atmospheric Administration (NOAA). It is designed to establish baseline data for assessing the environmental condition of the continental shelf of the northwest Atlantic Ocean from Maine to Cape Hatteras, North Carolina. The sampling program includes analysis of species abundance and distribution patterns in addition to the monitoring of physiological, behavioral, biochemical, pathological, and genetic differences of key species within the sampling area and comparison with ongoing laboratory studies on the effects of pollutants on these parameters.

Simulated Community Responses

Integration of organismal responses to pollution stress may be reflected in the competitive performance of coexisting species and changes in energy flow within an ecosystem. Several programs have been designed to evaluate these changes under simulated conditions.

The Controlled Ecosystem Pollution Experiment (CEPEX) program was part of the International Decade of Ocean Exploration, funded by the National Science Foundation (NSF). It was designed to evaluate the effects of pollutants on plankton communities (see *Oceanus*, Vol. 23, No. 1, p. 52). Using various sizes (68 to 1,700 cubic meters) of plastic experimental bags as the controlled ecosystems (Figure 4), large volumes of water and the indigenous organisms were trapped from Saanich Inlet, a body of water offshore from the Institute of Ocean Sciences, Sydney, British Columbia. Physical and chemical parameters, such as temperature, salinity, and nutrient concentrations, and population estimates of phytoplankton and zooplankton were monitored routinely. With the addition of pollutants, such as heavy metals and petroleum hydrocarbons, population changes in the microbial, phytoplankton, and zooplankton components of the ecosystem were compared with uncontaminated controlled ecosystems. Bacteria and phytoplankton with short generation times recovered more rapidly from pollutant additions than did zooplankton species; further, the responses of zooplankton to heavy metal additions were related to size, with smaller organisms being more sensitive than larger organisms.

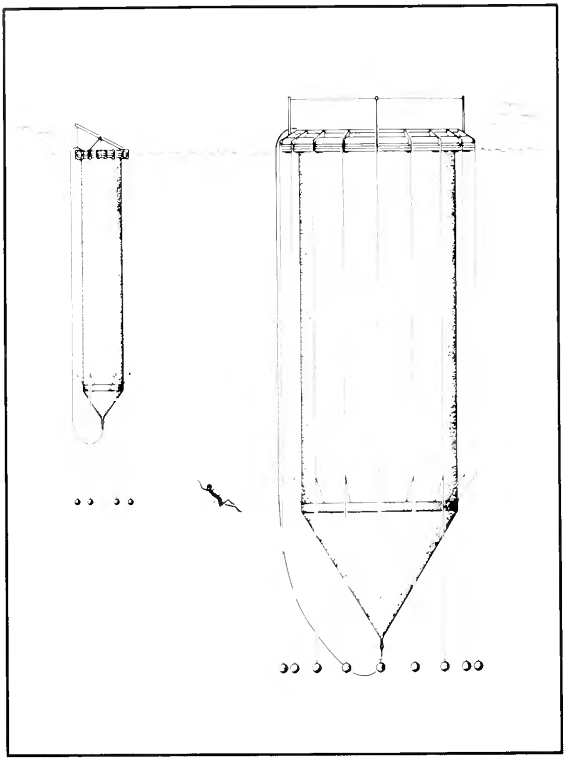
In a similar series of experiments conducted in Loch Ewe on the west coast of Scotland, the effects of North Sea oil on pelagic ecosystems were evaluated. Microbial degradation of selected hydrocarbons, heterotrophic activity, primary production, and estimates of phytoplankton and zooplankton populations were monitored routinely. Again, zooplankton were the most severely affected component of the simulated ecosystem, with eggs and developing stages being particularly sensitive to oil additions.

The Marine Ecosystems Research Laboratory (MERL) at the University of Rhode Island has been designed to consider both the pelagic and benthic components of enclosed ecosystems. The effects of chronic oil pollution on plankton communities and energetics, and on benthic communities and diversity, have been determined and compared with control ecosystems; an additional aspect of the program is to monitor the biogeochemical cycling of hydrocarbons and their metabolites between the pelagic and benthic habitats.

Although enclosed ecosystems are limited by a degree of artificiality in predicting the responses of populations and communities to pollutant stress, they are useful in establishing: a) the relative sensitivities of various trophic levels to a controlled pollution stress; b) the chemical interactions of pollutants with biota and expected trends in persistence and biogeochemical cycling of pollutants within the ecosystem; c) the potential disruption in energy flow as a result of pollution stress; and d) the recovery potential of the ecosystem after removal of pollution stress. The use of simulated communities thus provides a dimension beyond understanding the responses of an individual organism to stress and places organismal responses within the context of a functioning ecosystem.

Alterations in Population Dynamics

Defining a causal relationship between pollutant additions and alterations in population dynamics is an extremely difficult, sometimes unachievable, task. The responses of populations to pollution stress are generally nonspecific and are often



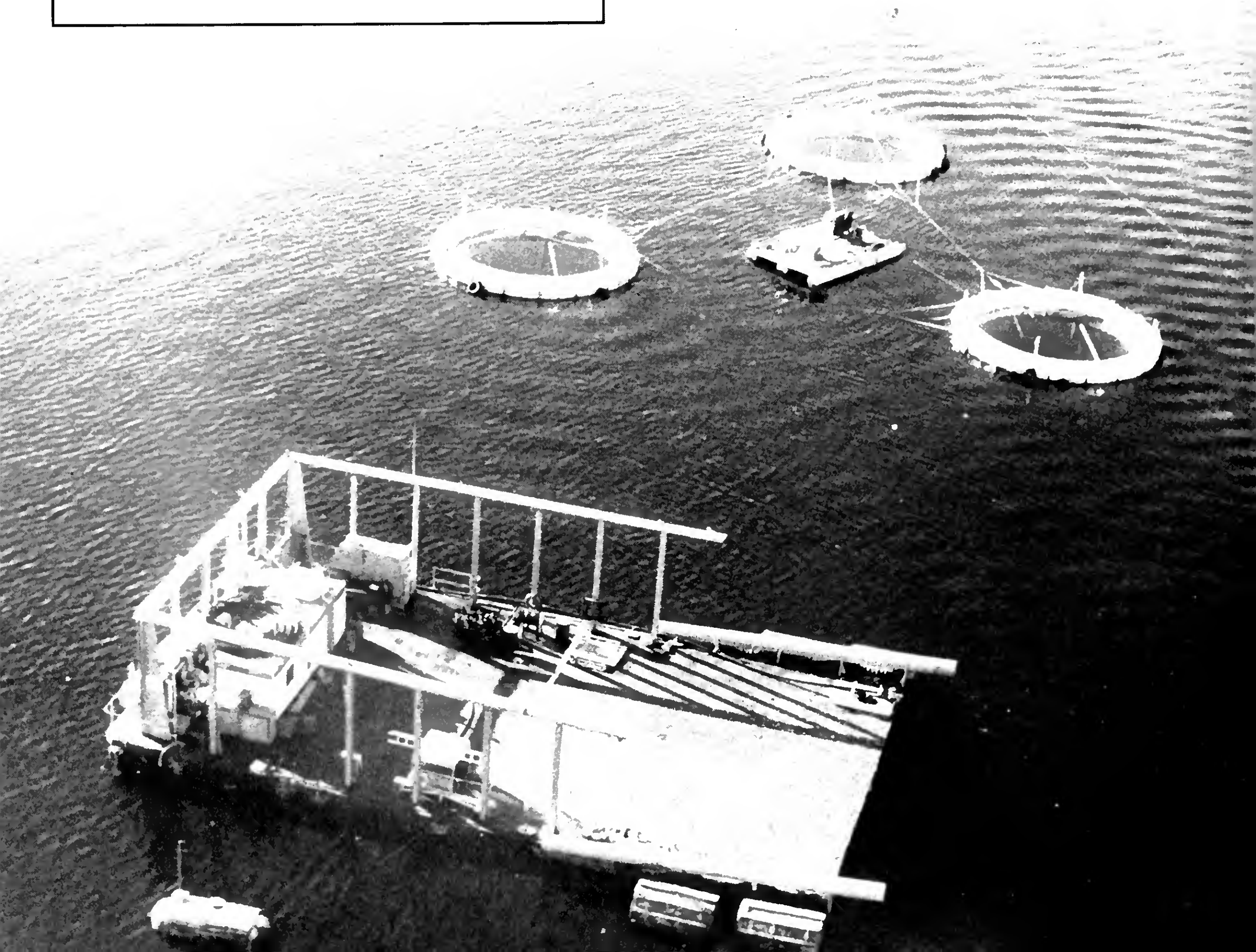


Figure 4. Aerial view and inset of the CEPEX bags.

indistinguishable from changes resulting from natural variability or natural environmental perturbations. Acute effects, attributable to a specific pollutant such as sewage effluent or an oil spill, may be easily detected because the changes that occur are significant within a short period of time. Chronic effects, however, attributable to a long-term input of many pollutants and increased degradation of the environment, are not so easily detected.

In the examination of populations for pollution effects, the following parameters are of interest: 1) the abundance and distribution of individual species, considering not only the range of occurrence but also the effective reproductive range; 2) population structure, identifying various age classes or generations; 3) growth rates of individuals within the various age classes; 4) reproductive success, including analyses of fecundity, reproductive season, and recruitment of new individuals to the population; and 5) the incidence of disease.

For comparisons of natural variability and pollution-induced variability of population parameters, adequate baseline data of individuals from existing uncontaminated habitats or from a history of pre-pollution conditions are necessary. For many commercially important species, a large inventory of background data on distribution, reproduction, and recruitment exists and thus is quite useful for comparisons with contemporary studies. For many other species, these data do not exist and thus one must rely on comparisons of populations from similar habitats (contaminated versus uncontaminated) or correlate population differences with the extent of pollution along a pollution gradient. In either instance, sampling strategies must consider spatial and temporal variations of populations, the possible differences in what are defined as "similar" habitats, the fate and effects of pollutants, and the implications of any measured effect.

Evaluation of pollution-induced changes in the population dynamics of individual species requires an understanding of the natural variability of population parameters, the effects of natural environmental perturbations on such variability, and the possible synergism between man-made and naturally occurring perturbations on variability. In concert with other monitoring techniques at the biochemical and organismal levels, early warning signs of population stress may be detected and recommendations for pollution abatement made before permanent alterations in populations and communities occur.

Community Dynamics and Structure

Communities are defined as assemblages of populations structured through the biological interactions of those populations and their interactions with the physical environment. When both the physical and biological conditions governing the community are stable and predictable, the community is highly diverse and relatively stable in numbers and species composition. With environmental perturbations, such as pollutant additions to the environment, the community is stressed, sensitive species are eliminated, diversity is reduced, and population sizes of opportunistic species increase.

As with populations, community responses to pollution stress are nonspecific and both acute and chronic pollution may occur. With acute effects, recovery of communities is characterized by a series of successional stages, beginning with the dominance of opportunistic species and low community diversity and eventually resulting in the reestablishment of a diverse, stable community. With chronic effects, the recovery potential of a community may never be fully realized.

Communities may be evaluated at both the structural and functional levels. Structural characteristics include estimates of species composition, abundance, trophic status, biomass and diversity, and the spatial and temporal variability of these estimates. Diversity indices relating the abundance of individuals per species, such as the Shannon-Wiener index, have been used traditionally in community comparisons and are useful in indicating long-term changes in community structure. Their usefulness in predicting the "health" of a community, however, is often masked by other community characteristics. For example, as was shown in the recovery of benthic populations in West Falmouth, Massachusetts, following a spill of No. 2 fuel oil in 1969, several successional stages were characterized by periods of high diversity before density and species composition returned to a stable level (see *Oceanus*, Vol. 20, No. 4). Other indices relating species variability and natural fluctuations in species abundance, as well as indices more sensitive to short-term stress, must be used in conjunction with the diversity index.

Functional characteristics of the community are related to energy flow through the community and include estimates of microbial activity, primary production, and trophic interactions of community members. An index relating the structural and functional characteristics of a community is the ratio of production to biomass (P/B). Its use as an index of community condition should be further explored.

Once changes resulting from pollution stress have occurred and been identified at the community level, adaptive responses of individual organisms and populations have been surpassed. Monitoring community changes provides an index of the adaptive capacity of the ecosystem and the duration and extent of community recovery.

Table 3. Summary of responses to pollutant stress.

Level	Adaptive response	Destructive response	Result at next level
Biochemcial-cellular	Detoxification		Adaptation of organism
		Membrane disruption Energy imbalance	Reduction in condition of organism
Organismal	Disease defense Adjustment in rate functions Avoidance		Regulation and adaptation of populations
		Metabolic changes Behavior aberrations Increased incidence of disease Reduction in growth and reproduction rates	Reduction in performance of populations
Population	Adaptation of organism to stress No change in population dynamics		No change at community level
		Changes in population dynamics	Effects on coexisting organisms and communities
Community	Adaptation of populations to stress		No change in community diversity or stability Ecosystem adaptation
		Changes in species composition and diversity	Deterioration of community
		Reduction in energy flow	Change in ecosystem structure and function

Conclusions

Assessing the effects of pollutants on the marine environment is not an easy task. It requires an understanding of the adaptive and disruptive responses at each level of biological organization and how that response affects responses at the next level. As can be seen in Table 3, all responses are not disruptive in nature and do not necessarily result in the degeneration of the next level of organization. Only when the compensatory or adaptive mechanisms at one level begin to fail, do deleterious effects become apparent at the next level. For predictive purposes, one must be aware of the early warning signs of stress at each level before compensatory mechanisms are surpassed. From the biochemical level to the community level, the degree of system complexity, the number of compensatory mechanisms available, and the lag time to measure a response increase exponentially, therefore increasing the predictive difficulties at each level. The standard bioassay as currently used in the establishment of effluent guidelines is inadequate in predicting the impact of pollutants at any level of biological organization in the marine ecosystem. Continued research is needed at each level of biological organization in order to insure a detailed, integrative understanding of the effects of pollutants on the marine environment.

Judith M. Capuzzo is an Associate Scientist in the Biology Department of the Woods Hole Oceanographic Institution.

References

Brown, D. A. and T. R. Parsons. 1978. Relationship between cytoplasmic distribution of mercury and toxic effects of zooplankton and chum salmon exposed to mercury in a controlled ecosystem. *J. Fish. Res. Bd. Can.* 35: 880-84.

Davies, J. M., and J. C. Gamble. 1979. Experiments with large enclosed ecosystems. *Phil. Trans. Roy. Soc. London,* Series B, 286: 523-44.

Gibson, V. R., and G. D. Grice. 1980. A compromise between a beaker and a bay: the big bag. *Oceans* 13: 21-25.

McIntyre, A. D., and J. B. Pearce, eds. 1980. Biological effects of marine pollution and the problems of monitoring. Proceedings from ICES Workshop held in Beaufort, North Carolina, 26 February-2 March 1979. *Rapp. P.-V. Réun. cons. int. Explor. Mer* 179: 1-346.

Miller, D. C. 1980. Some applications of locomotor response in pollution effects monitoring. *Rapp. P.-V. Réun. cons. int. Explor. Mer* 179: 154-61.

Moore, M. N. 1980. Cytochemical determination of cellular responses to environmental stressors in marine organisms. *Rapp. P.-V. Réun. cons. int. Explor. Mer* 179: 7-15.

NAS. 1971. Marine Environmental Quality. Suggested research programs for understanding man's effects on the oceans, 107 pp. Washington, D.C.: National Academy of Sciences.

NAS. 1980. The International Mussel Watch. Report of a workshop sponsored by the Environmental Studies Board, Commission on Natural Resources, National Research Council, 77 pp. Washington, D.C.: National Academy of Sciences.

Olla, B. L., ed. 1974. Behavioral bioassays. In *Proceedings of a workshop on marine bioassays*, pp. 1-31. Washington, D.C.: Mar. Tech. Soc.

Payne, J. F. 1976. Field evaluation of benzo [a] pyrene hydroxylase induction as a monitor for marine pollution. *Science* 191: 945-46.

Sanders, H. L., J. F. Grassle, G. R. Hampson, L. S. Morse, S. Garner-Price, and C. C. Jones. 1980. Anatomy of an oil spill: long-term effects from the grounding of the barge *Florida* off West Falmouth, Massachusetts. *J. Mar. Res.* 38: 265-380.

Sindermann, C. J. 1980. The use of pathological effects of pollutants in marine environmental monitoring programs. *Rapp. P.-V. Réun. cons. int. Explor. Mer* 179: 129-34.

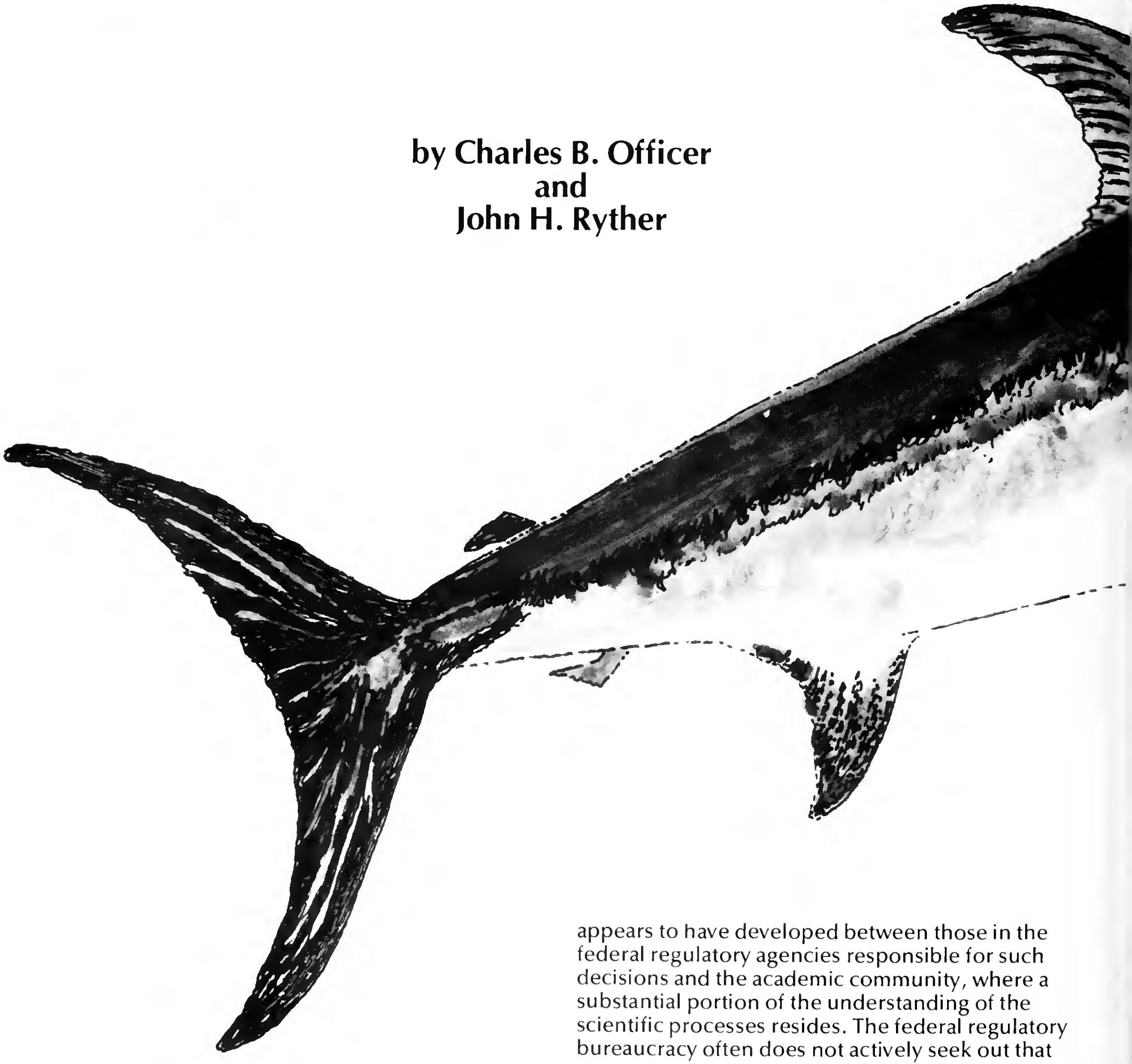
Stegeman, J. J. 1977. Fate and effects of oil in marine animals. *Oceanus* 20(4): 59-66.

———. 1978. Influence of environmental contamination of cytochrome P-450 mixed-function oxygenases in fish: implications for recovery in the Wild Harbor marsh. *J. Fish. Res. Bd. Can.* 35: 668-74.

Warren, C. E., and G. E. Davis. 1967. Laboratory studies in the feeding, bioenergetics and growth of fish. In *The biological basis of freshwater fish production,* S. D. Gerking, ed., pp. 175-214. Oxford: Blackwell Publications.

Swordfish and Mercury:

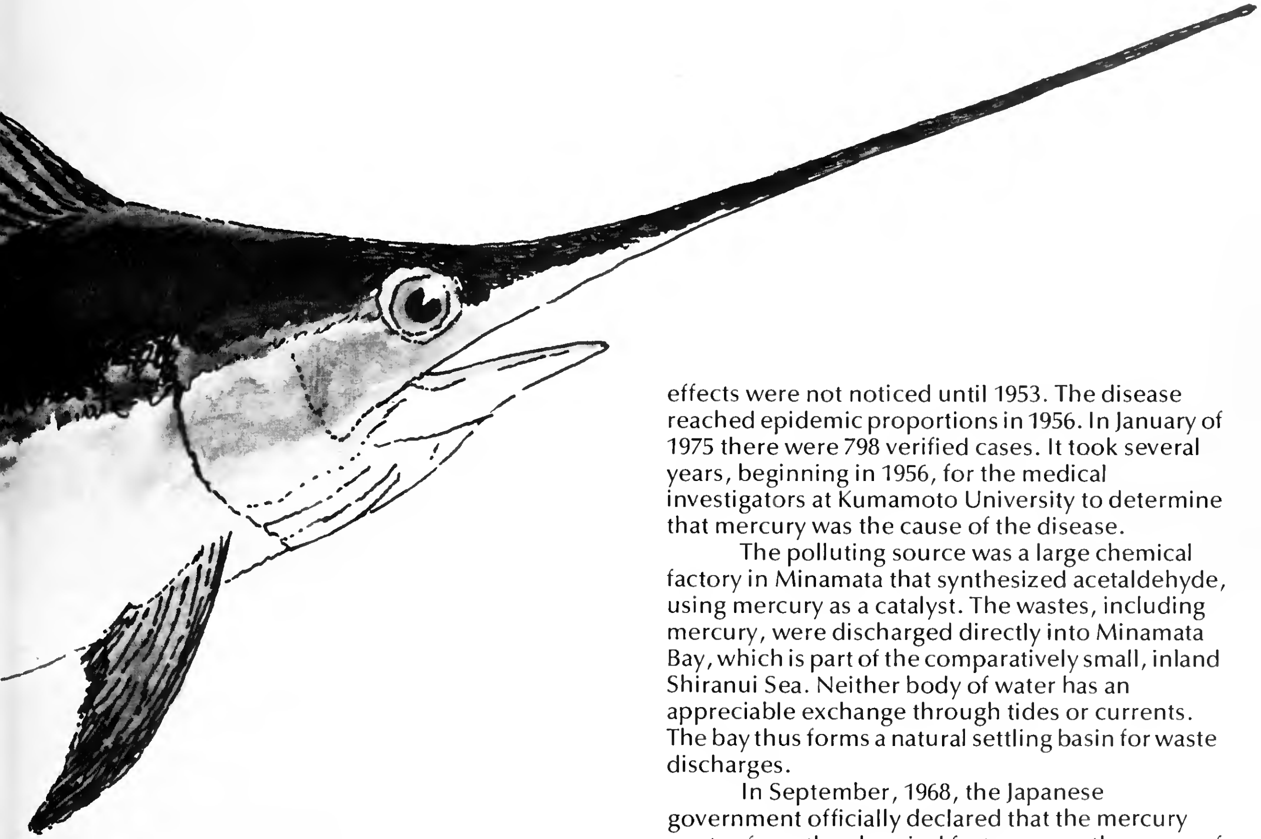
by Charles B. Officer and John H. Ryther



When complex problems arise in the marine environment and difficult management decisions have to be made, one would expect that knowledgeable marine scientists would be called upon to help find a solution. Unfortunately, this has not always been the case. A communications gap appears to have developed between those in the federal regulatory agencies responsible for such decisions and the academic community, where a substantial portion of the understanding of the scientific processes resides. The federal regulatory bureaucracy often does not actively seek out that expertise, nor does it adequately support long-term academic environmental research.

A case in point is the standard once set by the Food and Drug Administration (FDA) for tolerable limits of mercury in fish. At the time, the decision caused a nationwide scare and a financial hardship to some fishing groups and seafood processors. This was a decision that was ill advised and that

A Case History



could have been avoided had the knowledgeable people been brought in as partners to the deliberations. While it is now all history, it is instructive to review the case. In retrospect, it was difficult for us, the authors, to understand how the decision was made from the available facts.

What Happened

Concern for mercury pollution in the marine environment began with an epidemic that occurred in the 1970s in Minamata, Japan. The inhabitants there consumed fish and shellfish contaminated by the mercury waste discharges from a local industry. The poisoning that ensued is commonly referred to as Minamata disease. It is a severe, debilitating disease; those who have survived are left with some combination of constriction of the visual field, hearing impairment, incoherent speech, unsteady gait, and the inability to perform simple functions.

Although unusual changes in the marine ecology were observed as far back as 1950, human effects were not noticed until 1953. The disease reached epidemic proportions in 1956. In January of 1975 there were 798 verified cases. It took several years, beginning in 1956, for the medical investigators at Kumamoto University to determine that mercury was the cause of the disease.

The polluting source was a large chemical factory in Minamata that synthesized acetaldehyde, using mercury as a catalyst. The wastes, including mercury, were discharged directly into Minamata Bay, which is part of the comparatively small, inland Shiranui Sea. Neither body of water has an appreciable exchange through tides or currents. The bay thus forms a natural settling basin for waste discharges.

In September, 1968, the Japanese government officially declared that the mercury wastes from the chemical factory were the cause of the disease. In the same year, acetaldehyde production was stopped. The victims and their families then sought indemnification from the company. In March, 1973, the Kumamoto district court assessed a maximum indemnity of $68,000 for fatal or severe cases and a minimum of $60,000 for less severe cases. In its decision the court said that "in the final analysis . . . no plant can be permitted to infringe on and run at the sacrifice of the lives and health of the regional residents. . . ."

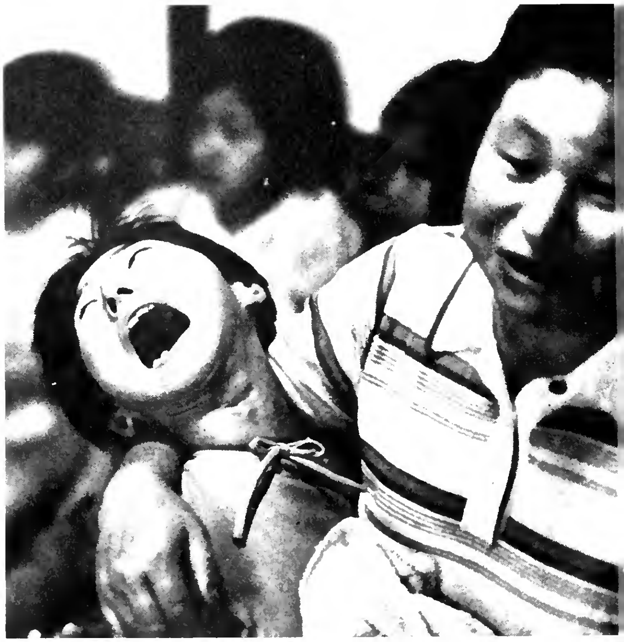
A second but unrelated outbreak of Minamata disease occurred at Niigata, Japan, in 1965. From 1965 to 1970 there were 47 cases reported. The circumstances were similar to those at Minamata. The disease mainly affected fishermen and their families. The fish and shellfish were heavily contaminated with methyl mercury. The contamination was tentatively ascribed to the wastes from an acetaldehyde factory that had ceased operations in January, 1965.

In the late 1950s and early 1960s, mercury pollution became an issue in Sweden.

Chemical factory on Minamata Bay, Japan. (Photo by W. Eugene Smith, Magnum)

Ornithologists there became concerned about the depleted bird population, particularly birds of prey. Intensive investigations were undertaken, and the cause was eventually traced to seed treated with methyl mercury compounds. Following this, and with the Minamata experience in mind, interest centered on the possible effects on fish of mercury wastes discharged from paper and pulp mills and chloralkali plants. Indeed, it was found that the mercury concentrations in fish caught downstream from the plant discharges were substantially higher than those caught upstream. The levels of elevation, however, were still 10 times less than those for Minamata Bay. No human effects were detected.

In 1969, the scene shifted to Canada and the United States, when elevated levels of mercury were discovered in the predatory freshwater fish of Lake St. Clair and the St. Clair River. These waters connect Lakes Huron and Erie. Average mercury levels of 2.9 parts per million (ppm) with a maximum of 5.0 ppm were found in walleye pike taken from the Canadian side of Lake St. Clair and corresponding average and maximum values of 1.6 and 2.4 ppm for St. Clair River pike. These measurements were later confirmed from similar measurements on the same species on the United States side of Lake St. Clair. The contaminating mercury source was traced to the waste discharges



Japanese mother with deformed child at Minamata hearings. (Photo by W. Eugene Smith, Magnum) from a chloralkali plant at Sarnia, Ontario. Fortunately, the fish-eating habits of the populace neighboring the lake did not approach those of the Minamata fishermen and the mercury levels were 10 times less than those in Minamata fish; there were no cases of mercury poisoning in humans. This was certainly a matter of concern but not of panic. In March 1970, the Ontario provincial government placed a ban on commercial fishing in these areas and demanded that the plant put in treatment facilities to curtail the mercury discharges. This was done.

On April 2, 1970, the FDA announced that it would enforce a guideline of 0.5 ppm. An FDA spokesman is quoted as having said: "The FDA is prepared to take legal action to remove from the market any fish found to contain more than 0.5 parts per million of mercury."

On April 13, 1970, the Governor of Ohio banned commercial fishing in the Ohio waters of Lake Erie, cautioning sports fishermen about the possible effects. Surveys of Lake Erie fish showed average levels of 1.5 and 0.6 ppm of mercury for walleye pike for the western and eastern regions of the lake, respectively, and levels of 0.6 and 0.4 ppm for yellow perch in the same regions. Also in April it became evident, given the 0.5-ppm standard, that mercury pollution was not limited to the Great Lakes but was nationwide in scope.

On July 14, 1970, the Secretary of the Interior stated that mercury pollution was "an intolerable threat to the health and safety of Americans." By September, 33 states had reported some form of mercury hazard and 16 had imposed sanctions. Estimates of losses from both sports and commercial fishing and fish marketing began to range in the millions of dollars, particularly for those states in the Great Lakes area.

Later in 1970, things took an even more serious turn. On December 3, analyses of canned tuna from a local supermarket were found to have mercury levels in excess of 0.5 ppm. These findings were confirmed by the FDA, and, on December 15, the Commissioner of the FDA announced that 23 percent of the 900 million cans of tuna packed in the United States in 1970 contained mercury in excess of the standard and that as a precautionary measure 1 million cans were being withdrawn from the market. The highest level of mercury found in the 138 samples tested was 1.1 ppm; the average was 0.4 ppm. The annual value of canned tuna at the processing plants before the wholesale and retail costs was given as $250 million. Around the same time, comparable levels were found in canned tuna in England; no action was taken. On February 4, 1971, the FDA reversed its position. The Commissioner stated that the "final statistics showed the problem of mercury in tuna to be less serious than had been feared" and that "stocks of the fish presently marketed in the United States are within the guidelines." The final tests showed that only 4 percent of the canned tuna contained more than the allowed amount.

The FDA also tested swordfish. The levels of mercury were substantially higher in swordfish than in tuna. In 1969, 25 million pounds of swordfish were consumed in the United States as compared to 469 million pounds of tuna. Furthermore, at that time 98 percent of the swordfish was imported. On December 23, 1970, the FDA recalled from the market nearly every brand of frozen swordfish after finding excessive amounts of mercury in 89 percent of the samples tested. The average level was 0.9 ppm with a maximum of 2.4 ppm.

Swordfish are ubiquitous and are caught in all the oceans. Consideration now had to be given as to whether the world's oceans were contaminated with mercury from man's activities. If the FDA standard of 0.5 ppm were applied, mercury pollution was now a worldwide phenomenon.

Many scientists began to express caution about possible dangerous amounts of mercury in seafood, or to express disbelief that the world's oceans were polluted with mercury. Others began to analyze museum and archaeological samples. One group reported levels of 0.38 ppm mercury for tuna caught between 1878 and 1909 as compared with 0.31 ppm for fresh tuna and an average level of 0.52 ppm for swordfish collected in 1946 as compared with a range of 0.23 to 1.27 ppm for fresh swordfish. Adding to the mounting disclaimer of a nationwide mercury scare was a report prepared under the auspices of the President's Science Advisory Committee (PSAC). On release of the report on January 9, 1974, the Science Advisor to the President commented on the relative importance of the risks from swordfish as compared with other items. He stated: "Cigarettes, which the Surgeon General and the Congress are convinced have health impairing effects on many people, are left on sale. Swordfish, where there is no clear evidence of individual ill effects, are taken off the market."

The FDA ban on foreign imports and interstate sales of swordfish still exists despite the PSAC report, the archaeological findings, and the doubts expressed by numerous competent individuals. Swordfish imports plummeted from 28 million pounds in 1970 to 25,000 pounds in 1975.

The FDA Standard

How did the FDA arrive at its standard of 0.5 ppm? It is useful to look at the concentrations of mercury in fish and shellfish, the amounts of fish ingested by various populations, and the mercury ingestion rates that led to the appearance of clinical symptoms of the disease. The data for the diseased groups comes from the Minamata and Niigata epidemics (Figure 1).

A convenient unit of measure for mercury concentrations in animals is parts per million. This

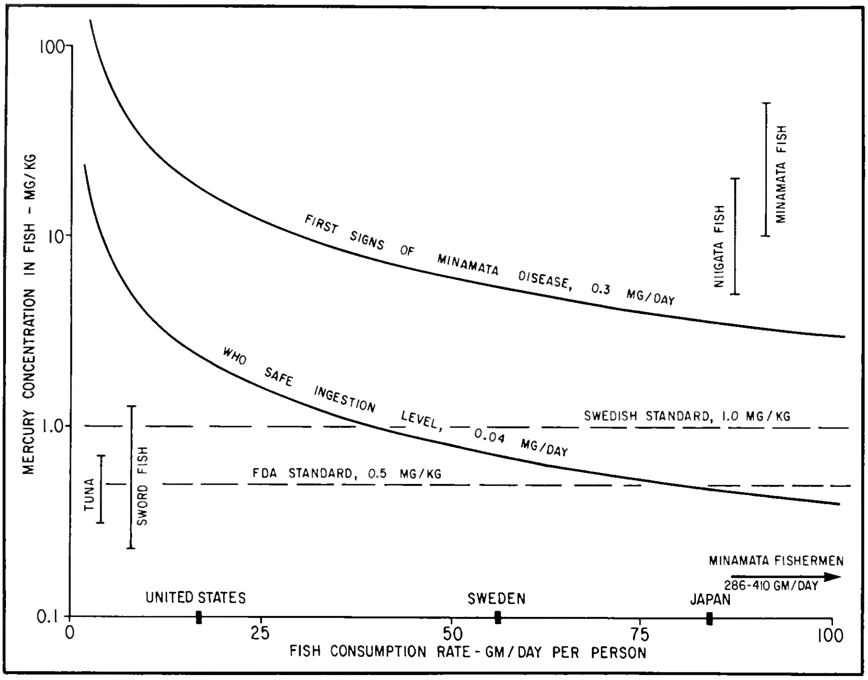


Figure 1. Mercury concentrations in fish, fish consumption rates for various populations, World Health Organization's (WHO) safe ingestion level of mercury, and level for first appearance of Minamata disease.

unit is the same as milligrams of mercury per kilogram (mg/kg) of the total wet weight of the fish. In the contaminated fish and shellfish of Minamata Bay the mercury concentrations were 10 to 55 ppm. These may be compared with levels of less than 1 ppm for the same species in uncontaminated coastal areas elsewhere in Japan. The Minimata fishing population consumes more than a half pound (286 grams) of fish per day during the winter and nearly a pound per day (410 gm/day) during the summer, a very high ingestion rate that is more than 20 times the per capita annual fish consumption in the United States.

Japanese investigators estimated that consuming 10 mg/day of methyl mercury compounds for a period of 200 to 300 days was lethal and that consuming 1 to 10 mg/day for the same period was toxic. The Swedish Commission on Evaluating the Toxicity of Fish has estimated from the Japanese experience that the lowest ingestion rates for the appearance of clinical symptoms of Minamata disease are 0.3 mg/day of methyl mercury.

The Swedish Commission argued that a safety factor of 10 should be used in setting standards for tolerable consumption rates. From the rate of 0.3 mg/day for the first appearance of clinical symptoms, they arrived at a safe ingestion rate of 0.03 mg/day of methyl mercury. Later the World Health Organization (WHO) in an independent appraisal, arrived at similar conclusions with safe ingestion rates of 0.04 mg/day of total mercury, of which no more than 0.03 mg/day should be in a methylated form.

The average consumption rates of fish for the Japanese, Swedish, and American populations are, respectively, 84, 56, and 17 gm/day per person. Using the WHO safe ingestion rate of 0.04 mg/day, we arrive at safe concentration levels of 0.5, 0.7, and 2.4 ppm of total mercury for the respective populations.

In 1968, the Swedish government adopted a standard of 1.0 ppm of methyl mercury for fish for sale. In the same year, the Japanese government adopted a thorough, reasonable, and comprehensive control procedure. The Japanese had had the only experience with mercury poisoning related to the consumption of contaminated fish; it is instructive to outline their regulations, which involve a step-by-step procedure. If, in any locality, more than 20 percent of the fish samples exceed 1.0 ppm of total mercury, further surveillance is required, which, if necessary, can lead to a ban on fishing by the Ministry of Health and Welfare.

In 1970, the United States set a standard of 0.5 ppm of total mercury for fish. The scientists who were advisors to the decisionmakers at an early stage suggested that a safe level of 2.0 ppm could be adopted for the United States, taking into consideration the much lower fish consumption rate of Americans in comparison with the Japanese and the Swedes. But in what was apparently an arithmetic mistake, the Swedish standard of 1.0

Commercial swordfish vessel Stephanie Vaughn *out of Scituate, Massachusetts. (Photo by Bill Hemmel)*

ppm was halved instead of doubled, resulting in the 0.5-ppm level that the FDA finally mandated. The stage was now set for what was to happen in the United States — a mercury poisoning scare, a temporary ban on tuna, and a permanent ban on imported swordfish.

It is interesting that after setting the 0.5-ppm limit, the FDA felt it important to back its decision with a full study report. Of the 10 committee members who conducted the study, four were from the FDA, four were from other governmental agencies, and the remaining two were members of the Secretary of Health, Education, and Welfare's Committee on Pesticides. There were no marine scientists. The report came out in November 1970, and was reproduced in its entirety in *Environmental Research.* The first conclusion agreed with the 0.5-ppm guideline. But, nowhere in the report did the committee justify how they arrived at this figure. The report is based on a 10-day visit to Sweden and Finland by the committee and refers almost in its entirety to the environmental mercury experiences and investigations in these two countries.

Since the report did not describe how the FDA arrived at the 0.5-ppm standard, we had to search elsewhere. An explanation was given by the Deputy Director of Foods, Pesticides, and Product Safety of the FDA, at a hearing of the Subcommittee on Energy, Natural Resources and the Environment, Committee on Commerce, United States Senate, on May 8, 1970. The Deputy Director correctly stated that the FDA had no direct experience in the area of tolerable mercury levels in fish and therefore had relied on the Swedish investigations. We quote his entire testimony relating to setting the 0.5-ppm level:

> *The Swedish reasoning toward a tolerance from this data was apparently the following:*
>
> *The average daily intake of fish was stated to be 200 grams, with a mercury content of 50 parts-per-million dry weight. It was assumed that at 5 parts-per-million wet weight no poisoning would occur, and that a rather low safety factor of 5 would provide an acceptable and safe level of 1 part-per-million mercury in fish. Thus, the Swedish tolerance of 1 part-per-million of mercury was established. However, it appears that the Swedish work contains a calculation error. A fish is approximately 80-percent water, thus, the actual concentration of mercury in the fish, based on wet weight, was 10-20 parts per million. Using the same reasoning as before, the level then becomes about 0.5 parts per million of mercury.*
>
> *A few facts to help you relate to the Lake St. Clair/Lake Erie situation.*
>
> *1. The 200 grams of fish per day is five times the U. S. average daily consumption of fish.*
>
> *2. The highest residue on a wet weight basis found in fish in our survey of the area was 2.3 parts per million, approximately nine times less than the average Japanese level.*
>
> *Since the Swedish tolerance was established, additional estimates of "allowable daily intakes" of methyl mercury have also been presented by Berland and Berlin (1969). These studies were based on data from both human and animal studies. The conclusion*

of their work was an allowable daily intake of 0.06 milligrams per day, or 0.42 milligrams per week of methyl mercury. This level would permit a daily intake of 120 grams of fish containing 0.5 parts per million mercury, well above the estimated average of 70 grams fish per day in Sweden and 40 grams of fish per day in the United States. The safety factor on the previously reported work was 5, while the safety factor used in this study was 10. This is the toxicological background that led to the establishment of FDA's 0.5 part per million mercury interim guideline in fish.

However, the toxicological picture was not the only consideration in our establishment of the 0.5 part per million interim figure. The sensitivity limits of the Association of Official Analytical Chemists (AOAC) procedure for mercury in fish is approximately 0.5 part per million. There are varieties of problems in the acid digestion of fish tissue and some problems with reagents when analyzing fish containing less than 0.5 part per million mercury. The AOAC procedure is still the method we use for regulatory actions. However, we are working as rapidly as possible to completely validate a newer, more sensitive method using atomic absorption spectroscopy.

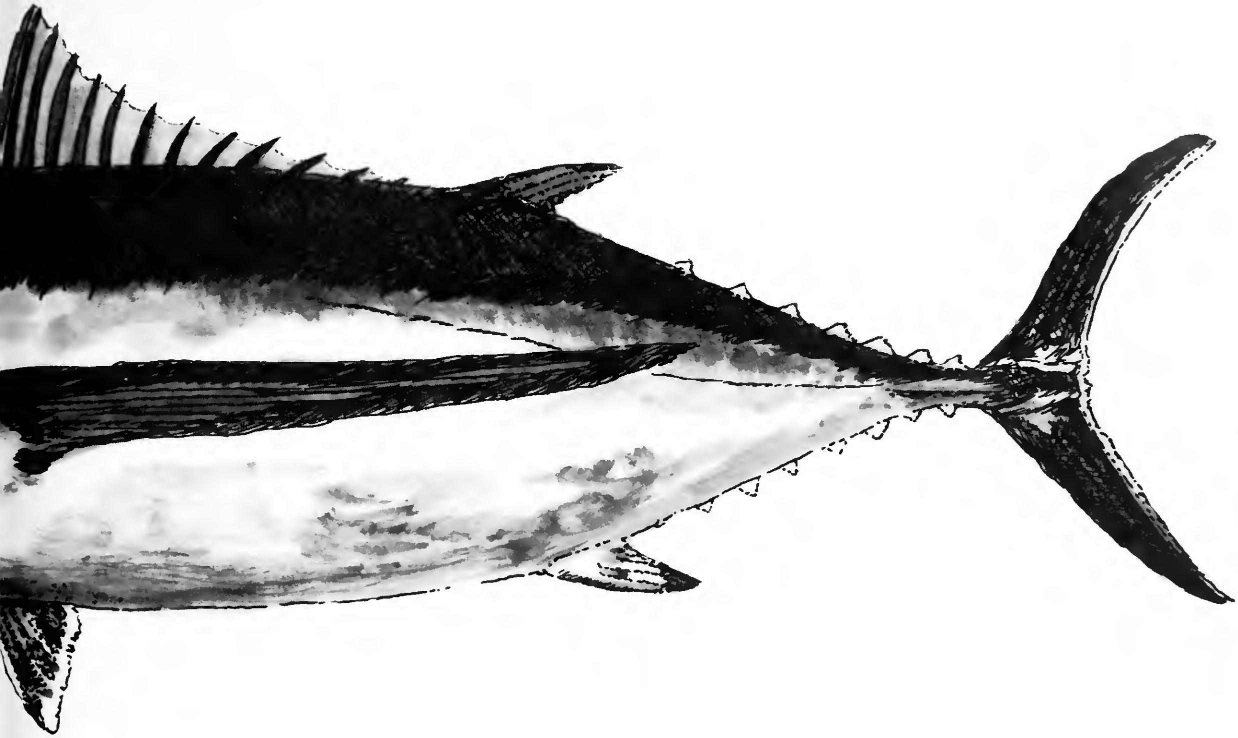
The second paragraph of the statement is rather confusing. The 200-gram figure presumably refers to the Minamata fishing population. He states that the 50-ppm dry weight of fish corresponds to 5-ppm of wet, or total, weight of fish, which would be correct for a fish containing 90 percent water. If a safety factor of 5 is used, the acceptable level becomes 1.0 ppm, which was the level adopted in Sweden. He goes on to state that the Swedish work includes an error in that 80 percent of the fish is water. This means 10 ppm of wet weight of fish corresponds to the specified 50 ppm of dry weight, rather than 10 to 20 ppm as given in the testimony. This, then, would result in a tolerance level of 2.0 ppm, following the same reasoning. The Deputy Director stated that this resulted in a 0.5 ppm level.

In the fourth paragraph, he states that the fish consumption in the United States is five times less than the 200-gram figure, or 40 grams per day. He repeats this figure in the sixth paragraph. The Food and Agricultural Organization (FAO) Yearbook of the United Nations states that in 1968 the consumption in the United States was 17 grams per day per person. The U. S. Bureau of Commercial Fisheries states that in 1976 and 1977 the U. S. consumption reached a maximum of 16 grams per day per person. We do not understand where the 40 grams per day figure came from.

In the next to last paragraph, the Deputy Director goes through the more refined reasoning on the basis of consumption rates for the establishment of the Swedish tolerance limit of 1.0 ppm for the population. For an allowable daily intake of 0.06 mg/day, 120 gm/day would be permitted with a mercury level of 0.5 ppm (0.5 mg/kg x 120 gm/day x 10^{-3} kg/gm = 0.06 mg/day) or 60 gm/day with a level of 1.0 ppm. The Deputy Director's figure of 70 gm/day for the Swedish consumption rate or the FAO figure of 56 gm/day leads to a tolerance limit of around 1.0 ppm, which was the standard adopted in Sweden. On the basis of the difference in the fish consumption rates between Sweden and the United States, the logical conclusion for the U. S. would be a tolerance level in excess of 1.0 ppm (1.5 ppm for a 40 gm/day U. S. consumption figure or 3.5 ppm for a 17 gm/day figure). The Deputy Director states that this reasoning led the FDA to the 0.5 ppm figure.

In the last paragraph, we encounter a different approach to setting the 0.5-ppm level. As we understand this paragraph, the Deputy Director is justifying a tolerance level on the basis of the sensitivity limits of established analyses techniques. Had the sensitivity level been 5.0 ppm or 0.05 ppm, would the standard have been set at either of these figures? This latter line of reasoning was, indeed, questioned by the Senate Committee staff at the hearing.

With regard to the natural occurrences of mercury in fish, concentrations increase proportionally to the size of the fish and from prey to predator fish through bioaccumulation. In this sequence, the mercury is selectively transformed from an inorganic to an organic form. For the most part, small marine fish, such as sardines, mackerel, and whiting, contain mercury concentrations of less than 0.1 ppm on the average, with maximum values being approximately 0.2 ppm. There is a dramatic increase in concentrations in the largest predator



fish. In one investigation of fish from the Indian, Pacific, and Atlantic oceans, tuna had average concentrations of 0.34 ppm of total mercury, swordfish 0.89 ppm, and shark 1.64 ppm of which 58, 69, and 56 percent were in a methylated form. In another investigation, tuna had 0.70 ppm of total mercury, marlin, 0.79 ppm, and swordfish, 1.24 ppm, of which 86, 94, and 93 percent were in a methylated form. Clearly swordfish will not meet the FDA standard of 0.5 ppm and tuna will be marginal.

Where there has been a mercury poisoning epidemic (Minamata and Niigata), the pollution source has been related to a nearby, substantial discharge of mercury wastes from industrial activities into restricted water bodies. Nevertheless, some consideration should be given to what the total effects of all mercury discharges have been on the world's oceans. The mercury content of the oceans is in excess of 70 million metric tons. Man's input from all sources is estimated to be 20 thousand metric tons per year. Thus man's effect on the total mercury content of the oceans as a whole is negligible, and most of man's input is probably deposited in sediments in estuaries and shallow coastal waters near the industrial discharge sources and does not get into the open ocean and its food chains. The amounts discharged by man's activities are about the same as those released through the natural geologic processes of rock weathering and vulcanism.

In summary, we argue that there was no need for the nationwide mercury scare in the United States or for the ban on swordfish. It is our opinion that this scare could have been prevented if the FDA study had been conducted before rather than after the guideline had been set and if the study had included scientists with backgrounds pertinent to the various aspects of the subject.

Charles B. Officer is Research Professor in the Earth Sciences Department, Dartmouth College, Hanover, New Hampshire. John H. Ryther is a Senior Scientist in the Biology Department, Woods Hole Oceanographic Institution.

Suggested Readings

Hartung, R., and B. D. Dinman, eds. 1972. *Environmental mercury contamination.* Ann Arbor, Michigan: Ann Arbor Science Publishers.

Krenkel, P. A., ed. 1975. *Heavy metals in the aquatic environment.* New York: Pergamon Press.

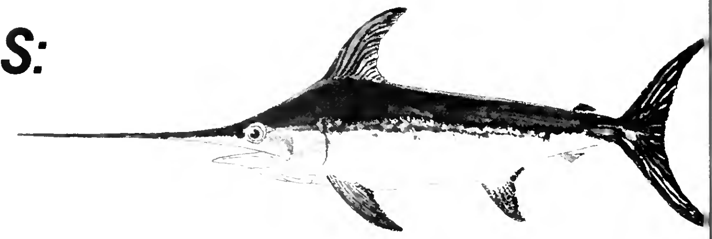
President's Science Advisory Committee. 1973. *Chemicals and health.* Washington, D. C.: National Science Foundation.

Smith, W. E., and A. M. Smith. 1975. *Minamata.* New York: Holt, Rinehart, and Winston.

Study Group on Mercury Hazards. 1971. Hazards of mercury: special report to the Secretary's Pesticide Advisory Committee, Department of Health, Education and Welfare. *Environmental Research* 4: 1-69.

United States Senate, Committee on Commerce, Subcommittee on Energy, Natural Resources, and the Environment. 1970. Effects of mercury on man and the environment. Hearings of May 8: 1-92.

THE FDA RESPONDS:



Mercury Levels in Fish

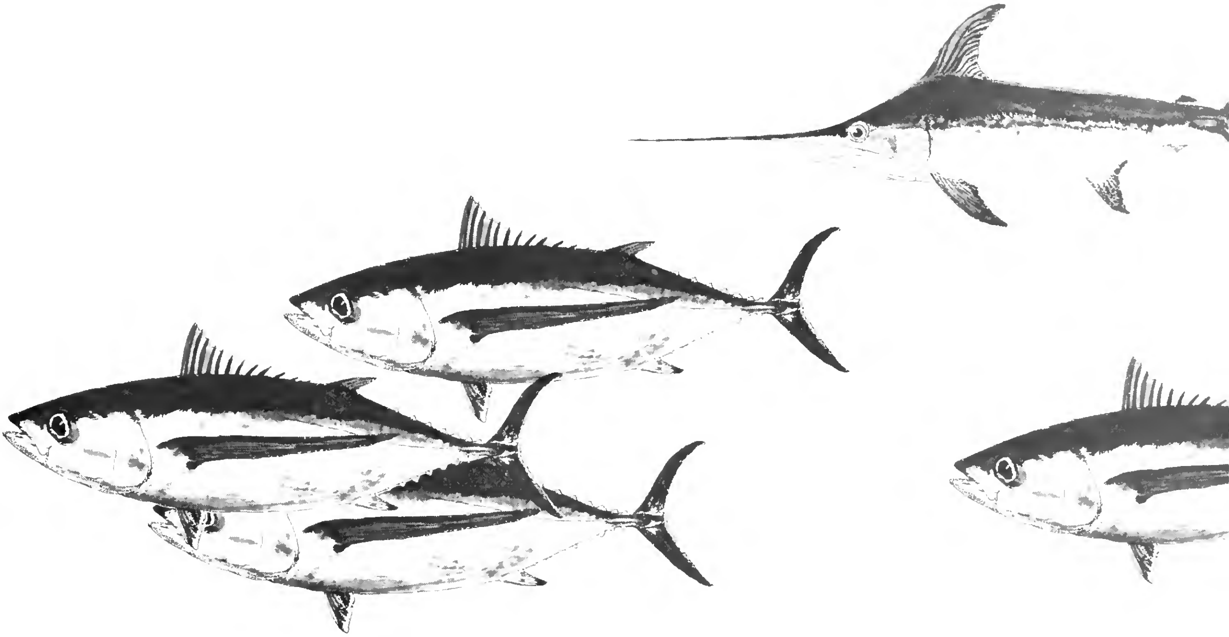
Scientists in a public health regulatory agency, such as the Food and Drug Administration (FDA), must take legal and other considerations into account in analyzing information. The programs of the FDA serve to demonstrate the interrelationship of science and law in the regulatory process. It would appear from the Officer and Ryther article that such considerations are not always completely understood.

Humans ingest or are exposed to a variety of substances that are under the regulatory control of the FDA, such as foods, food additives, color additives, drugs, vitamins, and minerals; residues found in animal feed, such as animal drugs, and pesticides; and even cosmetics. The statutes and regulations used by the FDA to control these substances vary with the form of ingestion or exposure, and the kind, amount, and length of exposure to these substances.

Section 406 of the Food, Drug, and Cosmetic Act, which provides the authority to regulate mercury in fish, states:

> *Any poisonous or deleterious substance added to any food, except where such substance is required in the production thereof or cannot be avoided by good manufacturing practice shall be deemed to be unsafe for purposes of the application of . . . Section 402(a); but when such substance is required or cannot be avoided, the Secretary shall promulgate regulations limiting the quantity therein or thereon to such extent as he finds necessary for the protection of public health, and any quantity exceeding the limits so fixed shall be deemed to be unsafe for purposes of the application of . . . Section 402(a). While such a regulation is in effect limiting the quantity of any such substance in the case of any food, such food shall not, by reason of bearing or containing any added amount of such substance, be considered to be adulterated within the meaning of . . . Section 402(a). In determining the quantity of such added substance to be tolerated in or on different articles of food, the Secretary shall take into account the extent to which the use of such substance is required or cannot be avoided in the production of each such article, and the other ways in which the consumer may be affected by the same or other poisonous or deleterious substances.*

At the time when an action level of 0.5 parts per million (ppm) for mercury in fish was determined, the estimate of tolerable weekly or daily intakes of methyl mercury was based primarily on Swedish studies of Japanese individuals poisoned in the episode of Niigata, which resulted from consumption of contaminated fish and shellfish. Data on mercury levels in blood and hair, and in some cases in the brains of poisoned patients, provided a basis for establishing methyl



mercury levels at which toxic effects were observed.

From these data, it was estimated that a blood level of 200 parts per billion (ppb) would be reached with a minimum daily intake of approximately 300 micrograms (μg) of mercury, present as methyl mercury in the diet. In setting intake standards for a whole population it is usual to apply a safety factor. In cases where human data are available the safety factor used is 10. Thus a maximum tolerable level would be 20 ppb of methyl mercury daily in the blood, or 30 μg methyl mercury daily in the diet.

The following limitations to this approach were recognized: 1) it was not known to what extent particular individuals are more or less sensitive to mercury than others, 2) the estimates were based on the "lowest level that caused an effect" rather than the normal procedure of using a "no effect dose level," 3) questions about dose/response relationships in human fetuses and newborn infants were unanswered, and 4) there is a possibility of subclinical effects arising from exposure to very low levels of methyl mercury.

In addition, at the time a considerable amount of uncertainty existed concerning fish consumption. As an estimate, two meals per week of 200 grams each was used. This provided a daily intake of approximately 57-60 grams per day. At the action level of 0.5 ppm, this would provide the daily intake of 30 μg of methyl mercury.

Concern for mercury in canned tuna fish arose because of the amount of tuna consumed by individuals involved in a variety of weight reduction programs, in particular the Weight Watchers clubs. Enforcement of the action level of 0.5 ppm in canned tuna was consistent with the policy of the FDA, which is to exercise its regulatory authority to prevent adverse human health effects rather than wait for such to occur.

Also consistent with the policy of the FDA are the actions that have been taken with the regulation of mercury in fish in light of new information concerning fish consumption in the United States. As is the case with all action levels or tolerances established by the agency, these are reviewed as new information becomes available and changes that are scientifically justified are made.

Frank Cordle
Bureau of Foods,
Food and Drug Administration,
Washington, D.C.

References

Cordle, F., and Kolbye, A.C. 1979. Food safety and public health. Interaction of science and law in the federal regulatory process. *Cancer* 43: 2143-50.
Federal Register. 1979. 44 (no. 14): 3990-93.

Photo of kelp by Bob Evans, La Mer Bleu Productions, Santa Barbara, California.

Ecological Effects of Ocean Sewage Outfalls:

Observations and Lessons

by Alan J. Mearns

In North America, sewage and sewage sludge reach the ocean in two ways: dumping from the surface via barges, on the East Coast (see page 55) and discharge via ocean outfalls, in Pacific insular and coastal areas by Honolulu, San Diego, Orange County, Los Angeles, San Francisco, Seattle, Victoria, and Anchorage.

Approximately 4.5 billion liters of sewage and sewage sludge, containing about 250,000 metric tons (mtons) of solids, are discharged each day via 30 ocean outfalls along the Southern California coast (Figure 1). About 90 percent of this sewage is discharged from five municipalities, including San Diego (440 million liters per day, mld^{-1}), Orange County (681 mld^{-1}), the County of Los Angeles (1,268 mld^{-1}), the City of Los Angeles (1,224 mld^{-1} into Santa Monica Bay and 120 mld^{-1} of secondary effluent into Los Angeles harbor), and Ventura County (City of Oxnard, 42 mld^{-1}).

These ocean outfall systems were designed to alleviate the problems of contaminated and closed beaches that were prevalent in the area prior to the 1950s and, through the use of diffusers, to dilute the sewage and minimize its toxicity to marine life. These objectives were achieved: public bathing beaches in the area are among the least contaminated in the world and there have been no fish kills attributable to the sewage in open coastal waters. Nevertheless, marine life is affected by these discharges and concern led to new studies in the 1960s and 1970s by universities, state and federal agencies, the dischargers, and by the Southern California Coastal Water Research Project. These studies, spanning nearly 20 years, produced hard data quantifying the amount of materials discharged; their dispersal and distribution along the coast; the range and magnitude of biological effects; the rates at which effects increase, stabilize,

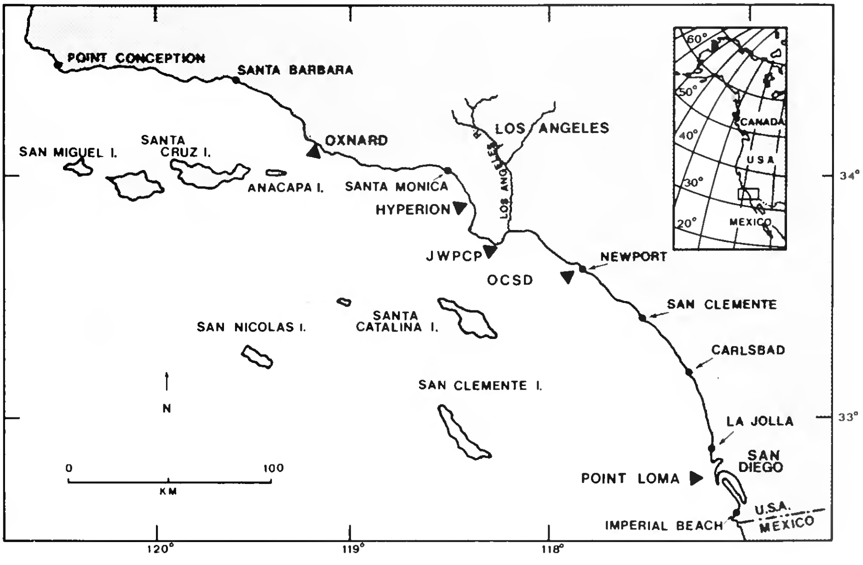


Figure 1. The Southern California Bight and adjacent coastal cities. Major municipal wastewater outfalls are located at Oxnard, in Santa Monica Bay (Hyperion Treatment Plant, City of Los Angeles), off Palos Verdes (Joint Water Pollution Control Plant, County of Los Angeles), off northern Orange County and off Point Loma (City of San Diego).

and decrease; and the degree of contaminant accumulation by marine life. The studies also have led to new methods for forecasting the fate of sewage-borne contaminants and for estimating the magnitude of future biological effects.

Characteristics of the Sewage

Muncipal sewage is a diluted mixture of fecal material, urine, pulverized food, and water. It contains by-products of everything we excrete and grind up in garbage disposal units, including enteric microorganisms, lipids, carbohydrates, proteins, urea, ammonia, a variety of cations and anions, and the trace chemicals present in our drinking water. As pointed out by Vaccaro and others, sewage solids (sludge) are not unlike marine detritus (see page 55). Thus, it is not surprising to find that it contributes to the production of detritus-based marine food webs.

Unfortunately, in major cities, such as Los Angeles and San Diego, sewage also contains measurable amounts of potentially toxic chemicals used every day at home and work; included are detergents and other surfactants, trace elements, acids, bases, volatile and semivolatile solvents, fuels, paints, and partially combusted oils. And, in highly industrialized sections of the cities, municipal sewage contains trace, but measurable, amounts of other potentially toxic synthetic chemicals, including an array of halogenated (mostly chlorinated) hydrocarbons. If such materials are present at toxic levels, they can act to negate the use of sewage by marine organisms.

Routine monitoring has given us a fairly clear picture of the concentrations and mass emission rates of several dozen types of materials discharged via the ocean outfalls into Southern California coastal waters. For example, during 1977, at least 236,000 mtons (1.34 million cubic meters) of suspended solids, 41,000 mtons of oil and grease, 840 mtons of zinc, 370 mtons of copper, 152 mtons of lead, 34 mtons of silver, 3 mtons of mercury, 1.6 mtons of polychlorinated biphenyls (PCBs), and 0.8 mtons of DDT were discharged into local coastal waters from the five largest municipal treatment systems. During the last decade, mass emission rates of some of these materials have decreased significantly because of pretreatment, source control, and increased solids removal (Table 1). In 1979, these effluents contained 75 to 195 milligrams (mg) 1^{-1} of suspended solids and 144 to 229 mg 1^{-1} of 5-day BOD (biochemical oxygen demand); these concentrations are considerably higher than the 30 mg 1^{-1} maximum required by Public Law 92-500.

Recent studies have partially quantified the concentrations of a variety of volatile and semivolatile organic solvents and related halogenated derivatives. Data from the Southern California Coastal Water Research Project in 1979 suggest that up to 1,000 mtons of volatile organic chemicals and up to 10 tons of extractable hydrocarbons may be discharged each year. Work is in progress to more adequately quantify these emissions.

Compared to other sources of contaminants, municipal sewage has been a major contributor of many of these materials to local coastal waters. However, winter runoff contributes at least as much solid material. Air (smog) is the dominant source of lead and, now, DDT and PCBs; vessel-related

Table 1. Comparison of flow and mass emission rates of 13 materials in wastewaters from the five major coastal public-owned treatment plants in Southern California, 1971 vs 1979. Data include emissions from the Los Angeles City (Hyperion) sludge outfall. Source control and reduction in solids emissions have reduced inputs significantly in recent years. Silver is a curious anomaly that merits investigating.

Constituent	1971	1979	Change
Flow, 1 x 10^6 d^{-1}	931	1,054	13.2% increase
Mass Emission Rates, mtons y^{-1}			
Suspended solids	288,000	243,000	15.6% decrease
B.O.D.	283,000	246,000	13.1% decrease
Oil and grease	63,500	45,000	29.1% decrease
Ammonia nitrogen	56,600	41,200	27.2% decrease
Zinc	1,880	724	61.5% decrease
Chromium	676	237	64.9% decrease
Copper	559	359	35.8% decrease
Nickel	339	256	24.5% decrease
Lead	243	223	8.2% decrease
Cadmium	57	42	26.2% decrease
Silver	18	42	138.0% increase
DDT	21.7	0.76	96.5% decrease
PCBs	19.5	1.5	92.5% decrease

activities contribute competitive amounts of zinc and copper.

The Outfalls: How They Work

The five largest treatment plants discharge their wastes via large outfalls that terminate at depths ranging from 20 meters (m), Oxnard, to more than 60 m, all other plants. With one exception, the outfalls are fitted with long — 0.5 to 2.0 kilometers (km) — multiport diffusers located 2 to 8 km from shore. The exception is a Los Angeles (Hyperion Treatment Plant) outfall that discharges waste-activated sludge via an open-ended pipe located 100 m deep at the head of a submarine canyon some 11 km from shore.

The diffusers were designed to mix sewage effluent with seawater at a ratio of approximately 1:100 (Figure 2). Field measurements confirm actual dilutions in the range of 1:80 to 1:300 depending on current velocity and direction and the specific type of diffuser.

Factors that affect the fate and effects of materials discharged from ocean outfalls include depth, fluctuations in current speed and direction, wave climate, temperature and stratification, oxygen transport into sediments, sediment deposition and resuspension rates, and phytoplankton nutrient limitations.

All of the Southern California outfalls are situated on a relatively narrow (2 to 10 km) mainland shelf that drops abruptly from an edge at 200 m into basins on the order of 1,000 m deep. There are at least two recognizable water masses overlying the shelf: 1) a surface mixed layer averaging 20 m deep and flowing mainly downcoast (to the southeast) at net velocities of 20 to 50 centimeters (cm) per second (sec) and 2) a subsurface layer (usually separated from the mixed layer by a sharp change in density, or pycnocline) flowing mainly upcoast (to the northwest) at a net velocity of 5 to 20 cm per sec. Both layers experience reversals and sometimes coincide in direction for many days.

Particulate matter from the sewage, together with flock (a combination of plankton and wastewater solids) formed during mixing, also undergoes initial dilution, but soon begins settling. Depending on depth and bottom currents, the settling material may create a deposit of organic matter and contaminants on the seafloor near the discharge point. Field and laboratory measurements conducted by the Coastal Water Research Project indicate that about 10 percent of the discharged particulates have settling velocities

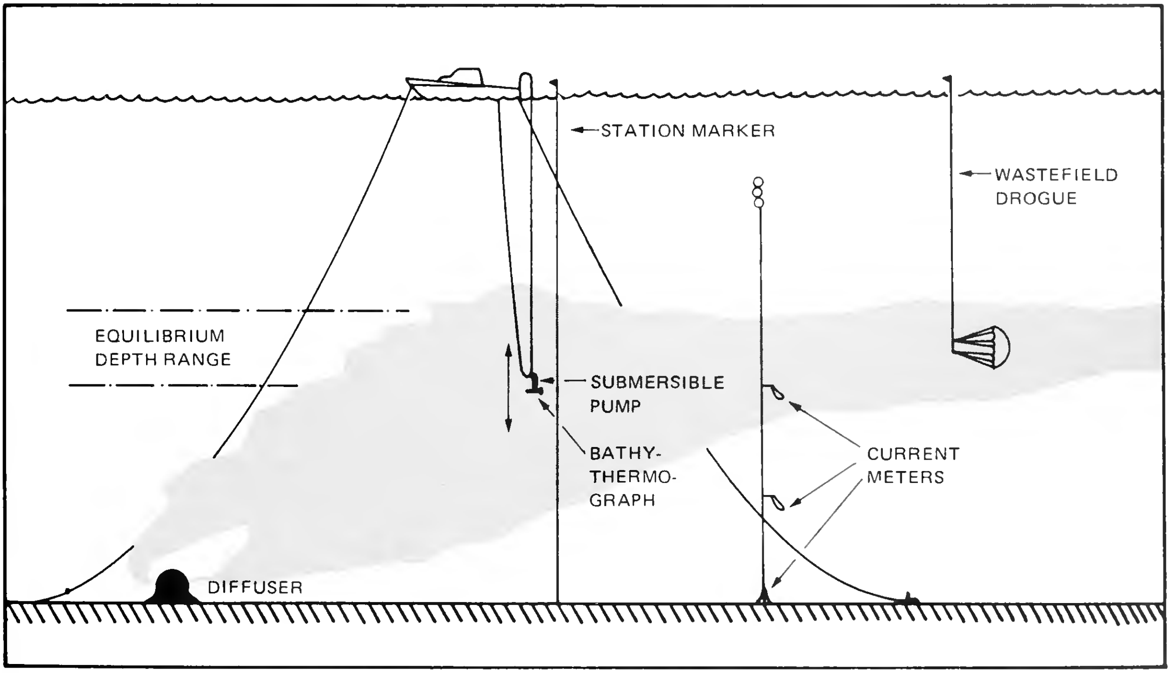


Figure 2. Section through a major outfall diffuser and the adjacent water column showing: effluent jets from lateral ports (creating 100:1 dilution with entrained seawater); the plume rising to the pycnocline (equilibrium depth range) and moving down-current (to the right); and oceanographic equipment used to sample the plume and adjacent water masses. (See article by Tareah J. Hendricks, pp. 41-51, Coastal Water Research Project Annual Report, 1977. Long Beach, Calif.)

sufficient to create the zones of deposition and contamination actually documented at these sites.

The deposition patterns are generally elliptical or oval in shape; such patterns are seen in Figure 3, which shows how benthic organisms respond. The epicenter (characterized by maximum concentrations of contaminants) generally occurs several km upcoast or downcoast of the diffusers, rarely at the diffusers.

The fate of the remaining 90 percent of the fine suspended particulate matter is still poorly known. Presumably, it remains in the water column, becoming progressively dispersed as it moves away from the discharge area. Particulate and filter-feeding planktonic organisms probably consume some of it, converting it to their own wastes and tissues. This hypothesis has yet to be confirmed at sea.

One set of factors not frequently considered in evaluating effects of ocean outfalls are the volumes, sources, and fate of water entrained during initial dilution. Assuming an entrainment of 100:1, the five major sewage outfalls entrain 366 billion liters of bottom water each day and pump it at least to mid-depth. In addition to the sewage outfalls, there also are 15 power generating stations on the Southern California coast. These plants take in and recycle 21.1 billion liters per day (bld) of seawater. If there is an entrainment of 10:1, the power plants pump an additional 211 bld. Overall, it is possible that municipal outfalls and power plants transport and use 598 billion liters of seawater every day, or 218 cubic kilometers (177 million acre feet) each year. This is equivalent to a cube of water 6 km (3.8 miles) on a side.

Of particular significance is the fact that this entrainment effectively takes nutrient-rich bottom water of slightly lower oxygen content, and raises it several 10s of meters or more, perhaps inducing unusual bottom currents and also putting the nutrients into the euphotic zone where they can contribute to phytoplankton production. Natural upwelling on this coast has been estimated to pump 900 cu km per year (during the three-month upwelling season) over 7,500 sq km of the coastal zone. Thus the man-induced upwelling could enhance natural upwelling by 24 percent. Clearly, this is not a trivial event, but it has rarely been taken into account in evaluating the effects of these discharges.

Effects and Noneffects

All wastewater outfalls cause some kind of physical, chemical, and biological changes in their

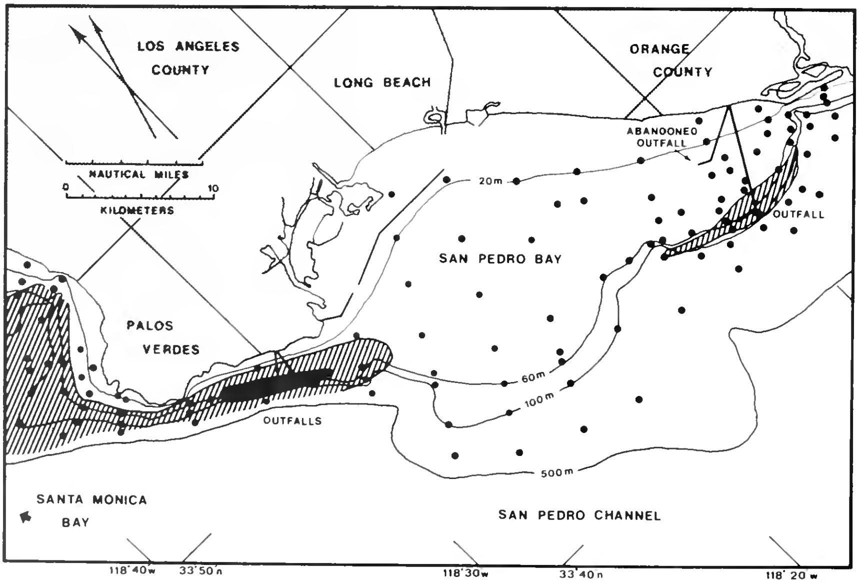


Figure 3. Distribution of "changed" and "degraded" benthic infaunal communities on the coastal shelf off southern Los Angeles County and northern Orange County, California, 1978-79. Normal communities (unshaded) are dominated by suspension-feeding species of invertebrates; "changed" communities are dominated by surface-deposit-feeding species; and "degraded" communities are dominated by subsurface deposit-feeding invertebrates. Dots are sampling stations. Data are part of a major benthic macrofaunal survey conducted along much of the Los Angeles, Orange, and San Diego county coastlines by the Southern California Coastal Water Research Project. (See reports by J. Q. Word and W. Bascom, Coastal Water Research Project Annual Report, 1978; Long Beach, Calif.)

surrounding environment. The changes may be subtle, such as a slight increase or decrease in the abundance of a few species of invertebrates or a visible discoloration in the water overlying the outfall. Or they may be quite obvious, such as major changes in sediment type and color and nearly complete replacement of bottom communities with previously rare species tolerant of the changed conditions. There is no such thing as no effect — it is all a matter of scale and degree.

Physical and Aesthetic Conditions

Although rarely detected by the casual observer, surface slicks and decreased transparency occur within a few kilometers of the deep-water ocean outfalls. Except at Palos Verdes, these conditions rarely extend inshore near public beaches and shorefishing areas. Increased treatment during the 1970s has reduced these effects even further, as documented in thousands of secchi depth and surface measurements from monitoring programs.

A 3-sq-km area in the head of a submarine canyon in Santa Monica Bay contains thick, silty sludge-like deposits — the result of 20 years' discharge of sludge from the Hyperion Treatment Plant. Otherwise, extensive visual surveys, using television, ciné cameras, and still cameras, reveal no sludge-like deposits throughout Santa Monica Bay, San Pedro Bay, or off Oxnard and Point Loma: thus, there is no justification for the point of view that a "sea of sludge" is about to wash ashore. However, flock does occur within diver depth near the outfalls at Point Loma and Palos Verdes.

Water Chemistry

For years, federal regulations have reflected a public fear that acidity (pH) and dissolved oxygen in open coastal waters are adversely affected by wastewater discharges. Hundreds of measurements have confirmed that pH of coastal waters adjacent to the Southern California outfalls is unaffected by the waste discharges. Thousands of measurements confirm that dissolved oxygen is largely unaffected by the waste discharges. There are occasional depressions (to about 10 percent below normal) at several sites; these depressions can be explained almost entirely by entrainment-induced upwelling of bottom water that naturally contains lower concentrations of dissolved oxygen.

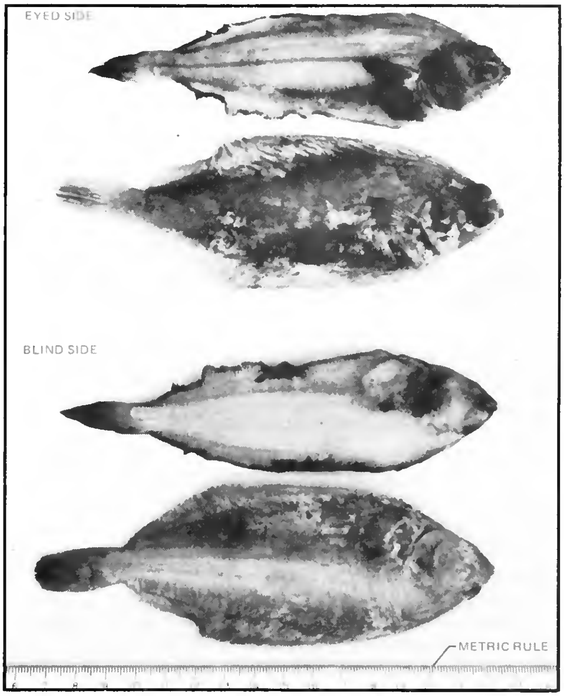
Trace metals — such as chromium, cadmium, and copper — are definitely elevated above natural levels in seawater near, and downstream of, the outfalls. The elevations are generally well below concentrations known to cause subtle effects in marine organisms; moreover, the elevations are almost entirely restricted to particulate-bound metals. Elevations of dissolved metals (the most toxic form) rarely occur outside the immediate discharge areas.

Plankton

Prior to converting to subpycnocline deep water discharge, effluent from a shallow-water (15-20 m) Los Angeles City outfall had a biostimulatory effect on phytoplankton and zooplankton in Santa Monica Bay. At present, plankton catch variations are too large to identify effects resulting from the existing deepwater outfalls. However, combined field and laboratory experiments aboard ships indicate that surface waters near all of the outfalls can stimulate phytoplankton growth in some seasons. Although sewage-induced blooms do not occur, special studies are required to further document to what degree phytoplankton are in fact stimulated in the field.

Seafloor Contamination

Surface sediments surrounding the largest outfalls (Point Loma, Orange County, Palos Verdes, and Santa Monica Bay) contain above-normal concentrations of carbon, nitrogen, trace metals, and synthetic organic chemicals. At three sites, the elevations are within a factor of two to three above background; but at Palos Verdes, some materials are elevated by more than a factor of 100. As a result, concentrations of trace metals and synthetic



Fin erosion in Dover sole. Top specimen, with severe fin erosion, was collected in May 1972 on the Palos Verdes shelf. Bottom specimen, with apparently unaffected fins, was collected in September 1975 off San Diego.

hydrocarbons are increased above normal in benthic infaunal invertebrates and some larger epibenthic invertebrates, such as crabs. Bottom fish from these areas contain measurable concentrations of DDT and PCBs; however, except at Palos Verdes, the concentrations are one-tenth or one-one hundredth of the Food and Drug Administration's safe concentration levels. Moreover, bottom fish at all sites (including Palos Verdes) do not accumulate excess trace metals, including mercury, in edible flesh. This observation, coupled with new data on feeding habits, indicates that metals from these wastewaters are not biomagnified through the food web (Figure 4).

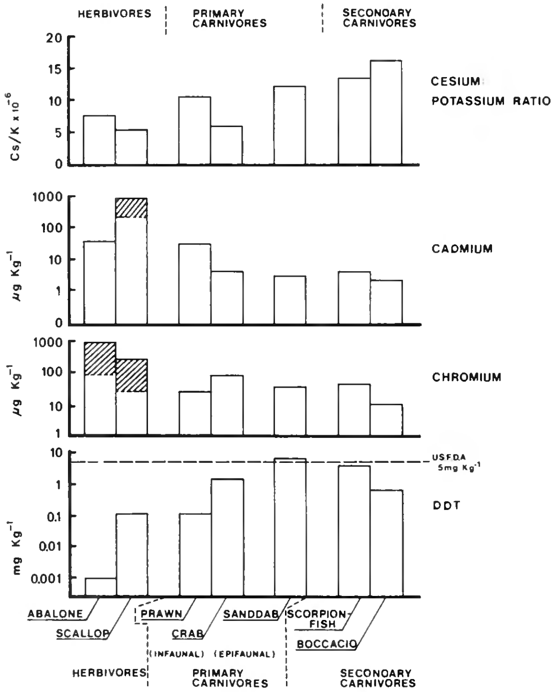


Figure 4. Concentrations of trace elements and the pesticide DDT in muscle tissue of seven popular sea-food organisms from the Palos Verdes shelf, 1975-76. Organisms are arranged, left to right, by trophic level (herbivores, primary carnivores, secondary carnivores). The ratio of cesium-to-potassium increases with increasing trophic level and is a useful index of trophic level. Cadmium and chromium decrease with increasing trophic level; hatched areas indicate the degree to which organisms are contaminated above levels at distant control specimens (only abalone and scallops were affected). In contrast, DDT appears to increase with increase in trophic level and with proximity to the benthic environment (boccacio are mainly water-column feeding fishes; others feed at or near the bottom). U.S. Food and Drug Administration DDT standard of 5 mg kg^{-1} *was just exceeded by the sanddab. New sampling is needed to determine if DDT in fish and metals in mollusks have decreased in recent years.*

Benthic Organisms

Repeated and standardized benthic surveys indicate that benthic infaunal communities are changed at all sites except Oxnard. The changes have been most pronounced at Palos Verdes (Figure 3) and at the terminus of the Hyperion sludge outfall where communities are dominated by dense concentrations of subsurface deposit-feeding polychaetes and mollusks. When surveyed in 1978 and 1979, about 12 sq km of seafloor (0.3 percent of the 3,640 sq km Southern California mainland shelf) was found to be occupied by these "degraded" benthic communities. "Changed" communities, characterized by an abundance of both surface and subsurface deposit-feeding organisms (including a number of species of polychaetes, mollusks, and crustaceans) occupied less than 1 sq km of sea bottom at Oxnard, 6 sq km at Point Loma, 10 sq km off Orange County (Figure 3), 60 sq km in Santa Monica Bay, and more than 94 sq km of the Palos Verdes shelf (Figure 3). Overall, about 4.7 percent of the Southern California shelf was occupied by infaunal communities changed as a result of the wastewater discharges.

At a given depth, abundance and diversity of bottom fish and larger epibenthic invertebrates, such as several species of crabs and shrimp, are generally the same as, or higher than, background. At Palos Verdes, however, bottom fish abundance has been extremely variable, and several species that might be expected to be abundant are not.

Bottom fish captured near the Oxnard, Point Loma, and Santa Monica Bay effluent outfalls have not exhibited any signs of disease attributable to waste discharges. Flatfish captured near the Orange County outfall and the Hyperion sludge outfall have exhibited signs of fin erosion in the past. Flatfish of several species captured near the Palos Verdes outfall frequently show signs of fin erosion, and it is clear that this site has been an epicenter of the disorder. Factors related to the disease include high tissue levels of PCBs and high frequencies in species living in closest proximity to the bottom. The disease has been induced in the laboratory by exposing healthy fish to sediments from Palos Verdes. Liver weight (normalized to body weight) is also higher in Dover sole, *Microstomus pacificus*, from Palos Verdes, Santa Monica Bay, and Orange County than in fish of the same species from Point Loma or other coastal sites (except one oil seep site). Dover sole along the coast also have a low frequency of skin tumors; the anomaly is *not* related to the waste discharges.

Effects on Fisheries and Nearshore Biota

Sport and commercial fish-landing data from large (16 by 16 km) statistical blocks indicate that catch rates are either no different or are higher near outfall areas than away from them. Data are not refined enough for a more detailed examination; however, they do reveal that more than 70 percent of all commercial fish landed from Southern California are taken within a 50 km radius of the three largest outfalls.

Beds of giant kelp, *Macrocystis pyrifera*, normally dominate the subtidal environment off Point Loma and Palos Verdes. However, kelp beds at both sites were greatly reduced in the past. Recovery took place at Point Loma about the same time discharge was initiated through the ocean outfall (1964). However, no recovery took place at Palos Verdes until the late 1970s when solids emissions were reduced, DDT controlled, and clear, warm oceanic water invaded the coastal zone (Figure 5). The specific cause of the decline is still not known, though recovery at both sites was certainly initiated and aided by transplanting and control of herbivores (sea urchins) by the California Department of Fish and Game. Kelp beds at Palos Verdes now occupy more than half their historical area of distribution.

Far Field Effects

The occurrence of DDT, originating from the Palos Verdes discharge, in intertidal biota along the coast and in pelicans and other seabirds at distant (100 km) island breeding colonies, confirms that some materials from these discharges can enter the upper pelagic zone and find their way to distant sites. Fortunately, source control of DDT in the early 1970s has been accompanied by significant (more than 10-fold) decreases in DDT contamination of biota throughout the coastal zone except at San

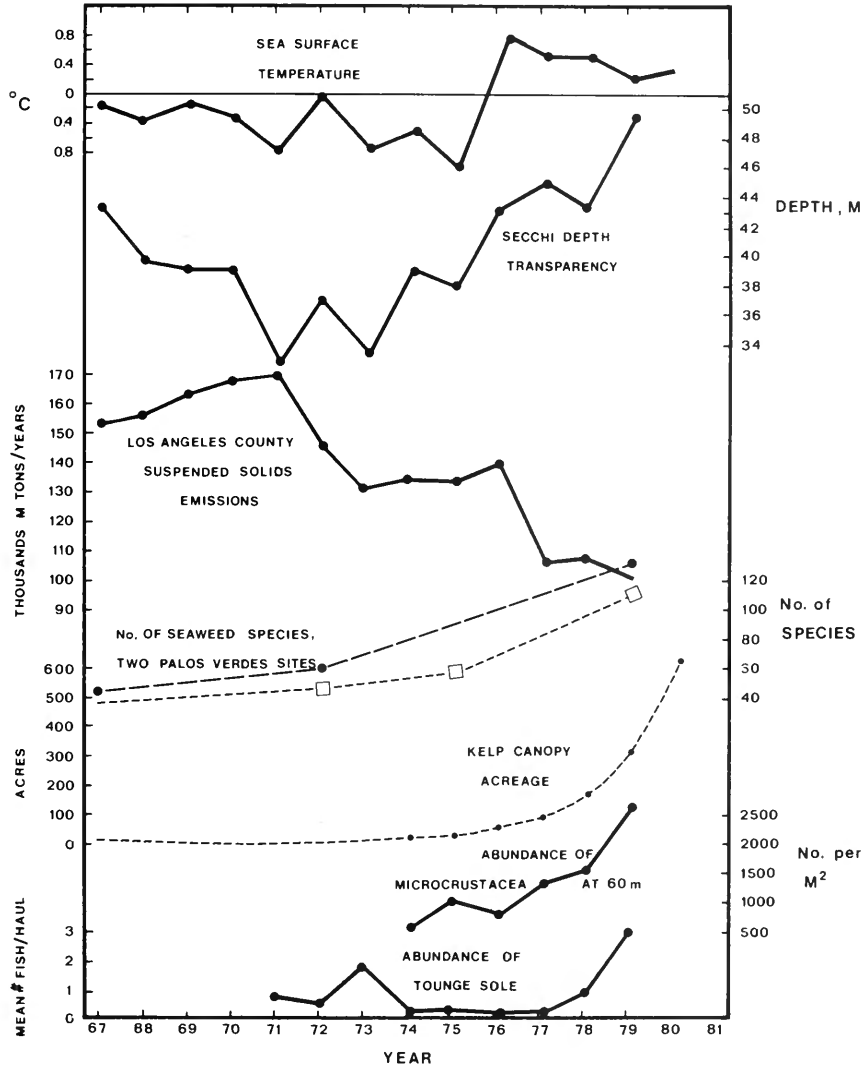


Figure 5. Changes in sea surface temperature, transparency, solids mass emission rates, number of intertidal seaweed species, kelp forest acreage, abundance of microcrustaceans at the 60 m isobath and abundance of tounge sole (a crustacean-eating flatfish) in the vicinity of the Los Angeles County sewage outfalls off Palos Verdes. Discharge was initiated in 1937. Subsequently, kelp beds diminished in size and there were decreases in the abundance and variety of intertidal seaweeds. Deep-water sampling was initiated in the early 1970s, producing data such as those represented by the microcrustaceans and flatfish. Increases in kelp, intertidal seaweeds, crustaceans, and the flatfish followed reduction in solids emissions; these events also coincided with a warming trend (1976-1980) so that both factors may be involved in the recovery.

Miguel Island where thousands of resident pinnipeds may be recycling previously acquired DDT.

Rates of Impact and Recovery

Effects of the ocean sewage outfalls do not occur immediately after discharge begins, nor are they permanent once they take hold. When discharge was initiated at the 60-m-deep Orange County outfall in 1972, fish and benthic infaunal communities showed no response for a full year. By 1976, fish catches were slightly higher near the diffuser than at distant reference sites. Between 1973 and 1976, benthic infauna became more abundant, but generally maintained their diversity. Copper concentrations in sediments near the diffuser slowly increased over a period of four years from a background of 15 mg kg^{-1} to 31 mg kg^{-1}, then leveled off (Figure 6).

Conversely, when discharge was terminated at the 20-m-deep outfall (following 15 years of continuous discharge), the infauna changed from deposit-feeding-dominated communities to the normal, suspension-feeding-dominated communities within three to six months. Copper concentrations in sediments returned to background within a year; trawl catches of bottom fish also decreased, relative to background, within one to two years of discharge termination (Figure 7).

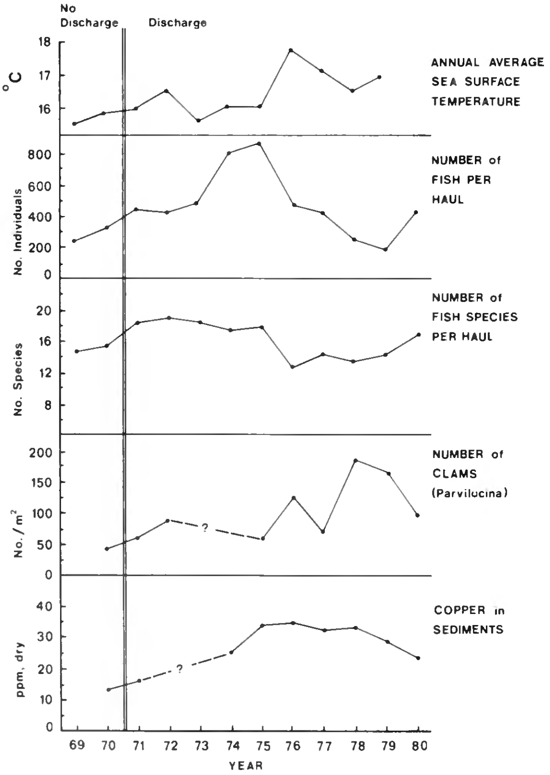


Figure 6. Changes in bottomfish, benthic invertebrates, and sediment copper prior to and following initiation of discharge via the 60-m-deep ocean outfall off Orange County. Data from samples taken within 1 km of the diffuser. Variations in fish abundance and species are related to changing oceanographic conditions as reflected in sea-surface temperatures.

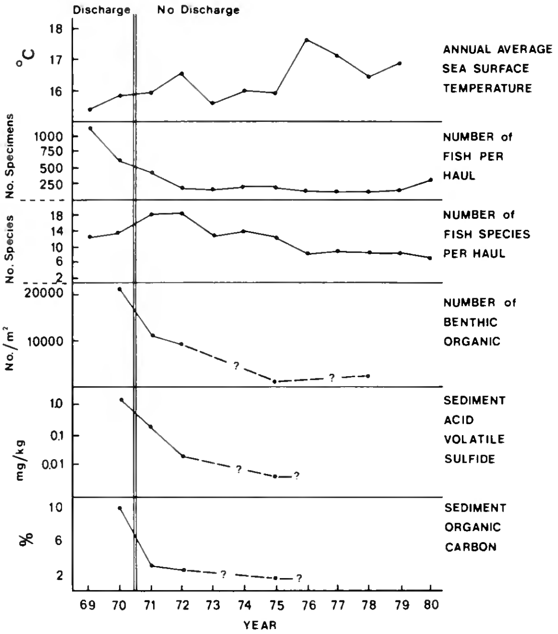


Figure 7. Decreases in bottomfish, benthic invertebrates, and sediment organic carbon following termination of discharge at a 20-meter deep outfall operated by the County Sanitation Districts of Orange County. Wastes were diverted to the deep outfall (Figure 6). Data from several sources as cited in Mearns, 1981 (in press).

Other examples of recovery or apparent recovery have already been cited (return of kelp beds, decline in DDT contamination of coastal biota, increased transparency, and decreased plankton volumes). In addition, intertidal and subtidal seaweeds and invertebrates have undergone dramatic increases in abundance and diversity during the last four years at Palos Verdes. This recovery appears to be a response to decreased emission from that discharge.

Conclusions, Lessons, and Needs

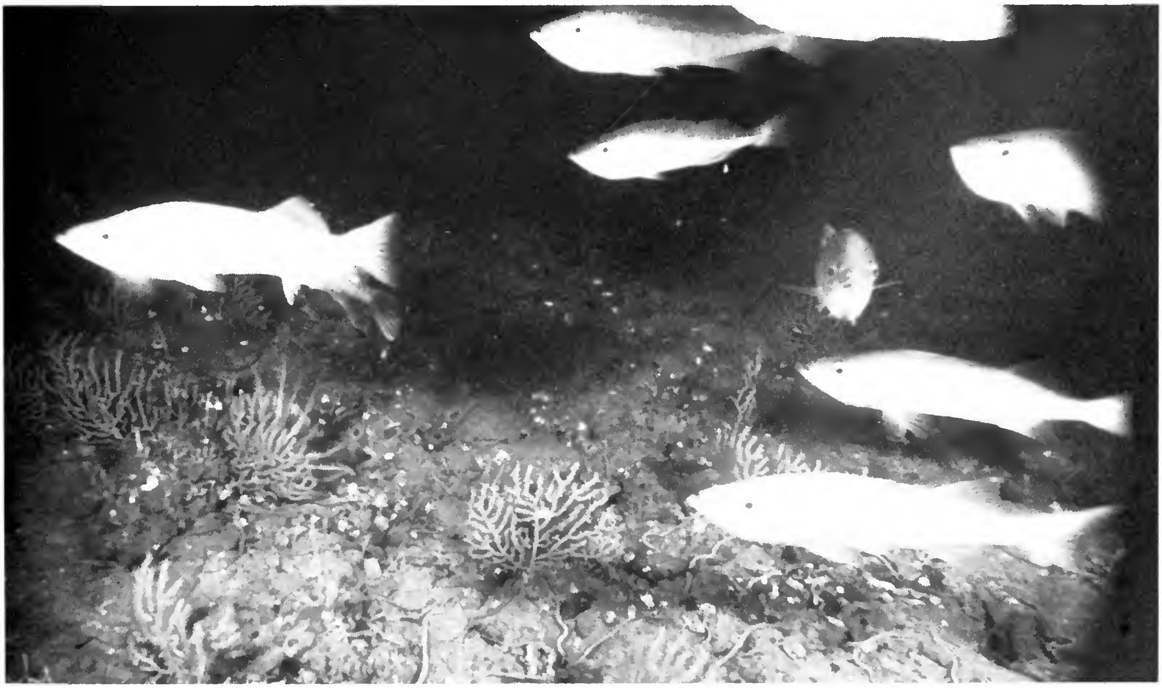
Several kinds of conclusions can be drawn about the effects of the Southern California sewage outfalls. It is clear there have been, and still are, effects of the large sewage outfalls on marine plant and animal communities. However, it is equally clear that many of the allegations of the past are unfounded. There is no sea of sludge about to wash ashore and no area of the shelf is void of marine life. Instead, we find measurable changes in the abundance, diversity, structure, and increased biomass of benthic infauna over a bottom area totaling perhaps 4 to 5 percent of the mainland shelf; changes in the relative abundance of bottom fish within several kilometers of four of the discharge sites; and apparently chronic fin erosion disease that affects bottom fish at two sites (but not the others); contamination of fish by synthetic chemicals but not by metals at several sites; and contamination of filter-feeding invertebrates at several sites and adjacent coastal areas.

Unquestionably, these are problems of concern, but certainly not panic. Conditions attributable to sewage discharges were considerably better in 1980 than in 1970. DDT levels in fish and seabirds have decreased, kelp beds and associated subtidal and intertidal plant and animal communities have returned to near normal levels along the Palos Verdes shelf, and the adjacent water mass is measurably clearer. These changes are in part a direct result of source control and reductions in solids mass emissions from Los Angeles County's Palos Verdes discharge.

What is in store for the near future? Most of the effluent from these plants is given primary treatment; two (Orange County and Los Angeles City) discharge a mixture of primary and secondary effluents. Public Law 92-500 requires that these and all other plants convert to full secondary treatment this year, unless they can show they are causing no adverse ecological impacts as defined in section 301h. The entire matter is now in the hands of the Environmental Protection Agency (EPA). Meanwhile, most of the plants are constructing facilities for additional treatment (but not full secondary) and these will be in operation soon regardless of the final decision by the EPA.

What ecological changes will result from these alternative approaches? Several years ago this question was put before scientists at the Coastal Water Research Project. Numerical models — based on the chemical composition of sewage and marine sediments, midwater and bottom currents, offshore sediment resuspension, and settling characteristics — predicted concentrations of metals, pesticides, and organic carbon that could occur at selected sites. Rates of change also were predicted. Obviously, most materials were found to decrease with decreasing waste input, but not DDT: in deep water (300 m) off Palos Verdes, DDT levels would increase with full secondary treatment because old deposits would be uncovered and mobilized.

Biological forecasting presented a formidable challenge. Nontraditional methods were developed to forecast changes in benthic communities. The result was that intermediate levels of treatment would reduce the excess biomass by 70 percent (from 15,000 to 5,000 mtons), the area occupied by changed communities by 75 percent (from about 160 sq km to 40 sq km), and the area occupied by "degraded" communities by 85 percent (from 12 to just under 2 sq km). Full



Boccacio, Sebastes paucispinis, *cruise among sea fans in a sand and cobble area 60 meters deep some 3 kilometers south of Hyperion outfalls in Santa Monica Bay.*

secondary treatment would reduce the excess biomass and sizes of areas affected by an additional 10 to 15 percent; there would still be small areas of the bottom affected.

Finally, regardless of treatment, a number of water quality and biological parameters would not change because they were not previously affected by wastewater quality or because sampling methods were not sufficiently sensitive to detect small changes attributable to the discharges. These parameters included dissolved oxygen, zooplankton abundance, sport and commercial fish landing statistics, and the incidence of skin tumors in pleronectid flatfish. Thus, whatever additional treatment is finally achieved, there will be a substantial reversal in effects on benthic communities but little or no change in traditional water quality parameters.

What are the lessons and needs for the immediate future? First, predictions are useless unless they can be tested at sea. The time to test them is upon us and every effort should be made to reorganize existing monitoring programs into hypothesis-testing surveys, even if it means abandoning traditional ideas and measurements. To do this, regulatory agencies, dischargers, and cooperative scientists must meet and agree on a common approach. New funds should be made available to assist the effort where needed. If this is not done, a great amount of funding for increased treatment could result in little documented benefit. Doing so could result in field validation of tools that would help put marine scientists into the planning and design stages of ecologically acceptable waste treatment systems.

Second, the public must be made aware of the actual ecological benefits of various treatment strategies, their costs, and the effects that might occur on land as a result of advance treatment. Scientists can help by providing information on the range of ecological conditions that are possible, the probability of alleged effects occurring, and the criteria that should be met to arrive at a desired objective. So far, in the area of marine waste disposal, we have not quite asked for this kind of help.

Finally, there are some general needs that have yet to be adequately addressed. High among the list of priorities is a need to more fully understand marine food webs and how various chemicals are or are not passed through them. The problem is not merely academically interesting because there are major differences between marine and terrestrial food webs that apparently remain unknown to Congress and regulatory agencies. It would help if we could encourage more exchange between ecologists and physical chemists. In addition, we need to encourage development and use of cost-effective measurements of the health of marine organisms so that dischargers and regulatory agencies can directly address effects rather than assuming effects are occurring just because there are contaminants present.

Alan J. Mearns is presently an ecologist with the Pacific Office of Marine Pollution Assessment, National Oceanic and Atmospheric Administration, Seattle, Washington. The research upon which this article is based was done while the author was employed by the Southern California Coastal Water Research Project. Views expressed are not necessarily those of NOAA.

Acknowledgments

The work cited in this article has been conducted by scientists at municipal sanitation laboratories, several universities, and at the Southern California Coastal Water Research Project. I am grateful for support from the local municipalities, the California State Water Resources Control Board, the U.S. Environmental Protection Agency, and the National Oceanic and Atmospheric Administration. I also wish to thank Willard Bascom, Tareah Hendricks, Phil Oshida, Marjorie Sherwood, M. James Allen, Jack Q. Word, Greg Pamson, Joe Nagano, Irwin Haydock, and Richard Swartz.

References

Bascom, W. 1978. Quantifying man's influence on coastal waters. *J. Ocean. Eng.* 3(4).

Coastal Water Research Project. Annual Reports for 1974 through 1978, available from National Technical Information Services, U.S. Department of Commerce, Springfield, Va.; and Biennial Report for 1970-1980, Southern California Coastal Water Research Project, Long Beach, Calif.

Mearns, A. J. 1981. Effects of municipal discharges on open coastal ecosystems. In *Marine environmental pollution*, ed. R. A. Geyer, pp. 1-41. Amsterdam: Elsevier.

Mearns, A. J., and J. Q. Word. 1981. Forecasting effects of sewage solids on marine benthic communities. In *Ecological effects of environmental stress*, ed. J. O'Connor and G. Mayer. Estuarine Res. Found., Spec. Publ. (In press).

Mearns, A. J., and D. R. Young. 1977. Chromium in the Southern California marine environment. In *Pollutant effects on marine organisms*, ed. C. E. Giam, pp. 125-142. Lexington, Ma: Lexington Books, D. C. Heath.

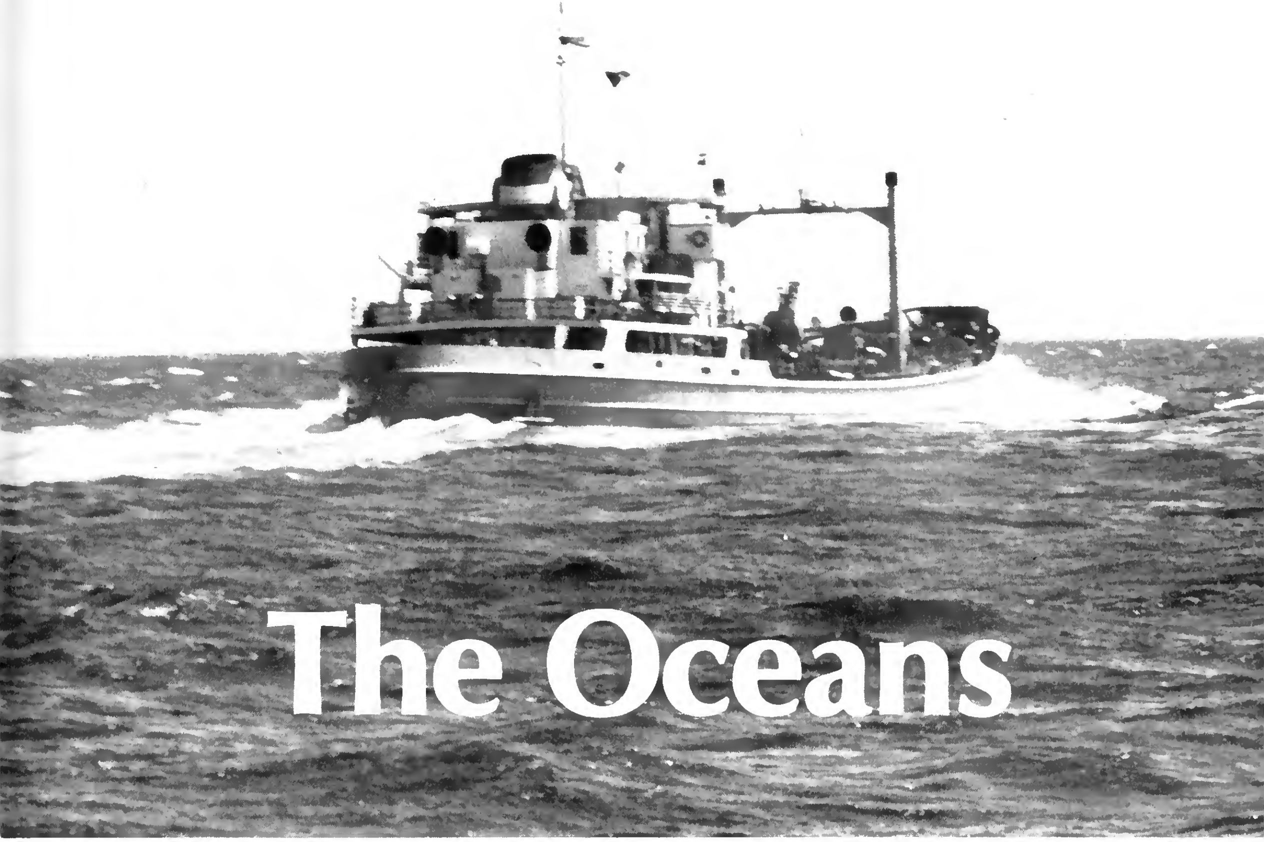
Oshida, P. S., T. K. Goochey, and A. J. Mearns. 1980. Effects of municipal wastewater on fertilization, survival and development of the sea urchin, *Strongylocentrotus purpuratus*. In *Biological monitoring of marine organisms*, ed. F. J. Vernberg, A. Calabrese, F. P. Thurburg, and W. B. Vernberg. N.Y.: Academic Press. (In press).

Sherwood, M. J., and A. J. Mearns. 1977. Environmental significance of fin erosion in Southern California demersal fishes. *Ann. New York Acad. Sci.* 298: 177-89.

Smith, R. W., and C. S. Greene. 1976. Biological communities near submarine outfall. *J. Water Poll. Cont. Fed.* 48(8): 1894-1912.

Young, D. R., and T. C. Heesen. 1978. DDT's and PCB's and chlorinated benzenes in the marine ecosystem off Southern California. In *Water chlorination: Environmental impact and health effects*, ed. R. L. Jolley, H. Gorchev, and D. H. Hamilton, Jr., pp. 267-290. Ann Arbor, Mich.: Ann Arbor Sci. Publ.

Young, D. R., A. J. Mearns, T. K. Jan, T. C. Heesen, M. D. Moore, R. P. Eganhouse, G. P. Hershelman, and R. W. Gossett. 1980. Trophic structure and pollutant concentrations in marine ecosystems of Southern California. *CalCOFI Rpts.* 21: 197-206.



The Oceans and U.S. Sewage Sludge Disposal Strategy

by Ralph F. Vaccaro, Judith M. Capuzzo, and Nancy H. Marcus

The practice of dumping barged sewage sludge at disposal sites along the northeast coast of the United States is scheduled to terminate by the end of this year. By law, only nonmarine solutions to sludge disposal will be acceptable at that time. However, this legislation is now being questioned because of doubts concerning the costly alternative disposal strategies being advanced by the regulatory agencies. Support for a more balanced approach to sludge disposal, utilizing the combined potentials of land, sea, and atmosphere, is slowly gaining favor. One of the obstacles to a balanced solution is the lack of information available on the effectiveness of offshore as opposed to nearshore receiving areas for sludge disposal.

Sewage sludge is the generic term applied to the mix of liquids and solids produced during domestic wastewater treatment. Its effective processing and disposal is a growing concern of wastewater management. Population growth and extensive upgrading of wastewater treatment, coupled with an inability to extend sludge disposal capacity, all contribute to the present sludge dilemma. About 40 percent of the nation's sewage sludge is now deposited in landfills, 20 percent is applied to agricultural lands, 25 percent is incinerated, and the remaining 15 percent is discharged to the oceans from barges or pipelines.

Above, the M/V North River *making a disposal run in the New York Bight. The vessel is 324 feet in length and has a sewage sludge capacity of 107,000 cubic feet. (Photo courtesy NOAA)*

Traditionally, the relatively shallow nearshore waters of the continental shelf have been exploited by large coastal cities as the sites for barged or outfall-directed sewage sludge. There has been little effort to explore the potential of deep-water sewage disposal. In a similar vein, there is a large amount of information available on the beneficial uses of sewage sludge in agriculture for which there is, unfortunately, no counterpart in the oceanographic literature.

The development of an oceanic role in sludge disposal has been more spontaneous than studied. It has generally meant an overburdening of the regenerative capacities of the shallow, readily accessible receiving waters. From an aesthetic and biological point of view, the result has been both benthic impaction and extensive water-column deterioration. Figure 1 shows the main sludge dumping sites assigned to the metropolitan areas of New York, New Jersey, and Pennsylvania as designated by the Environmental Protection Agency (EPA).

Negative impacts from indiscriminate sludge release in nearshore coastal waters include the accumulation of excessive concentrations of inorganic and organic nutrients (which diminish the quality of the local biochemical cycle via lowered oxygen tensions) and unfavorable species diversities. In extreme cases, anoxic conditions develop, resulting in odiferous and toxic hydrogen sulfide evolution. Such conditions usually signify extensive damage to the benthic biota. Of added concern are a variety of public health hazards, including the threat of long-term heavy-metal toxicity, the untoward accumulation of persistent chlorinated hydrocarbons, and infectious pathogenic viruses, bacteria, and parasites.

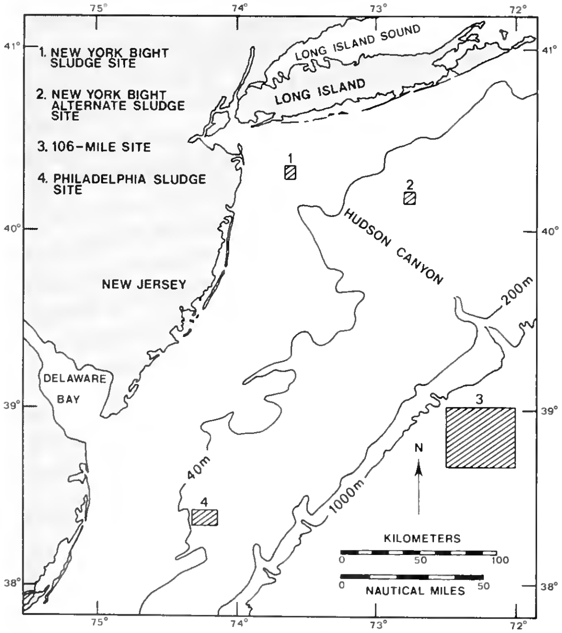


Figure 1. Operative and alternative Atlantic sewage sludge disposal sites.

The principal metallic elements in sewage sludge include cadmium, copper, lead, mercury, and zinc, whereas polychlorinated biphenyls (PCBs) are among the most troublesome hydrocarbons. Most of these chemicals are associated with the particles of sewage sludge. Consequently, their ultimate disposition in the ocean depends on the prevailing density gradients, turbulence, and horizontal transport at the time and place of release.

The threat of viruses, in particular the enteroviruses, which are primarily intestinal habitants, is of prime concern in terms of the pathogenic potential of sewage sludge. Viruses are known to be particularly resistant to conventional sewage treatment and often respond in an uncertain fashion to chlorination. Other recognized human pathogens commonly associated with sewage sludge include the etiological agents of typhoid fever, food poisoning, anaerobic dysentery, and a variety of human and animal parasites.

Legal Considerations

The broad intention of the legislation to halt ocean dumping is to prohibit the release of substances adversely affecting human health and welfare, as well as those disruptive to the marine environment and its economic potential. Enabling legislation for this decision is provided by Public Laws 92-532 and 95-153, known as the Marine Protection Research and Sanctuaries Act of 1972. The act not only applies to sewage sludge, but also to industrial wastes.

Enforcement of PL 92-532 is the responsibility of the EPA, which only in extraordinary or emergency situations will be allowed to issue ocean-dumping permits on a temporary basis. Strict interpretation of the law poses a severe problem for densely populated coastal areas accustomed to a marine sludge disposal solution.

The need to regulate sludge dumping at an international level was addressed during a 1972 convention in London.* Representatives from some 80 nations acknowledged the limited capacity of the oceans to detoxify and assimilate man's wastes and agreed to weigh future national policies in terms of their potential environmental impact. The meeting in London specifically referred to high-level radioactive wastes and to noxious substances associated with chemical, biological, or radiological weaponry. The recommendations of the convention were ratified by the U.S. Senate in 1973.

---

*Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter.

Shortly thereafter, PL 92-532 was amended to conform with the convention recommendations. Presently, more than 22 nations are signatory to the provisions of the convention.

Present and Future Concerns

An inability to agree on effective nonmarine alternatives for sludge disposal has already caused a one-year delay in implementing the sludge moritorium along the densely populated northeastern coast. Meanwhile, the regulatory agencies are pushing for new and more advanced wastewater treatment facilities that will increase the amount of sludge generated. In 1968, the total amount of sewage sludge dumped off New York and New Jersey was about 4.5 million metric tons. A conservative estimate of the amount of sludge from the same sources is expected to reach 16 million tons, an increase of 3.5 fold by the year 2000.

Skepticism is growing as to whether the nation can meet the EPA sludge directive by the end of this year. The Comptroller General (1977), the National Academy of Sciences (1978), and the Environmental Protection Agency (1978 and 1980) have voiced strong and sometimes varied opinions on sludge disposal policy. It is felt that there would be fewer uncertainties if there were a better assessment of the true assimilative capacity of the oceans for sewage sludge. Particularly useful would be a clear differentiation between sludge impacts in deep offshore as opposed to shallow nearshore waters. Many among the oceanographic community believe that this distinction, long ignored, is essential to a balanced solution of the nation's sludge dilemma.

Significant conclusions and recommendations from the Comptroller General's report of 1977 include:

- *The major municipalities now practicing ocean dumping will be unable to convert to the proposed alternative disposal methods until several years beyond the projected deadline.*
- *Thus far, there is insufficient information for determining whether greater use of the atmosphere, groundwater, and/or land as media for sludge disposal would be more or less disruptive than coastal dumping.*
- *Efforts should be made to locate oceanic sites that permit dumping at rates that would provide greater safety.*
- *Before phasing out ocean dumping, we should more thoroughly assess the effects of alternatives on the total environment.*

The report by the National Academy of Sciences' Committee on a Multimedium Approach to Municipal Management concluded that:

- *There needs to be a multidisciplinary effort, including ecologists, engineers, economists, and social scientists, to find a solution to the nation's sludge problem.*
- *Excluding the ocean as a site for sludge disposal precludes a balanced multimedia approach and places an unequal burden on the land and its attendant water resources.*
- *The EPA should reexamine current interpretations of those laws which preclude the disposal of domestic sewage sludge in the oceans.*
- *Recognition that an essential prerequisite for safe environmental sludge recycling is the point source removal of industrial heavy metals and other toxic sludge components.*
- *Scientists should undertake systematic mariculture research to assess the possibility of improving the fertility of coastal waters via the managed release of wastewater residuals to the sea.*

Both reports favor the development of a broadly based, multi-environmental approach to sewage sludge disposal. The EPA remains adamant, however, and insists that the only acceptable long-term solution to the safe disposal of potentially harmful sewage sludge is via land-based or atmospheric dissemination. Their recommended alternatives are:

- *Direct land application.*
- *Incineration and atmospheric disposal (possibly at sea).*
- *Pyrolysis – combustion under conditions of reduced oxygen and atmospheric pressure.*
- *Use in agriculture as a soil conditioner.*

Site Characteristics Affecting Sludge Disposal

In the shallow waters (average depth 29 meters) of the New York Bight, 13 permittees during 1975 released about 5.0×10^6 metric tons of sludge in an area of about 100 square kilometers. Off Philadelphia, about 2.5×10^4 metric tons were released in their 50-kilometer-square area that has an average depth of 40 meters. The shallow and relatively undifferentiated waters ensure that even small sludge particles (2 to 50 micrometers in diameter) descend rapidly and dominate the sediment regime.

At other locations with depths in excess of 150 meters, seasonal changes in water-column gradients exert a pronounced influence on sludge dispersal patterns. In such situations, sinking particles can be delayed in accordance with the strength and depth of the density gradients, and horizontal transport as opposed to vertical descent can become an overriding factor.

Recent observations by scientists of the Woods Hole Oceanographic Institution show that there is indeed a horizontal dispersal pattern in the deep waters (>2,000 meters) of the Atlantic continental slope (Orr and others, 1979). The instrumentation used was a 200-kilohertz acoustic backscattering system aboard the National Oceanic and Atmospheric Administration research vessel *Albatross IV*. The waste particles observed were fine hydrous ferric oxide particles that precipitated when acid-iron waste was released from a barge at sea. Soon after dumping commenced, high particulate concentrations accumulated within the maximum density gradient (15 to 30 meters). Thermocline layering persisted for at least eight hours, during which time iron particles became associated with internal waves and were dispersed in a horizontal direction (Figure 2).

A similar conclusion was reached by T. Ichiye in 1965. He reported that when water masses interact, they produce anisotropic dispersions at multiple fronts, shear lines, and layers of varying water velocities and turbulence. Under such conditions, horizontal dispersion rates can exceed sinking rates by as much as 100 fold.

Many marine zooplankton feed on particles to obtain the carbohydrates, fats, and proteins necessary for their activities (Heinle and others, 1977). They also may have special requirements for essential amino acids, trace metals, and vitamins. The release of substantial amounts of nutrients in the form of small particles of sewage sludge could therefore provide additional options beyond the normal herbivorous or carnivorous feeding habits of these organisms.

Detritus feeding by zooplankton is responsive to the particle size, shape, sinking rate, and nutritive composition of target particles (Roman, 1977; Paffenhoffer and Strickland, 1970; Paffenhoffer and Knowles, 1979). Although detritus *per se* is considered an incomplete diet for zooplankton, it could provide a potentially important supplementary food source.

The organic and nutritional value of sewage sludge in terms of calorific value, fat, and protein content, is not unlike that of marine detritus. Studies where poultry, cattle, rabbits, and rats were offered rations of sludge have clearly demonstrated its value as a dietary supplement. In these studies, adverse effects from heavy metals were not observed for mixed diets containing 10 percent or less of sewage sludge. Therefore, it is conceivable that under ideal circumstances, sludge particles could make a substantial contribution to marine food chains. If so, the use of sludge to promote fertility in the oceans could help provide a broader

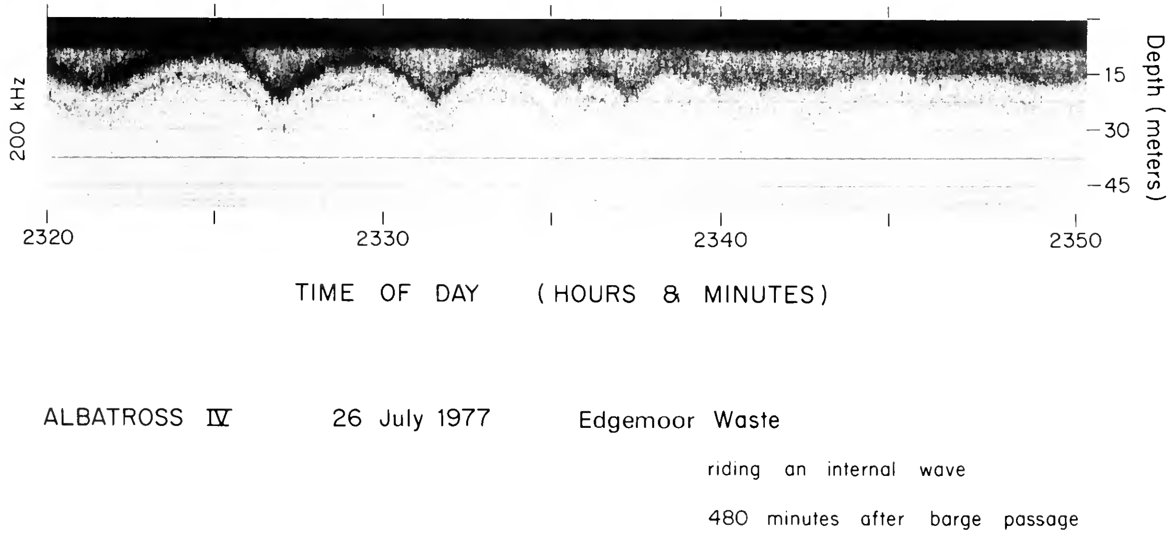


Figure 2. Acid iron waste from DuPont plant, Edgemoor, Delaware, July 26, 1977. The waste is riding on an internal wave 480 minutes after passage of the disposal barge. This gray scale record was made by the 200 kHz high frequency acoustic backscattering system carried on the Albatross IV. *Denser scattering areas indicate greater concentrations of scattering particles, hence the particulate phase of the chemical waste. Note that there are two scattering layers on the left-hand side of the figure, indicating that the particles of waste are slowly settling through one density gradient to another. (Orr and others, 1979)*

and more effective solution to the nation's sludge disposal problem.

Conclusions

Thus far, barged sewage sludge has been dumped in relatively shallow coastal waters of the continental shelf. There has been little scientific effort toward exploring deep-water locations. This is in marked contrast to the knowledgeable use of sludge in agriculture, which is becoming increasingly popular in the United States.

Because of predictions that areas off the northeast coast will soon be overloaded with sludge, PL 92-532 was effected, which calls for the termination of all barged sludge dumping by the end of 1981. This legislation is working an economic and procedural hardship on the densely populated northeastern seaboard. There also is a question as to the utility of recommended alternatives for sludge disposal. There is a growing belief that a solution of the nation's sludge disposal problem will require a more balanced use of the full assimilative potential of the land, ocean, and atmosphere. Recent observations on deep-water sludge disposal encourage a look toward a broader oceanic role in future management.

Ralph F. Vaccaro is a Senior Scientist in the Biology Department of the Woods Hole Oceanographic Institution. Judith M. Capuzzo is an Associate Scientist and Nancy H. Marcus is an Assistant Scientist in the same department.

Acknowledgment

Partial support for this study was provided by the Department of Commerce, NOAA, Office of Sea Grant under Grant No. NA79AA-D-00102 and by the Office of Marine Pollution Assessment under Grant No. 04-8-M01-42.

Literature Cited

Comptroller General of the United States. 1977. Problems and progress in regulating ocean dumping of sewage sludge and industrial wastes.

Day, D. L., and B. G. Harmon. 1974. Nutritive values of aerobically treated sludges and municipal wastes on livestock. Presented at the conference on use of wastewater in the production of food and fiber. March 6-8, 1974. Oklahoma City, OK.

Environmental Impact Statement (EIS) for 106-Mile Ocean Waste Disposal Site Designation. 1980. United States Environmental Protection Agency, Marine Protection Branch.

Heinle, D., R. Harris, J. Ustach, and D. Flemer. 1977. Detritus as food for estuarine copepods. *Marine Biology* 40: 341-53.

Ichiye, T. 1965. Diffusion experiments in coastal water using dye techniques. Proc. Symposium on diffusion in oceans and fresh waters, pp. 54-62. Palisades, New York: Lamont-Doherty Geological Observatory.

National Academy of Sciences, National Research Council. 1979. Report on a multimedium management of municipal sludge. Vol. 9.

Orr, M. H., L. Baxter, and F. R. Hess. 1979. Remote acoustic sensing of the particulate phase of industrial chemical wastes and sewage sludge. Tech. Rep. WHOI-79-38.

Paffenhoffer, G., and J. Strickland. 1970. A note on the feeding of *Calanus helgolandicus* on detritus. *Marine Biology* 5: 97-99.

Paffenhoffer, G., and S. Knowles. 1979. Ecological implications of fecal pellet size, production and consumption by copepods. *Journal of Marine Research* 37: 35-39.

Roman, M. 1977. Feeding of the copepod *Acartia tonsa* on the diatom *Nitzschia closterium* and grown algae *Fucus vericulosus* detritus. *Marine Biology* 42: 149-55.

United States Environmental Protection Agency. 1978. Final environmental impact on the ocean dumping of sewage sludge in the New York Bight. USEPA, Region II, New York, New York.

Radioactive Waste: The need to calculate an oceanic capacity

by G. T. Needler and W. L. Templeton

During the last few decades, a substantial amount of radioactive material has reached the ocean as the result of the detonation of nuclear weapons, the deliberate dumping or coastal discharge of wastes from the nuclear power industry, and a variety of other sources. Some questions that must be answered if we are to continue to use the ocean for the disposal of radioactive waste are presented in this article. In principle, one can determine an oceanic capacity to receive such wastes on the basis of estimates of their potential hazard to man and the environment. Some, no doubt, will wish to use this capacity. The scientific community faces the challenge of providing the scientific basis which is necessary if all sectors of the population are to understand the implications of such use.

Sources of Oceanic Radioactivity

The oceans contain large quantities of naturally occurring radionuclides, including the primordial elements potassium-40, rubidium-87, uranium-235, thorium-232, and uranium-238, the last three of which provide relatively short-lived daughter nuclides through their decay series. Incoming cosmic radiation produces other radioactive elements such as tritium, beryllium-7, and aluminum-14. The total activity in the world's oceans amounts to more than 5×10^{11} curies (Ci)*, consisting mostly of potassium-40 but including, for example, 10^9 Ci of radium-226, which is considerably more hazardous. The concentration of these naturally occurring radionuclides throughout the oceans varies greatly, depending on their source, half-life, and interactions with the biosphere and suspended particulate matter. Some, such as radium-226 and carbon-14, with half-lives of 1,700 and 5,700 years, respectively, have sources and distributions that make them useful for tracing large-scale oceanic circulation. These naturally occurring radionuclides contribute to the radiation exposure to marine organisms and to human populations.

---

*A unit quantity of any radioactive nuclide in which exactly 3.7×10^{10} disintegrations occur per second.

A thermonuclear detonation in the Pacific on February 28, 1954. (Photo courtesy Lookout Mountain Air Force Station)

Since 1944, artificial radionuclides have been introduced into the oceans, mostly through atmospheric fallout, as a result of the production and testing of nuclear weapons. The deposition of these radionuclides was three or four times greater in the northern hemisphere than in the southern and a large portion has reached the oceans. Estimates of the global and North Atlantic inventories for major fallout radionuclides in the early 1970s are shown in Table 1.

Fallout remains the largest contributor but because it is spread throughout the oceans, it has resulted in low concentrations of individual elements. The accuracy of analytical techniques and the absence of significant radionuclide background to obscure the input, however, make it possible to

Table 1. Inventories of artificial radionuclides.

	Plutonium-239,-240 (kCi)	Cesium-137 (kCi)	Strontium-90 (kCi)	Carbon-14 (kCi)	Tritium (kCi)
Total worldwide fallout by early 70s	320	16,700	11,500	6,000	3,000,000
North Atlantic Ocean — early 70s	63	3,300	2,300		650,000
Windscale, 1957-78 discharge	14	830	130		370
	Total α-emitters	Total β/γ-emitters (other than tritium)			
The NEA dumpsite (1967-79)	8.3	258			262

trace the progression of many of these radionuclides through the environment. Some, such as tritium and krypton-87, have provided us with insight into the rate at which the ocean can receive CO_2 and other atmospheric gases.

The second largest source of artificial radioactivity in the ocean arises from the nuclear fuel cycle and, unlike fallout, its releases are localized. Nuclear power producing reactors release small quantities of radioactive liquid effluents (10 to 200 curies per year) exclusive of tritium. Nuclear fuel reprocessing plants, such as exist at Windscale (Britain), Cape de la Hague (France) and Dounreay (Britain), however, contribute far more to this source through the release of liquid effluents to the marine environment. The largest of these, as well as the best documented in terms of discharge rates and environmental surveillance, is the British Nuclear Fuels plant at Windscale on the northeast Irish Sea. It began operations in 1952, and during the years 1957 to 1979 discharged the amount of selected radionuclides given in Table 1. Smaller quantities of other radionuclides also have been discharged.

Although deep-sea dumping of low-level packaged radioactive wastes onto the seafloor is permissible under international agreement and has been carried out in a number of locations, the only significant dumping operation in present use is that coordinated, since 1967, by the Nuclear Energy Agency of the Organization for Economic Cooperation and Development (NEA/OECD). From 1967 to 1979, a total of about 65,000 tonnes of packaged solid wastes have been dumped at depths of about 4,000 meters at a site in the northeast Atlantic Ocean. The integrated input of these radionuclides is given in Table 1. The amount dumped at this site per annum has been gradually increasing: about 30 percent of the amounts given in all three categories was dumped during the last two years of the period. Dumping at the site in 1980 was expected to continue this trend.

Other large potential sources of radioactivity in the oceans are the two U.S. nuclear submarines Thresher and Scorpion, which were lost in the Atlantic Ocean in 1963 and 1968, respectively. To date, the reactor systems have remained intact and there is no evidence that radionuclides from the fuel elements have been released.

Man-made radionuclides also arise in relatively small quantities from medical, pharmaceutical, industrial, and research uses of radionuclides, civilian and aerospace nuclear reactors, and power generators. (The disposal of nuclear weapons presents a larger potential source. However, it is estimated that the wastes arising from the commercial use of the nuclear fuel cycle will be increasingly important compared to those of military origin.) Tailings from uranium mining operations could contribute to the oceanic load, especially of radium-226.

Two accidents resulting in significant releases of radionuclides to the marine environment have occurred. A U.S. aircraft carrying nuclear weapons crashed near Thule, Greenland, depositing plutonium isotopes on the ice and into the water. Most of it apparently reached the marine sediments. In 1964, an aerospace nuclear power generator, containing about 17,000 Ci of plutonium-238, reentered the atmosphere, in an unmanned satellite, following a malfunction during launch. The plutonium in the device completely ablated and ultimately 10,000 Ci were deposited in the world oceans. This event accounts for more than half of the oceanic deposit of plutonium-238.

A future source of radionuclides in the deep ocean may arise if high-level wastes are deposited beneath the seabed. However, it is widely accepted that before disposal beneath the seabed is approved, there must be conclusive evidence showing that waste can be contained over many half-lives in the marine sediments and that at most an exceptionally small portion might reach the water column. On the other hand, the possibility of accidents during transportation of high-level waste to a sub-seabed disposal site has to be considered. This is being done as part of the investigation of the seabed disposal option (see *Oceanus*, Vol. 20, No. 1). The oceanographic questions that must be addressed are very similar to those pertinent to dumping of low-level waste onto the seafloor.

Principles of Radiological Protection

Radiation protection as applied by regulatory agencies is concerned primarily with the protection of man and his progeny rather than with other living systems. In the view of the International Commission on Radiological Protection (ICRP) in 1977, the level of safety required for the protection of human beings is likely to be more than adequate to protect other species, though not necessarily individual members of those species.

The ICRP uses the quantity, dose equivalent, as the best available measure of the detriment to an exposed individual member of the public, and has adopted a system of dose limitation that includes dose-equivalent limits, as applied to critical groups and to individual members of the public. These limits are over and above that received from natural radiation and medical irradiation of all sorts. It should be noted, however, that the natural background can vary depending on the mineral content of an area, materials used in building construction, altitude above sea level, and so on. In certain areas of the world, doses received are comparable to the ICRP dose limit.

The ICRP dose limits only relate to the protection of the individual; they are unaffected by the number of individuals exposed. However, the ICRP system is not confined to the dose limits but also addresses the question of the health detriment to the population at risk. The overall system of limitation is aimed at insuring that (ICRP No. 26): a) "no practice shall be adopted unless its introduction produces a positive net benefit"; b) "all exposures shall be kept as low as reasonably achievable, economic and social factors being taken into account"; and c) "the dose equivalent to individuals shall not exceed the limits recommended by the Commission for the appropriate circumstances."

Thus it is important to estimate the exposure of the general population and the doses to which the population will be committed in the future in order to justify a particular waste disposal option. For assessing the total dose received by an exposed population, in dose equivalent terms, use is made of the *collective dose equivalent*. To assess the long-term effect of a disposal option, use is made of the integral in time of the collective dose equivalent rate, which is called the *collective dose equivalent commitment*. In order that the "as low as reasonably achievable" philosophy is applied to waste management, a method of "optimization" is recommended to maximize the net benefit in relation to the collective dose commitment. This is an attempt to allow quantification of how much money and effort should be spent to achieve a desired low rate of release. In order to justify the implementation of total retention, one needs to evaluate what can be saved in terms of harm done. Since nuclear power is designed to produce electricity, one needs to consider the benefits that arise from its production and take into account, in addition to the matter of dose limitation, cost/risk and cost/benefit factors.

In practice, only the last of the three requirements just given, observance of dose limit, is relatively straightforward to implement: the other two are not as yet subject to simple quantitative treatment and still require the exercise of professional judgment. Indeed, the first principle, justification, is only taken into consideration, at most, at a national level, although in terms of long-term exposure at low levels to large numbers of people, it may merit consideration at a regional if not a global level. In the context of deep-sea disposal in international oceanic waters, there is no agreement as to what constitutes an optimized radiation exposure level, and although upper limits to release rates have been agreed to internationally, actual rates of disposal within these limits have not.

In relation to disposal at sea, it is mandatory to apply the ICRP dose limits and hence to identify, or postulate, critical groups of exposed individuals. It also is necessary to make estimates of the collective dose commitment to larger groups of people, so that some judgment as to health detriment can be formed.

The approach is, if course, based on the recognition that many of man's activities present risks to himself and the environment. The question of the risks associated with nuclear waste disposal often has been clouded by widespread refusal to consider whether the relative hazard of the nuclear industry is acceptable when compared to other energy options. It is difficult, for example, not to note that the death of 10 coal miners in Cape Breton, Nova Scotia, at roughly the same time as the Three-Mile Island accident, outweighs the most pessimistic estimates of the after-effects of the incident in Pennsylvania, even though such a direct comparison ignores the variety of social and economic conditions that exist for different populations and individuals and which may cause them to view their situations very differently. Similarly, general statements about the need to hold radioactive wastes for some definite, finite length of time must be examined critically. It is often said, without consideration of quantity or location, that plutonium wastes must be held for 250,000 years, roughly 10 times the half-life of plutonium. Although only about one-thousandth of the original plutonium in the waste would remain after this period of time, the possibility exists that in releasing the material to the environment immediately, there would be no substantial risk to individuals of the critical group. On the other hand, it may turn out that releasing the material to the environment after 250,000 years still would be unacceptable. The requirement of optimization and keeping radiation doses as low as reasonably achievable may of course dictate that, instead of our releasing the waste to the environment at any time, we should dispose of it in some alternative fashion. For oceanographers, the implication is that the risks associated with nuclear waste disposal in the oceans can only be kept in proper perspective relative to other options if accurate estimates are made of the fate of radionuclides in the marine environment and of their transfer rates back to man.

The two principal marine sources of radioactivity from the nuclear industry are deep-sea dumping and outfalls from land. They are controlled somewhat differently. Deep-sea dumping is limited by a requirement under the London Dumping Convention that the concentrations of various radionuclides in dumped material must be less than prescribed values. The values have been set by international panels of the International Atomic Energy Agency (IAEA) on the basis of estimates of the doses to critical groups from long-term deep-sea dumping at a fixed rate (Ci/yr). Although the London Dumping Convention limits the concentration of radionuclides in dumped toxic materials, the primary concern is the release rate of radionuclides to the deep sea. The responsibility for carrying out a hazard assessment for a particular dumping operation has been left to the national authorities. No mechanisms have been established to apportion any oceanic capacity to various dumping operations or in fact between dumping operations, land outfalls, and other existing or potential sources of radioactivity to the marine environment. In the case of the dumpsite in the northeast Atlantic, member nations of the Nuclear Energy Agency of the Organization for Economic Cooperation and Development, including both dumping and non-dumping nations, collaborated on the site assessment.

Land outfalls are the responsibility of national authorities despite the fact that the impact of the radioactivity may be on other national populations far removed from the outfall. In the case of the Windscale outfall, the British authorities have estimated both the radiation dose to the critical group and the collective dose for the British population and the exposed population of continental Europe. (Britain and France also have developed a joint methodology for collective dose estimations embracing the North Atlantic and the Mediterranean.) The estimates support the need to consider the problem from a global point of view since although the dose to a critical group was clearly greatest for segments of the British population, the collective dose, or total health detriment to the exposed population of continental Europe, was only 10 to 20 percent lower than that for Britain. Since Windscale and/or Cape de la Hague nuclides can now be detected in the Norwegian and Greenland seas and will undoubtedly eventually reach the deep Arctic and North Atlantic oceans, the need for a hemispheric approach to circulation models is obvious.

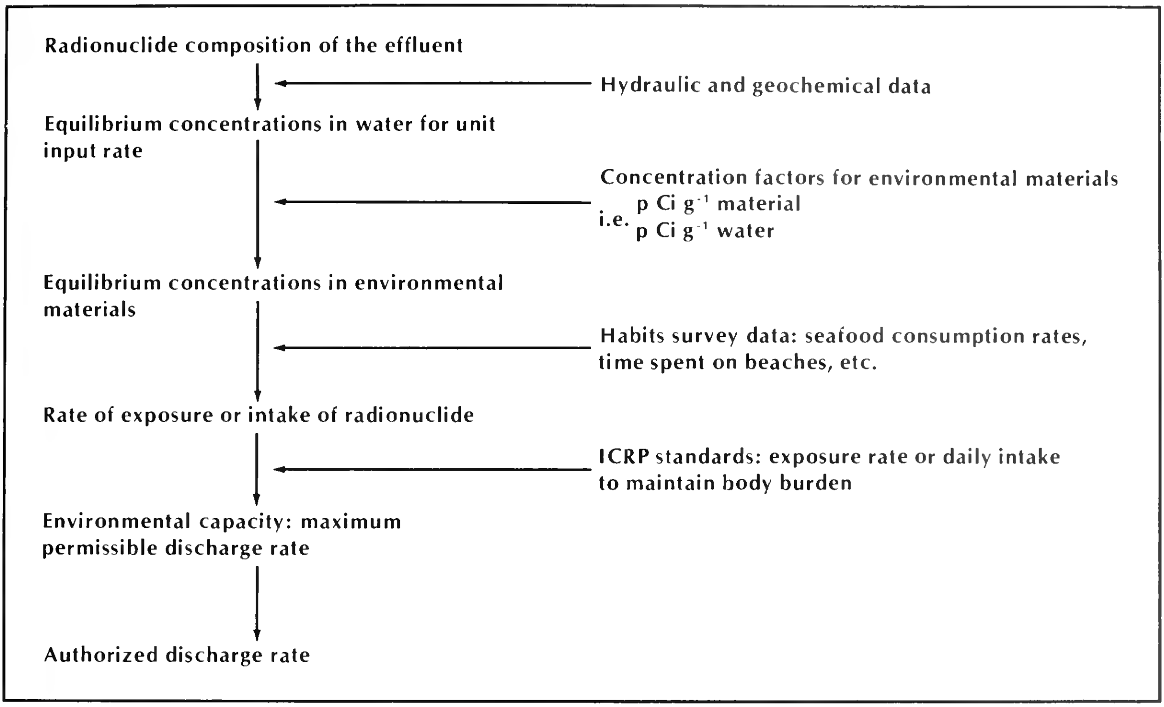
Oceanographic Modeling Problems

The basic applied problem for oceanographers is the estimation of the transfer rate of radionuclides from the deep sea or from an outfall to that point where they interact with man or the biota in the ecosystem. A knowledge of concentrations in seawater and in the food web, consumption rates, and those factors appropriate to exposure by other pathways allows the calculation of the radiation doses. An example of an outfall situation is given in Table 2.

The present acceptable dumping rates for solid, low-level radioactive wastes in the deep ocean have been calculated by the IAEA on the basis of very simplisitc oceanic estimates of the transport and transfer rates of radionuclides. They are primarily dependent on two considerations. One is of the average concentration that would arise from the uniform mixing of dumped material throughout an ocean basin. This provides an approximation for the concentration of the very long-lived radionuclides, such as plutonium, for which the half-life is much greater than characteristic oceanic mixing times. The second consideration is potential direct, short-term, transfer mechanisms to critical groups. The resulting estimates of transfer rates are probably very conservative as is perhaps appropriate, since it is clearly very difficult to make sure that one includes all important paths considering the complexity of oceanic processes.

Consideration of dose to critical groups and use of the IAEA oceanographic and radiological models led to estimated annual release rate limits for an ocean basin slightly smaller than the North Atlantic of 10^5Ci for alpha-emitters, 10^8Ci for beta/gamma-emitters, and 10^{12}Ci of tritium. For α-emitters, the critical radionuclide in most radioactive wastes is plutonium-239 because of its abundance and toxicity. Based only on the IAEA's consideration of the dose to critical groups, one obtains a capacity for the world oceans for plutonium by itself (as long as it could be distributed uniformly) of approximately 5×10^{10}Ci. A capacity

Table 2. Outline of the critical pathway approach to the assessment of discharges of radioactive wastes.



calculated in this way, however, can only be taken as an upper limit that must not be exceeded. Plutonium spread throughout the oceans would lead to large collective doses and collective dose commitments for the population at large. Consideration of the ICRP's principles of optimization and keeping risks as low as reasonably achievable should be expected to keep such a limiting capacity from ever being approached.

Modeling radionuclide concentrations from a coastal outfall also is difficult because of the variability of coastal zone processes. Observations of the fate of radionuclides from outfalls, however, are much easier. By measuring concentrations of radionuclides in the biosphere, the British have refined the dose estimates for the populations adjacent to the Windscale outfall. In the deep sea, radionuclides from dumping operations, at least on the large scale, cannot be distinguished from fallout. However, total quantities of some dumped radionuclides in the northeast Atlantic basin are now comparable to those originating from fallout.

It might be argued that the exhibited capacity of a small region like the Irish Sea to accept Windscale releases, while giving a limited radiation dose to the adjacent population, is an indication that dumping of small quantities of radionuclides in the deep sea is safe. However, this ignores the fact that for long-lived radionuclides the total ocean itself has a finite capacity and in the long run may be the ultimate limiting factor. At Windscale, it is the cesium dose to fish eaters that is the critical pathway for local populations. On longer time scales, these wastes will be present in the ocean at large. Because of its short half-life, however, cesium entering the deep North Atlantic may only be of scientific curiosity and of no hazard to human populations; on the other hand, for long-lived radionuclides, such as plutonium, this may not be the case.

Coastal regions are continually being flushed by water from the open ocean, which dilutes pollutants. It is possible to show that in a simple, two-compartment system, the concentration on the long term in the two compartments depends on their volume, the exchange rate between the compartments, and the half-life of the pollutant being considered. By considering the volumes and exchange rates appropriate to the North Atlantic and the Irish Sea, we learn that several thousand years of continuous release from Windscale would lead to the concentration of plutonium over the whole North Atlantic being comparable to that observed in the Irish Sea. Such a model is, of course, very simplistic because, among other things, it neglects all biogeochemical removal processes. Nevertheless, it serves to indicate the finite nature of the ocean for the release of long-lived substances such as plutonium. This is of particular importance for long-lived materials since populations far removed from an outfall could ultimately be the recipients of doses comparable to those received by the populations close to the outfall. It also emphasizes that when studying the capacity of the oceans to receive long-lived waste, one must consider all sources to an ocean basin.

More accurate modeling for radioactive inputs from either the deep sea or an outfall is difficult. Relatively simple estimates, such as exist in the present IAEA model, may be treated as first approximations to the transfer rates and in some cases may be relatively robust estimates of limits to transfer rates although this may be difficult to prove. The problem by its very nature is multidisciplinary, involving interacting physical, geochemical, and biological processes. One only has to think of the existing distributions of heavy metals or nutrients to understand the variety of processes that must be addressed. In the case of heavy metals, the role of particulate transfer is relatively well established, at least in concept, but the overall oceanic balances are far from determined.

None of today's models adequately reflect the interaction between radionuclides, suspended matter, and the sediments. It is thought that a large proportion of the atmospheric fallout of plutonium was transported rapidly to the sediments by particles. However, sampling indicates that deep layers of the oceans contain concentrations much higher than the overlying water. It also is known that although more than 90 percent of the plutonium discharged from Windscale appears to reside in the sediments of the Irish Sea, soluble forms can be detected moving out of the northern Irish Sea. The behavior of plutonium appears to be controlled largely by two generalized equilibrium processes, a redox equilibrium between higher and lower oxidation states and an equilibrium between water and sediment. Although the sediments often have been considered the ultimate sink for plutonium, in the long term, because the association with sediment particles is a reversible process, a fraction of the plutonium must reside in the water column since the sediments can act as a source to it. Physical and biological processes have been shown to perturb the upper layers of the sediment and to influence the rate of isolation due to sedimentation. All these processes, both in coastal water and in the deep ocean, play an important role in deciding the transport, fate, and availability of the material. They need to be considered more fully in future models.

Perhaps one of the most difficult problems of all for modelers will be to deal effectively with the problem of identifying the critical paths for the transport of radionuclides back to man. If the system could be completely understood, of course, an exhaustive study of all possibilities would ensure the identification of critical paths. Deep-ocean transfer processes, however, are not well understood and it is difficult to ensure that the most significant pathway has been identified. Oceanographers are becoming increasingly aware, for example, of the existence of relatively undiluted lenses of water, which it seems have traveled thousands of kilometers during periods of time greater than a year. In order to determine how important such features could be in transferring radionuclides to a critical group, one would need to know, among other things, their frequency of occurrence, whether or not biological populations remain with the lens, and the possibility of fishermen obtaining contaminated foodstuff from them. Although making accurate estimates of transfer rates to man involving such complicated processes is clearly difficult, there do exist limiting constraints on various biological, chemical, and physical transport rates that in many cases enable one to consider the maximum transport rates that are consistent with our knowledge of the oceans. This can be satisfactory for ensuring the safety of critical groups but may not be sufficiently accurate for estimating collective dose commitments. On the other hand, collective dose estimates are in some situations relatively insensitive to the details of extreme transfer events as long as their nature and average transfer properties are understood.

Other Considerations

The recent efforts to regulate the disposal of radioactive wastes to the oceans are based on estimates of radiation doses from the continuous release of radionuclides. The IAEA model, for example, assumes that the releases could continue for 40,000 years before the dose limit is reached. If a shorter time period were assumed (since it can be argued that the wastes from the fission process may only arise over the next few hundred years because of limitations on the world's exploitable supply of uranium and thorium), the release-rate limits would be increased significantly. To do this would be shortsighted since future technologies, such as power generation by fusion, might produce radioactive wastes. It might be more important to reserve some of the oceanic capacity for them if they present special disposal difficulties or if alternative options have been fully used by other technologies.

Oceanographers have been asked to model the impact of the disposal of radioactive wastes in a generic sense, although it is more difficult to provide estimates or construct models that are generically applicable than it is to provide reasonably robust estimates for a given set of assumptions in a site-specific sense.

Modeling of waste releases by various national and international agencies must be done in a consistent manner. Because a national or regional disposal operation may impact populations in other nations, particularly those who have not decided to exercise this option, we need to ask for consistent modeling efforts so that all nations might understand how they are being affected. On the longer time scales, all releases will utilize a part, large or small, of the total capacity of the world oceans. It is certainly not clear that by considering radioactive waste releases only on a case-by-case basis one is providing the essential protection for the global population. The institutions and mechanisms for that do not as yet exist in a form capable of resolving the problems.

Strictly political decisions also may influence the choice of disposal options. One must hope that the decision to use the marine environment will not be influenced by the fact that the hazard to the producing nation is reduced by marine disposal or that the population is against local disposal, even though the potential hazard to other populations may be much larger. In this context, one must recognize that the land-based options for various nations are very different. If one assumes that the land areas of nations with favorable geological formations will not be made available to others, some nations on the basis of the optimization requirement may have no choice but to use the marine environment. Another potential danger is that nations will be pressured into applying disposal options before enough scientific evidence is available to clearly decide on their relative merits. In this context, sufficient forethought must be given by national authorities in order to allow enough time to collect the primary scientific and technical data necessary to determine the feasibility of the option.

One of the important aspects is the need to field validate the models that are being used and those which may be developed in the future. The disposal operation in the Irish Sea has been operating long enough so that measurements of the radionuclides in the critical pathways and in other biological indicator species provide us with a high degree of confidence in the actual dose rates received by critical groups and regional and national populations. The present estimates of collective dose commitments to the European populations provide the basis for improved estimates in other locations. The introduction of radioactive wastes into the deep ocean, on the other hand, creates a more difficult problem since the transfer times from source to man and his marine resources are likely to be in the decades, since it is the long-term transport processes that are the most important. It may not be possible to validate some of the assumptions in the models before there is pressure to increase the rates of disposal or before other disposal operations are initiated. We should intensify our efforts to use the results from existing disposal sites in order to construct and validate models. In this context, an international monitoring and surveillance program is being initiated for the NEA dumpsite.

In the case of the open ocean, most of our knowledge of oceanic transport processes comes from observing the distribution of materials that have surface sources. There are very few observations of the transport of materials from the deep sea. Well-designed experiments, albeit expensive in terms of dollars and scientific effort, are needed to study the scientific nature of the important transfer processes so that estimates of transfer rates may be obtained from first principles. This will help assure that the data on radionuclide distribution, and other non-nuclear materials, are properly interpreted. Although there will be international involvement by the oceanographic community, we need to impress upon international and national funding agencies that this is a scientific challenge that must be squarely faced. Adequate long-term commitments in terms of planning and allocation of resources must be made if we are to make use of the ocean's capacity to receive these materials, whatever they may be, within the constraints of the protection of man and the marine environment.

G. T. Needler is Director of the Atlantic Oceanographic Laboratory, Bedford Institute of Oceanography, Dartmouth, Nova Scotia, Canada. W. L. Templeton is Associate Manager, Ecological Sciences Department, Battelle, Pacific Northwest Laboratories, Richland, Washington.

Acknowledgment

This work was done under contract DE-AC06-76RLO-1830 between Battelle and the Department of Energy.

References

Bowen, V. T., V. E. Noshkin, H. D. Livingston, and H. L. Volchok. 1980. Fallout radionuclides in the Pacific Ocean; vertical and horizontal distributions, largely from GEOSECS stations. *Earth and Planetary Science Letters* (In press).

High-level nuclear wastes in the seabed? 1977. *Oceanus*, Vol. 20, No. 1, Winter 1977.

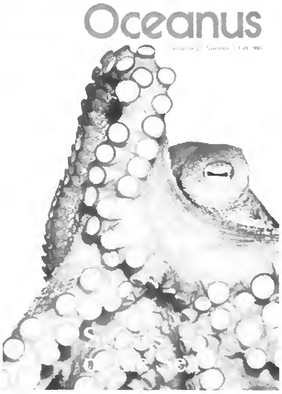
Hunt, G. J. 1979. Radioactivity in surface and coastal waters of the British Isles. 1977. Aquatic environment monitoring report, Ministry of Agriculture, Fisheries and Food Directorate of Fisheries Research, ISSN 0142-2499.

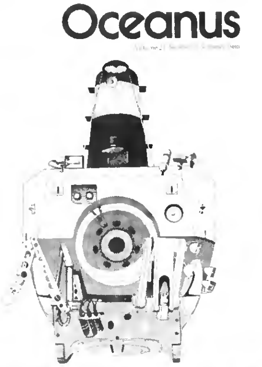
International Atomic Energy Agency. 1980. Extended synopses resumés analytiques, international symposium on the impacts of radionuclide releases into the marine environment.

National Oceanic and Atmospheric Administration. 1979. Assimilative capacity of U.S. coastal waters for pollutants. Proceedings of a workshop held at Crystal Mountain, Washington, July 29-Aug. 4. Environmental Research Laboratories, U.S. Department of Commerce.

Nuclear Energy Agency. 1980. Review of the continued suitability of the dumping site for radioactive waste in the North-East Atlantic. Organization for Economic Co-operation and Development.

OCEANUS BACK ISSUES





Limited quantities of back issues are available at $4.00 each; a 25% discount is offered on orders of five or more. We accept only prepaid orders. Checks should be made payable to Woods Hole Oceanographic Institution; checks accompanying foreign orders must be payable in U.S. currency and drawn on a U.S. bank. Address orders to: Oceanus Back Issues, 1172 Commonwealth Avenue, Boston, MA 02134.

The Coast, Vol. 23:4, Winter 1980/81—Celebrating the Year of the Coast, this issue is dedicated to the more than 80,000 miles of our nation's shorelines. Included are articles on barrier islands (federal policies and hazard mapping), storms and shoreline hazards, off-road vehicles on Cape Cod, the Apalachicola experiment, and coastal resource conservation and management.

Senses of the Sea, Vol. 23:3, Fall 1980—Marine animals have complex sensory systems. Here we learn that lobsters can taste and smell, bacteria can sense their world magnetically, and some fish can sense electrically. We discover that octopuses have a sophisticated sense of equilibrium, and that some insects use the water surface to communicate. Underwater vision, hearing, and echolocation are also discussed.

General Issue, Vol. 23:2, Summer 1980—A collection of articles on a range of topics, including: the dynamics of plankton distribution; submarine hydrothermal ore deposits; legal issues involved in drilling for oil on Georges Bank; and the study of hair-like cilia in marine organisms.

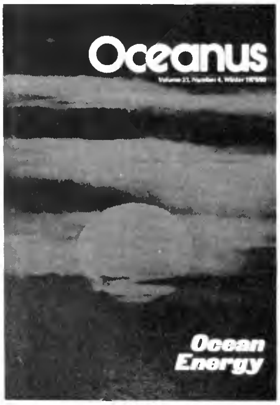
A Decade of Big Ocean Science, Vol. 23:1, Spring 1980—As it has in other major branches of research, big science has become a powerful force in oceanography. The International Decade of Ocean Exploration is the case study. Eight articles examine scientific advances, management problems, political negotiations, and the attitudes of oceanographers toward the team approach.

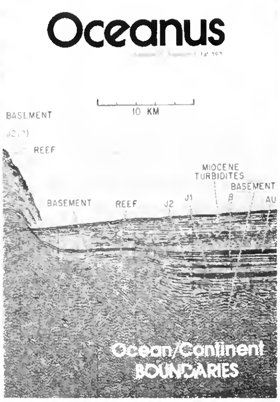
Ocean Energy, Vol. 22:4, Winter 1979/80—How much new energy can the oceans supply as conventional resources diminish? The authors in this issue say a great deal, but that most options—thermal and salinity gradients, currents, wind, waves, biomass, and tides—are long-term prospects with important social ramifications.

Ocean/Continent Boundaries, Vol. 22:3, Fall 1979—Continental margins are no longer being studied for plate tectonics data alone, but are being analyzed in terms of oil and gas prospects. Articles deal with present hydrocarbon assessments, ancient sea-level changes that bear on petroleum formations, and a close-up of the geology of the North Atlantic, a current frontier of hydrocarbon exploration. Other topics include ophiolites, subduction zones, earthquakes, and the formation of a new ocean, the Red Sea.

General Issue, Vol. 22:2, Summer 1979—This issue features a report by a group of eminent marine biologists on their recent deep-sea discoveries of hitherto unknown forms of life in the Galápagos Rift area. Another article discusses how scuba diving is revolutionizing the world of plankton biology. Also included are pieces on fish schooling, coastal mixing processes, chlorine in the marine environment, drugs from the sea, and Mexico's shrimp industry.

Harvesting The Sea, Vol. 22:1, Spring 1979—Although there will be two billion more mouths to feed in the year 2000, it is doubtful that the global fish harvest will increase much beyond present yields. Nevertheless, third world countries are looking to





Oceanus

The International Magazine of Marine Science and Policy

Published by Woods Hole Oceanographic Institution

SUBSCRIPTION ORDER FORM

Please make checks payable to Woods Hole Oceanographic Institution.
Checks accompanying foreign orders must be payable in U.S. currency and drawn on a U.S. bank.
(Outside U.S. add $3 per year to domestic rates.)

Please enter my subscription to OCEANUS for

☐ one year at $20.00	☐ payment enclosed.
☐ two years at $35.00	(we request prepayment)
☐ three years at $50.00	☐ bill me

Please send MY Subscription to:

Name (please print)

Street address

City State Zip

Please send a GIFT Subscription to:

Name (please print)

Street address

City State Zip

Donor's Name

Address

9/84

Oceanus

The International Magazine of Marine Science and Policy

Published by Woods Hole Oceanographic Institution

SUBSCRIPTION ORDER FORM

Please make checks payable to Woods Hole Oceanographic Institution.
Checks accompanying foreign orders must be payable in U.S. currency and drawn on a U.S. bank.
(Outside U.S. add $3 per year to domestic rates.)

Please enter my subscription to OCEANUS for

☐ one year at $20.00 ☐ payment enclosed.
☐ two years at $35.00 (we request prepayment)
☐ three years at $50.00 ☐ bill me

Please send MY Subscription to:

Name (please print)

Street address

City State Zip

Please send a GIFT Subscription to:

Name (please print)

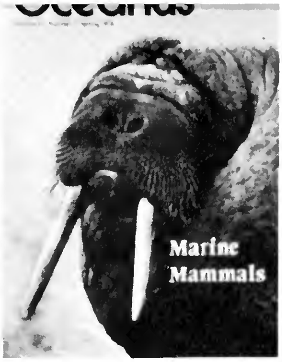
Street address

City State Zip

Donor's Name

Address

9/84

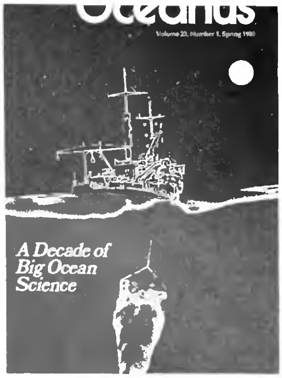


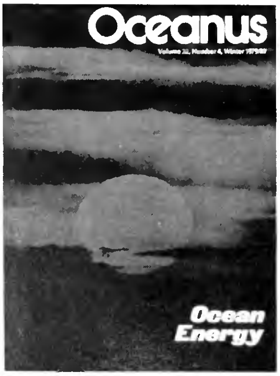
PLACE
STAMP
HERE

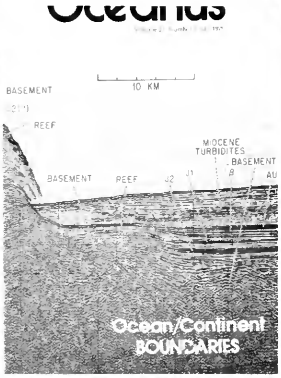
Oceanus
Woods Hole Oceanographic Institution
Woods Hole, Mass. 02543

PLACE
STAMP
HERE

Oceanus
Woods Hole Oceanographic Institution
Woods Hole, Mass. 02543

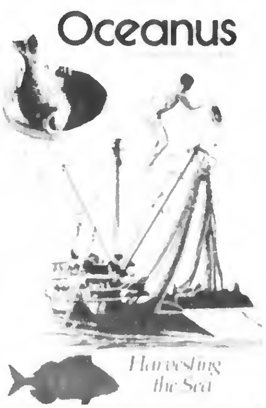






A Valuable Addition to any Marine Science Library

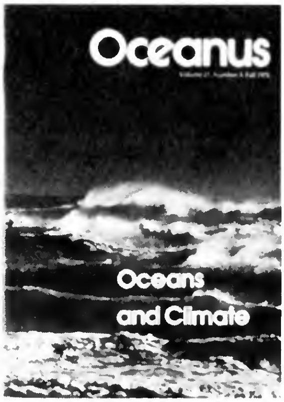
more accessible vessel and fishery technology to meet their protein needs. These topics and others—the effects of the new law of the sea regime, postharvest fish losses, long-range fisheries, and krill harvesting—are discussed in this issue. Also included are articles on aquaculture in China, the dangers of introducing exotic species into aquatic ecosystems, and cultural deterrents to eating fish.



Oceans and Climate, Vol. 21:4, Fall 1978—This issue examines how the oceans interact with the atmosphere to affect our climate. Articles deal with the numerous problems involved in climate research, the El Niño phenomenon, past ice ages, how the ocean heat balance is determined, and the roles of carbon dioxide, ocean temperatures, and sea ice.

General Issue, Vol. 21:3, Summer 1978—The lead article looks at the future of deep-ocean drilling, which is at a critical juncture in its development. Another piece—heavily illustrated with sharp, clear micrographs—describes the role of the scanning electron microscope in marine science. Rounding out the issue are articles on helium isotopes, seagrasses, red tide and paralytic shellfish poisoning, and the green sea turtle of the Cayman Islands.

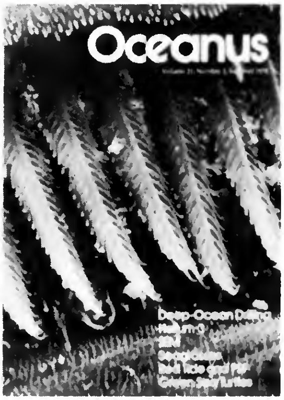
Marine Mammals, Vol. 21:2, Spring 1978—Attitudes toward marine mammals are changing worldwide. This phenomenon is appraised in the issue along with articles on the bowhead whale, the sea otter's interaction with man, behavioral aspects of the tuna/porpoise problem, strandings, a radio tag for big whales, and strategies for protecting habitats.



The Deep Sea, Vol. 21:1, Winter 1978—Over the last decade, scientists have become increasingly interested in the deep waters and sediments of the abyss. Articles in this issue discuss manganese nodules, the rain of particles from surface waters, sediment transport, population dynamics, mixing of sediments by organisms, deep-sea microbiology—and the possible threat to freedom of this kind of research posed by international negotiations.

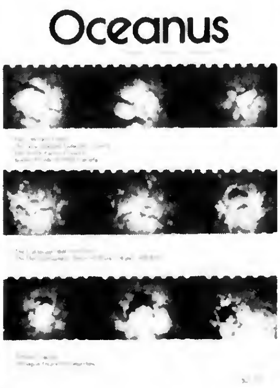
General Issue, Vol. 20:3, Summer 1977—The controversial 200-mile limit constitutes a mini-theme in this issue, including its effect on U.S. fisheries, management plans within regional councils, and the complex boundary disputes between the U.S. and Canada. Other articles deal with the electric and magnetic sense of sharks, the effects of tritium on ocean dynamics, nitrogen fixation in salt marshes, and the discovery during a recent Galápagos Rift expedition of marine animal colonies existing on what was thought to be a barren ocean floor.

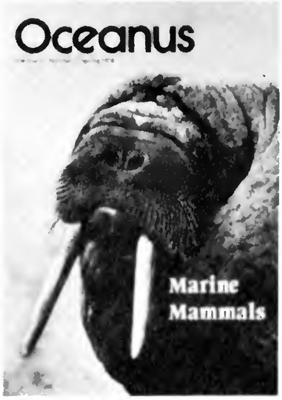
Sound In The Sea, Vol. 20:2, Spring 1977—Beginning with a chronicle of man's use of ocean acoustics, this issue covers the use of acoustics in navigation, probing the ocean, penetrating the bottom, studying the behavior of whales, and in marine fisheries. In addition, there is an article on the military uses of acoustics in the era of nuclear submarines.



ISSUES OUT OF PRINT: Sea-Floor Spreading, Vol. 17:3, Winter 1974 **Air-Sea Interaction,** Vol. 17:4, Spring 1974 **Energy And The Sea,** Vol. 17:5, Summer 1974 **Marine Pollution,** Vol. 18:1, Fall 1974 **Food From The Sea,** Vol. 18:2, Winter 1975 **Deep-Sea Photography,** Vol. 18:3, Spring 1975 **The Southern Ocean,** Vol. 18:4, Summer 1975 **Seaward Expansion,** Vol. 19:1, Fall 1975 **Marine Biomedicine,** Vol. 19:2, Winter 1976 **Ocean Eddies,** Vol. 19:3, Spring 1976 **General Issue,** Vol. 19:4, Summer 1976 **Estuaries,** Vol. 19:5, Fall 1976 **High-Level Nuclear Wastes In The Seabed?** Vol. 20:1, Winter 1977 **Oil In Coastal Waters,** Vol. 20:4, Fall 1977

Out-of-print issues and those published prior to Winter 1974 are available on microfilm through University Microfilm International, 300 North Zeeb Road, Ann Arbor, Michigan 48106.





Oceanus

(ISSN 0029-8182)
WOODS HOLE
OCEANOGRAPHIC
INSTITUTION
Woods Hole, MA 02543
Postmaster: Please Send
Form 3579 to Above Address

SECOND-CLASS
POSTAGE PAID
AT FALMOUTH, MASS.,
AND ADDITIONAL
MAILING POINTS