A MARINE ENVIRONMENTAL MONITORING AND ASSESSMENT PROGRAM

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During my flight on a Pan Am clipper from Newark to Norfolk, I happened to read the airline magazine called Pan Am Clipper. In the particular issue there was an article entitled, "The future imperfect". The topic of the article had to do with the success of the various pundits and prognosticators to predict what might happen in recent decades. The article noted that the accuracy of many individuals who tended to be pessimistic about the future world, when they were making their predictions some decades ago, was extremely poor; individuals who were talking about the world of 1984 or the "brave new world" of the 60's and 70's generally turned out to be quite wrong. However, the optimists who were making predictions about the world in which citizens of the 1970's and 80's would live free of the worry of starvation, war, or some other disaster were also equally wrong. Many of the so-called futurists had predicted that by this time man would be living in self-contained units at the floor of the sea and would be producing all of the foodstuffs and other of life's requirements that would meet the needs of the world's population.

What turned out to be the case is that where mankind has had modern technology at his disposal he has often, for various reasons, not taken advantage of the technology. In some cases it would be possible to build living units under the sea where the general citizen could carry out his life activity in terms of harvesting living and mineral resources. As we know, in certain cases we are now doing this for limited periods; divers can now acclimate to pressures of 700 to 800 m under the surface of the water, and there are many new techniques for harvesting fish and installing deepwater mineral recovery devices. The reality is, however, that there is no good economic reason at the present time for most of us to dive to these depths or to use new methods of fish harvesting when living resources of the sea are probably already being over-exploited.

The reality though will be that as mankind moves into the 21st century it will be faced with the problem of feeding a world population which will have doubled from the present 4 billion to well over 8 billion people. This increase in population is occurring at a time when many of our agrarian and forestry resources are already being over-harvested and, perhaps, at a time when severe climatic change is already resulting in droughts which will severely reduce the production of food items from the earth's surface. Thus, mankind will have to look to the seas for increased yields of proteins and other foodstuffs. If mankind is already harvesting or over-harvesting fishery resources, what can be done? As I will show in a few minutes, there are a number of nations that have already begun projects in ecological aquaculture and sea ranching, which is essentially a form of aquaculture pursued in open waters, and without use of ponds, aquaria, and other devices to contain the fishes of interest. New technology will allow us to greatly increase the productivity of the oceans, especially estuaries and coastal habitats.

At the same time that new technology is to be used to develop coastal aquaculture and sea ranching it will be necessary to have in place an intensive monitoring program for the environmental health of the coastal zone, as well as estuaries and the open sea. Monitoring is a topic that today draws mixed reactions. In the mid 70's, the National Academy of Science produced a report on petroleum development on the continental shelf. This report stated that monitoring in the traditional sense was not a fit subject for research in relation to petroleum exploration and development. However, the authors also emphasized at that time that it was important to understand the sources, fate, and effects of pollutants (including petroleum products). At about the same time this report was being developed, several international groups associated with the United Nations and the International Council for the Exploration of the Sea (ICES) had noted that while it was possible at the time to develop a listing of the sources of pollutants and while it was also possible using state-of-the-art technology to approximate or estimate movements of contaminants from their sources, it was not equally easy to understand the effects of various contaminants on living marine resources of interest to man or the food chains which sustain the commercially or recreationally important species.

Thus, the United Nations Group of Experts on the Scientific Aspects of Marine Pollution (UN GESAMP) and ICES established several working groups that were concerned with investigating the best way to carry on biological effects monitoring so as to actually understand how pollutants impacted on living marine resources. Both groups held a number of work sessions and ICES sponsored a major international symposium on biological effects monitoring which was sponsored by NOAA/NMFS and EPA, and held in Beaufort, North Carolina (Duke Marine Laboratory) in February 1979.

The results of these meetings indicate strongly that it is possible, using techniques presently available, to monitor the effects of pollutants on living marine resources. The Beaufort meeting concluded that there is presently, within the disciplines of biochemistry, ecology, behavior, physiology, genetics, pathobiology and bioassays the possibility to determine how pollutants might affect various categories of marine life over extensive areas of the coastal zone and continental shelf (ref. 1).

Within the general area of ecology, it has been seen that in recent years coastal eutrophication has resulted in measurable changes in phytoplankton populations and primary productivity (ref. 2). In coastal waters of the Middle Atlantic Bight, for instance, it has been demonstrated that eutrophication results in unusually high levels of primary production which may result in extensive standing stocks of carbonaceous material, much of which may not be available to normal food chains culminating in commercially valuable fish. This is largely because in waters such as Raritan Bay the producing organisms are often of unusually small cell size (nanoplankton) and such cells are not easily used as food by many of the zooplankton and other secondary producers. As will be noted later in this talk, organic materials which are not culled from the water column often are attached by bacteria and thus may result in greatly lowered oxygen values.

It is now possible, using either traditional collections and measurements from vessels or remote sensing techniques, to measure levels of standing stocks of chlorophyll over extensive areas of coastal waters. Such measurements, using remote sensing capabilities, can often be performed in a matter of hours, whereas in collections and measurements from vessels literally days are required to census effectively the standing stocks of chlorophyll over the continental shelf area of interest.

In recent years it has become apparent that high technology, as used in remote sensing, can be effectively applied to problems of eutrophication and biostimulation and may also be used in estimating contaminant flow from estuaries, which are probably a principal source of marine pollution. This is a case where, until recently, existing technology has not been applied extensively to help deal with one of mankind's more important problems. Fortunately, during the past two or three years the remote sensing capabilities of NASA have been brought together with the oceanographic and fishery ecology capabilities of the National Marine Fisheries Service (NMFS). Our interactions started on a relatively informal and limited basis in the early 1970's. In 1979 we implemented the first of our joint programs which was called LAMPEX, or Large Area Marine Productivity/Pollution Experiment. This activity indicated convincingly that it was feasible to use remote sensing over extensive portions of the coastline in the Middle Atlantic Bight, as well as Georges Bank and Gulf of Maine, to assess standing stocks of chlorophyll; approximately 20 different institutions participated in this program to demonstrate that it was possible to measure synoptically standing stocks of chlorophyll over broad geographic areas.

More recently, we have begun to use remote sensing techniques to establish the sources, fates and effects of materials being carried from Chesapeake Bay in the form of the so-called Chesapeake Bay plume. It is these recent activities, involving both NASA and NMFS in the Chesapeake Bay plume, that will be reported upon during this meeting.

Since many of the people involved in the present Superflux Symposium are not fully aware of some of the problems which have been dealt with in the past using conventional techniques, I thought it would be most appropriate to indicate briefly some of the problems that have been investigated in the past using more conventional techniques. It is well-known that the population of the northeastern sector of the United States is largely concentrated in the coastal zone. This is demonstrated in figure 1. It is this dense population that produces the extensive amounts of pollutants which enter coastal waterways in several ways. For instance, each day the Hudson River carries seaward approximately one billion gallons of pollutants which enter the New York Bight apex and may have a residence time of several weeks depending upon prevailing weather conditions. Another source of pollution in our coastal waters is due to extensive dumping activities at two sites approximately 10 to 15 km off the base of Sandy Hook. Dumping includes some 3.8 million cubic meters of sewer sludge and somewhere between 4 and 9 million cubic meters of contaminated dredging spoils each year. In addition a variety of industrial wastes are disposed of at a site in close proximity to the aforementioned dumping areas. Finally, there is extensive surficial runoff from the land mass as well as atmospheric inputs of combustion materials and other pollutants to the seawater/air interface. As I will show in a series of illustrations, there have been numerous effects from the various categories of waste which enter the estuaries and coastal waters of the Middle Atlantic Bight.

In 1979, the International Council for the Exploration of the Sea (ICES) asked me to have investigators located at our major east coast estuaries to develop a series of papers which present the status of these estuaries. Various scientists, including Dr. Peter Larsen in Maine (ref. 3), Mr. Ken Pecci of New Hampshire (ref. 4), Dr. Donald Phelps in Narragansett Bay (ref. 5), Mr. Robert Reid who covered Long Island Sound (ref. 6), Dr. Donald Maurer who dealt with Delaware Bay (ref. 7), and Dr. Robert Lippson who reported on Chesapeake Bay (ref. 8), as well as myself, who developed a paper on Raritan Bay (ref. 9), developed short essays on what was known about these estuaries.

The estuaries on the south shore of the Maine coastline are generally thought to be relatively unpolluted except for harbor areas such as Casco Bay upon which the port of Portland, Maine is located. It was also noted that the central part of the Gulf of Maine was relatively unpolluted, although other investigators have noted that the area off Boston Harbor is extensively affected by a variety of pollutants. Narragansett Bay was shown to be heavily polluted going back to the time of our Revolutionary War (ref. 5). The effects of pollution can be seen and measured in the northern third of the Bay, but the Lower Bay is still relatively free from heavy pollution. Scientists have noted a gradient of effects on mussel populations as they have been investigated from the inner reaches of Narragansett Bay seaward. Long Island Sound also shows a gradient of pollutant effects with the western third of the Sound showing evidence of extensive contamination and changes in the biological populations. Perhaps most important, relatively small harbor areas such as Milford Harbor can be shown to be affected by man's activities, and the larger harbors, as characterized by the New Haven Harbor area, are extensively polluted, to the point that living marine resources cannot legally be harvested. Raritan Bay is, perhaps, the classic example of an estuary which has been over-utilized by man and which can be demonstrated to have a historical record of pollution beginning at the time of the Civil War. In the 1870's, Newark Bay was already so polluted with petroleum products that shellfish and fish taken from this small bay could not be sold for human consumption because they tasted of kerosene. By the time of the First World War, pollution had spread from Newark Bay through Arthur Kill to the western part of Raritan Bay. Shellfish biologists at Rutgers University reported at the time of the First World War that oysters in Raritan Bay were being affected by heavy metals from industrial wastes. These biologists stated at that time that if something was not done about this pollution the oysters would disappear from the bay; by the 40's this had happened.

Today, we are able to compare the conditions in Raritan Bay which changed between the mid 1950's and the early 1970's. Dean and Haskin reported in their earlier studies of the bay that there were up to 13,000 ampeliscid amphipods (small shrimp-like animals valuable as forage for fish) per square meter at that time (ref. 10). Our studies, conducted in the early 1970's, did not yield a single ampeliscid amphipod even though the number of sampling stations and the frequency of sampling were significantly increased relative to the earlier study (ref. 11).

The changes in Raritan Bay cannot be ascribed to any single pollutant although it is known that the bay is heavily contaminated with petroleum, heavy metals, PCB's, and other wastes that are deleterious to a variety of marine life. Figures 2, 3, 4 and 5 show the levels of petroleum hydrocarbons in sediments and waters as well as the levels of heavy metals found in sediments and waters at the same general localities. It can be seen easily that the western third of Raritan Bay contains levels of contaminants which have been shown in laboratory and field studies to be lethal to a variety of marine life (refs. 12 and 13). The amphipods are known to be particularly vulnerable to petroleum hydrocarbons. Following a spill in Wild Harbor at the western margin of Cape Cod, it has taken over a decade for the fauna (including the vulnerable amphipods) to return to the former levels of abundance (ref. 14).

The waters emanating into the New York Bight from Raritan Bay are, as was previously mentioned, heavily contaminated by a variety of pollutants. Studies done at the sites where ocean dumping is conducted have shown that bottom-dwelling organisms are impacted by the numerous contaminants associated with dumped materials and the high levels of pollutants flowing seaward from the Hudson River estuary. In 1976, there was an event of unparalled proportions. At that time the level of dissolved oxygen declined markedly and much of the bottom-dwelling life of the entire Middle Atlantic Bight off the New Jersey coastline was affected by the extremely low levels of dissolved oxygen. This hypoxia has not been ascribed to any single contaminant or waste, but rather seems to have resulted from complex physical and biological forces, probably associated with intense eutrophication (ref. 15)

It has also been shown since the early 60's that there has been a higher than expected prevalence of disease in fish taken from the New York Bight apex. A wide range of bottom-dwelling and pelagic fish have shown effects of a disease syndrome generally referred to as fin rot disease (figure 6). In addition, a wide range of crustaceans which dwell on the sea floor have also been shown to suffer from a higher than usual incidence of exoskeleton disease. Again, it is difficult to ascribe these syndromes to a particular contaminant, although recent investigations have shown that increases in a toxic trace metal, copper, can result in an increase in disease of the exoskeleton of shrimp. This metal is found in elevated amounts in the polluted Raritan Bay (ref. 16). There are increasing pieces of evidence suggesting a relationship between fish and shellfish disease and the level of pollution in waters of the Middle Atlantic Bight.

The ICES papers suggest that in Delaware Bay and Chesapeake Bay, there are changes in water quality and concomitant changes in the well-being of biota similar to those which have been demonstrated for the Lower Hudson estuary, Raritan Bay and the New York Bight apex. Investigators in both of these major estuarine systems have reported significant decreases in the production of shellfish in those portions of the bays receiving heavy pollution loads.

It is obvious that the resources (dollars and personnel) available to society to monitor and demonstrate the changes which are occurring in living resources are limited and thus we must look to new ways of rapidly assessing long-term change in habitat quality and consequent effects on living marine resources. One way to do this is to have comprehensive monitoring and assessment studies, on sufficient geographic and temporal scales, in areas which are known to be receiving pollutants as well as in areas which are relatively free from pollution. By establishing benchmarks for present levels of pollutants in the physical and biological compartments, and for the responses of organisms to these pollutants in areas which are heavily impacted and relatively free from pollution, we can begin to gain an understanding of how future change may affect organisms. By having such information at hand, we can more effectively manage the habitats of fishes and the living marine resources themselves at the same time as we are carrying out economic activities such as transportation, ocean dumping, development of mineral resources and the development of offshore energy supplies.

The National Marine Fisheries Service has developed such a program and it has been operating in a pilot mode during the past two years. We are presently developing our first annual report which will be a status of the health of the coastal and shelf environments of the northeast. The report will indicate that materials such as PCB's and coprostanol are spread over a much wider area than might have been expected based on studies conducted during the past few years (figures 7 and 8). Moreover, the study has indicated that a variety of fish are heavily contaminated, i.e. have unexpectedly high body burdens of pollutants such as petroleum hydrocarbons and PCB's. The fish showing these elevated levels of pollution were caught not only near the mouths of estuaries which are known to be polluted, but were taken over the entire continental shelf to the shelf slope-break (ref. 17), areas that are hundreds of kilometers from a source of the pollutant.

At the same time that we have been investigating levels of contaminants in sediments, waters, and biota we have developed a pilot program to look at the different physiological and biochemical responses to a variety of contaminants. We have also been establishing benchmarks for the incidence of genetic anomalies in waters known to be polluted or relatively free from pollution. Finally, we have intensified our studies of the expression of disease due possibly to increased pollutant loadings. Information to date continues to suggest organisms in heavily polluted habitats show a much higher level of genetic aberration, disease, and changes in physiological and biochemical responses. Our benchmark studies have also shown the aforementioned effects are expressed in changes in the standing stocks of populations of bottom-dwelling organisms. This, in the end, is the kind of change that is most important to mankind; while the change in an individual organism, or a small sector of the population, is an indication of or expression of environmental impact on living resources, it is the large-scale change in populations and communities which is most significant. It is not so significant whether change is seen in an entire benthic community or in the disappearance of a population of amphipods or whether the change occurs in a phytoplankton population or physiological function; in the end, changes in the various trophic levels are manifested in changes in populations of finfish and shellfish which are important to man for food and recreation.

As mentioned earlier, the resources available for the monitoring and assessment of environmental effects are limited. Future activities will have to depend upon new technology and new protocols for carrying out investigations of environmental or habitat change. Techniques such as remote sensing provide us with an opportunity to monitor rapidly and assess significant changes within coastal and shelf habitats. Other papers in this conference publication are concerned with the type of remote sensing devices and their relative efficacy in detecting variables or changes in variables which are of interest to oceanographers and marine ecologists. The coastal zone color scanner and ocean color scanner are apparatus which already can detect variables that may be of immediate significance to oceanographers. The active laser techniques will undoubtedly have paramount application in understanding the quality of various plant pigments which are of interest to man. Changes in the quality of chlorophyll and other plant pigments may well be the immediate indicators of significant change in phytoplankton populations. Such changes can then be related to change in the primary and secondary levels of production within the water column.

Finally, there will be semi-conservative relationships between the presence of suspended material which can be detected by remote sensing systems and the levels of several categories of contaminants. Again, by using remote sensing techniques, it will be possible to monitor rapidly how plumes containing suspended materials and associated contaminants move from the major estuarine systems over the continental shelf and eventually impact on living resources.

We do indeed live in a remarkable time when it will be possible to use modern, extremely sensitive remote sensing techniques to aid us in rapidly and synoptically assessing the relative health and production of coastal waters and estuaries. Today's presentations will be a large step in establishing a solid foundation for the use of remote sensing in basic oceanographic studies and the management of man's wastes; there is little doubt that within this decade satellite imagery will be used on a frequent basis to guide modern waste disposal vessels to appropriate dumping areas, thus insuring that wastes are not entrained in warm core eddies and other water masses likely to return to shore. Many applications of remote sensing to problems of ocean research and management can now only be guessed at. What is obvious is that we now have in hand a powerful tool which can only be used to maximum levels if marine and space scientists work closely in coherent and cooperative programs such as Superflux.

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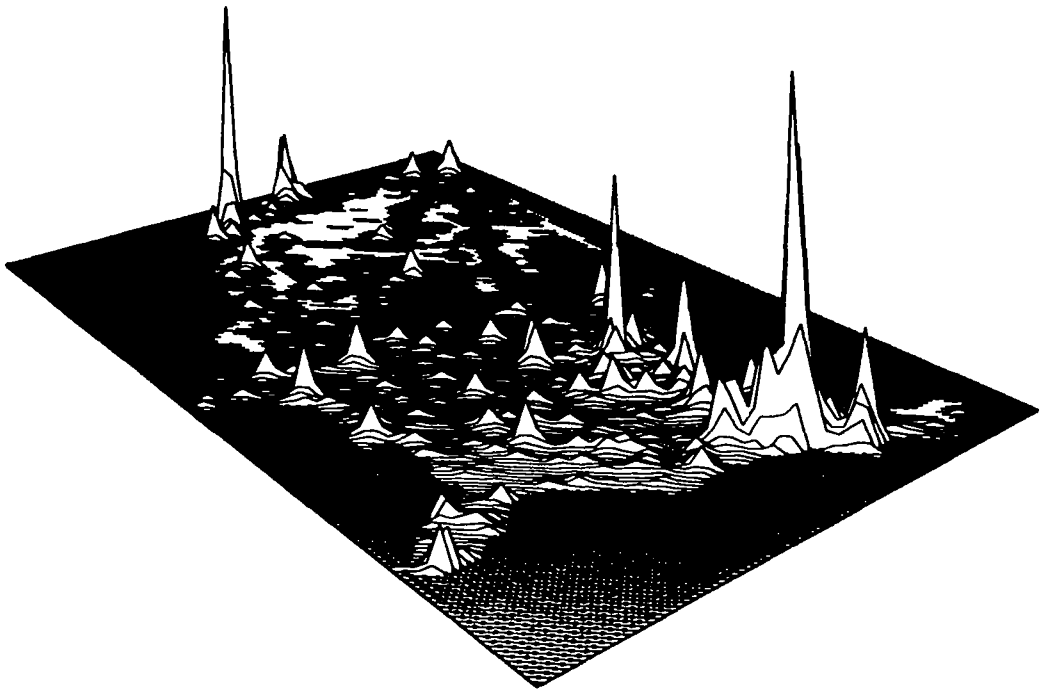

Figure 1. Relief map of population density in U.S. from 1970 census data (courtesy of the Laboratory for Computer Graphics and Spatial Analysis, Harvard University).

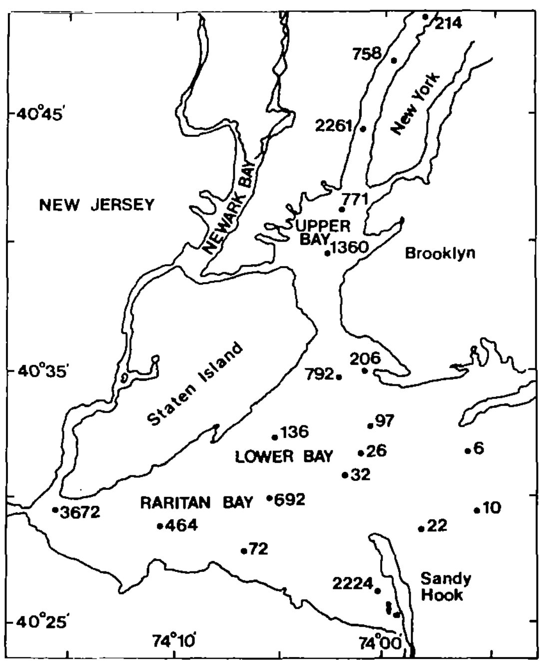

Figure 2. Concentration of C_{15+} hydrocarbons at 19 stations in New York Harbor, Hudson River, and Raritan Bay (expressed in PPM by weight of dry sediment).

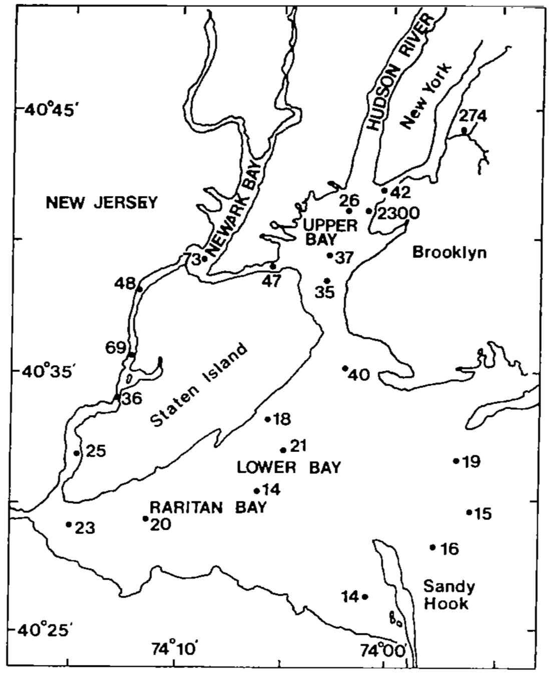

Figure 3. Concentrations of hydrocarbons in water samples collected from New York Harbor, the Hudson and East Rivers, and Raritan Bay (expressed in µg/l).

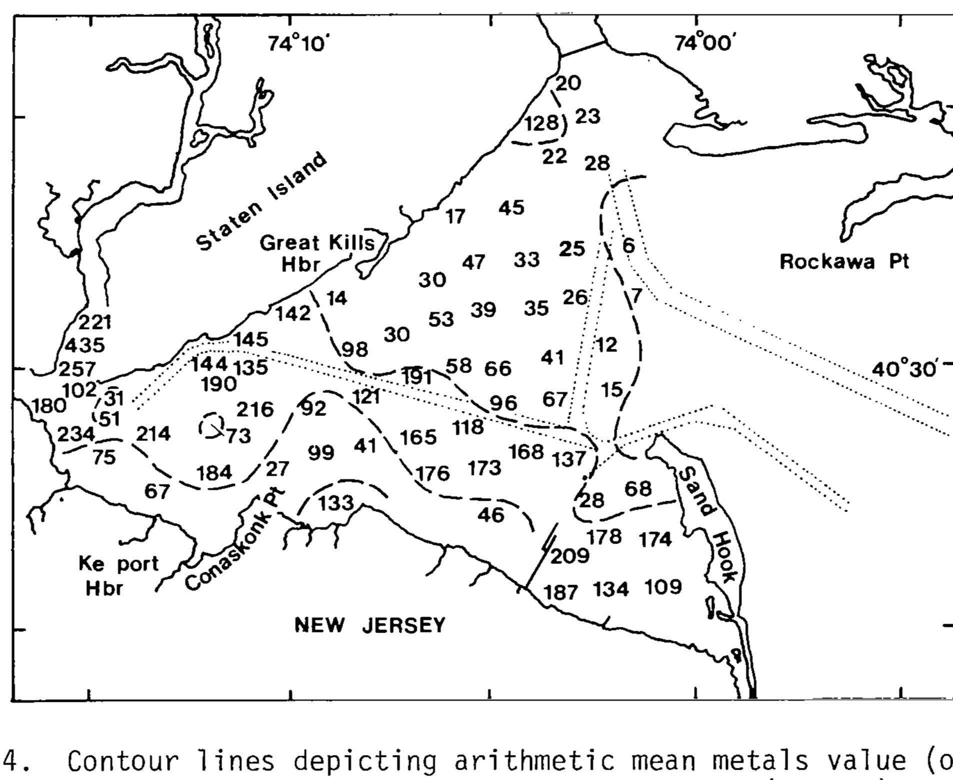

Figure 4. Contour lines depicting arithmetic mean metals value (obtained by combining each of the individual values (in PPM) for metal species) for sediments collected in Raritan Bay.

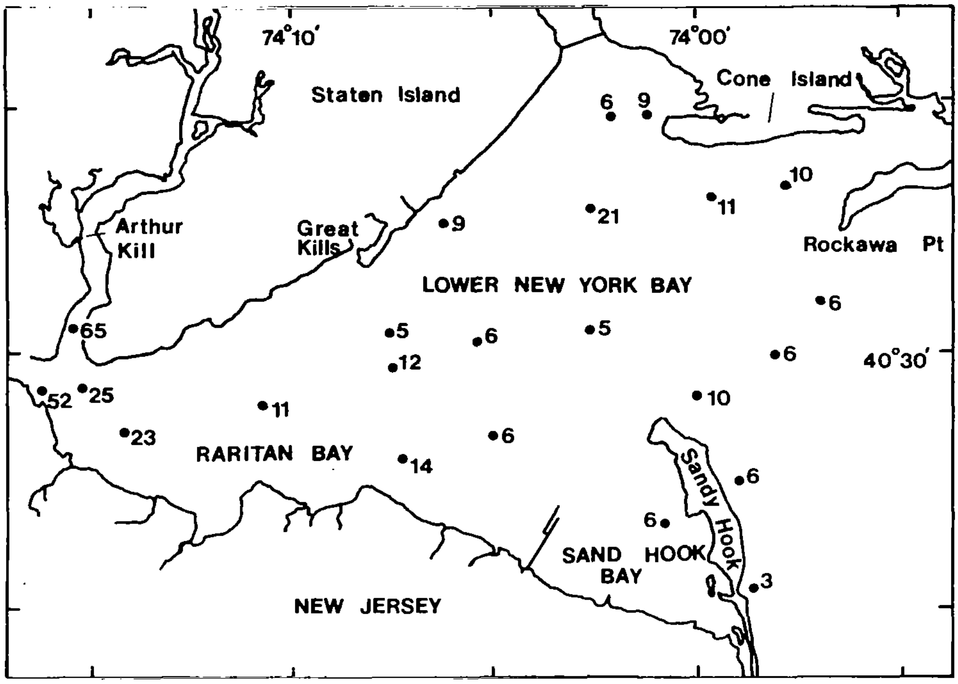

Figure 5. Concentrations of copper in bottom waters of Raritan Bay ($\mu g l^{-1}$).

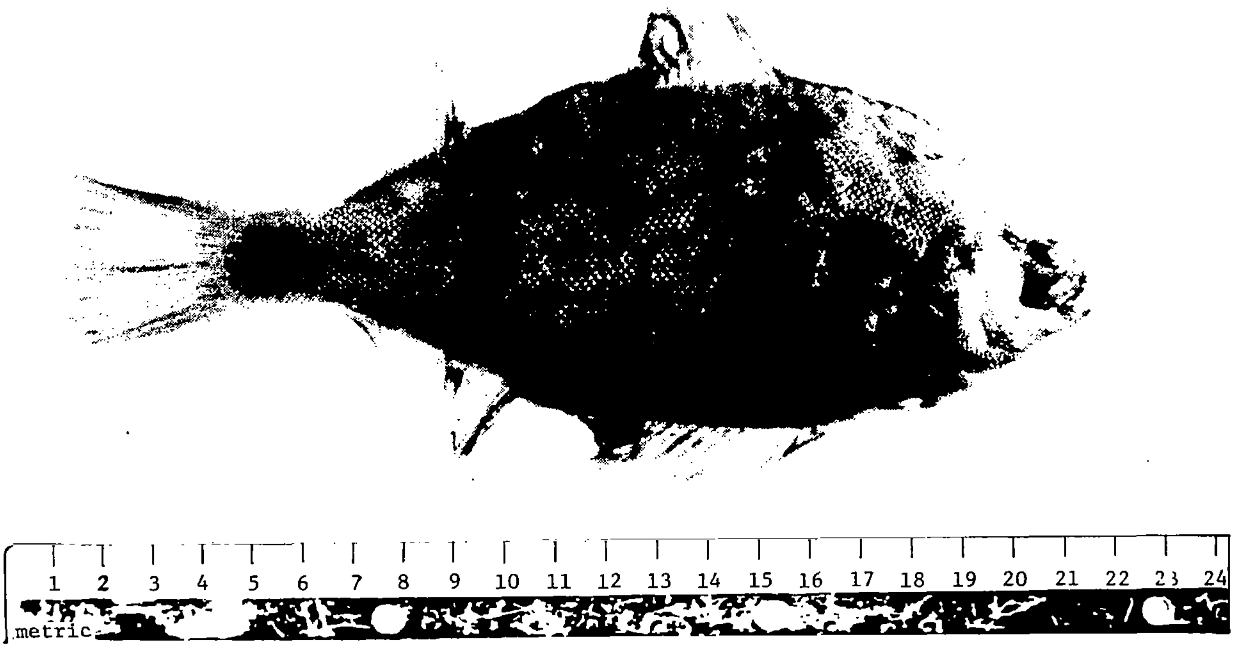

Figure 6. A flounder collected from the New York Bight showing severe fin erosion; such a syndrome is often common in fish taken from heavily contaminated waters.

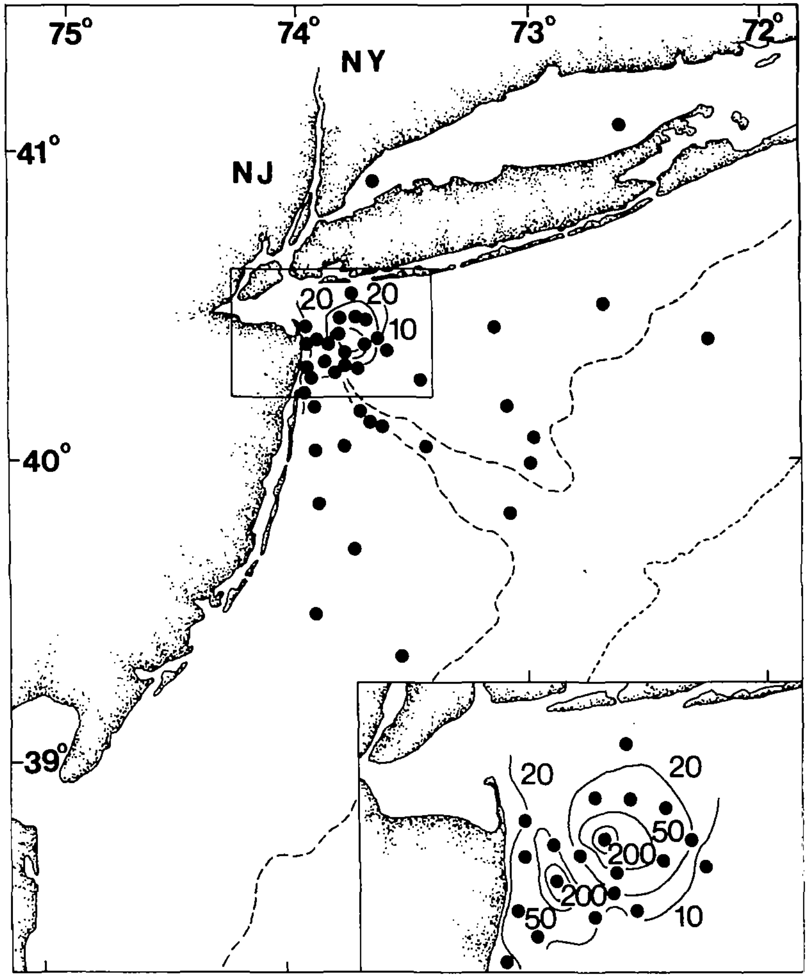

Figure 7. PCB concentration (PPB) in sediments of the New York Bight.

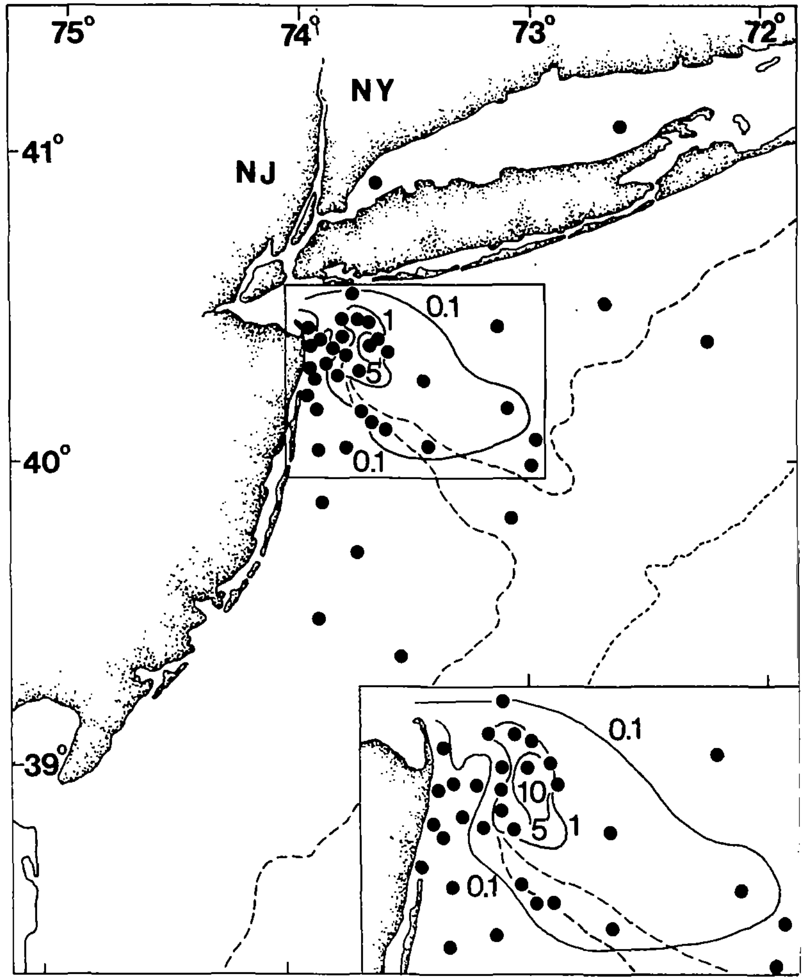

Figure 8. Coprostanol concentration (PPM) in sediments of the New York Bight.