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EFFECTS OF NUTRIENT AND CARBON LOADINGS ON COMMUNITIES AND ECOSYSTEMS IN THE NEW YORK BIGHT AND ADJACENT WATERS

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INTRODUCTION

Over 200,000 metric tons of nitrogen and 950,000 metric tons of organic carbon enter waters of the New York Bight each year. Much of this nutrient and carbon input, together with measureable quantities of potentially toxic materials, results from direct waste discharge into the Hudson River Estuary and New York Bight Apex. Scientists and laymen alike are concerned that the additional inputs of these materials have adversely changed the diversity and productivity of marine life in these local waters. Many believe the reductions of these waste inputs will result in an increased richness and abundance of marine life in local coastal waters, but others are not certain there is a large problem.

Purpose and Objectives

The purpose of this report is to summarize the findings of a panel inquiry into the actual effects of nutrient and carbon from waste discharges on the abundance, diversity and production of marine life in the New York Bight and adjacent marine and estuarine waters. The objectives of the panel inquiry were to:

1) identify the most serious ecological problems associated with present nutrient and carbon loading.
2) determine to what extent oxygen depletions are caused by these loadings.
3) identify uncertainties that remain in our assessment of effects and how the uncertainties might be resolved.
4) suggest what could be done to alleviate identified ecological problems without causing new or larger problems.

Approach

To accomplish our objectives we reviewed recent published and unpublished data on nutrient and carbon inputs, nutrient cycling. AND ON We considered a variety of marine communities that might be affected but focused our attention on phytoplankton and marine benthic invertebrate communities (benthic macrofauna) because they are at the base of the food web leading to harvestable resources such as shellfish and fish. Accordingly, we reviewed data on phytoplankton production and biomass, factors limiting phytoplankton growth, dissolved oxygen levels and year-to-year variation in oxygen, spatial and temporal variations in benthic invertebrate densities, and variations in diversity and community structure of benthic invertebrates. We also focused attention on three general regions (a) the Hudson River Estuary including Upper and Lower New York Bays and Raritan Bay, (b) the New York Bight Apex area and (c) the New York Bight beyond the Apex. We examined data from other coastal areas as well.

Summary of Findings

Although there is considerable production of marine life in the New York Bight area, we concluded that the abundance and composition of phytoplankton and benthic macrofaunal communities are not normal in the Lower Hudson Estuary and in the Apex area. More over, near the bottom in both areas, dissolved oxygen concentrations are frequently lower than they should be. We also concluded that there has been a reduction in the richness and abundance of benthic macrofaunal communities in Raritan Bay and that this reduction may be caused by toxic chemicals in water or sediments. We recommend that nutrient and carbon inputs be reduced commensurate with the results of a more penetrating study of the Lower Hudson Estuary. However, we also caution that major reductions of inputs of carbon and nutrients will not completely eliminate episodes of low dissolved oxygen because such episodes can be caused and maintained by natural mechanisms.

Our analysis begins with a review of why there is concern about nutrient and carbon inputs and what local coastal waters might be like in the absence of the inputs introduced by waste discharges (BACKGROUND). Next, we summarize specifically what is known about the magnitude and fate of recent inputs, together with a region-by-region account of the known or suspected effects of these inputs on phytoplankton, dissolved oxygen, and benthic communities. Finally, we return to the original questions and offer our answers, uncertainties, and recommendations.

BACKGROUND

Cause for Concern

Inputs of nutrients and carbon from land are important in maintaining rich and productive coastal plant and animal communities. However, excessive inputs, such as from sewage or urban runoff, could cause biological changes that eventually result in changes in the abundance and variety of marine shellfish and fish populations. This can be especially true in areas of poor circulation where oxygen can be depleted by excessive planktonic growth. There are three water types off New York and New Jersey (e.g., the New York Bight), (1) offshore areas of strong circulation where overall biological production is low and controlled by the ocean, (2) shallow inshore areas of variable circulation (e.g., the Apex) where overall production should be somewhat higher and partially under the influence of natural inputs (such as rivers), and (3) estuarine areas (Raritan Bay--Hudson River) where production should be high and controlled mainly by nutrient inputs from rivers and runoff.

Within these three types of coastal waters, diverse phytoplankton communities, dominated in the spring by diatoms and in the summer by chlorophyles should form the bases of the food web. The benthos should be abundant (thousands per m^2) and include a variety of molluscs, polychaetes, crustaceans and echinoderms, many of which should serve as food for several abundant species of bottomfish and shellfish. In addition, anadromous fishes such as shad and striped bass should make annual, generally unimpeded, migrations through the area and into the river systems.

Factors Limiting Phytoplankton Production

In coastal marine waters, phytoplankton productivity (i.e., primary productivity) is usually limited by nitrogen, but rarely by other nutrients such as phosphorus (Ryther and Dunstan, 1971). Therefore, increased nitrogen inputs could stimulate the growth of phytoplankton. In situations where nitrogen loading is extremely high, massive phytoplankton blooms could result. During such a bloom, oxygen would be consumed by all living organisms associated with the bloom and by decay of their excretory products. Following the bloom, the plankton biomass would die and undergo microbial decomposition creating an even greater demand on the dissolved oxygen supply. Finally, a portion of the phytoplankton biomass would eventually fall to the sea bottom and provide extra nutrition for growth of benthic organisms or, in extreme situations, completely exhaust bottom water oxygen and thus reduce the abundance and diversity of benthic organisms including fish and shellfish.

Nutrients other than nitrogen may become limiting to certain conditions. For example, silica is required for the growth of diatoms which are considered a significant link in marine food webs and important to commercial fisheries (Ryther, 1969; Lasker, 1978, and Lasker et al., 1975). If nitrogen inputs exceed available silica inputs, silica limits the growth of diatoms and allows the growth of other phytoplankters not requiring silica (Ryther and Officer, in press). In such a situation, the animals that use diatom-based food chains (such as clams) could become food limited relative to those that do not (Ryther and Officer, in press).

Other factors can limit primary production in coastal waters. These include inert or living suspended solids which scatter and absorb the light required for photosynthesis and unusual concentrations of specific toxicants or trace elements (McLaughlin et al., 1977; Kleppel, 1979; Dunstan, 1975; McIsaac et al., 1979). Runoff and wastewaters contribute to the suspended solids load and could limit phytoplankton production. Self-shading by phytoplankton themselves can limit productivity. Toxic materials can act directly on phytoplankton to decrease production (O'Connors et al, 1978). Finally, Dunstan (1975) proposed that certain minerals required by phytoplankton (e.g. iron) can occur in low or fluctuating concentrations which when macronutrients are available at saturating concentrations may themselves become liniting factors (Dunstan, 1975).

Because of variation in runoff, natural nutrient input, and occasional and unusual wind conditions which bring to the surface cold water containing low oxygen and high nutrient concentrations, we would normally expect to see occasional episodes of local plankton blooms and reduced levels of dissolved oxygen in shallow inshore waters.

Factors Limiting the Benthos

Bottom life can also be altered by both nutrient and carbon inputs. Raymont (1949) and Gross (1949) experimentally enriched Scottish sea lochs with inorganic fertilizers and over a period of 2-3 years observed a doubling of benthic production and accompanying increases in the growth rates of bottomfeeding fish. Field experiments adding processed sewage sludge to subtidal benthic populations resulted in increased biomass and densities of certain benthic species (Young and Young, 1978). In areas affected by sewage outfalls in California, it was demonstrated that growth rates of a benthic feeding flatfish were greater than in control areas (Mearns and Harris, 1974).

Potential Effects of Sewage

Sewage contains nitrogen and other nutrients in forms essential to many kinds of phytoplankton. It also contains carbon in forms which can undergo decay by marine microorganisms. Thus, in the absence of toxic materials, certain amounts of sewage discharged into coastal waters serve to stimulate primary production and the growth of benthic populations, including fish. However, large scale nutrient loading may under certain conditions lead to oxygen depletion and mortality of benthic organisms including fish and shellfish. Semienclosed and poorly flushed areas such as estuaries are especially sensitive to this sort of deterioration.

Sewage and other wastewaters also contain potentially toxic materials such as trace metals, synthetic hydrocarbons and petroleum hydrocarbons. Thus, the full production expected from nutrient and carbon inputs might in fact be inhibited by toxic materials.

Our analysis of each area, described below, required us to take all these factors into consideration.

SITUATION IN THE NEW YORK BIGHT AND ADJACENT WATERS

Inputs of Nutrients and Carbon

Each year waters of the New York Bight receive nearly 9 million m tons (metric tons) of suspended solids, one million m tons of organic carbon, 200 thousand m tons of nitrogen and 50 thousand tons of phosphorus from the adjacent coastline and human population of New York at New Jersey (Mueller et al., 1976 and Tables 1 and 2). Recycling, advection, upwelling and mixing also add to the nutrient loading and maintenance of nutrient cycling in the Bight (Walsh et al., 1978).

Of the land-based sources, barge dumping and atmospheric fallout are the largest direct sources to the Apex of suspended solids and total phosphorus (68% and 51%, respectively) but the Hudson River Estuary (Hudson River-New York Harbor waters) represents the largest source of total organic carbon, total nitrogen (including ammonia, nitrate and nitrite) and is a competitive source of phosphorus (Table 1). Inputs from the New Jersey coastline south of Sandy Hook and from the south coast of Long Island are relatively trivial except for nitrate and nitrite nitrogen (Table 1).

In terms of types of sources, barging is the dominant direct input into the Bight of suspended solids, total organic carbon, ammonia nitrogen and phosphorus while aerial fallout is a competitive direct source of total nitrogen and the dominant direct source of nitrate and nitrite nitrogen (Table 2). From the coastline itself, runoff (urban and rural) is the largest source of suspended solids and nitrate and nitrite nitrogen, and is a conpetitive source with wastewater of total organic carbon (Table 2).

Wastewaters, on the other hand, are the dominant coastal sources of total and ammonia nitrogen and total phosphorus (compare percentages in Table 2). Within the wastewater category, industrial sources of nutrients and carbon are trival compared to municipal wastewaters (Table 2). As noted above, the Hudson River Estuary is the dominant geographical nutrient source and we conclude it receives most of the liquid waste water generated by the urban population of 16 million (Mueller et al., 1976). The Hudson River is also a large source of silica; the 40 to 340 m tons per day varies with river flow and includes a small amount (20 m tons per day or 6 to 50%) of sewage-origin silica (McLaughlin et al., in press).

The Hudson River Estuary

Phytoplankton and Red Tides. Most authors agree that only small amounts of the nutrients entering the estuary are actually used in primary production within the Estuary (Garside et al., 1976; Ingram, 1979; and McLaughlin et al., in press) and that less than 10 percent of the nitrogen is used in phytoplankton production. There are a number of reasons for this. First, it appears that the remaining 90% or more of the nitrogen passes out into the Apex, or into the sediments of the Hudson River-Raritan Basin (Garside et al., 1976). Concentrations of nitrogen in estuarine waters vary seasonally and inversely with river flow.

The high periodic flow of the Hudson River (range 60 to 1700 m^3 sec^{-1}) also appears to wash plankton biomass from the estuary faster than it is produced (Malone, 1977 and Kleppel, 1979).

Laboratory tests (Kleppel, 1979; Samuels, 1979; McLaughlin et al., 1977 and McLaughlin et al., in press) also indicate that diatom production become periodically limited by low concentrations of silica and "micronutrients" (Vitamin B_{12}, trace metals). These observations support the hypothesis of Dunstan (1975) that in cases of macronutrient (i.e., nitrogen) saturation, micronutrients (i.e., silica) may limit phytoplankton growth.

Episodic blooms (i.e., 100,000 cells/ml) of several "red tide" flagellates have occurred in New Jersey and Lower New York Bay nearshore waters since the early 1960's. Although the factors causing these are still poorly understood, laboratory investigations (Mahoney and McLaughlin, 1977) suggest that urea and intrate (from sewage effluents and river runoff, respectively) may be the pre-fered nitrogen forms of the major New Jersey red tide algae and that certain strongly-chelated metals (from industrial effluents in the Raritan Bay area) influence initiation of the blooms (Mahoney and McLaughlin, 1977). This is unusual since it has been previously thought that all algae prefer ammonia over urea or nitrate as a nitrogen source. Relatively little is known about the red tides in New Jersey, yet the economic losses (beach closings) incurred by these blooms suggests the need for more data.

Dissolved Oxygen. As previously noted, wastewaters and runoff are both important sources of carbon to the Estuary. The contribution of carbon from these sources and from phytoplankton production to the benthic environment are poorly understood. In either case, low dissolved oxygen levels (10 percent saturation) are common in many parts of the Estuary, presumably from the high carbon loading (Suszkowski, 1973). The dissolved oxygen levels are clearly too low to support diverse populations of fish and shell fish.

The Benthos. Benthic populations in this Estuary should be abundant (thousands per m^2) and moderately diverse. However, a recent study of Raritan Bay (Michael, 1979; McGrath and Michael, 1979) found abnormally low densities and number of species of benthic macrofauna. As recently as 1957, Dean (1975) showed that a species of *Ampelisca*, an amphipod, was a dominant member of the benthic community in Raritan Bay (sampled in densities of up to 13,000 individuals/m^2, and present at 125 out of 193 stations). In contrast, McGrath and Michael (1979) collected only 1 individual of this genus in samples from 88 stations 16 years later. Total abundances of all macrobenthic species averaged less than 100 in 1973, a noticeable decrease from those recorded by Dean (1975). Thus, there have been some relatively recent and dramatic changes in the abundance and diversity of the benthos in Raritan Bay.

This unexpected benthic condition merits special attention. The silty sediments of Raritan Bay and New York Harbor are a sink for river-born solids, organic materials, and various associated contaminants. The sediment content of approximately 5% organic matter in Raritan Bay is comparable to sewage-enriched areas in southern California (Word and Mearns, 1979) and the Baltic Sea (Anger, 1975) which support benthic densities two orders of magnitude greater than those observed in New York Harbor.

High levels of heavy metal contaminants in sediments have been reported adjacent to sewage outfalls in California, but benthic densities in these affected regions reach 21,000 individuals/m^2 or four times higher than background. In contrast, Sandy Hook Bay has significantly lower metal concentrations and these are associated with lower densities (100 individuals/m^2) of benthic infauna (McGrath, 1974). The minor differences between sediment types and habitats in the Hudson-Raritan Estuary and southern California do not explain the drastic differences in benthic invertebrate densities.

Michael (1979) noted that the patterns of distribution and abundance of macrobenthos in Raritan Bay are related to hydrocarbon contaminants, while McDonough (1976) concluded the low densities of macrobenthic organisms were related to high heavy metal levels (even though these levels are lower than yet higher levels at the southern California sites). The residence time of such contaminants in sediments is a function of both physical dispersal processes and bioturbation activities (i.e., biological reworking of sediments). An example of effects from physical dispersal processes may be seen in a comparison of lower New York Bay with the Ambrose Channel. In the Channel, there are low concentrations of organics and a dense benthic population, dominated by haustoriid amphipods; the converse is characteristic of lower New York Bay (McGrath, unpublished data).

It is probable that benthic production, particularly of suspension feeders, is partly dependent on net phytoplankton production, and that the nannoplankton which dominate the lower estuary in summer are not utilized as food. Although further investigation is required to determine whether or not this possibility is supportable, it appears that macrofaunal abundance and diversity in Raritan Bay is not limited by carbon or nitrogen inputs.

Summary. In summary, the Hudson River Estuary directly receives inputs of nitrogen and carbon from sewage and runoff. However, because of the rapid flow, only a small fraction of the nitrogen in assimilated by phytoplankton. Nevertheless, nitrogen is not limiting production; other factors such as reduced light and micronutrients may be limiting. The causes of red tide blooms in lower bay or Jersey coast are not well understood, and need to be investigated. Dissolved oxygen in estuary is low; again the specific contribution from sewage-origin carbon is uncertain, but excess carbon whether from sewage or plankton, is a likely cause of the depression. The benthos is poorly studied except in Raritan Bay, where a large area of the bottom in 1974 contained a fauna with both low diversity and low abundance. Since N and C (organic matter) is not limiting overall production, we speculate that either low total oxygen or the presence of toxic materials is limiting benthic diversity and abundance.

The Apex

Inputs and Recycling. As noted above, river runoff, wastewaters and direct sludge dumping are major sources of carbon and nitrogen and other nutrients into Apex waters of the New York Bight. Unlike the estuary, however, coastal and oceanic processes contribute to inputs and modify concentrations.

Although oceanographic inputs of nitrogen by advection and diffusion are generally believed to be small, Walsh et al. (1978) have suggested variations in storm frequencies and upwelling may be important in delivering deep water nitrogen to localized areas.

In the summer, a thermocline develops that effectively separates the upper (20 m) mixed layer from bottom waters. Thus, during this period, wastewaters and estuarine inputs became extremely important in contributing nitrogen and carbon to upper waters while sludge (on the bottom) becomes a less important source of nutrients. As a result mainly of estuarine input, dissolved nitrogen concentrations of Apex waters are higher than in adjacent coastal areas at equivalent depths (Malone, 1979).

Phytoplankton. Most of the nitrogen discharged from the Estuary is assimilated by phytoplankton in the Apex and 70 to 80% is used within 20 km of the Hudson River mouth (Malone, 1979). Malone (1979) also estimated that the area required to assimilate the dissolved inorganic nitrogen input (ammonia, nitrate and nitrite) varied seasonally from 670 km^2 to 1350 km^2; i.e. 54 to over 100% of 1250 sq km area of the Apex.

Although it would appear that phytoplankton production in the Apex might be nitrogen-limited, Malone (1977) considered light an important limiting factor while McLaughlin *et al*. (in press) and Malone and Garside (1980) consider silica possibly limiting in some seasons. In fact, regeneration and recycling of nitrogen from subsurface waters for use in the euphotic zone are probably the most important processes maintaining phytoplankton production within the Apex (Malone, 1979).

Dissolved Oxygen. The Apex has suffered several episodes of nearly anerobic water but also experiences less severe depressions almost yearly. In terms of biological effects, midsummer is a critical period. As noted above, the thermocline (at approximately 20 m) reduces mixing between the surface mixed layer and bottom water creating an isolated bottom water pool. Phytoplankton grow rapidly in the surface mixed layer and may concentrate at the thermocline. On the average, dissolved oxygen levels in the bottom water drop to 25 percent or less of saturation (2 ml/l), (Malone, 1979), compared to an average depression of 50%-90% saturation in apparently unaffected bottom waters south of the Apex (Sharp, 1979). Although these are average conditions, there is a good deal of year-to-year variation. For example, during July 1976, a region-wide "anoxic" episode was triggered by unusual wind conditions and a bloom of *Ceratium tripos* (Walsh *et al*, 1978). Dissolved oxygen concentrations dropped to below 10 percent saturation over much of the coastal shelf south of the Apex (Sharp, 1976; Walsh *et al*, 1979; Atwood *et al*, 1979). In contrast, conditions in 1978 generally produced only very slight dissolved oxygen depressions (i.e. 80-90% saturation) over most of the shelf (Sharp, 1979).

Despite a number of comprehensive surveys, there is still no agreement concerning the degree to which wastewaters contribute to dissolved oxygen depressions. Depressions to 50% O_2 saturation are naturally occurring and to be expected. However, the additional depression (to 25% or less saturation) which now occur frequently in Apex bottom waters is generally agreed to be unusual and probably (through increased primary production) due to the excess nitrogen input from wastewaters in the estuarine areas rather than to the oxygen demand from sludge and dredge wastes (Segar and Berbarian, 1976). However, it may be argued that the subsurface oxygen demand from organic carbon in solid wastes is mitigated by excess daytime oxygen production from phytoplankton, and that if estuarine and wastewater nitrogen inputs were reduced, this mitigation would cease and dissolved oxygen depressions above the dumpsites would become more apparent.

The Benthos. The condition of the benthos in the New York Bight Apex is markedly different from that in the Estuary. As a result of direct dumping, sediment organic carbon concentrations are higher at the Apex dumpsites than in adjacent areas at comparable depth (Pearce *et al.*, 1979). Benthic population densities were an average of at least two orders of magnitude greater than in the Estuary (Pearce *et al.*, 1979). However, there is a noticeable absence or decrease in the abundance of amphipods in both areas (Pearce, 1972; McGrath, 1974) as also is the case in sediments surrounding one particular southern California sewage outfall (Word *et al.*, 1977).

Ampeliscid amphipods are thought to be sensitive indicators of chronic petrochemical pollution (Blumer et al., 1970). There is also an absence of echinoderms as in a similar area of the coast of California (Word and Mearns, 1979).

The impact of sludge dumping in the Apex centers around the eastern end of the disposal site. The most depauperate portion of the dumpsite occupies an area of 10-15 km^2 while the enhanced (in terms of abundance) transitional areas occupy 240 km^2 (Boesch, 1979). The areas of impact compare favorably with an equivalent sized point source discharge in southern California (Bascom et al., 1979). While the two locations are not directly comparable their relative sizes and similarities and differences in faunal composition suggest a need to more thoughtfully compare outfall and dumpsites in various coastal areas around the United States (Mearns and Word, 1979).

Waters Beyond the Apex

Studies at coastal sites distant from the Apex and Raritan Hudson River Estuary indicate that primary production is nitrogen limited (Sharp, 1979). Variations in dissolved oxygen concentrations are consistent with expected physical oceanographic variations (Sharp, 1979; Walsh, 1979). At present, areas south of eastern Long Island and off southern New Jersey are not measurably affected by nutrient and carbon inputs from New York - New Jersey Metropolitan areas. The important question is whether or not distant waters will be affected in the future. If the relationships between primary production, dissolved oxygen depression and waste inputs are linear, then slight changes in nutrient inputs will produce little change offshore. However, it is more likely that they are not linear (perhaps geometric or exponential, Mearns and Word, in press), that is, a slight increase in nitrogen input could trigger a much larger increase in production (Segar and Berbarian, 1976). Uncertainties ex exist, and they are due to our still inadequate understanding of interactions between recycling and regeneration of nutrients, upwelling of nutrients, inputs from runoff and wastewaters, and variations in physical oceanographic conditions.

Time did not permit a review of benthic macrofaunal data in waters distant from the Apex. It is clear from studies near the Apex, however, that true "control" or "background" conditions for benthic macrofauna are not reached at the edge of Apex study areas (Pearce _et al_., 1979).

CONCLUSIONS AND RECOMMENDATIONS

In the judgment of this panel, the most serious ecological consequences of nutrient and carbon loading are the effects on dissolved oxygen, especially in the Lower Hudson Estuary and, with due credit to our uncertainties, in the Apex area. With respect to the benthos, the most serious problem appears to be in the Raritan Bay-Lower Estuary region because potential production is not being realized (as it is in the Apex). We also wonder what macrofaunal densities are like elsewhere in the Hudson River-Estuary. The apparent suppression in the densities of benthic organisms in organically rich sediments of Raritan Bay indicates that, unless bottom water dissolved oxygen levels are nearly zero, nitrogen or carbon inputs are not limiting their abundance, but toxicant(s) might be. We suggest that BOD, H_2S, and heavy metals are less likely candidates for this contaminant material than chlorinated hydrocarbons, petrochemicals, or some other as yet unidentified anthropogenic material.

Bottom water dissolved oxygen levels also need to be examined more thoroughly. The occurrence of low dissolved oxygen levels in the Lower Hudson Estuary is probably caused by local carbon loading. Outside the Estuary in the Apex and adjacent coastal shelf waters, low dissolved oxygen episodes are exaggerated by nutrient input primarily from Estuarine (wastewater discharge) sources, but there is still uncertainty about the actual contribution and year to year variations. The low dissolved oxygen episodes of the coastal shelf waters are, however, not initiated by these inputs but by oceanographic and meteorological conditions.

Uncertainties in present knowledge are indicated in foregoing discussions. The most important ones are related to the lack of quantitative knowledge about the specific contribution of waste-water nitrogen to biostimulatory conditions (especially in the Summer) in the Apex, uncertainties about where the edge of "no effect" is on Apex benthic macrofaunal communities, the contribution of sewage-borne nitrogen to these communities, and uncertainties about the role of toxicants and micronutrients (such as silica, trace elements and vitamins) in limiting primary and secondary production in Raritan Bay and the condition of benthic communities elsewhere in the Hudson River Estuary.

At this stage, we conclude the following:

1) Control of nitrogen inputs from wastewaters will help reduce the problem of low dissolved oxygen in the Apex area but zero discharge will not eliminate them; they will occur in the future due to natuarl causes (but may not be as severe).
2) Unless source control can be made so effective that nitrogen becomes a limiting factor (i.e., removal of more than 90 percent supplied to the estuary), managers will have little control over primary production and species composition in the estuary and Apex. Control of a variety of potentially limiting nutrients may be useful, but additional goal-oriented research is needed to better quantitatively define how these nutrients vary and are used.
3) The most critical area for the benthos is in Raritan Bay-Hudson Estuary rather than at the offshore dumpsite because benthic production is apparently limited by some unknown factor

in the Bay other than organic carbon. Benthic production is probably not limited by sediment-bound metals or H_2S, but rather by some as yet unidentified anthropogenic material. A management strategy specific to this part of the ecosystem will be required if benthic productivity is to be improved. Benthic environments in other parts of the Hudson River should be examined.

4) More understanding of seasonal and year-to-year variations is necessary; management strategies should not rely on mean conditions. For example, nitrogen inputs need to be controlled more during the summer (when excess nitrogen is contributing to phytoplankton blooms) than during the winter.

It should now be obvious that the factors limiting biological production and species composition in the New York Bight and adjacent waters are complex enough to merit caution in implimenting any management plan. Certainly reductions in waste inputs will help improve the quality and biological diversity of local waters, but we are unable at this time to forecast exactly what will change and where it will happen. This should be the specific goal of a renewed attack on the problem.

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Table 1. Mass emmissions of suspended solids, carbon, nitrogen and phosphorus into the the New York Bight and adjacent waters summarized by location of input. Direct includes barge dumping and aerial fallout. After Mueller et al., 1976.

	Total Mass input, thousands metric tons/year	Percent Contribution by Location			
			Coastal		
		Direct	Hudson NY Harbor	New Jersey	Long Island
Suspended solids	8,760	68	31	0.6	0.1
Total Organic Carbon	949	37	58	4.0	0.6
Total Nitrogen	190	29	65	4.0	2.0
Ammonia Nitrogen	77	28	67	3.0	2.0
Nitrate and Nitrite Nitrogen	44	33	55	10.0	2.0
Total Phosphorus	50	51	45	2.0	2.0

Table 2. Mass emmissions of suspended solids, carbon nitrogen and phosphorus into the New York Bight and adjacent waters. After Mueller *et al.*, 1976. Summarized by type of input.

	Total Mass Input, thousands metric tons/year	Percent Contribution by Source				
		Direct		Coastal Wastewater		
		Barge	Atmosphere	Municipal	Industrial	Runoff
Suspended solids	8,760	63	5	4	0.2	28
Total Organic Carbon	949	25	12	29	1	33
Total Nitrogen	190	16	13	40	2	29
Ammonia Nitrogen	77	24	4	55	3	14
Nitrate and Nitrite Nitrogen	44	0.1	33	6	0.3	61
Total Phosphorus	50	50	0.7	35	1	13