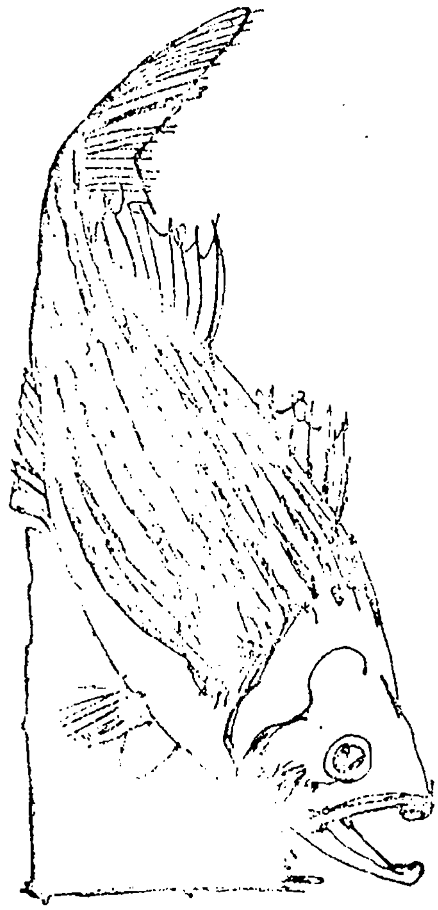
Water quality in industrial areas: profile of a river

The lower Hudson, like most tidal areas, must serve many needs, and its biological status is a direct measure of its ability to do so

The Hudson River drainage area, one of the major watersheds of eastern North America, encompasses about 12,400-14,500 square miles, and supports a human population of about 10.5 million. The flow in the southerly portion is controlled by a dam at Troy, about 155 miles north of the river mouth. The channel of the river can be traced well out into the Atlantic, and, at the northern limit of the tide at Troy, the river bottom is still four feet below sea level. The physical characteristics of the river bed indicate that it is a "drowned river."

The lower Hudson is a major transportation artery and, at the same time, a source of water for industrial and domestic purposes, an unsurpassed recreational resource in an area of great natural beauty and important historical associations, and serves as a drain for industrial and domestic wastes. The economic, industrial, and recreational potential of the river can hardly be overemphasized, yet, regrettably, little is known about its hydrology, biology, or chemistry. At a time when there is a need to predict the impact of projected developments, much basic data still are unavailable or controversial.

Part or all of the lower Hudson can be defined as estuary. The more seaward stretches are mesohaline (from two thirds to one third seawater), an intermediate zone is oligohaline (one third to one tenth seawater), and there is a final limnetic (or fresh water) stretch. The extent of these zones in the lower Hudson is closely dependent on fresh water runoff from the drainage area, and,



consequently, the saltfront—or the intrusion of seawater—varies from year to year, and with the seasons.

Hydrology

The average annual fresh water inflow into the lower Hudson at Green Island has been estimated at between 12,000-23,000 cubic feet per second (c.f.s.). This flow is uneven, with spring maxima as high as 40,000 c.f.s. (as in April 1967), and summer minima as low as 2000 c.f.s. The summer low flow period lasts from four to seven months each year. As the fresh water flow diminishes, the salt water front pushes upstream from its spring limit near Tappan Zee (30 miles from Battery Park, Manhattan), reaching Newburgh (59 miles), Poughkeepsie (74 miles), or even Kingston (88 miles) in the summer and fall, depending on the annual rainfall. At any station on the river, the salinity increases progressively from May to November. There is generally a minor additional flow of fresh water before the cold temperatures of mid-winter reduce the flow. Although salinity is reduced somewhat (and the salt front pushed southwards), it remains relatively high throughout the winter, until the spring thaw brings about a massive dilution in March or April.

As seawater pushes up a river at flood tide, it tends to form a wedge of more dense saline water at the bottom of the river bed. Since the Hudson River is more than 100 feet deep in places, this saline water might be expected to remain near the bottom. In fact, only relatively slight differences have been seen between the surface and the bottom, indicating that the water gets fairly well mixed, at least north of the Tappan Zee.

The northward motion of the tides at some periods apparently reverses the river flow; since the tidal flow is massive—approximately 300,000 c.f.s.—it dwarfs the summer fresh water flows. Upstream flows of 19,000 c.f.s. have been measured at Governor's Island, 5000 c.f.s. at Riverdale, and even 2100 c.f.s. at West Point. The Federal Water Pollution Control Administration's Hudson-Champlain project, using dye marking studies, showed virtually no flow during the summer of 1965, when dyes added to the river at different sites were followed for 14 tidal cycles. At the head

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of the tidal influence at Troy, the tidal excursion was only three miles, but the velocity of net movement of the dye mass downstream was a mile and a half for each tidal cycle, or about 20 miles in a week. At Kingston and further south, while tidal excursions were greater, there was no net movement of the dye downstream.

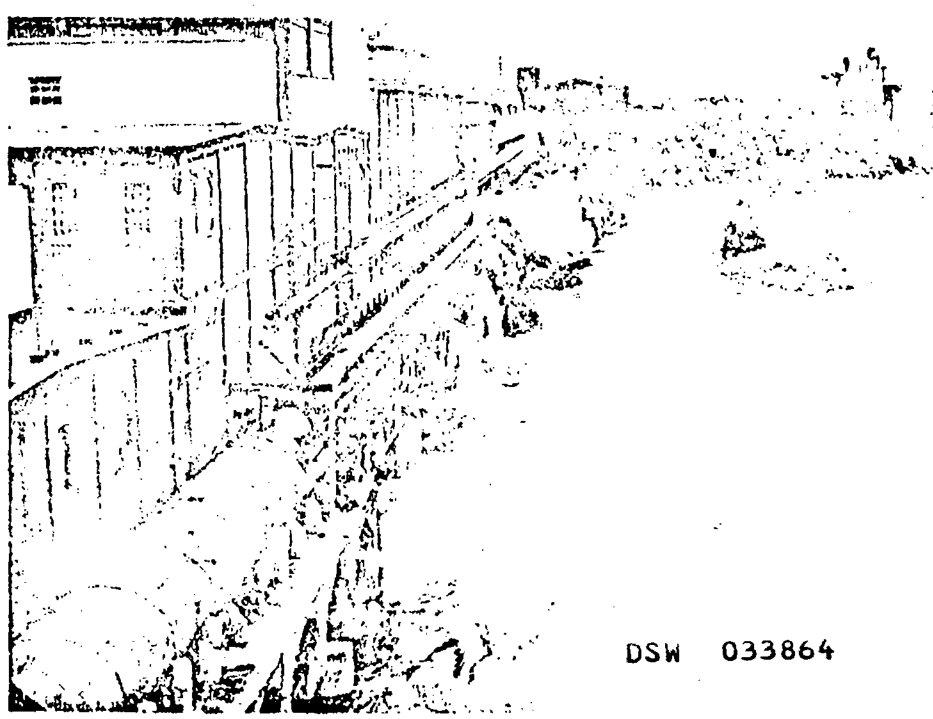
The overwhelming effect of the tidal flux appears to produce a seiche-like movement of the brackish water, but little effective exchange. The implication for pollution and eutrophication effects are clear. The large volume of water (150 miles long with an average cross section of 150,000 feet) behaves as a brackish lake rocked north and south by the tide. The inflow is sufficient to exchange only 0.3-2% each day, assuming the simplest model of a single compartment, no evaporation or withdrawal, and no rain or additional inflow. The mean life of pollutants that remain in solution or suspension thus ranges from 40 days to more than 300 days, depending on the flow. Effluents and nutrients discharged into this brackish lake will, as in a true lake, be recirculated during dry summers between water, sediments, and biota. Only the high spring flows provide a flushing volume of water necessary to prevent an accumulation of pollutants and eventual eutrophication.

Too little is known about the physical hydrology of estuaries generally, and of the complex Hudson River system in particular. Without detailed knowledge of the self-purifying capacity of a river or an estuary, we cannot make a reasonable forecast of the effects that will follow a polluting load. A British study of pollution in the River Thames demonstrated that the narrow parts of estuaries have a comparatively limited capacity to purify polluting material. The water flowing to and fro is substantially the same water from one day to the next, and, at times of low fresh water flow, pollutants may remain within the system for several months, building up in concentration. The narrow tidal stretches of the Hudson, then, are most vulnerable to pollution, with a limited surface area and mud-water interface available as either a source or a sink for pollutants.

Hudson ecology

The Laboratory for Environmental Studies, part of New York University Medical Center's Institute of Environmental Medicine, has been studying aspects of Hudson River biology and chemistry since 1963. The study, financially supported in part by the New York State Health Department and the Consolidated Edison Co., developed initially from an interest in environmental radioactivity problems, and has broadened into a wider ecological study of the effects of various pollutants on the biota. We are accumulating survey data from the river, and trying to relate our information to that from other studies, especially those of water flow and industrial use of the river.

Those who have been actively engaged in this study (aside from the authors) are A. Perlmutter and H. Hirshfield of the biology department, and A. McCrone of the geology department at the Washington Square



Campus of New York University, and Dale Bath at the Lanza Laboratory.

Investigators pursued several lines of study:

• Considerable knowledge was acquired about the abundance, distribution, and variety of animals and plants in the river, from microscopic forms to fish.

• Seasonal changes in the nutrient anions as well as trace cations were followed.

• A long, continuing study was made of levels of radioactivity—both natural and man-made—in the water and biota.

• A study was made of levels of organo-chlorine pesticides in the river water and mud, and their accumulation in selected species of the biota.

• Present and future effects of heat additions to the river from industrial cooling and processes are being evaluated.

We are trying to see how the effects of varying fresh water flow and tidal cycle influence the distribution of inorganic pollutants, nutrients, pesticides, and heat, and how these affect the biota of the river. In short, we are trying to predict the future of the river in terms of eutrophication, in the face of increasing industrial and domestic utilization.

Nutrient loads

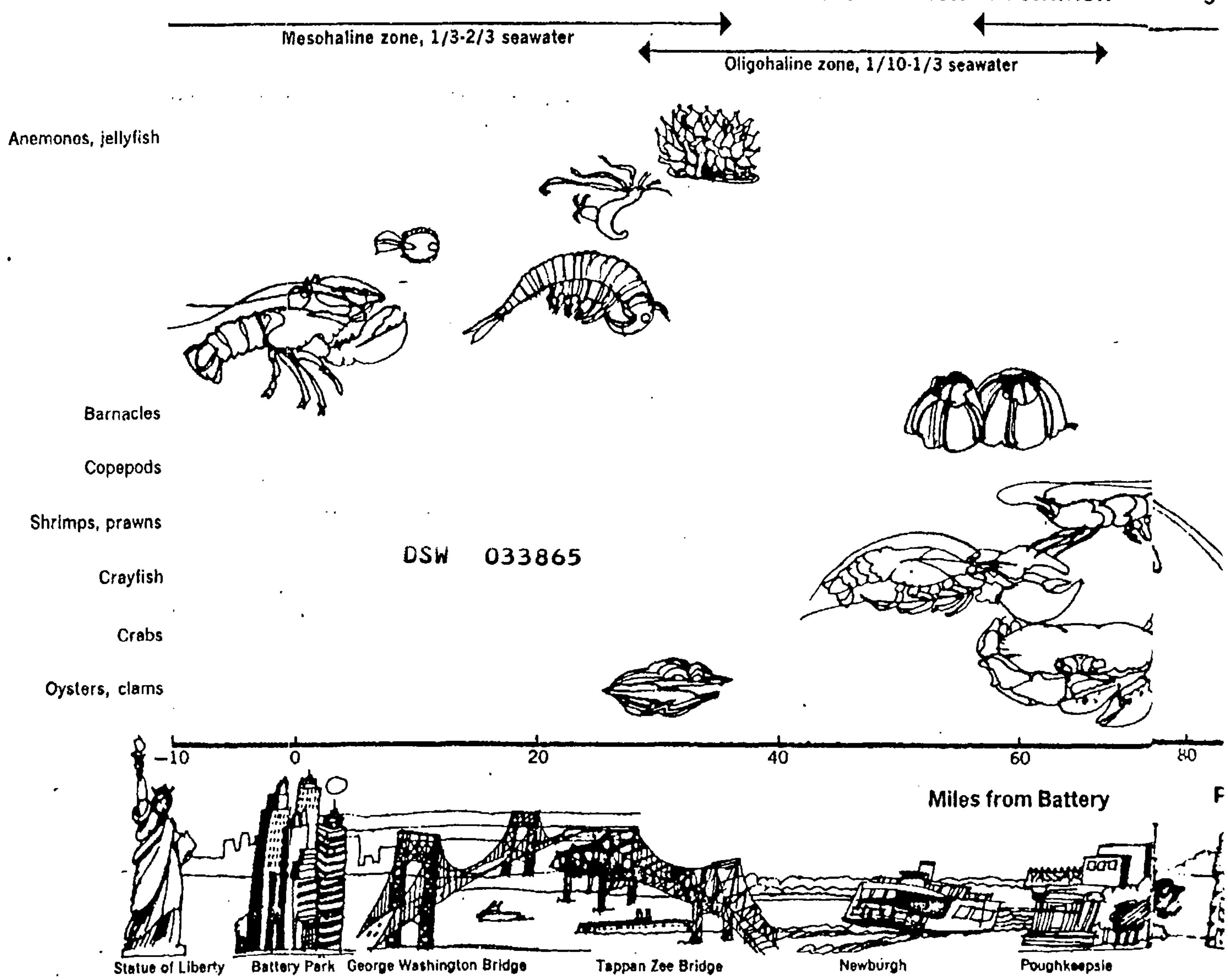
The sparsely populated agricultural Mohawk watershed, stocked with farm animals and supplied with fertilizers, provides significant nutrient input. This is seen in the relatively high nutrient levels of Mohawk river water (0.85 mg. nitrogen/l.) compared with other northeastern American rivers. About 17% of this could be attributed to natural runoff, and the remainder to artificial sources.

The 10.5 million population of the Hudson watershed produces 61 million kg. of nitrogen and 5.5 million kg. of phosphorus as domestic waste in a year, much of which ultimately will be carried seawards by the river. Other wastes such as domestic detergents (contributing two thirds of total phosphate in one municipal discharge), and wastes from meat and dairy industries, yeast production, and paper manufacture, also contribute to the nutrient load.

Present municipal waste discharges north of Yonkers provide 1.6% of the spring volume of river flow, and 16% in the summer. At the Verrazano Narrows (Brooklyn), the proportions are much greater, because of the population density of the New York City area. The use of some rivers as sewage conduits has led to deoxygenation and conditions impossible for fish life, especially when sewage disposal is coupled with other industrial uses.

The nutrient content of the river water reflects its use. At Indian Point (43 miles from the Battery), the phos-

Distribution of common



phorus content of the water ranges from 9.5-2.5 μg.-atoms/l. and, at the southern tip of Manhattan, a maximum of 12 μg.-atoms/l. was recorded. (Seawater has about 2 μg.-atoms/l.) Most of the phosphorus (70%) is present as inorganic phosphate, available for immediate plant assimilation and growth, while the remainder is dissolved organic phosphorus or particulate material. In general, phosphorus in river water usually is higher than in lakes, but these values are high by any measure—2.8 μg.-atom/l. is the approximate upper limit of unpolluted water. Lake Washington (Seattle, Wash.), where eutrophication is slowly being reversed by a costly sewage diversion, has a phosphorus concentration of 7.5 μg.-atoms/l.

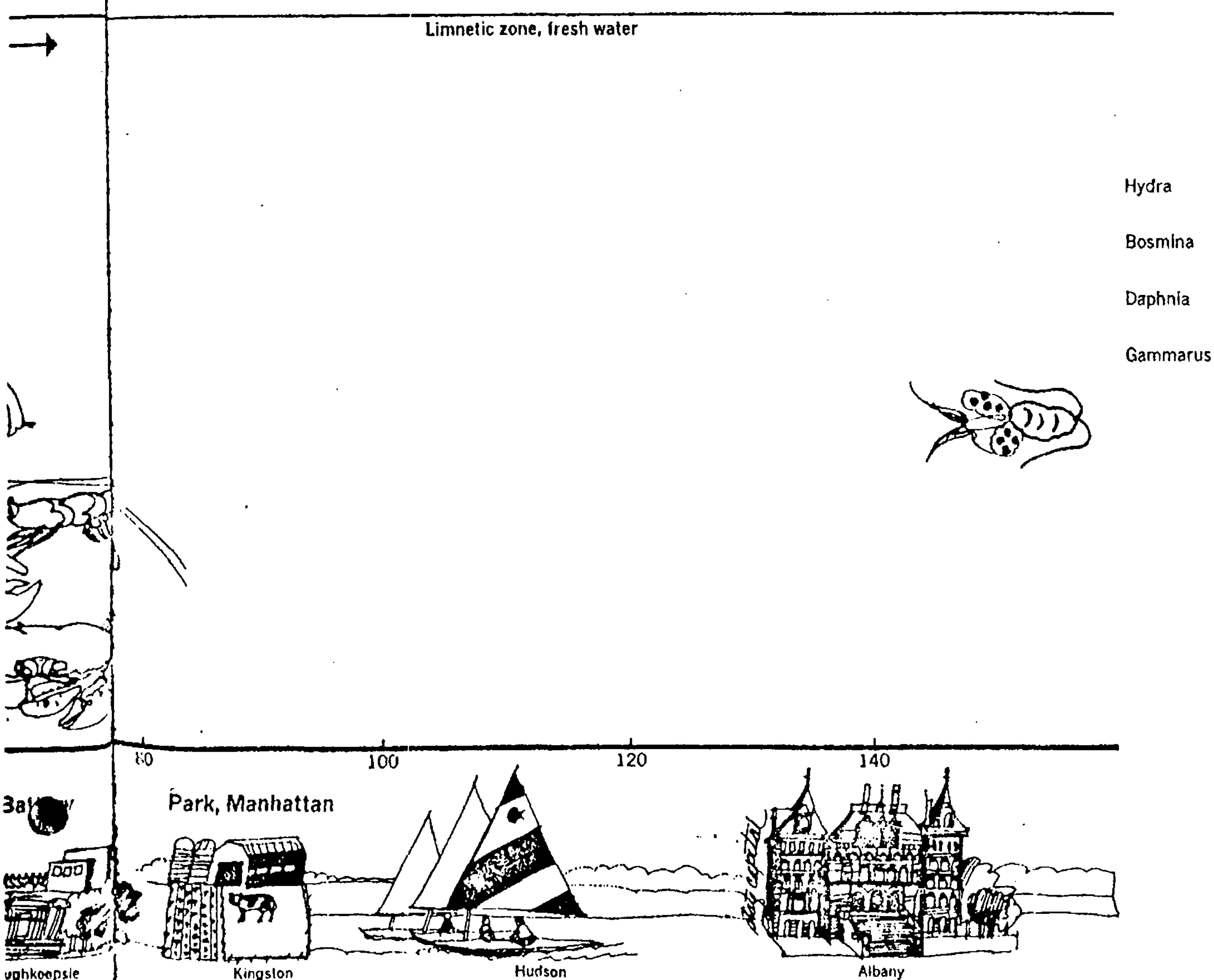
Ketchum deduced a theoretical relationship that oxygen demand is equivalent to the oxygen supply from photosynthesis at concentrations of about 2 μg.-atoms of phosphorus/l. At higher phosphorus concentrations, the net oxygen demand during darkness will deplete the dissolved oxygen levels in the water. On this basis, we might expect that south of Albany, and around Manhattan, there will be net oxygen depletion. This has been shown to be true by monitoring studies of dissolved oxygen and biological oxygen demand levels. However, at many sites on the river, the dissolved oxygen level is adequate to maintain a healthy fauna in spite of the high phosphorus content.

Nitrate nitrogen concentrations in the mid-Hudson range from 0.2 mg. to as much as 1 mg. N/l., and are somewhat related to the tidal incursion. Inflowing water from the upper Mohawk watershed has a concentration of about 0.85 mg. N/l. These levels may be compared with values of 10 mg. total N/l. in the Thames River in England, and values around 1 mg. or less in relatively unpolluted lakes. A seasonal fall in nitrate concentrations, such as that seen in the late spring of 1968 at Indian Point, could be a limiting factor in phytoplankton growth in this region, although many other factors may be implicated. Nitrates can act as an important reserve of oxygen, even with appreciable concentrations of dissolved oxygen, but, in anaerobic conditions, nitrogen compounds are reduced to nitrogen or even to ammonia. The nitrogen cycle is related to dilution, oxygen, and temperature, and complicated by the effects of nitrogen fixation or denitrification by bacteria or plants.

Preliminary data on sulfate levels indicate about 25 mg. SO_4/l. at Nyack, fairly closely related to salinity. As with nitrate, sulfate can be reduced to sulfide by bacteria in anaerobic or near anaerobic conditions.

The availability of these important anions—nitrate, phosphate and sul-

mon species in the Hudson River



Common invertebrates of the lower Hudson River	Mesohaline zone	Oligohaline zone	Limnetic zone
Protozoa	Dinoflagellates	*Difflugia* *Arcella* *Ochromonas* *Polytomella*	*Volvox* *Synura* *Paramecium* Amoebae
Coelenterates	Sea anemone (*Sagartia*) Jelly fish Ctenophores	*Hydra oligactis* Occasional jelly fish	*Hydra oligactis*
Rotifers	*Trichocerca* sp.	*Keratella cochlearis*	*Philodina*
Worms	Polychaetes	Polychaetes	*Tubifex* sp. *Aeolosoma* Nematodes
Crustacea	Harris crab (*Rhithropanopeus*) Blue crab (*Callinectes*) Prawn (*Palaemonetes*) Shrimp (*Crangon*) *Bosmina longirostris* Barnacle larvae Copepods: *Microarthridion* *Cyclops bicuspedatus* *Acartia tonsa*	*Gammarus fasciatus* Prawns Shrimps *Bosmina longirostris* Barnacle larvae Copepods: *Microarthridion* *Cyclops bicuspedatus* *Eurytemora hirundoides* *Ectinosoma eurticorne*	*Gammarus fasciatus* Crayfish (*Orconectes*) *Bosmina longirostris* *Daphnia pulex* Copepods: *Microarthridion* *Cyclops bicuspedatus* *Diaptomus pallidus*
Mollusca	Snails (*Physa*) Clam (*Mya*) Oyster (*Crassostrea*)	*Congeria leucophaeata* *Sphaerium*	*Elliptio complanatus*
Insecta	None	*Chaoborus albipes* *Tendipes*	Chironomid larvae Dragon fly larvae Stone fly larvae May fly larvae

fate—is important in a consideration of possible eutrophication of the lower Hudson. The present move to treat sewage so as to provide a liquid effluent may do little to reduce the nutrient levels of Hudson River water. In fact, it may worsen the present situation, since the treated effluent will provide nutrients in a readily available soluble form. Nitrate and phosphate levels in the Hudson are more than sufficient to develop algal blooms. Profuse blooms would result in a net oxygen depletion, with the subsequent reduction of nitrate and sulfate to noxious gases. In a flowing aquatic system, the interaction of nutrient concentrations and water temperature may be of major importance in controlling algal growth rates. If algal production exceeds the rate of removal by downstream flow and predation, nuisance blooms could result.

Heat additions

A further problem of growing importance is the use of water for industrial cooling. At the present rate of increase of water use in U.S., about [illegible]0% of the total fresh water runoff in the next 10 years will be required for cooling. Considering seasonal variations, about half of total runoff will be required for two thirds of the year. In the highly developed northeastern states, there are a number of rivers whose total flow is utilized, sometimes more than once in the passage downstream. Excessive water use will build up the heat load of fresh waters and estuaries; fortunately, heat is not conserved and can be dissipated to the atmosphere, provided the volume of water is adequate. Here is a situation where good management of water resources is essential to maintain water quality. The siting and design of power stations must be considered from the point of view of biological effects, so that overuse of the water resource is prevented. The difficulty lies in determining at what level of heat addition the biological effects are significant.

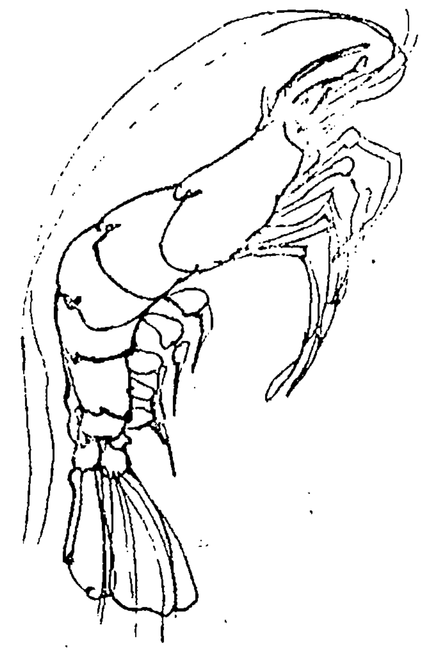
Long-term heat changes have been well documented for the Thames River, where heat released to the river rose from 555 mW in 1930 to about 3700 mW in 1950. The total volume of cooling water was approximately 2000 c.f.s. with a summer minimum of only 260 c.f.s. Of the total heat load in 1950, 75% was contributed by fossil fuel power stations, 6% by industrial effluents, 9% by sewage effluents, 6% by fresh water discharges, and 4% by biochemical activity. The yearly average temperature in the river over these 20 years rose from about 53° F. to about 60° F. (an estimate corrected for changing meteorological conditions). On the basis of the proportions of contributors above, three quarters of the 7° F. rise (or about 5.3° F.) is due to about 3000 mW of power. The biological effects of such a temperature rise are not known, but the additional temperature in the Thames increased the oxygen deficit by about 4%. This effect is not large, and the estuary would have remained anaerobic even if its water had not been used for cooling. However, it was calculated that the reducing conditions, together with the temperature, increased the evolution of hydrogen sulfide by 20%. Following the introduction of strict legislation to control the quality of industrial discharges other than heat, hitherto fishless zones of the metropolitan Thames once again support fish life, albeit of species tolerant of the low oxygen.

The flow of the Hudson is about 15 times greater than that of the Thames. The thermal capacity of the four power stations on the river is only 3000 mW, but projected development within the next few years includes an additional 10,000 mW. While the flow of the Hudson is not so intensively utilized as the Thames, and ambient air temperatures in the two countries are not the same, the paraltel is interesting, indicating the sort of temperature change, if not the magnitude, we might expect.

Biology of the Hudson

The variety of plants and animals in the Hudson is known only imperfectly. A study by the New York State Conservation Department some 30 years ago gives a good account of fish and rooted vegetation, but little information about the plankton or benthos (bottom living fauna) of the river. To evaluate the effects of such pollutants as excessive nutrients, trace metals, pesticides, and heat, we have been inventorying the kinds of animals and plants in the river, their relative abundance, and their distribution with respect to salinity. With so little baseline information, it is difficult to draw conclusions about changes in the biota that may have occurred. Even for fish studies, the methods of investigation have not been repeated. Hopefully, our present knowledge will be adequate to allow us to predict future changes in the river.

Our studies indicate there are two rather distinct environments in the Hudson River—the main channel and the shore. The main channel has abundant plankton, a rich variety of species of protozoa, diatoms, algae, rotifers, and the small crustacea which are important as food for larval fish. The shore has a rather different fauna and flora, partly because of different physical conditions, but also perhaps



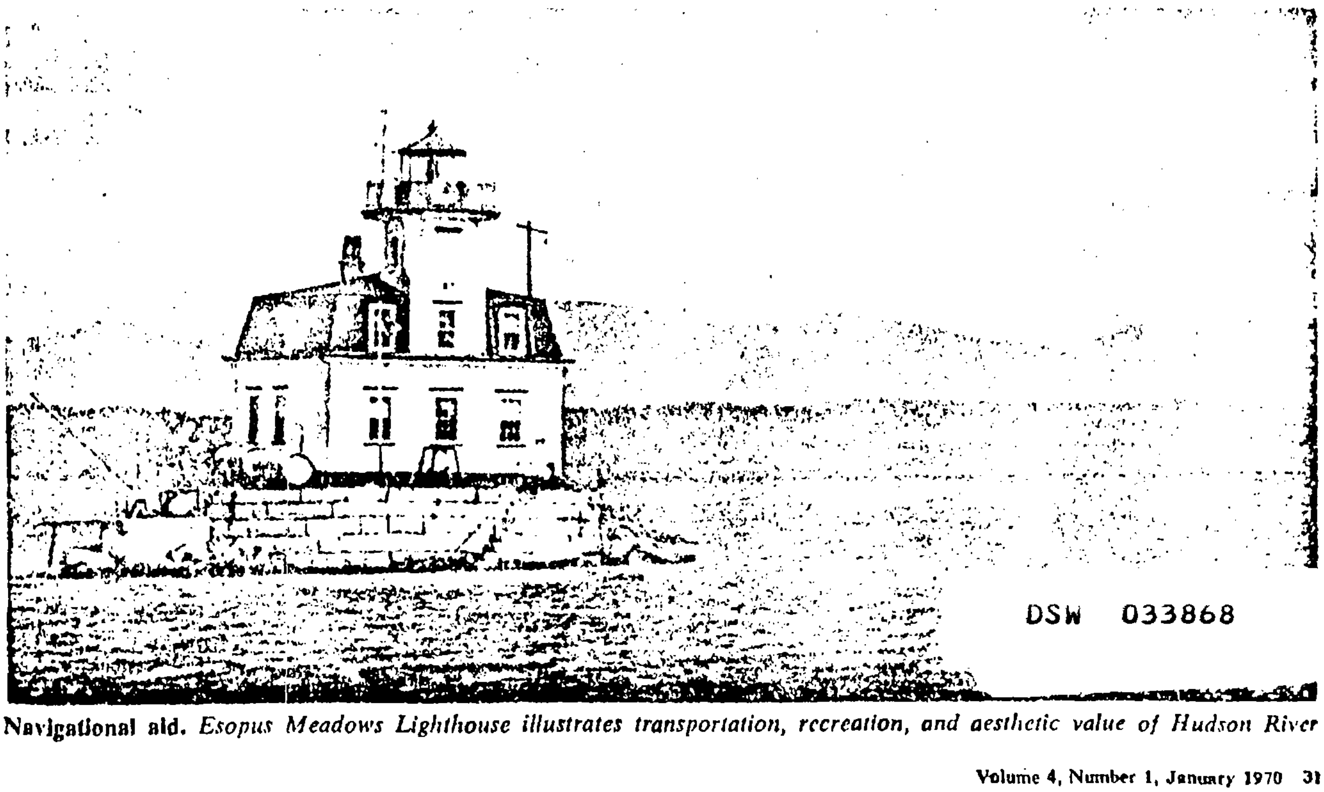
because pollutants from shore-sited industry sweep along the shores before they are diluted by the main body of the river.

In the oligohaline stretch of the river, the dominant phytoplankter during the spring and summer is the *Melosira ambigua*, but, during the fall, this species gives way to others. At the same time, salinity rises with the summer seawater intrusion, allowing survival of a more marine-type biota at this site. When the estuary water is diluted by early winter or spring rains, a return of *Melosira* is seen, together with a variety of other fresh water forms.

At a more southerly station on the river, a similar microflora to that at Indian Point was found during the summer. The limnetic zone in the summer is characterized by other species of *Melosira* and by other fresh water species. At all stations along the river, a number of species are found which might be considered as indicators of eutrophication. None of these were found as blooms, but the biological potential for nuisance algal growths (eutrophic species and more than adequate nutrient levels) undoubtedly is there.

The zooplankton characteristically is dominated by the microcrustacea, largely a flourishing copepod fauna. A number of crustaceans appear to be ubiquitous throughout many miles of the Hudson. Barnacle larvae are common in the plankton of mesohaline and oligohaline zones, derived from a benthic adult population extending to Peekskill. (Some of the copepod species show a transition with changing salinity.) An important zooplankter for fish nutrition, *Mysis oculata*, was found at Indian Point only in the fall of 1968, when salinity reached about 25% of the seawater levels.

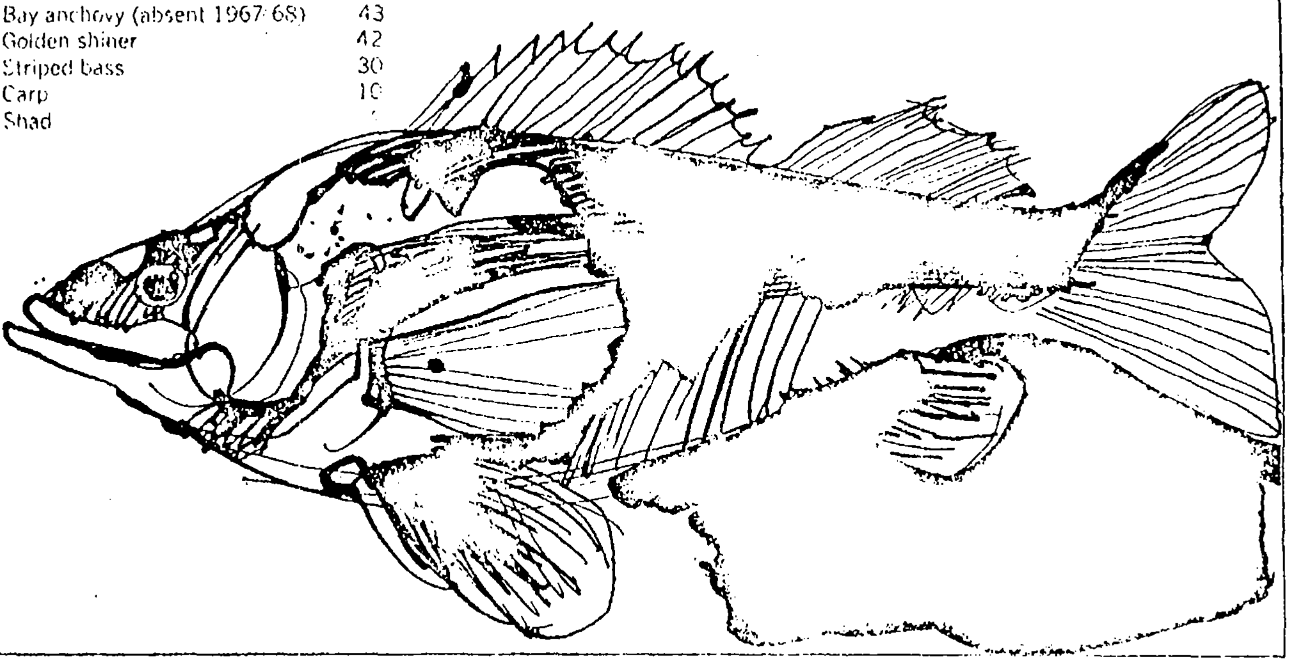
Another group common in the zooplankton is the rotifers, sometimes frequent enough to be termed blooms, again with a succession of species inhabiting different zones. The rotifer fauna appears to be rich and varied.



Navigational aid. *Esopus Meadows Lighthouse illustrates transportation, recreation, and aesthetic value of Hudson River*

Fish seined on lower Hudson shores, July–August 1965-68

	Mean number/100,000 ft²
Blueback herring	598
Freshwater killifish	512
Spot-tail shiner	333
Northern silverside	317
Johnny darter	200
White perch	180
Common sunfish	164
Alewife	102
Goldfish	93
Bay anchovy (absent 1967-68)	43
Golden shiner	42
Striped bass	30
Carp	10
Shad	



The protozoan fauna is also rich in species in all parts of the river, but we do not have quantitative assessments of the relative dominance of species. Ciliates (25 genera) and flagellates (15 genera) are common, as are shelled amoebae (15 genera), in shore collections. Of the larger invertebrate inhabitants of the river bottom and of the shores, we know little about relative abundance, but something about distribution. Larger crustacea are represented by the Harris crab and blue crab in the more seaward stretches of the estuary, and by shrimps and prawns in less saline water. Replacing these decapods in the limnetic zone are crayfishes. The presence of the crabs upstream of Tappan Zee seems to depend on the seawater intrusion during the late summer. The apparent scarcity of crabs in very recent years may then not be due to pollution, but rather to freshening of the river after the drought years of 1964-66.

Mollusks also show a salinity related distribution. One species of oyster has been found as far north as the Tappan Zee; in the fresh water, gastropods are common. Insects are scarcely present in the more saline reaches, only the larval *Chaoborus* and *Tendipes* extend into the oligohaline zone. Other insect larvae are found in the limnetic zone, but are restricted to the shore, except for chironomids. River mud provides habitat for worms.

The river has a large population of endemic fishes. Some 70 species recorded in 1936 include a tremendous migrant population of diadromous fish, many of which migrate into the Hudson or its tributaries to spawn. The shore environment serves as a nursery ground for the juvenile fish who feed on the snails, shrimp, and insects available there. This population has been sampled at selected stations along the river for the past five years by shore seining, and about 35 species have been recorded. The fish sampled by this technique are mostly in their first or second year, and some fish known to be present in the river—such as the hogchoker and the sturgeons—have not been seen. The shore sampling thus does not represent the true population, but only juvenile and small species which seek sheltered and shallow inshore areas. However, the consistent annual sampling can be used to indicate water quality changes. Most of the fish show little distribution related to salinity, since they are euryhaline, and able to live in waters of a wide range of salinity. The fresh water variety of killifish is dominant in the upper reaches of the river, while the euryhaline type is more common further south, and their distribution reflects the seawater intrusion. It is difficult to make valid comparison of the fish fauna of the river now and in 1936, but it is clear that the Hudson still presents an environment rich in variety and quantity of fish, even though commercial fishing in the river has severely declined.

Radionuclides

The lower Hudson River receives direct industrial waste discharges, as well as material from the watershed area, and the levels of some waste products in the river and its biota are of interest. We followed radionuclide and pesticide concentrations in the water and mud and their accumulation in the biota of the river.

The radionuclides are derived from three sources:

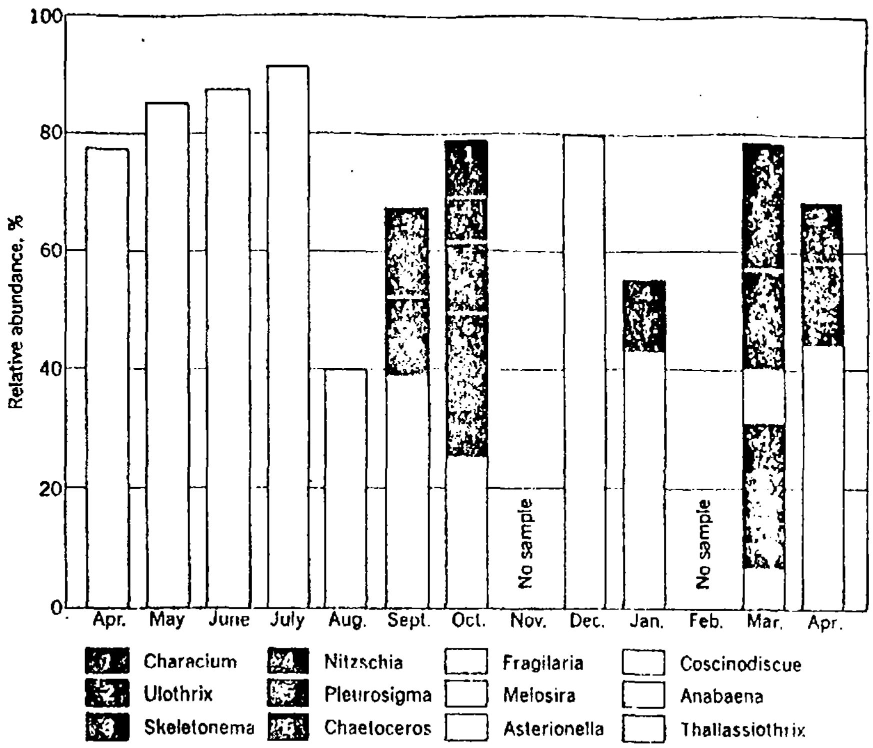
• **Natural products, such as radium and potassium-40.** This group reflects the geological character of the watershed and the degree of salt water intrusion. Potassium-40 is the major contributor of radioactivity in estuarine water and its biota. South of West Point, the mean potassium-40 concentration during the past five years was 22 picocurie per liter (pCi/l.), less than 10% that of seawater, while, in the limnetic zone, it is only 1.5 pCi/1. Natural radium-226 and radium-228 derived from soils each contribute only about one tenth of a pCi/1.

• **Fission products, derived from fallout from weapons testing.** The nuclides derived from fallout are cesium-137, strontium-90, cerium-144, and ruthenium-106. Levels of these nuclides in the water or biota are low, and together contribute only about 1 pCi/1.

• **Activation products released as a result of nuclear production.** This group is the most interesting, even though levels are very low in water. Among the nuclides seen are cobalt-60 and manganese-54. Although their levels are so low that accurate estimates are difficult to make, their accumulation in plants or animals leads to the use of selected species as natural monitors. The situation is illustrated best by manganese-54, which is found in river muds, especially downstream of the nuclear power station at Indian Point, where physical and chemical conditions of seawater promote the salting out of manganese compounds.

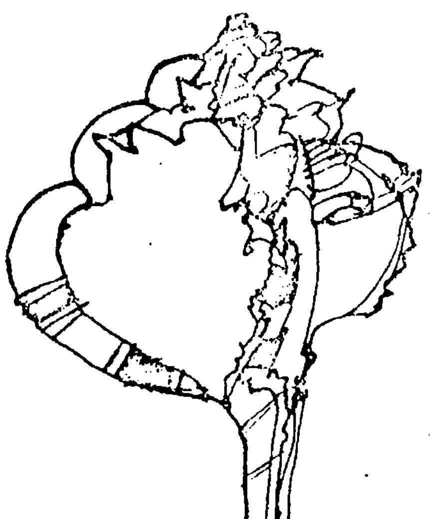
Both stable manganese and its radioactive analog are accumulated by some water plants, especially those in the genera *Chara, Potamogeton, Valisneria,* and *Myriophyllum*, which are found along the shores of the Hudson. Those plants growing closest to a reactor effluent site naturally show the highest levels of activity. The natural soluble manganese concentration in Hudson River water ranges from less than 0.5 to 12 μg./l., and total manganese (mostly particulate) about 1 mg./1. In *Potamogeton crispus*, it is about 2.3 mg./g. wet weight, indicating a concentration factor of about 190,000, with regard to the soluble nuclide concentration in the water, or 2300 to the total nuclide concentration. The total radioactive manganese levels in river water during 1966-68 indicate concentration factors of about 10,000 (range 3000-18,000) for this and similar species, in the same order of

Phytoplankton species in Hudson River at Indian Point



magnitude as total manganese. Plants of other genera, or phytoplankton samples, showed much lower levels of manganese or manganese-54.

Fish with a stable manganese content of only about 6 μg./g. wet weight do not show appreciable accumulation of radioactive manganese, even though exposed to the same concentrations in the ambient water. Even if species of fish which are known consumers of plants are considered, there is no appreciable accumulation of manganese-54 observed. Hence, although these fish may ingest food high in manganese-54, low absorption by the gut probably limits its uptake in fish. Among invertebrates in the river, blue crabs did not show any manganese-54, and only traces of two fission products, cerium-144 and cesium-137 (in 1964). Other crustaceans—crayfish, prawns, and shrimp—have similarly low concentrations. On the other hand, fresh water clams, which feed by filtering plankton and sediment from the water, showed a larger accumulation of radionuclides, including manganese-54, though not so much as plants. Other filter feeders—barnacles, oysters, etc.—were not sampled, but might be expected to have similar values. The relative accumulation from the two routes—direct uptake from the aquatic environment and uptake from ingested food—is not known.



Pesticides

While the distribution of radionuclides in the river water, mud, and biota reflects the distribution of the stable elements, as well as chemical interactions and the physiology of the biota, the distribution of pesticide residues reflects more clearly accumulation through trophic levels of the biota. Hudson River water contains numerous pesticide residues of the chlorinated hydrocarbon type, but only during the spring runoff are concentrations as high as 0.25 μg./1. At other times of the year, the levels are too low for effective quantitation, generally less than 0.010 μg./1., but the residues can be more readily identified in biological samples.

Like other major northeastern rivers, the Hudson River water appears to have little DDT, although its metabolites are present. Dieldrin is present in about the same levels of concentration as the DDT metabolites. This pattern of occurrence is reflected in the biota, where accumulations of dieldrin and DDT metabolites are seen, rather than DDT itself. The muds take up pesticides from the water or retain them in settled sediments after the spring runoff. Muds contain the pesticides at 0.01-0.05 μg./g. dry weight, generally several thousand times higher than the water. Plankton in the water, perhaps feeding on both microforms and suspended particles, build up concentrations of pesticides of about 0.02-0.06 μg./g. wet weight (0.1-0.3 μg./g. dry weight). This is about five to ten times higher than the sediments and about 20,000 times higher than water.

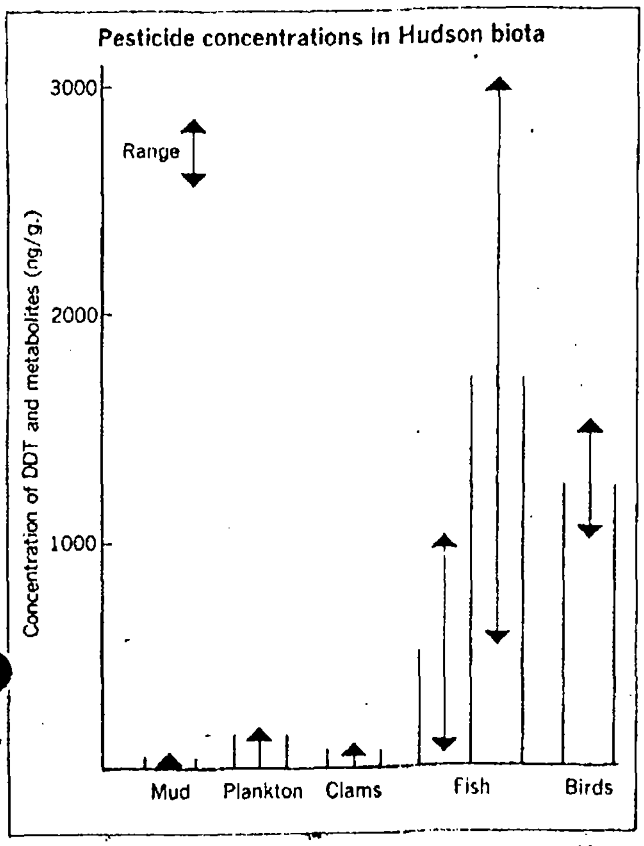
Clams feeding on the plankton would be expected to accumulate the residues to an even higher degree, but, in fact, pesticide concentrations in the fresh water clam are of the same order, 0.03-0.07 μg./g. wet weight. Various fish species in the river have pesticide concentrations ranging from 0.05-0.8 μg./g. wet weight. Local birds, such as heron and killdeer, thought to be consuming fish or invertebrates from the river, have 0.3-3 μg./g. wet weight on a whole body basis. The pesticide residues are particularly concentrated in fat. Thus, the continuing concentration through the food chain results in relatively high pesticide concentrations at the top of the food chain even though the base levels in the water are relatively undetectable. This has been observed in other environments.

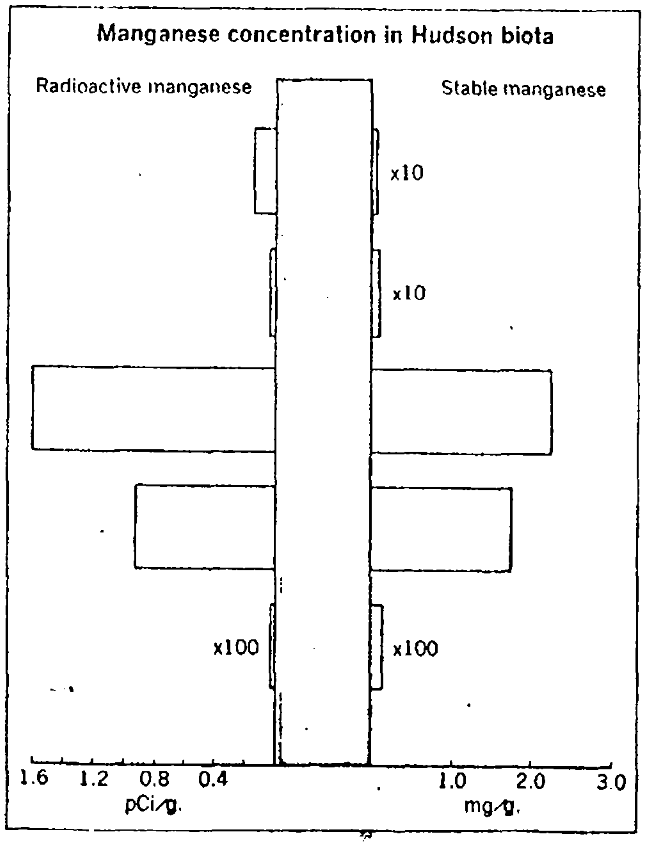
Trace element concentrations in the river water show great variability with sampling station, state of the tide, and temporal differences which, perhaps, reflect intermittent discharge of effluents from industries. Generally, in the limnetic zone, levels of trace metals are much less than those permitted by state or federal drinking water standards and do not appear to cause nuisance. In the more estuarine reaches of the river, high concentrations of iron, copper, and cadmium have been seen. Extensive studies would be required to locate the sources of such sporadic trace metal concentrations. Evaluation of potential biological effects would require application of sophisticated multivariate analysis.

Muds in the river may play an important role in the sequestration or regeneration of toxic material derived from pollutants, in addition to their role in the oxygen cycle. Our survey of radionuclides and pesticides has indicated that muds always are much higher in concentrations of these materials than the overlying water. There are other indications from gas chromatograph tracings that they are accumulators of diverse organic residues as well.

Most mud samples from the lower river are clay silts with about 5-6% of easily oxidizable humic material, 50% silt, and 20-45% clay. The cation exchange capacity of the muds is considerable, even in the brackish reaches where cations are readily available in the water. Consequently, most of the exchange sites on the muds are occupied by hydrogen under predominantly reducing conditions.

The muds contain a substantial amount of manganese, (0.72 μg./g. wet) compared with the ambient water, (0.01 μg./ml.). Hence, there is a sedimentary reservoir of manganese which could be available if reducing conditions prevail. Appreciable amounts of iron in the ferrous state also are present. Organic matter in the muds, oxidizable by hydrogen peroxide, accounts for more than 65% of the cation exchange capacity. Together with the unsaturated nature of the exchange sites, this indicates that, in relatively well oxygenated





conditions, the muds may have considerable capacity to absorb chemical pollutants, including radionuclides. More research is needed to evaluate the role of the muds in this capacity.

Conclusions

It is not difficult to predict an increased use of the Hudson River for the disposal of sewage wastes, industrial effluents, and cooling water, and for augmenting existing water supplies. At the same time, the burgeoning population of the area has a need and a right to use the river for recreation. How can further development be controlled, so that the water resources can be exploited, but still provide for that refreshment of the spirit so necessary for the urban inhabitant? Changes that might be expected from increased use are:

- First, an increasing nutrient load from domestic sewage and some industrial processes.
- Second, an increasing heat load.
- Third, an increased demand for industrial and domestic water.

Our studies have made clear that potential eutrophic nuisance species of algae are present in the river, and that the shores are populated by animals indicative of sewage pollution. Yet, serious fouling and deoxygenation have so far been avoided for most of the river. From this it could be deduced that the present situation need cause no concern; however, examples of other eutrophic water bodies give us warning of the potential rapidity of changes, and should encourage effective sewage treatment and the control of nutrient sources.

Heat additions to the aquatic environment are a major concern. In the Hudson, the volume of tidal flow can be utilized to disperse such heat; at the same time, it is clear that the capacity of the river as a heat sink is severely limited during the peak summer demand by a low net flow and high ambient air temperatures. If significant overall temperature rise in the river were allowed, it is highly probable that the species composition of the fauna and flora would be unbalanced. This interacting with the high nutrient levels in the river could easily tip the balance between nuisance conditions and the relatively healthy biological situation seen today. The effects of a temperature rise restricted to localized sites on the river have yet to be evaluated. There is a great need for more detailed hydrological and thermal studies of the river to evaluate the capacity of the Hudson to receive heat addition. There is also need for studies of species endemic to the river to determine their response, singly and together, to changes in temperatures.

The extraction of additional water for any purpose—pumped storage schemes, industrial use, or domestic use—is also of great importance, and is closely related to the other uses of the river. Almost any increased water extraction, except industrial cooling intakes, will make a volume of water unavailable at least for limited periods or limited stretches of the river. The effects of this on the present hydrological pattern in the river remain largely unknown. It seems probable, however, that the extent and duration of salt water intrusion up the river will increase. This will limit the sites for drinking water extraction and reduce the capacity for exchange of effluent discharges with the ocean which depends largely on the net fresh water flow.

How can the situation be controlled? We need more information about all aspects of the hydrology of the estuary, about the fauna and flora of the river and their response to existing and predicted conditions. We need strictly controlled use of the river for all purposes and at all levels. And, finally, we need to know how to alleviate pollution problems when they have arisen and how to channel waste materials, including heat, to other outlets.

ADDITIONAL READING

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