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The Disposal of Waste in the Ocean

Contrary to some widely held views, the ocean is the plausible place for man to dispose of some of his wastes. If the process is thoughtfully controlled, it will do no damage to marine life

by Willard Bascom

No one would dispute the wisdom of protecting the sea and its life against harm from man's wastes. An argument can be made, however, that some of the laws the U.S. and the coastal states have adopted in recent years to regulate the wastes that can be put into the oceans are based on inadequate knowledge of the sea. It is possible that a great effort will be made to comply with laws that will do little to make the ocean cleaner.

This discussion of waste disposal will be limited to disposal in the ocean; it will not take up disposal in lakes, rivers, estuaries, harbors and landlocked bays. Indeed, part of the problem is that insufficient distinction has been drawn between the ocean and the other bodies of water, whose chemistry, circulation, biota and utilization differ from those of the ocean in many ways. It is not sensible to try to write one set of water-quality specifications that will cover all bodies of water. My concern here is only with the quality of ocean water and marine life along the U.S. Atlantic, Gulf and Pacific coasts. The scientific findings in those areas apply, however, to nearly any other coastal waters that are exposed to ocean waves and currents.

Some of the changes that human activities have wrought in the ocean environment are already irreversible. For example, rivers have been dammed, so that they release much smaller quantities of fresh water and sediment. Ports have been built at the mouth of estuaries, changing patterns of flow and altering habitats. On the other hand, certain abuses of the ocean have already been stopped almost completely by the U.S. Nuclear tests are no longer conducted in the atmosphere, so that radioactive material is no longer distributed over the land and the sea; the massive dumping of DDT has been halted, and the reckless development of coastal lands has been restrained by laws calling for detailed consideration of the impact on the environment.

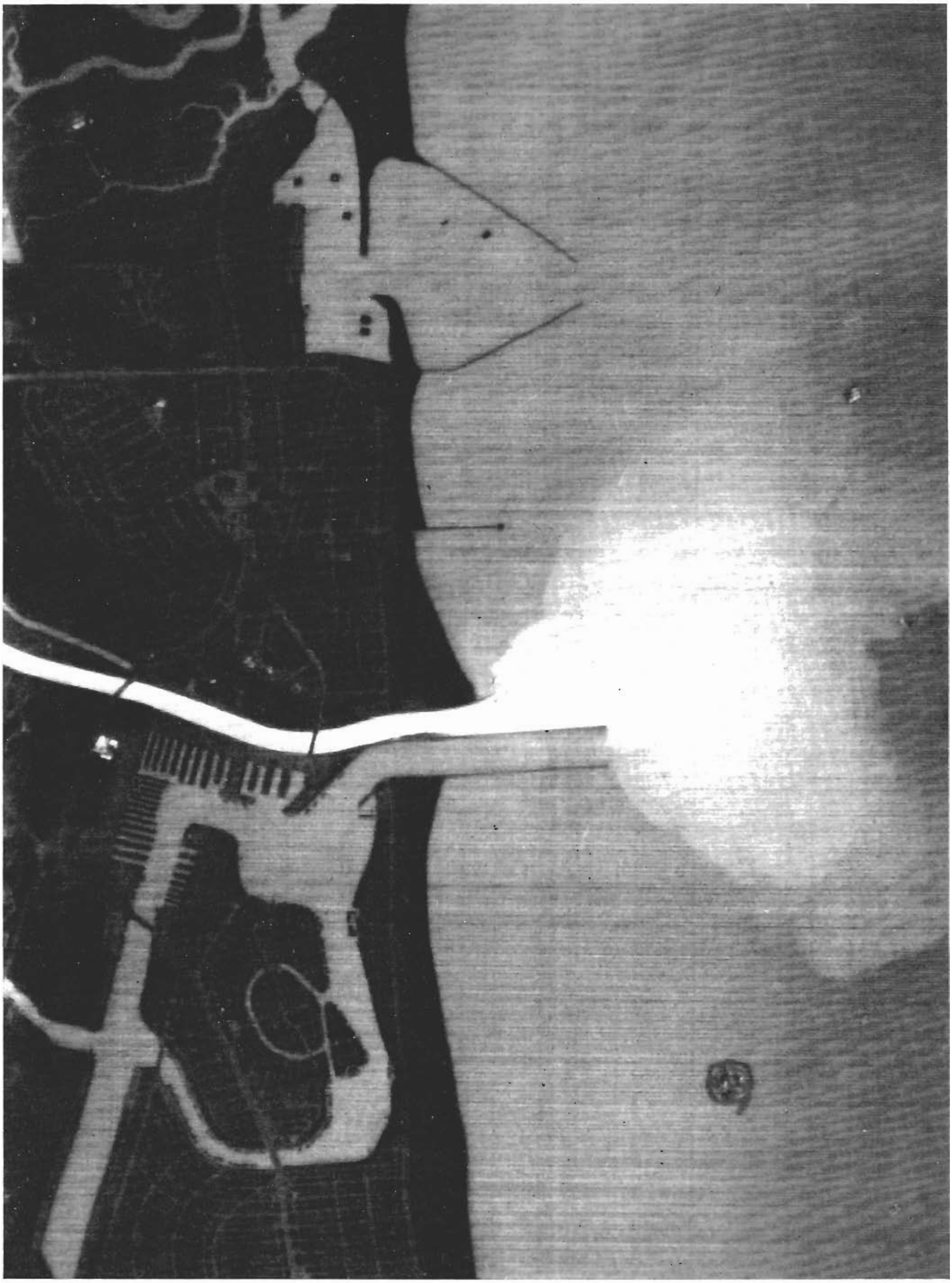
Between these extremes is a broad realm of uncertainty. Exactly how clean should the ocean be? How unchanged should man try to keep an environment that nature is changing anyway? The problem is to decide what is in the best interest of the community and to achieve the objective at some acceptable cost. At the same time it is necessary to guard against the danger that excessive demands made in the name of preserving ecosystems will lead to action that is both useless and expensive.

Waste disposal automatically suggests pollution, which is a highly charged word meaning different things to different people. A definition is needed for evaluating accidental and deliberate inputs into the ocean. Athelstan F. Spilhaus of the National Oceanic and Atmospheric Administration, who has written extensively on pollution, defines it as "anything animate or inanimate that by its excess reduces the quality of living." The key word is excess, because most of the substances that are called pollutants are already in the ocean in vast quantities: sediments, salts, dissolved metals and all kinds of organic material. The ocean can tolerate more of them; the question is how much more it can tolerate without damage.

One approach to the question was suggested by the National Water Commission in its report of June, 1973, to the President and Congress: "Water is polluted if it is not of sufficiently high quality to be suitable for the highest uses people wish to make of it at present or in the future." What are "the highest uses" that can be foreseen for ocean waters, particularly those near the shore? They are probably water-contact sports, the production of seafood and the preservation of marine life.

Water-contact sports are occasionally

MONTEREY BAY in California appears in a deliberately overexposed aerial photograph on the opposite page. The overexposure through a filter is a technique that shows details of turbidity in the water caused by mud, organisms or waste. At bottom right a harbor projects into the bay. The light spot of water along the shore above and slightly to the left of the harbor is a sewage outfall. The dark brown spots are beds of kelp, and the reddish purple is a "red tide" consisting of large numbers of the marine organism *Gonyaulax*.



THERMAL EFFLUENT from generating plants of the Southern California Edison Co. and the Los Angeles Department of Water and Power appears in a thermograph of the San Gabriel River, which is the white strip at center, and San Pedro Bay. The intake temperature of cooling water from the bay was 18.9 degrees Celsius. On discharge into the river it was 26.7 degrees C. At the point where the river enters the bay the water temperature was 24.4 degrees C. The two plants jointly generate 900 megawatts of power.

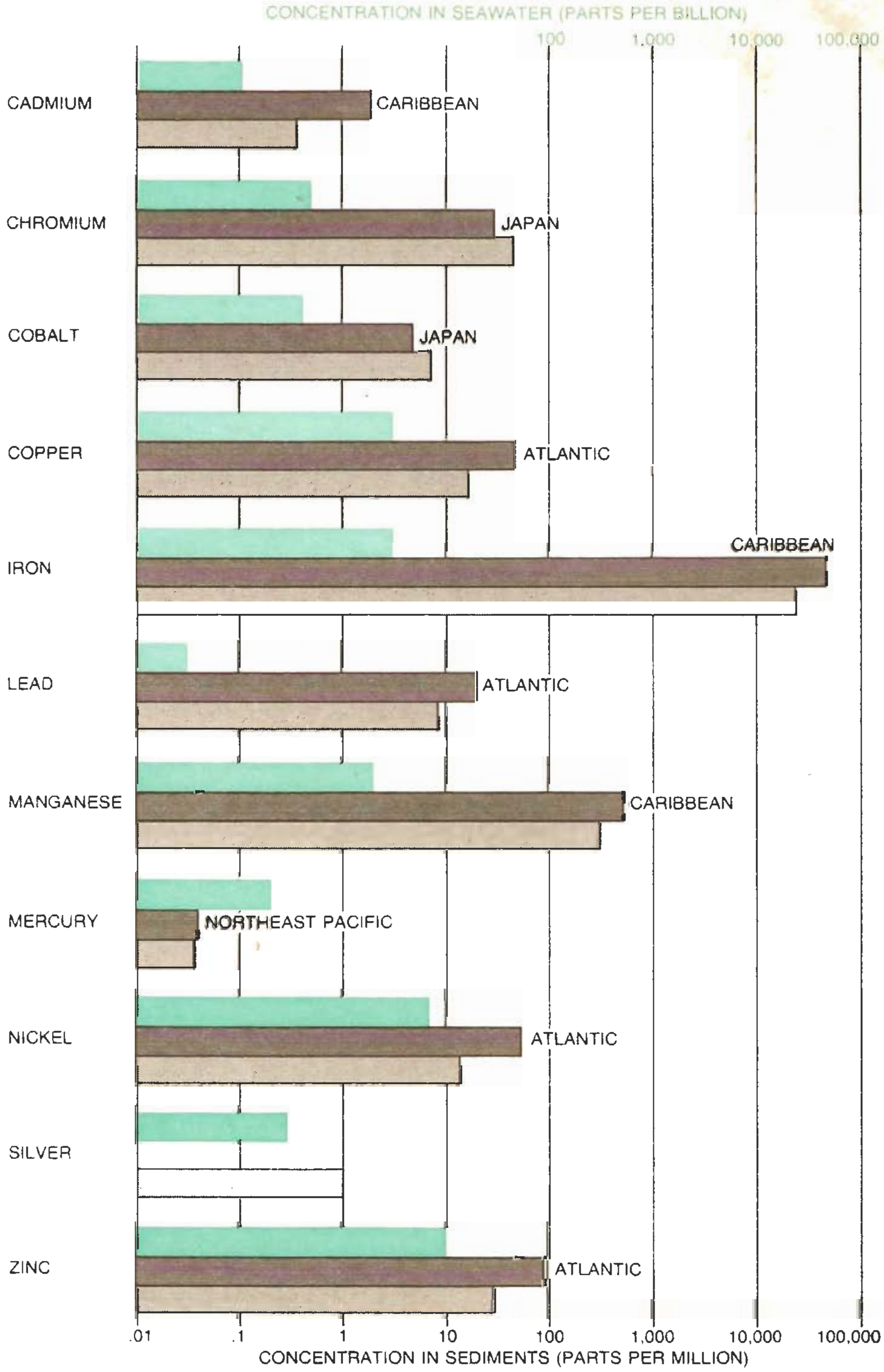
inhibited by pollutants on the seacoasts of the U.S. Where such conditions exist they should be corrected at once. Even where coastal waters are clean the community must be alert to keep them so.

To maintain the ocean waters at an acceptable level of quality it is necessary to consider the main inputs of possible pollutants resulting from human activity. One of them is fecal waste (75 grams dry weight of solids per person per day), which after various degrees of treatment ends up in the ocean as "municipal effluent." Wastes also flow from a host of industrial activities. They are usually processed for the removal of the constituents that are most likely to be harmful, and the remaining effluent is discharged through pipes into the ocean. Dumping from barges into deep water offshore is a means of disposing of dredged materials, sewage sludge and chemical wastes. Thermal wastes include the warmed water from coastal power plants and cooled water from terminals where ships carrying liquid natural gas are berthed. In addition ships heave trash and garbage overboard and pump oily waste from their ballast tanks and bilges.

Such are the intentional discharges, but pollutants reach the ocean in other ways. Aerial fallout brings minute globules of pesticide sprayed on crops, particles of soot from chimneys and the residue of the exhaust of automobiles and airplanes. Painted boat bottoms exude small amounts of toxicants intended to discourage the growth of algae and barnacles. Forest fires put huge amounts of carbon and metallic oxides into the air and thence into the sea. Oil spills from ship collisions and blowouts during underwater drilling operations add an entire class of compounds.

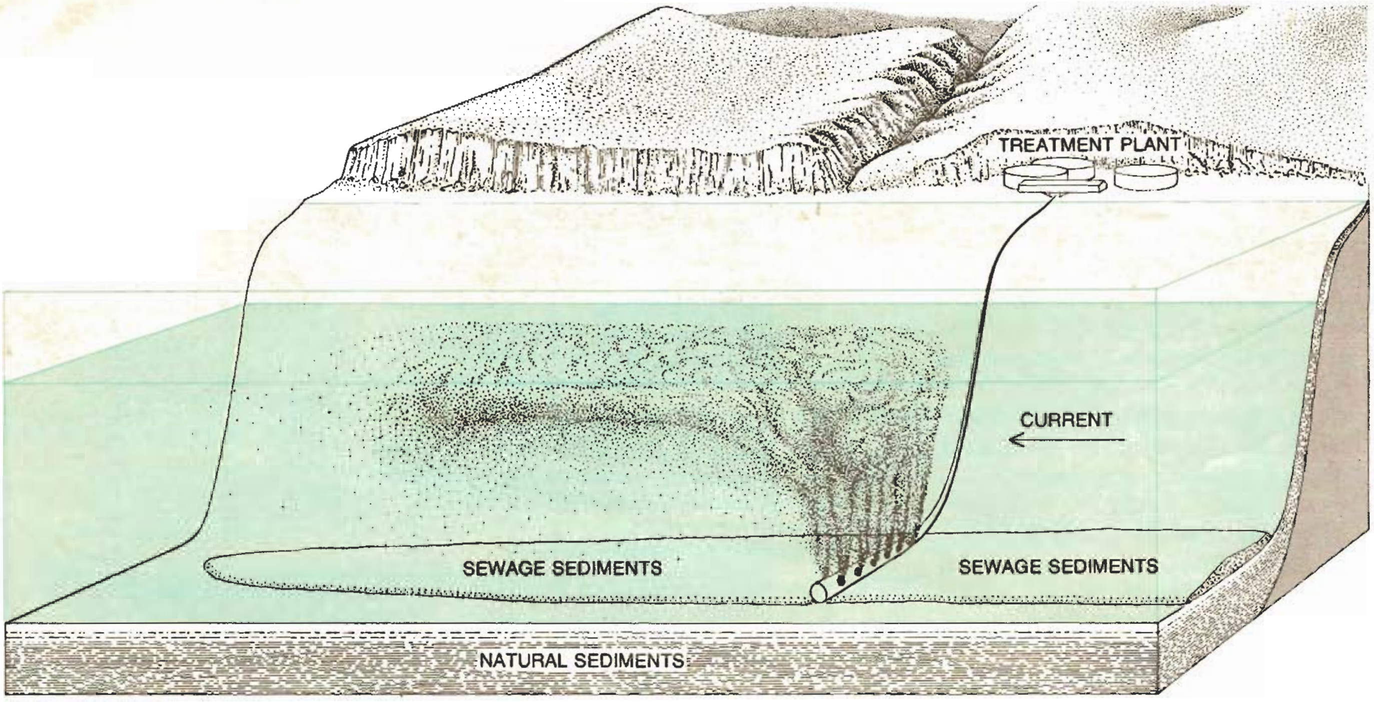
Moreover, natural processes contribute things to the sea that would be called pollutants if man put them there. Streams add fresh water, which is damaging to marine organisms such as coral, and they also bring pollutants washed by rain from trees and land. Volcanic eruptions add large quantities of heavy metals, heat and new rock. Oil has seeped from the bottom since long before man arrived.

Finally, the ocean is neither "pure" nor the same everywhere. It already contains vast amounts of nearly everything, including a substantial burden of metals at low concentration and oxygen at relatively high concentration, plus all kinds of nutrients and chemicals. It has hot and cold layers, well stratified by the thermocline (the boundary between the warm, oxygen-rich upper layer and the cold, oxygen-poor depths). Waves and currents keep the water constantly in motion. It is against this complex background that man must measure the effects of his own discharges.

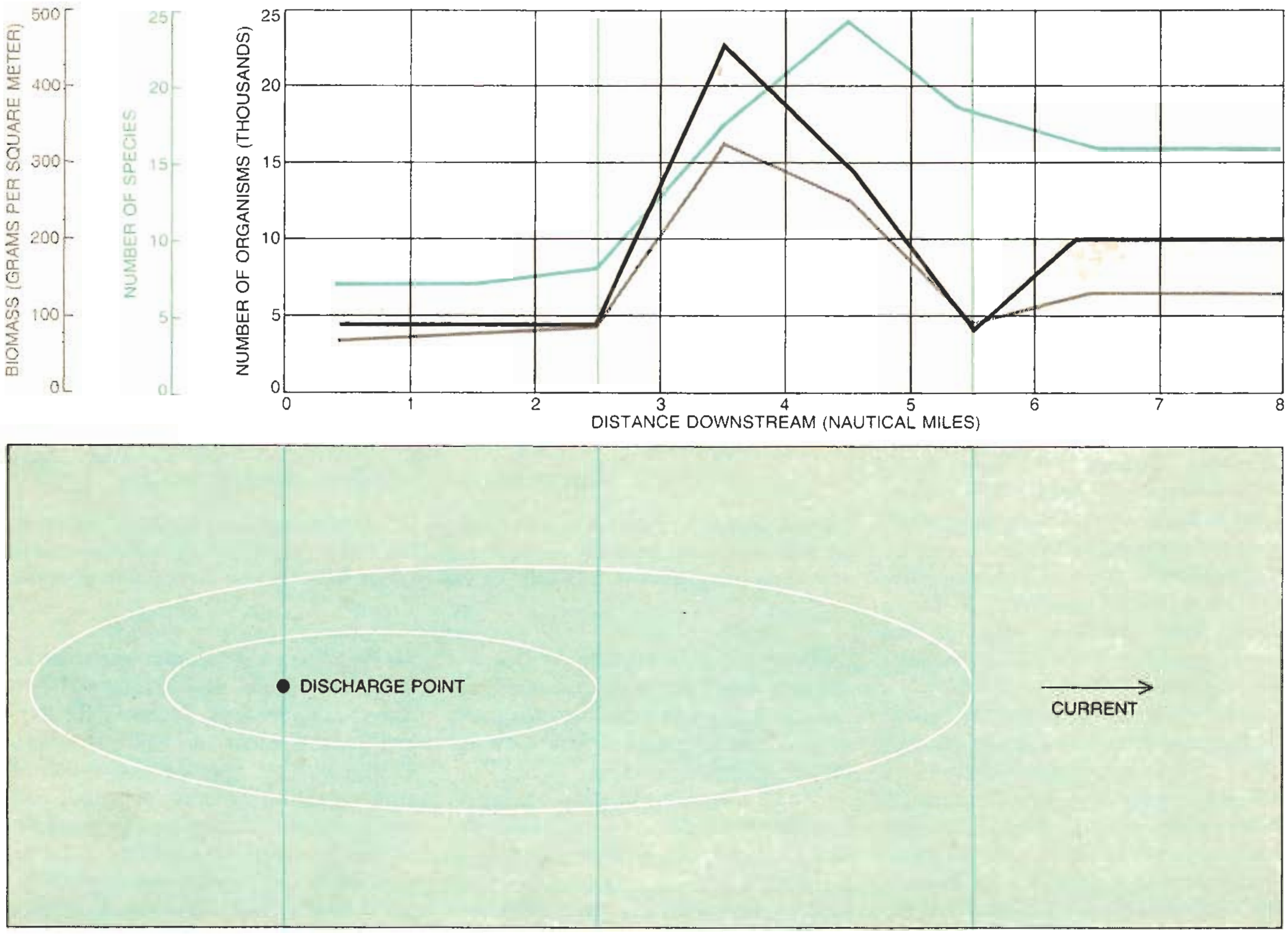


TRACE METALS in seawater (*color*) and top 10 centimeters of sediment (*gray*) are charted. Seawater figures are a worldwide average. The darker gray bars show concentrations at several sampling sites and the lighter bars the average from five sites along California coast.

Even if there were no people living on seacoasts, it would be impossible to predict accurately the kind and quality of marine life because of the natural variability of the ocean. The biota shifts constantly because the temperature and the currents change. Great "blooms" of plankton develop rapidly when conditions have become exactly right and then die off in a few days, depleting the oxygen in the water on both occasions. Within a single year the population of such organisms as salps, copepods and euphausids can change by a factor of 10. When the waters off California become warmer as the current structure shifts, red "crabs" (which look more like small lobsters and are of the genus *Pleuroncodes*) float by in fantastic numbers, fol-



OCEANIC DISPOSAL of waste from a sewage-treatment plant is portrayed. The system is for a plant with a capacity of about 100 million gallons per day. Effluent from the plant flows a distance of from two to five miles through an outfall pipe that is from six to 12 feet in diameter. For about a quarter of a mile at its end the pipe has dozens of six-inch discharge ports. The mostly liquid material it discharges rises to the thermocline, which is the boundary between deep, cool water and the warmer surface layer. Prevailing current mixes material and moves it to one side or the other, depending on wind and tide. Some solid particles settle on the bottom.



EFFECT OF OUTFALL on a community of polychaete worms is depicted. For about three miles downstream from the outfall the worm population is reduced. For the next three miles it is above normal. Thereafter it is about the same as in uninfluenced seabed.

lowed by large populations of bonito and swordfish. They came in 1973 as they did in 1958 and 1963, but the water soon turned cold again and the fish departed, leaving windrows of dead *Pleuroncodes* along the beaches.

The investigator's problem is to learn enough about the major natural changes so that he can tell whether or not human activities have any effect, either positive or negative. It is a signal-to-noise problem; here the changes one is trying to detect are often only a tenth of the natural biological and oceanic background variations. Both types of variation are hard to quantify.

In the case of the sardine, however, a record of the natural changes has been preserved below the floor of the Santa Barbara Basin off the coast of southern California. The bottom of the basin is anaerobic, that is, lacking in oxygen and so supporting little life. The particles that sift down to form sediments are undisturbed by burrowing creatures and therefore remain exactly as they land, in thin strata, layer on layer, one per year. The years can be counted backward, and the count can be confirmed with the lead-210 dating technique.

Some years ago John D. Isaacs of the Scripps Institution of Oceanography, who is also director of the California Marine Life Program, discovered in work with Andrew Soutar that each layer contains identifiable fish scales. Each layer showed a more or less constant number of anchovy and hake scales, but the sardine scales were present erratically, indicating major changes in the population. When the sardines disappeared about 1950, human activities were blamed. The geologic record clearly shows, however, that the sardines had come and gone many times before man arrived. Someday they will return.

It is obvious that some of man's wastes can be damaging to sea life; indeed, products such as DDT, chlorine and ship-bottom paint have been specifically designed to protect man against insects, bacteria and barnacles. Ionic solutions of certain metals are also known to be toxic at some level, as are numerous other substances. The problem is to determine what level is harmful, remembering that some of the substances are actually required for life processes. For example, copper is beneficial or essential for a number of organisms, including crabs, mollusks and oyster larvae. Other marine animals seem to require nickel, cobalt, vanadium and zinc.

Oceanographers would like to be able to demonstrate cause and effect in the ocean, that is, to show that some specific level of a metal does not harm marine life. Proving the absence of damage, however, including long-term and genetic effects, is difficult. Only on fairly rare occasions has it been possible to directly link a specific oceanic pollutant with biological damage. Examples include the finding by Robert Risebrough of the University of California at Berkeley that the decline of the brown pelican off California was attributable to DDT, which inhibits the metabolism of calcium and so makes the shells of the eggs so thin that the mother pelican breaks her own eggs by sitting on them. After patient scientific detective work the source was found to be a single chemical plant in the Los Angeles area. As a result of the work the plant was required to stop discharging DDT wastes into the ocean, and the brown pelican is now returning to California.

From what I have said so far it can be seen that the question of what is a pollutant or what amount of a substance represents pollution is not always easy to answer. Let me now try to put the main kinds of waste in proper perspective.

Municipal sewage containing human fecal material is the type of waste one usually thinks of first. It is certainly a natural substance; indeed, as "night soil" it has long been in demand as a fertilizer in many countries. Since it is not appreciably different from the fecal material discharged by marine animals, is there any reason to think it will be damaging to the ocean, even without treatment? Isaacs has pointed out that the six million metric tons of anchovies off southern California produce as much fecal material as 90 million people, that is, 10 times as much as the population of Los Angeles, and the anchovies of course comprise only one of hundreds of species of marine life.

Two aspects of municipal sewage do require attention. One of them is disease microorganisms. Human waste contains vast numbers of coliform bacteria; they are not themselves harmful, and they die rapidly in seawater (90 percent of them in the first two hours), but they are routinely sampled along public beaches because they indicate the level of disease microorganisms. When there are no endemic diseases in the city discharging the waste (the normal condition in the U.S.), there will be none in the water. It should be noted, however, that the assumption that disease microorganisms die off at the same rate as coliform bacteria is being questioned. It is necessary to guard against the possibility that such organisms will survive in bottom muds long enough to be stirred up by a major storm.

The usual way of reducing the bacterial count is to add chlorine to waste water that is about to be discharged. This approach seems reasonable, since chlorine is commonly added to drinking water and swimming pools to kill bacteria and algae. The trick is to add just the right amount, so that the chlorine exactly neutralizes the bacteria and no excess of either enters the ocean.

The other problem with sewage is one of aesthetics. People do not like to look at discolored water or oily films. A greater effort to reduce effluent "floatables" (tiny particles of plastic, wood, wax and grease) will help to reduce such effects. It will also reduce the number of bacteria reaching the shore, since many of them are attached to the particles.

Petroleum products are perhaps the most controversial marine pollutants. They are seen as small, tarlike lumps far out to sea and on beaches, as great slicks and as brown froth. From two to five million metric tons of oil enter the ocean annually. At least half of it is from land-based sources such as petroleum-refinery wastes and flushings from service stations. Significant quantities of oil enter the marine environment from airborne hydrocarbons. A considerable amount of oil must enter the ocean as natural seepage from the bottom, but it is obviously difficult to estimate how much.

Oil pollution from ships is the most serious problem. Oceangoing vessels shed oil in three ways: by accidents such as collisions; during loading and unloading, and by intentional discharge, which includes the pumping of bilges, the discharge of ballast by tankers and the cleaning of oil tanks by tankers. The ballast component is the worst.

After a tanker unloads its cargo of oil it takes on seawater (about 40 percent of the full load of oil) so that it will not ride too high in the water and be unmanageable. Any oil that remains in the tanks mixes with the water and is discharged with it when the ballast is pumped out in preparation for reloading the vessel with oil. The discharge of oil can be reduced in two ways. One is to wash the tank with water and stow the water aboard in a "slop tank," where the oil slowly separates from it. Then the water is discharged and the next load of oil is put on top of the oil that remains in the slop tank. This practice, which is described as being 80 percent effective, is followed in tankers carrying about 80 percent of the oil now transported at sea. The other stratagem is to build segregated ballast spaces into the double bottoms of new tankers, which reduces the discharge by 95 percent.

A system of international controls could virtually eliminate such discharges. There is an extra incentive for international controls because wherever oil is discharged, and by whatever ship, there is no telling to what shore it will be carried by winds, waves and currents. Substantial progress toward this kind of agreement has been made recently.

Ships are also responsible for most of the littering of the ocean and its shores. Waste consisting of paper, plastics, wood, metal, glass and garbage is customarily thrown overboard. The heavier material sinks quickly, littering the bottom; paper products disintegrate or become waterlogged and sink slowly, and the foods are soon consumed by marine scavengers. The wood, sealed containers and light plastics float ashore.

The estimated yearly litter from ships is about three million metric tons, much of which seems to come from the fishing fleets. The litter that Americans see and are annoyed by comes mostly from the land by way of streams or is thrown into harbors or tossed overboard from pleasure craft. Littering is an aesthetic problem rather than an ecological one, but it certainly reduces the quality of living. It can be curbed by the force of public opinion.

Dumping is a word with a specific meaning; it should not be confused with littering or with discharges from pipes. Dumping means carrying waste out to sea and discharging it at a designated site. Barges carrying solids simply open bottom doors and drop their cargo. Barges carrying liquids generally pump the material out through a submerged pipe into the turbulent wake of the vessel. Still other barges dump wastes enclosed in steel drums or other containers.

Much of the material is dredge spoil sucked up from harbor bottoms by hopper dredges to deepen ship channels. Some 28 million tons of this material were dumped into the Atlantic in 1968. Next in quantity in the New York area is relatively clean material removed from excavations for buildings, then comes sewage sludge, and finally industrial waste such as acids and other chemicals.

The amount of sludge dumped annually into New York Bight is about 4.6 million tons. Much of it is sewage sludge, which is a slurry of solid waste formed by sedimentation in primary sewage treatment or by secondary treatment in the activated-sludge process. For ocean discharge the material is thickened by settling or centrifuging to from 3 to 8 percent solids. Much of the solid material is silt, but complex organic materials and heavy metals are also present.

In some parts of the country the sludge is not dumped but is discharged into the ocean through special pipes. In others it is buried in landfill or spread as fertilizer, although the metals it contains may cause problems later. A broad spectrum of industrial effluents (solvents from pharmaceutical production, waste acid from the titanium-pigment industry, caustic solutions from oil refineries, metallic sodium and calcium, filter cake, salts and chlorinated hydrocarbons) are dumped intermittently at certain sites under Government license.

What damage is done to marine organisms by materials of this kind? The turbidity created by dumping is usually dispersed within a day. Dumped dredge spoil buries bottom-dwelling animals under a thin blanket of sediment, but many of them dig out and the others are replaced by recolonization in about a year. Sewage sludge is high in heavy metals, which may be toxic, particularly when they combine with organic materials to create a reducing (oxygen-poor) environment in which few animals can live. Sludge can also have a high bacterial count. It is clear that much industrial waste could be harmful to marine life and should not be dumped into the sea.

The entire matter of dumping needs more study. With reliable data it will be possible to retain the option of disposal at sea for some materials, such as dredge spoil, and to reject it for others, such as chemicals. Deep-water sites could be set aside for dumping on the same logic that applies to city dumps, namely that it is a suitable use for space of low value where few animals could be harmed.

Thermal waste is discharged into the sea by power plants because the sea is a convenient source of cooling water. The temperature of the water on discharge is typically 10 degrees Celsius higher than it was on intake. The difference is within the range of natural temperature variations and so is not harmful to most adult marine animals. The eggs, larvae and young animals that live in coastal waters, however, are sucked through the power plant with the cooling water. They are subjected to a sudden rise in temperature and decrease in pressure that is likely to be fatal. For this reason and others it would seem logical to put new power plants offshore. There they could draw deeper and cooler water from a level that is not rich in living organisms. For a nuclear plant the hazards of a nuclear accident would be reduced; for an oil- or coal-fired plant fuel could be delivered directly by ship, and the shoreline could be reserved for nonindustrial purposes.

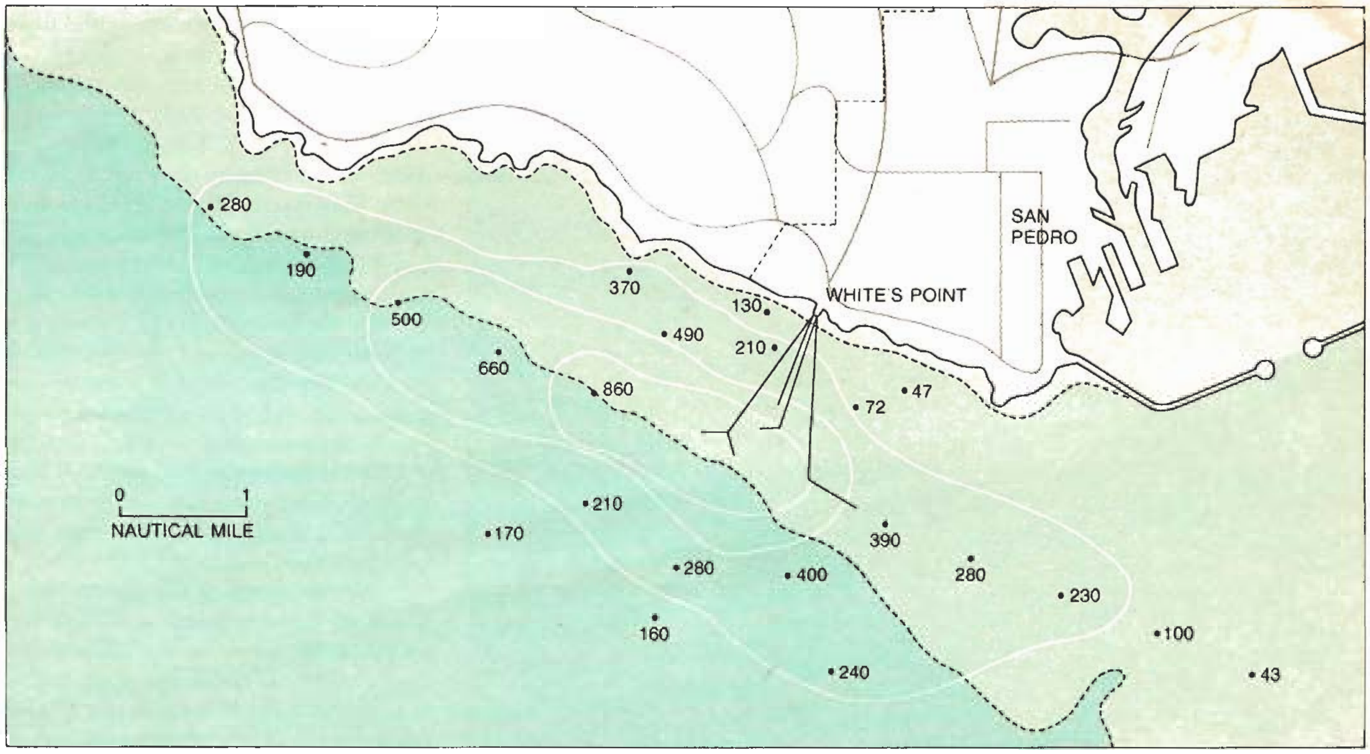
Some industries discharge substantial quantities of heavy metals and complex organic compounds into municipal waste-water systems whose effluent reaches the ocean. Certain of the metals (mercury, chromium, lead, zinc, cadmium, copper, nickel and silver) are notably toxic and so are subject to stringent regulation. The most dangerous substances, however, are synthetic organic compounds such as DDT and polychlorinated biphenyls. The discharge of these substances as well as the heavy metals must be prevented. The best way to do so is by "source control," meaning the prevention of discharge into the sewer system. Each plant must be held responsible for removing and disposing of its own pollutants.

Other waste substances that generate controversy are those with nutrient value. Since they are decomposed by bacteria, oxygen is required. This biological oxygen demand is commonly measured in units that express how much oxygen (in milligrams per liter) will be required in a five-day period.

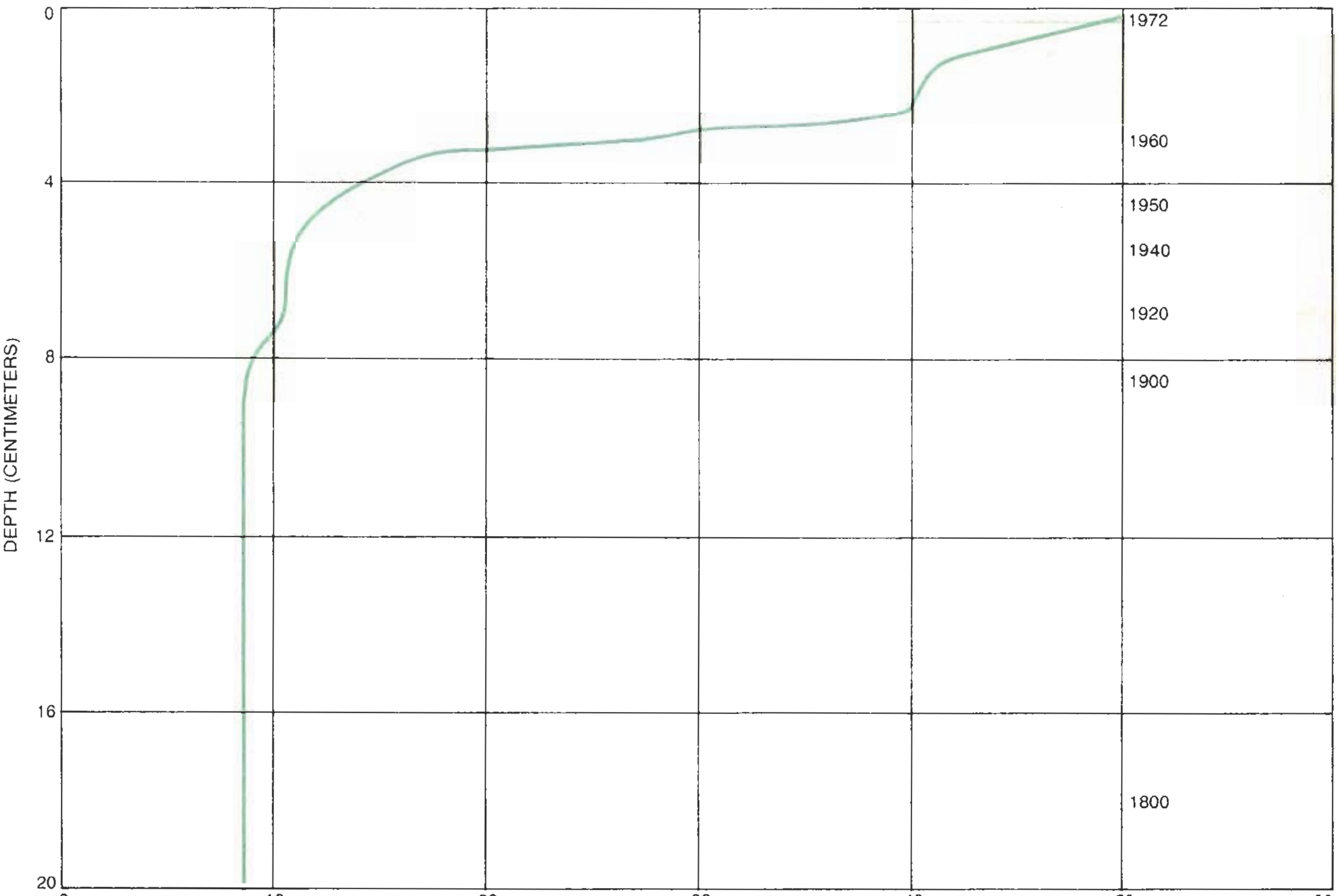
There is good reason to restrict the amount of nutrient material that is discharged into lakes and rivers, where oxygen is limited and a reducing environment can be created. The ocean is another matter. It is an essentially unlimited reservoir of dissolved oxygen, which is kept in motion by currents and is constantly being replenished by natural mechanisms.

It is nonetheless possible to overwhelm a local area of the ocean with a huge discharge of nutrient material that may form a deposit on the sea floor if the local conditions are not carefully considered. The materials must be presented to the ocean in the right places and at reasonable rates. Among the ways of achieving that objective are the use of discharge pipes that lead well offshore and have many small diffuser ports and, if the volume of discharge is exceptionally large, the distribution of the effluent through several widely dispersed pipes.

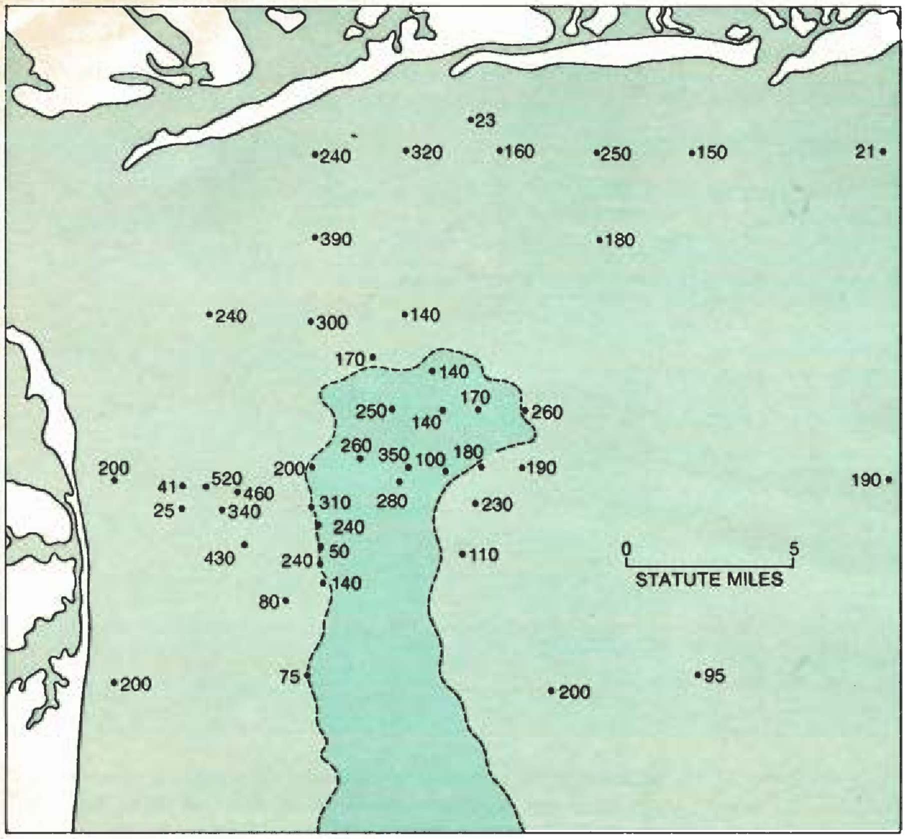
Problems caused by the addition of nitrogen and phosphate to inland waters, which they overfertilize, do not apply to the ocean. There they could be helpful by producing the equivalent of upwelling, the natural process that brings nutrients from deep water to the surface waters where most marine organisms are found. As Isaacs has pointed out, "the sea is *starved* for the basic plant nutrients, and it is a mystery to me why



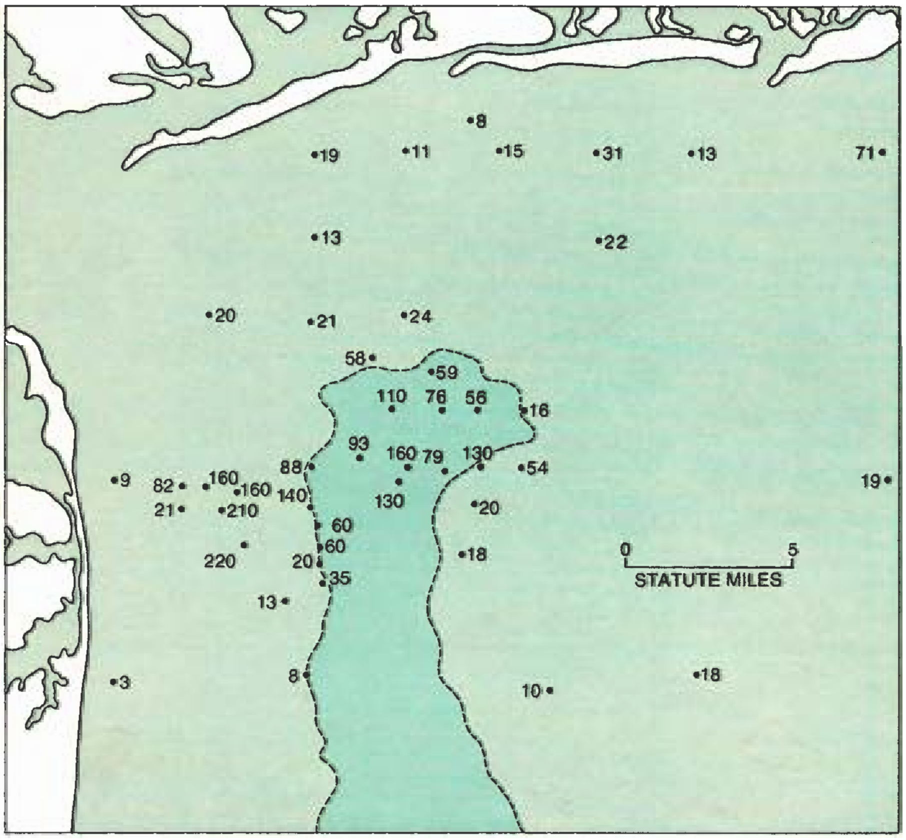
CONCENTRATION OF CHROMIUM in the upper sediments adjacent to a major industrial outfall off San Pedro, Calif., is charted in parts per million. Four outfall lines enter the sea from White's Point. The smallest area surrounded by an elliptical contour line is the area where the concentration is 800 parts per million or more, and the larger contoured areas have concentrations above 500 and 200 parts per million respectively. A depth of three fathoms is shown by the broken line close to shore. Farther out is a 50-fathom line. Other heavy metals discharged into the ocean make similar patterns based on current structure and the slope of the bottom.



CONCENTRATION OF LEAD in the sediments of the San Pedro Basin shows an increase in recent years because of airborne lead that originates mainly from automobile emissions. The figures are based on samples of the sediments obtained by means of coring.



EFFECT OF DUMPING on sediments of the New York Bight is indicated by the concentration of chromium in parts per million in and around the dumping area. A bight is an open bay formed by a bend in a coast. Material transported to the bight to be dumped includes sewage sludge and rubble. The broken contour line represents a depth of 30 meters.



COPPER CONCENTRATION in sediments of the dumping area of the New York Bight is shown in parts per million. Data on chromium and copper in the New York Bight are based on work by Grant Gross of the oceanography section of the National Science Foundation.

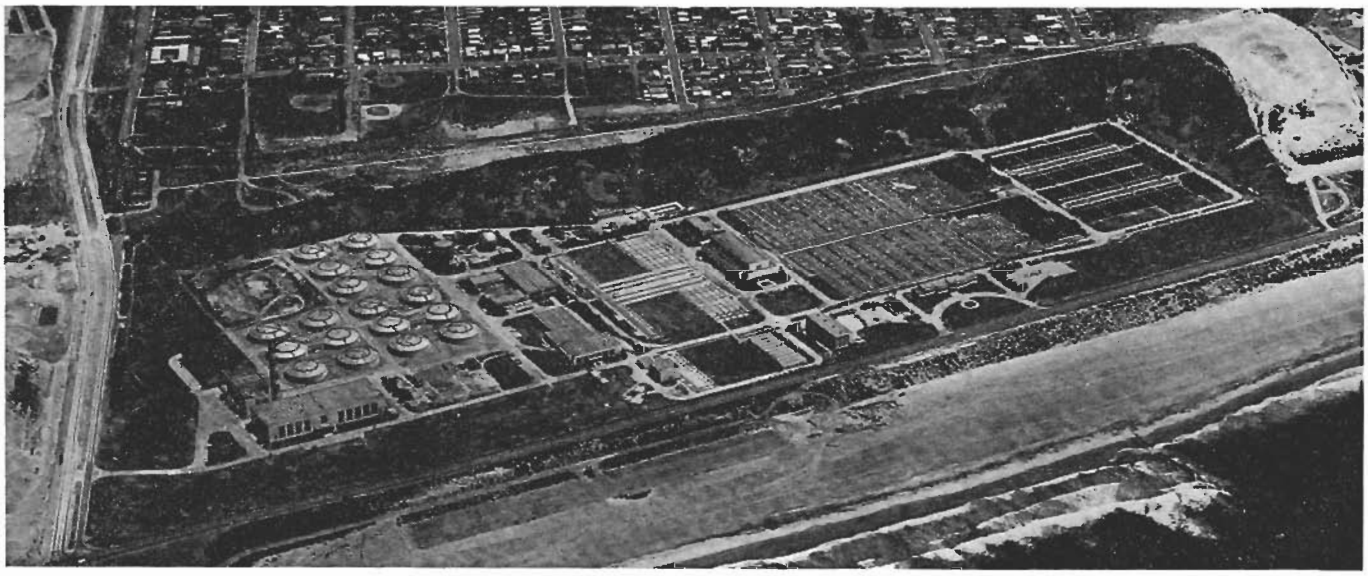
we should be concerned with their thoughtful introduction into coastal seas in any quantity that man can generate in the foreseeable future."

Once possible pollutants reach the ocean it is necessary to keep track of where they go, the extent to which they are altered or diluted and what animals they affect. In order to obtain this information many of the techniques of oceanography are brought into play. Currents are measured above and below the thermocline; other instruments measure the temperature, salinity and dissolved oxygen. Water is sampled at various depths, and so are bottom sediments. It is also useful to directly monitor any changes in plant and animal communities with divers or television cameras.

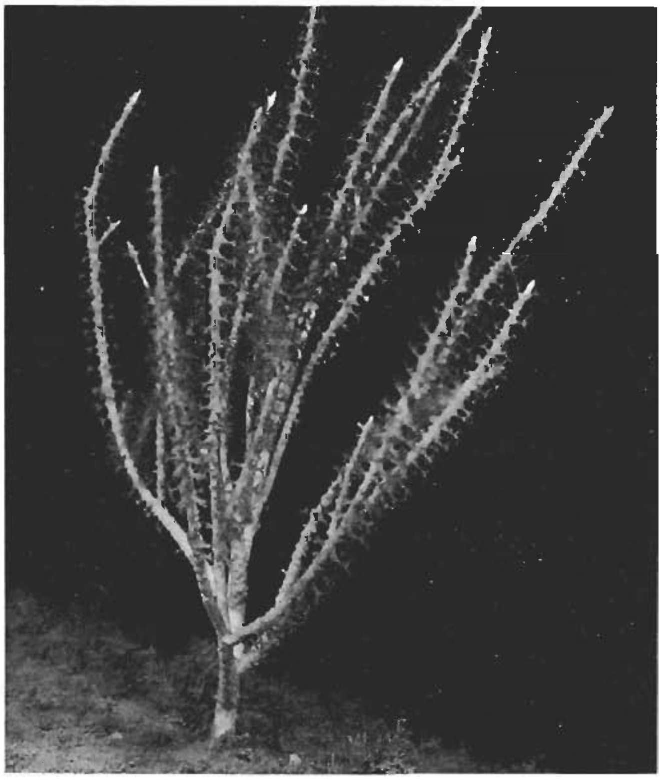
A good indicator of change is the response of the polychaete worms in the bottom mud. Close to an effluent-discharge point the number of species may be as low as from four to 10 per sample and the total weight of worms as low as 50 grams per square meter. A short distance away the number of species may be 40 or more and the total weight 700 grams per square meter. At greater distances the figures drop off to normal: about 25 species and 300 grams per square meter. This local enrichment shows that worms thrive at some optimum level of organic material. Laboratory tests by Donald Reish and Jack Word of California State University at Long Beach show that worms have a similar optimum for toxic metals such as zinc and copper.

Man must do something with his wastes, and the ocean is a logical place for some of them. No single solution will be sensible for all kinds of waste or all locations, but the following suggestions may help to protect both the land and the sea in the long run. (1) Clearly define what is ocean, separating it from inland freshwaters and from harbors and shallow bays, and make laws that are appropriate for each environment. (2) Avoid the assumption that anything added to the ocean is necessarily harmful and consider instead what substances might cause damage and eliminate excesses of them. (3) Rigorously prohibit the disposal in the ocean of all man-made radioactive materials, halogenated hydrocarbons (such as DDT and polychlorinated biphenyls) and other synthetic organic materials that are toxic and against which marine organisms have no natural defenses. (4) Set standards based on water quality (after reasonable mixing) that are compatible with what is known about the threshold of damage to marine life, providing a safety factor of at least 10. (5) Work to obtain international cooperation in prohibiting ships from disposing of litter or oil and from pumping bilges. (6) Set aside ocean areas of deep water and slow current where certain materials can be dumped with minimal damage. (7) Require each discharger to make studies to demonstrate how his specific effluent will influence the adjacent ocean. (8) Support additional research on the effect of pollutants on the ocean and its life. (9) Anticipate pollutants that may become serious as technology produces new chemical compounds in greater quantities.

A more rational basis is needed for making decisions about how to treat wastes and where to put them. No oceanographer wants damaging waste in the ocean where he works or on land where he lives. Since the waste must go to one place or the other, however, one would prefer the choice to be based on a knowledge of all the factors. Unemotional consideration of which materials can be introduced into the sea without serious damage to marine life will result in both an unpolluted ocean and a large saving of national resources.



SEWAGE-TREATMENT PLANT serves the City of Los Angeles, discharging into the Pacific Ocean about 235 million gallons per day of primary treated effluent and 100 million gallons per day of secondary effluent. The discharge pipe is 12 feet in diameter and nearly five miles long. At the discharge end it is in 197 feet of water. The plant separately discharges sludge, consisting of about 1 percent solids, through a seven-mile pipe to a depth of more than 300 feet. The sludge is discharged at the brink of a marine canyon.



MARINE ORGANISMS grow on the outfall pipe from the Los Angeles sewage-treatment plant. At left are anemones about three feet high and at right is a gorgonian. The location is near the discharge point of the outfall pipe at a depth of approximately 200 feet.