ozone production occurs near 30 km; consequently, integrated effects such as the O_3 column and surface temperature will be most sensitive to water vapor that is transported upward from the flight altitudes. Brewer and Wilson (*12*) have emphasized the importance of ozone transport downward from the high stratosphere as, possibly, the rate-limiting process near the tropopause. The calculations presented here illustrate the potential role of transient injections of water vapor into altitudes near 30 km.

It should be remarked additionally that by vertical transport of ozone downward from the stratosphere into a region where, due to shielding from the solar flux, the ozone is relatively long-lived, the total ozone column is in fact enhanced appreciably above that resulting from this or other models of photochemical steady states. For this reason, relative perturbations of the ozone column, computed by steady-state models, are greater than those that will in fact occur.

With Leovy's collection of rate constants, cross sections, and fluxes, the fit between computed and observed ozone profiles is remarkably good, especially at altitudes near 30 km where the ozone concentration is greatest. To test the sensitivity of the present calculations to changes in input constants, the model was recomputed with the new rates described by Crutzen (*13*). On the basis of these rates, the ozone profile is altered appreciably by enhanced concentrations above 30 km. However, with one exception, the relative perturbations shown in Figs 1 and 2 are unchanged, within the uncertainties introduced in the estimates of added water. The exception occurs in Fig. 2 for the temperature changes at 30 km; in this case, the exalted ozone profile results in a temperature *rise* (+ 0.1°K at 3.6 ppm), instead of the fall which is shown. Obviously, this result should be treated cautiously. Indeed, natural variations in water, temperature, and ozone profiles will make all of the estimates of this study extraordinarily difficult to observe. Finally, it should be emphasized that the temperature changes in Eqs. 2 and 3, as applied in Fig. 2, represent rather ruthless spatial and temporal averages to obtain *global* perturbations.

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Mercury Compounds Reduce Photosynthesis by Plankton

Abstract. *Concentrations of organomercurial fungicides as low as 0.1 part per billion in water reduced photosynthesis and growth in laboratory cultures of one species of marine diatom and several natural phytoplankton communities from Florida lakes. The acute toxicity of mercury compounds to phytoplankton is dependent on the chemical nature of the mercury compound and on cell concentrations.*

Mercury pollution is presently a serious problem in many parts of the world. Humans have died as a result of eating fish from mercury-contaminated coastal areas of Japan, high concentrations of mercury in fish and birds have been traced to industrial and agricultural discharges in Scandinavia, and at least 17 states in the United States have banned fishing in contaminated waters or warned against eating fish and shellfish contaminated with mercury. The sources and environmental pathways of mercury in the affected areas of Japan and Scandinavia have been studied (*1*). Investigations of mercury pollution in the United States are beginning.

An almost total lack of information on the biologic effects of mercury prevents the establishment of adequate water-quality standards. The Bureau of Water Hygiene, United States Public Health Service, and the Soviet Union have tentatively adopted a standard of

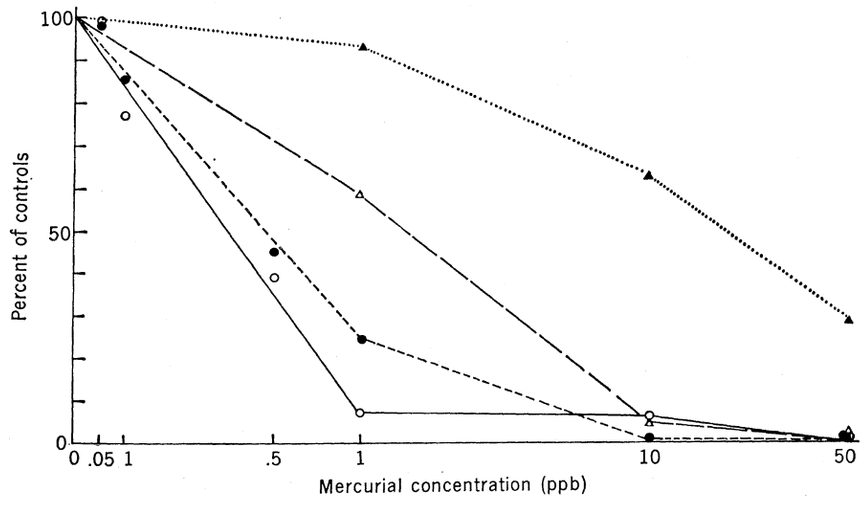

Fig. 1. Photosynthesis by *Nitzschia delicatissima*, a marine diatom, measured by uptake of carbon-14 relative to uptake by controls, after 24 hours of exposure to the following mercurials: Filled triangles, diphenylmercury; open triangles, phenylmercuric acetate; filled circles, methylmercury dicyandiamide; open circles, MEMMI.

5 parts per billion (ppb) for mercury in drinking water (*2*). In Japan a maximum allowable concentration of 10 ppb for methylmercury in industrial waste water has been adopted for the protection of humans (*3*). The present water-quality standards for mercury are inadequate to protect phytoplankton, organisms which are basic elements of almost all aquatic food chains.

Our experiments were designed to evaluate the acute effects of four commonly used organomercurial fungicides on a marine diatom, *Nitzschia delicatissima Cleve*, isolated from waters near Puerto Rico, and a naturally occurring phytoplankton population taken from Lake Jackson, a shallow freshwater lake near Tallahassee, Florida. The dominant genera in the freshwater phytoplankton population included *Merismopedia* sp. (Agmenellum), *Navicula* sp., *Crucigenia* sp., *Staurastrum* sp., and *Ankistrodesmus* sp. These phytoplankton were exposed to concentrations varying from 0 to 50 ppb of the following organomercurial compounds: phenylmercuric acetate (PMA or Phix); methylmercury dicyandiamide (Panogen); *N*-methylmercuric-1,2,3,6-tetrahydro-3,6-methano-3,4,5,6,7,7-hexachlorophthalimide (MEMMI); and diphenylmercury.

All experiments were conducted in a growth chamber equipped with a balanced bank of Gro-lux and Daylight (Sylvania) fluorescent lights. The light intensity was maintained at 1×10^4 erg cm^{-2} sec^{-1}. The chamber was programmed for a photoperiod of 12 hours light, 12 hours dark and maintained at 25° ± 0.5°C.

When the concentrations of *N. delicatissima* reached 7.5×10^4 cell/ml and the population was in the logarithmic phase of growth, 50-ml portions were exposed to varying concentrations of the fungicides. After 24 hours of exposure to the mercurials, 5 μc of [^{14}C]-$NaHCO_3$ was added to each of two light bottles and to one dark bottle. The flasks were returned to the growth chamber for 5 hours of exposure to light, then the contents were filtered, and the radioactivity was counted on a Picker proportional counter.

The Lake Jackson sample was exposed to the four mercurials and grown in 500-ml flasks. At 24, 72, and 120 hours after initial exposure, 150 ml was withdrawn from each flask. A 50-ml portion was put into each of two light bottles and one dark bottle. Then 5 μc of [^{14}C]$NaHCO_3$ was added to each bottle. All bottles were then returned to the growth chamber for 5 hours of exposure to light, then the contents were filtered, and the radioactivity was counted on a Picker proportional counter.

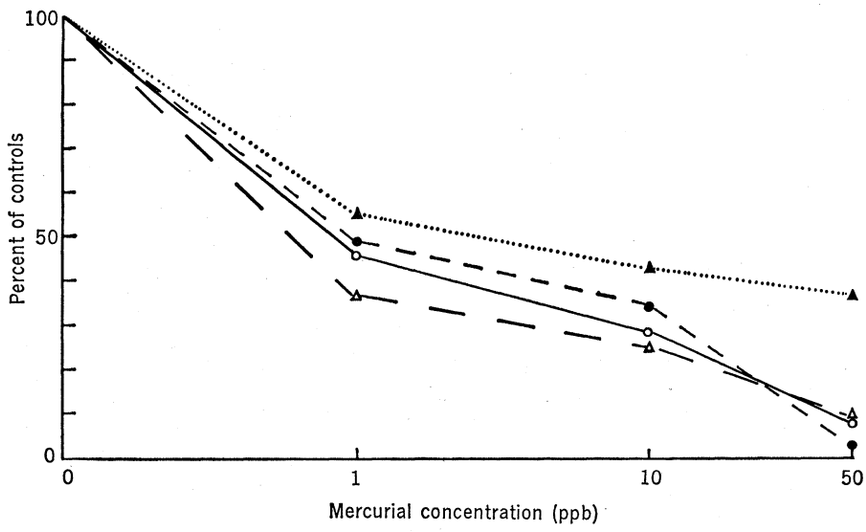

Fig. 2. Photosynthesis by a freshwater phytoplankton population, measured by uptake of carbon-14 relative to uptake by controls, after 120 hours of exposure to the following mercurials: Filled triangles, diphenylmercury; open triangles, phenylmercuric acetate; filled circles, methylmercury dicyandiamide; open circles, MEMMI.

In all experiments the count obtained from dark bottles and the background count were subtracted from the average of the two light bottles. The effect of the mercurials on photosynthesis and growth is calculated by dividing the net count at each concentration by the net count of the control sample and is expressed as uptake of carbon-14 as percent of controls.

Of the four mercurials, studied, diphenyl mercury was the least toxic (Figs. 1 and 2). At 1 ppb of the other three mercurials, a significant reduction in photosynthesis and growth is observed in cultures of *N. delicatissima* and the freshwater phytoplankton. At 50 ppb essentially all uptake of inorganic carbon is stopped; cell counts also indicate complete inhibition of growth. The reproducibility of these experiments, determined by exposing five identical samples from Lake Jackson to 1 part of methylmercury dicyandiamide per billion, was ± 11 percent. In related experiments, not shown in the figures, the toxicity of mercuric chloride to the Lake Jackson phytoplankton population was similar to that of diphenylmercury. We have also noted that the toxicity of any particular mercurial compound decreases with increasing cell concentration in lake samples in a manner similar to effects of chlorinated hydrocarbons (*4*).

Our studies indicate that at least some marine and freshwater phytoplankton species are sensitive to much lower concentrations of mercurial compounds than have been observed to affect fish in short-term tests of toxicity (*5*). It is also clear that concentrations of mercurial compounds well below the proposed water-quality standards can have detrimental effects on phytoplankton. We conclude that the use of organomercurial compounds in any way that permits their discharge into natural waters should be stopped as soon as possible. The long-term effects of mercury pollution below concentration of 1 ppb must be determined to establish adequate water-quality standards.

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