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CONDITIONS LEADING TO MASS MORTALITY OF FISH AND ZOOPLANKTON IN LAKE VALENCIA VENEZUELA

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ABSTRACT

Extensive mortality of fish and zooplankton ocurred in Lake Valencia, Venezuela, between 29 November and 6 December 1977. No large mortalities of this type have been documented in previous years. The mortality was preceded by an extended calm period during which the lower part of the water column became anoxic and accumulated large amounts of reduced substances. Sudden increases in the wind strength brought about complete mixing of the water column leading to greatly reduced oxygen levels and high concentrations of hydrogen sulfide, ammonia, and nitrite. Large numbers of fish, particularly of the genus *Rhamdia*, and about 90% of the total zooplankton population were killed during the sudden mixing. A study of the chemical conditions indicates that the lethal factors were more likely to have been hydrogen sulfide and oxigen depletion, than the latter and other reduced substances. Continued eutrophication and reduced water volumen of Lake Valencia make the repetition of this phenomenon in future years more likely because oxigen depletion in deep water will be ocurring more rapidly.

CONDICIONES QUE CONDUCEN A UNA MORTANDAD MASIVA DE PECES Y ZOOPLANCTON EN EL LAGO DE VALENCIA, VENEZUELA

RESUMEN

Una gran mortandad de peces y zooplancton se produjo en el Lago de Valencia, Venezuela, entre el 29 de noviembre y el 6 de diciembre de 1977. En años anteriores no se había observado tal fenómeno. La mortandad fue precedida por un largo período de calma, durante el cual la parte inferior de la columna de agua se hizo anóxica y acumuló grandes cantidades de sustancias reducidas. Un incremento repentino en la fuerza del viento provocó la mezcla total de la columna de agua y la disminución, a niveles muy bajos, del oxígeno disuelto, así como altas concentraciones de sulfuro, amonio y nitritos. Gran número de peces, particularmente del género *Rhamdia* y aproximadamente el 90% del zooplancton total, murieron durante ese período de rápida mezcla. El estudio de las condiciones químicas indica que los factores letales fueron más bien el sulfuro de hidrógeno y el agotamiento de oxígeno que otras sustancias reducidas. El avance de la eutroficación y la reducción del volumen del Lago de Valencia aumentan la posibilidad de que este fenómeno se repita en los años venideros, porque el agotamiento del oxígeno en las aguas profundas ocurrirá más rápidamente.

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INTRODUCTION

A massive mortality of fish and zooplankton ocurred in Lake Valencia during late November and early December of 1977 (Fig. 1). This lake has only been studied intensively for the last few years, there is no previous record of massive fish mortality. The fish mortality therefore seems to have been associated with special conditions which ocurred in the year 1977. In the course of the following analysis we will show, however, that the future ocurrence of these conditions is more likely as the lake becomes more eutrophic.

Figure 1. Fish mortality in Lake Valencia.

Regular sampling of Lake Valencia at bi-weekly intervals has been underway since late 1975 at several locations (Fig. 2), and an intensive field program began in August 1976. Over this period we have observed a small, steady mortality of all fish species, but never a mass mortality of fishes an zooplankton such as that which ocurred in late 1977.

On 29 November, 1977, large numbers of dead fish of several species were floating on the lake surface. The mortality continued throug 5 December 1977, after which time it was no longer observed. During the period of mortality, lake surface smelled distinctly of hydrogen sulfide and was divided into large distinctive patches or water masses which varied in color and strenghth of odor of hydrogen sulfide. The patches were frequently 1 km or more in diameter. At the same time, large numbers of dead larvae of the planktonic dipteran genus *Chaoborus* were observed floating on the surface of the lake.

Figure 2. Morphometric map of Lake Valencia showing the sampling stations that are referred to in the text.

Physical and Chemical Conditions Leading to Mortality

Lewis and Weibezahn[4] speculated on theoretical grounds that Lake Valencia would be warm monomictic, i.e., that it would be thermally stratified most of the year but would become insothermal and mix completely for an extended period once each year. The most likely time for the isothermal mixing period is the season of minimum air temperatures and maximum wind strength, which ocurr together during the months of December-March. On the basis of the documentation which has been gathered thus far, it would appear that mixing does occur every year during the cool windy season.[1] The mass mortality in Lake Valencia thus ocurred at the onset of the seasonal mixing period. Since mass mortality does not normally accompany the seasonal mixing, however, certain special physical and chemical conditions must have developed during 1977 which caused the seasonal mixing to result in massive mortality of fish and zooplankton. Physical and chemical conditions in the lake were under intensive study during 1977, so it is possible to reconstruct and analyze the conditions leading to the massive mortality.

Figure 3 summarizes some of the physical and chemical data that are critical to the interpretation of fish and zooplankton mortality. The first and second panels of the figure show the coincidence of fish mortality with changes in mean daily wind strength and in the oxygen profile of the water column. During the weeks just prior to the fish mortality, the water columm was stratified with a thermocline at about 20 m. Above the thermocline, oxygen concentrations were consistently near saturation. Below the thermocline, oxygen was completely depleted and strong reducing conditions had developed. At the time of the fish mortality, there had been no oxygen in the bottom 10 m of the water columm for 17 weeks. The anoxic bottom layer was specially thick because the mean wind strength had been very low (Figure 3), which minimized the transfer of oxygen by direct mixing or by eddy diffusion into deeper water.

An abrupt change in mean wind strength occurred during the last week in November (Figure 3). In particular, the day of 29 November was characterized by very strong wind far exceeding any which had occurred during the previous weeks. As indicated in Figure 3, the sudden increases in wind strength caused a sudden mixing of the epilimnion an hipolomnion, which brought large amounts of anoxic water and large amounts of reduced substances into the upper water column. Although mixing to a depth of 30 m occurred very suddenly as shown in Figure 3, a small residual anoxic layer about 5 m thick remained just above the sediments (30-35 m) in mid-lake on 29 November but was slowly incorporated into the upper water column over the following week. This residual anoxic layer had completely disappeared by 6 December. After 6 December, the water column remained isothermal under the influence of continued heavy winds and cooling which resulted from declining air temperatures and heat losses due to evaparation. The oxygen content of the entire water column increased subsequent to 6 December as diffusion at the air-water interface began to compensate the oxygen debt of the water column.

Figure 3 clearly shows that the sudden mixture of the water column on or about 29 November was not preceded by any significant heat loss from the upper water column. For this reason, the sudden mixing must be attributed to changes in wind strength rather than to seasonally reduced stability of the water column due to a declining heat content in the upper layer. We believe that this is unususal insofar as some cooling and partial mixing by convection and wind would usually occur prior to full circulation of the water column. This would spread the chemical changes of the upper water column over a longer period of time and thus render them much less likely to cause mortality. The unusual feature of the 1977 events thus appears to be the sudden nature of the mixing of upper and lower water masses by an unusual wind pattern.

Although the mortality of fish and zooplankton can be attributed with certainity to chemical changes in the water column, the exact cause of death of the fishes is more difficult to ascertain. The two major potential causes of the mortality are 1) oxygen depletion, and 2) chemical poisoning by reduced substances including hydrogen sulfide, nitrite, and ammonia.

Substantial oxygen depletion did occur, as indicated in Figure 3, but even during the period of most intense fish mortality there remained approximately 1 mg/l of dissolved oxygen in the water columm, at least in Stations 3 & 10. Although the oxygen requirements of the Lake Valencia fishes are unknown, a wide variety of fishes can withstand oxygen depletion to 1 mg/l if they are allowed access to the water surface.[3] The patchy condition of the lake surface and actual measurements of dissolved oxygen in several stations of the lake, however, showed that there were pockets of completely deoxigenated water sufficiently large to cause substantial mortality (Fig. 4).

Figure 3 shows the amounts of nitrite and ammonia in the water column. Either of these substances can be lethal to fishes in large amounts. The toxicity of nitrite has not been widely investigated, but recent studies of the channel catfish (*Ictalurus punctatus*), a warm-water species with environmental requirements generally similar to the Valencia genus *Rhamdia*, is capable of 95% survival at concentrations ranging up to 30 mg/l NO_2.[2] The peak concentration in Lake Valencia at the time of mortality was far below this (Fig. 3). Nitrite combines with hemoglobin to prevent oxygen transport from the gills, and severe nitrite poisoning is usually accompanied by chocolate color of the gills. The fishes were checked for chocolate gills and did not show any evidence of this symptom. For this reason, and because the nitrite concentrations were far below the probable lethal levels, we conclude that nitrite poisoning did not cause the fish mortality. Vulnerability of invertebrates to nitrite poisoning is unknown.

Ammonia is highly toxic in relatively small amounts. The toxicity derives from the unionized form, which becomes

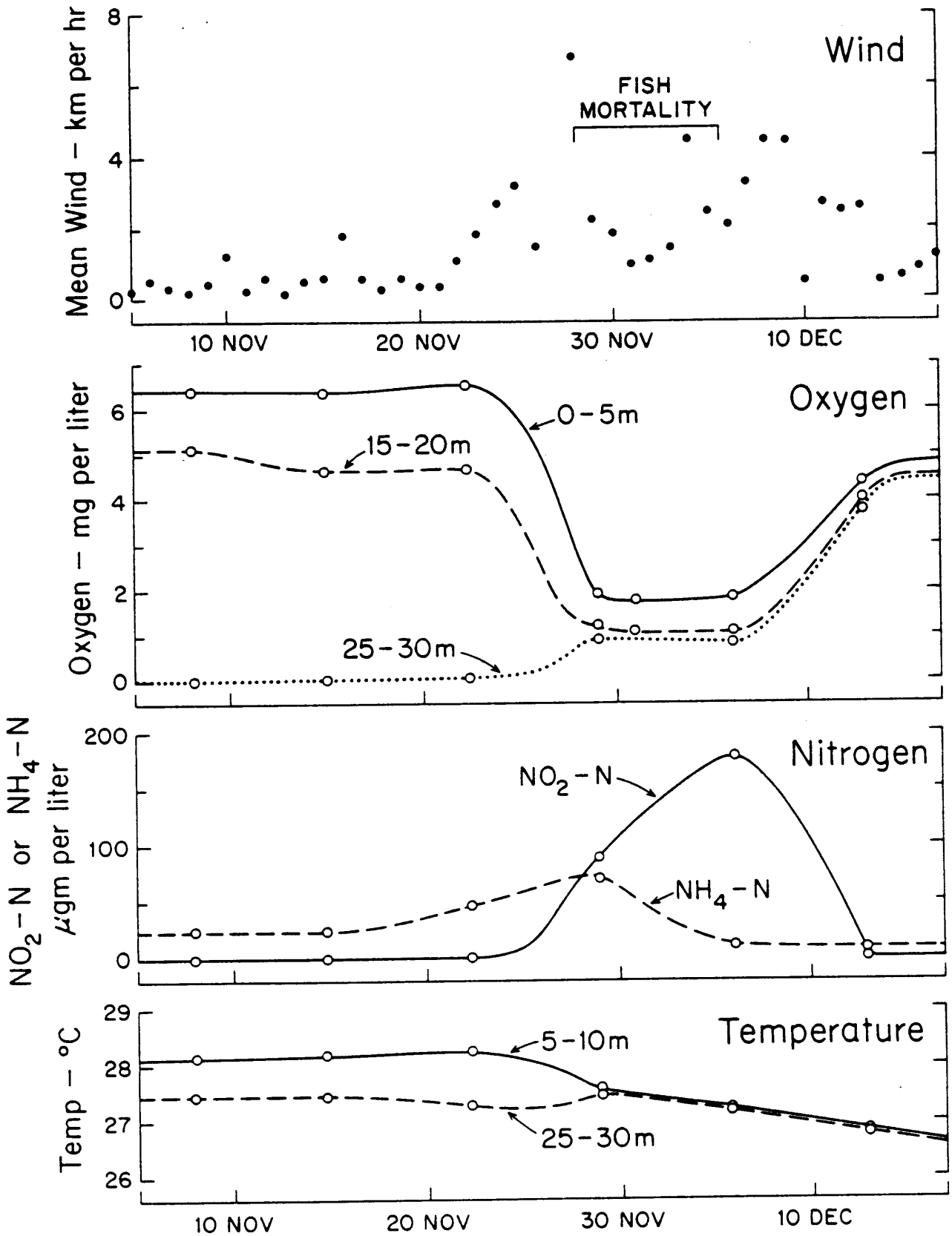

Figure 3. Physical and chemical conditions in Lake Valencia prior to, during, and just after the mass mortality of fish and zooplankton. Chemical data are from Station 10.

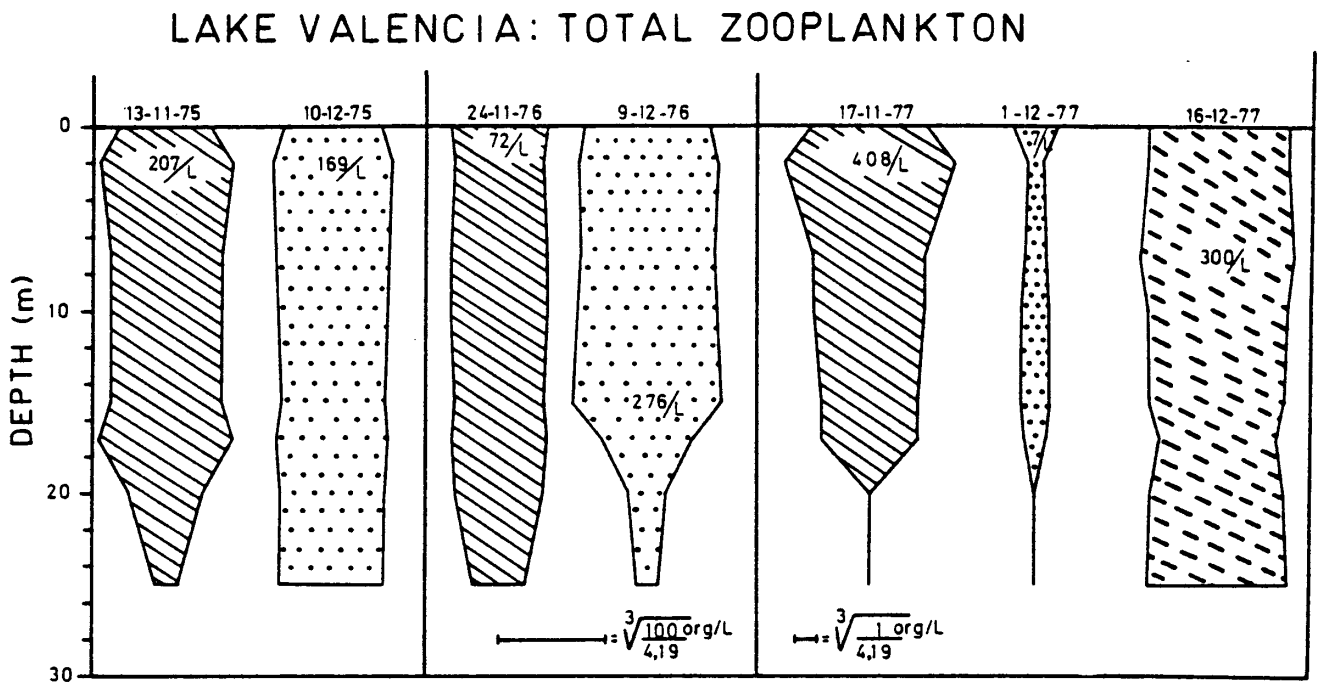

Figure 4. Total zooplankton abundance and distribution in November and December for 3 consecutive years, including the year of mass mortality (1977)

increasingly predominant at high pH values. Studies by Robinette[5] on the channel catfish have shown that this species can tolerate as much as 2 mg/l of unionized ammonia. Such a concentration is considerably above the total ammonia concentration observed in Lake Valencia during the fish mortality (Fig. 3), so it seems unlikely that significant mortality can be attributed to ammonia poisoning.

The mortality of fishes was accompanied by the presence of hydrogen sulfide at the surface of the lake. A definite odor of hidrogen sulfide was detectable throughout the mortality period. Although the amount of hydrogen sulfide in the water column was not determined, hydrogen sulfide must usually be present in amounts avobe 0.1 mg/l if it is to be detected by smell.

Hydrogen sulfide is more lethal to fishes than either nitrite or ammonia. Studies by Smith et al.[6, 7] have shown that concentration in the range of 0.05 mg/l are lethal to juvenile and adult bluegill sunfish (*Lepomis macrochirus*), warm-water centrarchid. The same study indicates a similar toxicity for goldfish (*Carassius auratus*), and toxicity at even lower concentrations for mayfly larvae (Ephemeroptera). Thus while nitrite and ammonia do not appear to have been responsible for the mortality, hydrogen sulfide may well have been a contributing factor or principally responsible for the fish and zooplankton mortality. Conditions for formation of hydrogen sulfide are extremely favorable because of the high decomposition rates in the lake and the large amount of sulfate in solution (390 mg/l).

Extent of mortality

Lake Valencia contains over 20 species of fish, but the most common are as follows: *Petenia krausii* (San Pedro), *Sarotherodon mossambicus* (Tilapia), *Geophagus surinamensis* (Cara de caballo), *Rhandia sp.*, *Aequidens sp.* (Chusco), *Xenomelaniris venezuelae*, *Hoplias malabaricus* (Guabina), and *Astyanax bimaculatus* (sardina). These species were observed in different numbers on the surface of the lake at the time of mortality. The catfish *Rhamdia* was by far the most common among the dead fishes. *Rhamdia* is a benthic species which inhabits water of moderate to great depth. *Petenia* and *Sarotherodon* are the two most abundant species in the lake, but these were killed only in relatively small numbers. Both *Petenia* and *Sarotherodon* inhabit shallow water and may thus have been protected to some degree from the spread of deoxigenated water by poor circulation of water near the shore. The atherinid *Xenomelaniris* is very common in the pelagic zone and was observed among the dead fish on some occasions but not nearly so often as *Rhamdia*. The dead *Rhamdia* individuals were for the most part very small (less than 15 cm). Representatives of other species were observed among the dead fishes, but only in small numbers.

Some caution in warranted in the interpretation of the observed fish mortality because individuals of some species float more readily than others when they are killed. If the observed mortality is proportional to the actual mortality, however, the observations suggest that the frequent occurrence of such mass mortality would be particularly damaging to

Rhamdia, a native genus, but would not greatly affect the two dominant introduced cichlids, *Petenia* and *Sarotherodon*.

In addition to fishes, zooplankton were killed in large numbers by the change in water chemistry. The only zooplankton species large enough to be observed at the surface of the lake is *Chaoborus*, which has gas bladders that apparently cause it to float when it is killed. Large numbers of dead *Chaoborus* of all sizes were observed floating on the lake at the time of the fish mortality. *Chaoborus* is extremely resistant to oxygen depletion and typically inhabits the deepest portions or even the sediments of lakes during the daytime. It is therefore surprising that the chemical conditions were severe enough to result in massive *Chaoborus* mortality. Since the *Chaoborus* mortality probably cannot be attributed to oxygen depletion, to which the species in extremely resistant, it is more likely that one of the toxic reduced substances, probably hydrogen sulfide, was responsible for the death of the zooplankton species.

Other zooplankton species besides *Chaoborus* were killed in large numbers. Figure 5 shows the radical decline in total zooplankton during the time that the fish mortality was observed. We conclude that the change in chemical conditions associated with deep mixing in late November were lethal to the zooplankton. Figure 5 also shows the numbers and vertical distribution of total zooplankton in 1975 and 1976 when no fish mortality occured. Clearly the zooplankton could be expected to maintain a stable population during the months of November and December if the sudden chemical changes in the upper water column had not occurred.

DISCUSSION

The evidence indicates that the fish and zooplankton mortality resulted from a particular combination of weather conditions that first allowed the development of a sizable anoxic layer between the depths 20 and 35 m in the water column followed by the sudden disruption of layering by heavy winds. Mortality would not have occurred if the oxygen deficit in deep water had been less pronounced or if incorporation of the anoxic water into the upper water columm had occurred more slowly. Figure 4, which summarizes the oxigen profiles in early December for 1975, 1976, and 1977 suggests that the more normal for the lake is a less pronounced oxygen deficit in deep water in early December. Thus the most critical condition in 1977 may have been the lengthy period of calm weather preceding the mixing.

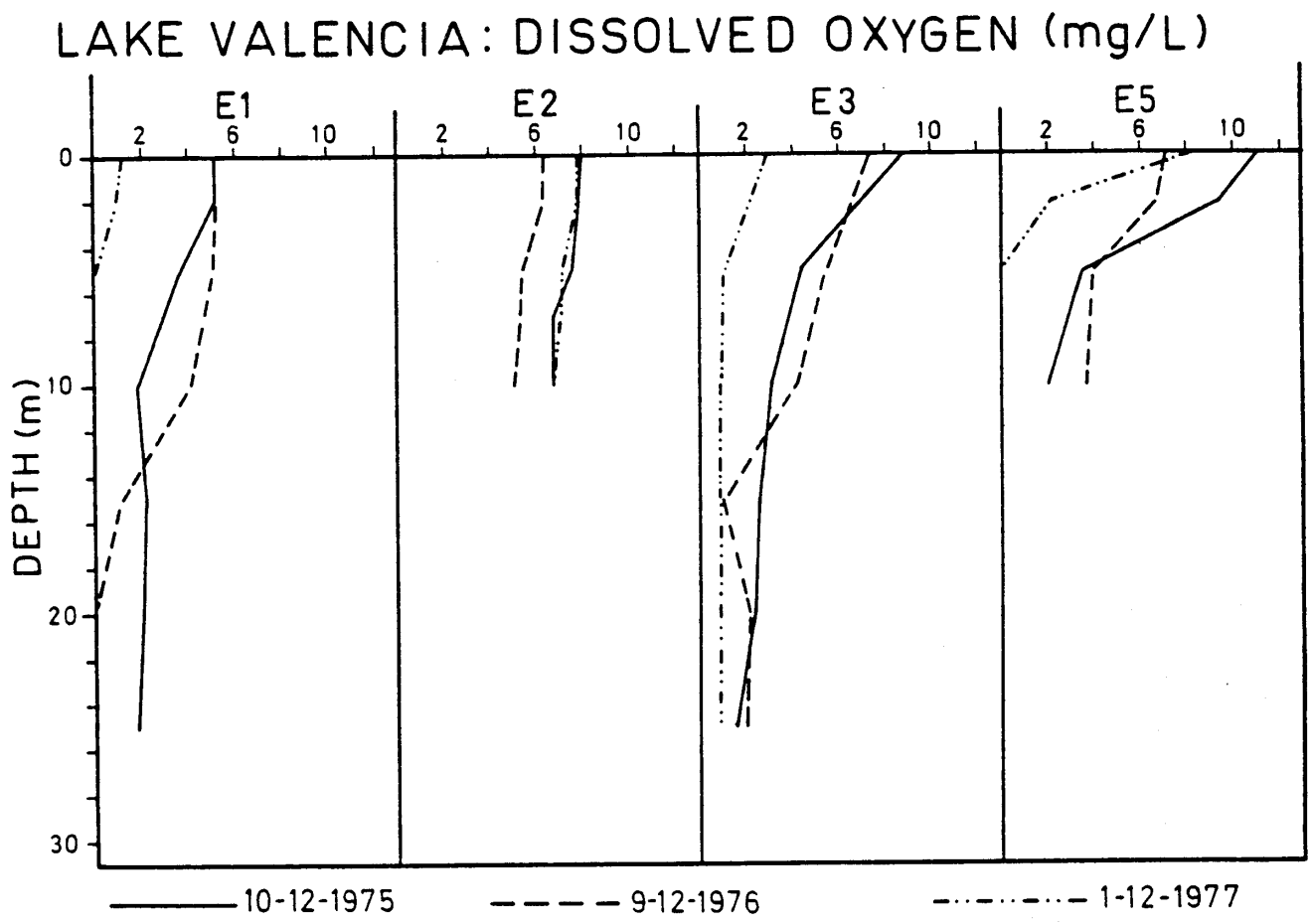

Figure 5. Oxygen profiles at several sampling stations during December for 3 consecutive years, including the year of mass mortality (1977).

Lake Valencia receives large amounts of organic matter and nutrients every year from urban and industrial sources surrounding the lake. Moreover, the total lake volume is smaller every year because of the declining lake level, hence the amount of organic matter and nutrients added on a volume basis to the lake would increase substantially even without any increase in the total loading. We would expect these factors to cause an increasing tendency toward the development of severe oxygen deficits in deep water. While we believe that the conditions during 1977 were unusual insofar as they were connected with climatic peculiarities, we feel that the mortality will occur more frequently in the future simply because the oxygen deficits can develop more rapidly.

ACKNOWLEDGMENTS

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