THE DISTRIBUTION OF AMMONIA IN THE WATERS OF THE GULF OF MAINE

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In the decomposition of organic residues in the sea ammonia is apparently the first simple inorganic compound of nitrogen to be set free. Since it does not commonly occur in large quantities, it is evidently oxidized rapidly to nitrate and nitrite. As an ephemeral intermediate in the cycle of regeneration of nitrate, it is of interest in indicating the places in which the decomposition of nitrogenous material is taking place.

The present paper presents the results of a survey of the occurrence of ammonia in the waters of the Gulf of Maine based on observations made during cruises of the "Atlantis" in September, 1933 and May and June, 1934. The only previous measurements of ammonia in these waters of which we are aware are those made by Seiwell (1931) in Penobscot and Frenchman's Bays and those recorded by Rakestraw (1936) in a study of the occurrence of nitrite in the sea. Our results are correlated with the studies of nitrite made by Rakestraw of the phosphorus cycle by Redfield, Smith and Ketchum (1937), and with observations on the distribution of plankton, based on collections made during these cruises.

Methods

Ammonia was determined by the Teorell titration of the vacuum distillate as described by Krogh (1934). The apparatus could be used practically on shipboard, using alcohol lamps burning pure alcohol for heating and a Cenco Hyvac pump as a source of low pressure. Ammonia-free water was prepared ashore. It was found necessary to steam out the apparatus before the start of each series of analyses and to make blank analyses between each pair of unknowns. To be reliable, all determinations must be made in duplicate, since unforeseen contamination frequently occurred.

The sea water samples were taken in Nansen reversing bottles, from which they were immediately transferred, with double rinsing, to glass-stoppered bottles. These were stored in the refrigerator and

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analyzed as quickly as possible. Experiments recorded in Table I showed that sea water stored for about eight hours underwent no appreciable change in ammonia content. With longer periods of storage there is a progressive decrease in the ammonia content, which is not prevented by the addition of 0.1 per cent mercuric chloride (Keys, Christensen and Krogh, 1935). The reason for this loss is unknown.

Results

The positions of the stations at which reasonably complete and satisfactory observations on the distribution of ammonia were obtained

Table I

Stability of ammonia in stored sea water samples *

First analysis		Second analysis		Third analysis	
Hours after collection	NH_3-N, mg./M^3	Hours after collection	NH_3-N, mg./M^3	Hours after collection	NH_3-N, mg./M^3
1	40	7	41	290	10
2.5	27	8.5	19	290	8
3.0	35	7	35	290	15
2.5	28	8	30	290	2
4	20	—	—	90	13
4	62	17	54	90	45
6	42	—	—	90	25
6	44	18	24	—	—
6	57	18	46	90	37
5	49	17	28	90	23
4	46	17	32	—	—
5	42	18	30	90	20
†1.5	36	290	8		
†2	25	290	4		
†2.5	21	290	15		
†8.5	31	290	16		

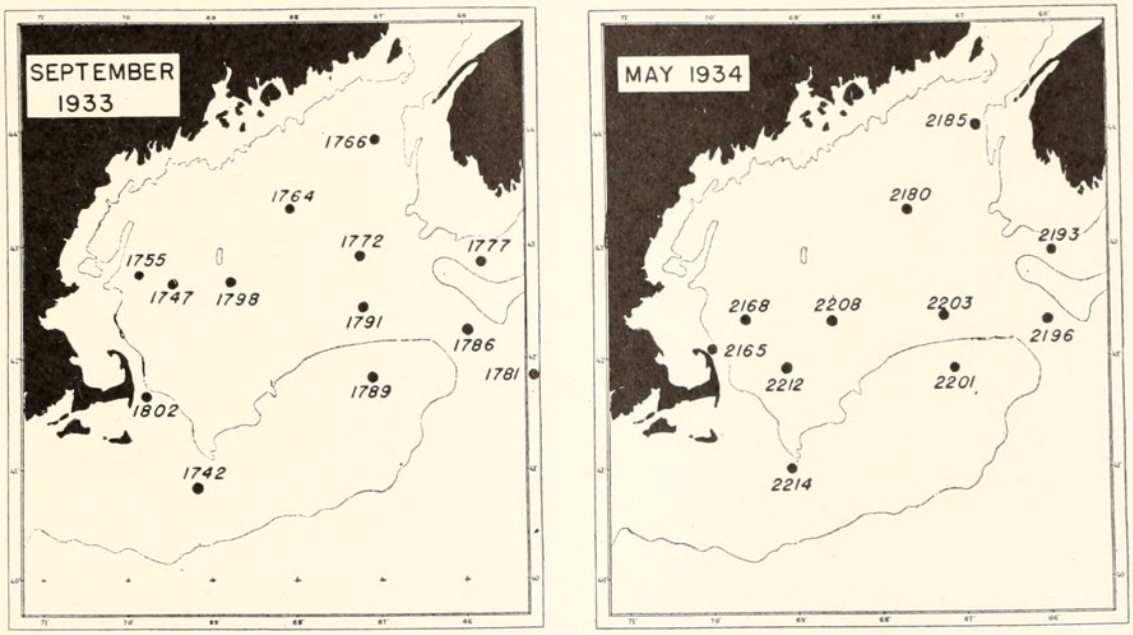
* All values are averages from duplicate analyses.
† $HgCl_2$ added to sample at time of collection.

in September, 1933 and May, 1934 are shown in Figs. 1 and 2. Observations were also made at six stations in the Gulf between June 25 and June 30; the results obtained at that time did not differ from those of a month earlier except that on the whole smaller amounts of ammonia were present. In presenting the results it is convenient to separate the observations made in deep water where the stability of the water column preserves its heterogeneity from those obtained in shallow water and in the shallower channels across the banks where a high degree of turbulence prevails.

Observations in Deep Water

Figure 3 represents the concentrations of ammonia at various deep stations in September and in May. The stations are arranged as far as possible in the order of the positions through which the water is thought to circulate on penetrating the Gulf. Stations occupied in May are placed under stations occupied in comparable positions in September.

In September, Station 1781, 45 miles southeast of the Eastern Channel, showed the presence of some 10 mg. N per cubic meter in the upper 60 meters, diminishing to zero at 100 meters, below which level no ammonia was detected down to the depth of 2,000 meters. The ammonia in the water in the Eastern Channel was similar in distribution, there being none observable below 125 meters. Within the



Figs. 1 and 2. Position of stations at which distribution of ammonia was determined in September, 1933 and May, 1934 respectively.

Gulf, on the other hand, the concentration of ammonia was distributed rather uniformly throughout the water column. The concentrations of ammonia occurring at any station increased towards the western basin of the Gulf, where amounts exceeding 50 mg. N per cubic meter were found.

In May the distribution of ammonia was very different. Amounts in excess of 10 mg. N per cubic meter were rarely observed in the upper 20 meters and at depths greater than 100 meters. Between these depths, at 30 to 60 meters, maximal concentrations occurred ranging in value from 10 mg. N per cubic meter in the Eastern Channel to 45 mg. N per cubic meter in the southern part of the western basin. In the following month similar conditions were observed save that the maximal concentrations did not exceed 25 mg. N per cubic meter.

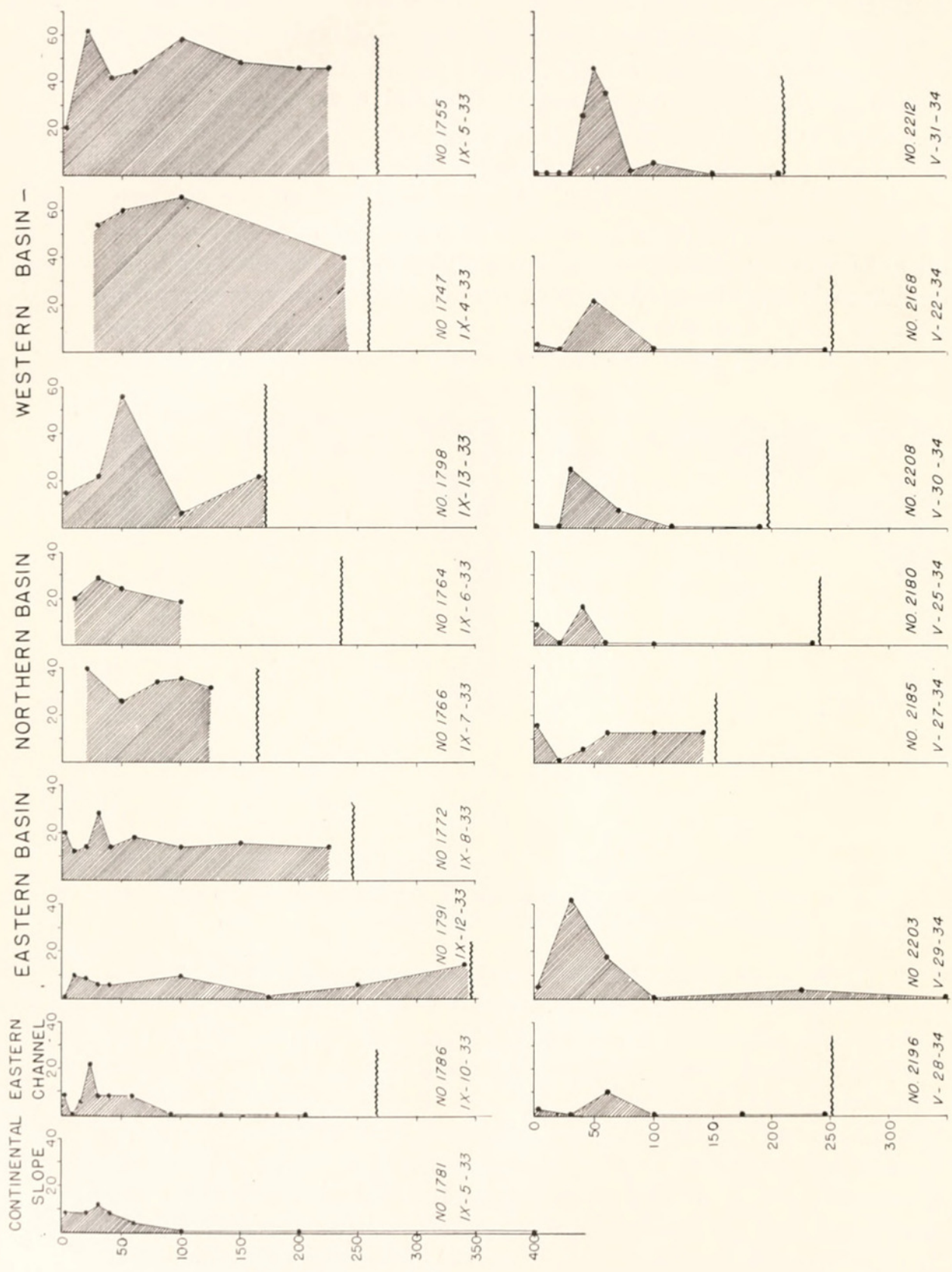


FIG. 3. Vertical distribution of ammonia in the deeper waters of the Gulf of Maine. Upper row, in September, 1933; lower row, comparable positions in May, 1934. Depths measured in meters downward along the ordinate. Concentrations of ammonia expressed as milligrams ammonia nitrogen per cubic meter along the abscissa.

Observations in Shallow Water

Figure 4 shows the distribution of ammonia at shallow stations off Cape Cod and on Georges Bank and in the strong tide ways of the South and North Channels. No definite difference in the seasonal picture is evident. In the channels considerable concentrations of ammonia occurred at all depths, though in May a maximal concentration a short distance below the surface was present in the North

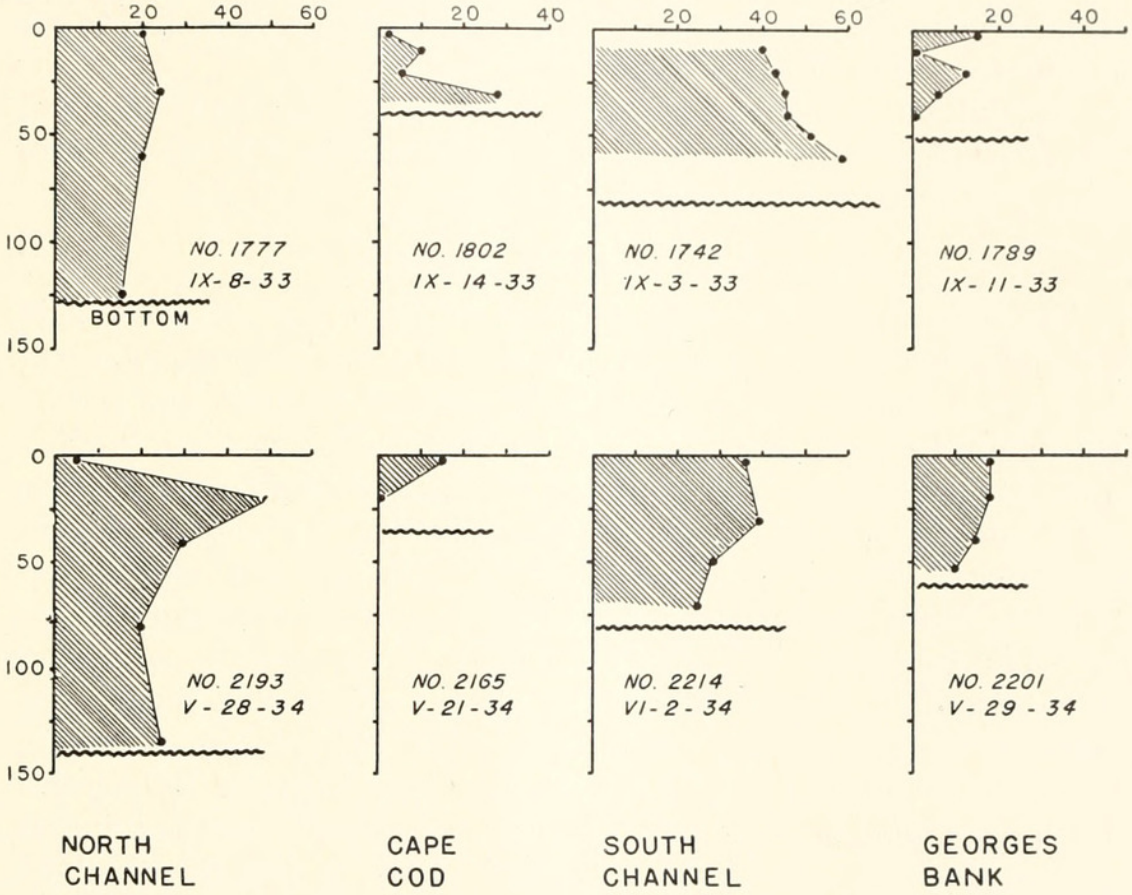


Fig. 4. Vertical distribution of ammonia in shallow waters of the Gulf of Maine. Upper row, in September, 1933; lower row, comparable positions in May, 1934. Concentrations of ammonia expressed as milligrams ammonia nitrogen per cubic meter along the abscissa.

Channel. In the shallow stations the concentration sometimes increased with depth, sometimes the reverse.

Discussion

The distribution of ammonia appeared very irregular when the observations were first made. The magnitude of the concentrations of ammonia observed agreed well with the general range of observations made by earlier workers in various regions (Robinson and Wirth, 1934). It appeared, however, that great differences might be observed

in similar situations at any time and in the same situation at different times.

In several ways our observations support the conclusions drawn from similar studies of ammonia in the English Channel made by Cooper (1933). He considers the formation of ammonia to be a "surface" phenomenon with lesser activity at the bottom. In the spring the surface concentrations decrease from utilization by phytoplankton. Our May observations would appear to be adequately explained on these assumptions. He also observed a general increase in summer and autumn, as did we in September.

As additional evidence has accumulated concerning the biology and chemistry of the Gulf, a number of correlations appeared which seem to give the findings additional significance.

Relation to Phosphate Cycle

The most striking difference between the occurrence of ammonia in September and in May is its relative abundance in the deep water at the end of summer compared with its absence there in the spring. This is precisely the relation found for another intermediate product of decomposition—dissolved, organic phosphorus compounds. These were found by Redfield, Smith and Ketchum (1937) to disappear from the water of the western basin in mid-winter and gradually to accumulate during the summer, reaching a maximum observed concentration in November. Like the ammonia in September, the concentration was quite uniform at all depths. In the spring these phosphorus compounds appear in the subsurface layers, as does the ammonia, before they may be detected in considerable quantity in the depths. It will be of interest to observe whether the ammonia does not almost entirely disappear from the water in mid-winter, as does the dissolved organic phosphorus.

Like the organic phosphorus, ammonia appears to accumulate at all depths in late summer. This should not be thought of as the accumulation of an inert product, however, for von Brand, Rakestraw, and Renn (1937) have shown, at least in a laboratory experiment, that the ammonia of decomposing plankton is nitrified completely in 30 days. It is probable that the ammonia is formed by decomposition throughout the water column, for in September there are no well-marked gradients of ammonia concentration which are necessary for its transport by eddy conductivity. There is no evidence, except in a few of the shallow stations, of increasing concentrations near the bottom, such as Seiwell (1931) observed in shallow bays and as might occur if decomposition on the sea bottom was responsible for a considerable part of the regeneration of nitrogen.

Relation to Nitrite

If the view to which Rakestraw (1936) has recently lent support is correct—that nitrite arises in the water through the oxidation of ammonia—one would expect a close correlation in the distribution of these nitrogen compounds. This expectation is in part fulfilled. The distribution of ammonia in May closely parallels that of nitrite, as shown in Fig. 5. Both may be explained through decomposition taking place in the subsurface waters. Rakestraw explains the absence of nitrite from the water immediately below the surface as being due to

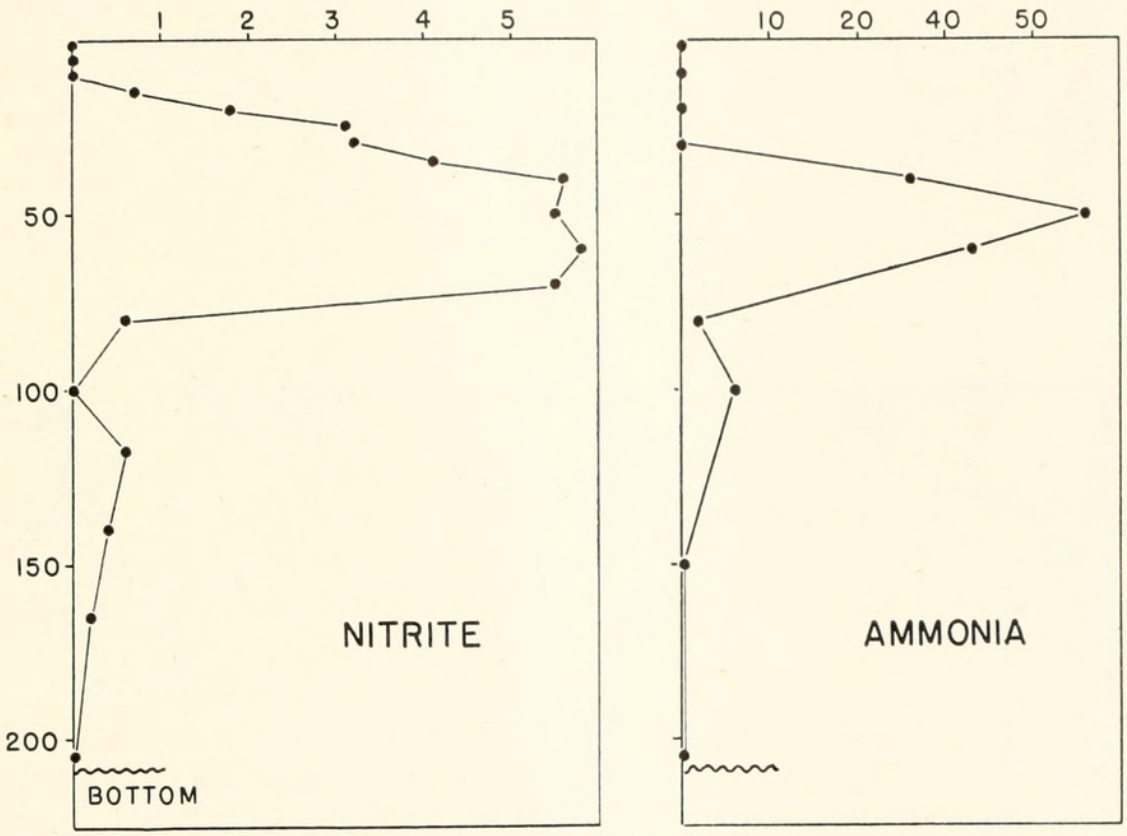


Fig. 5. Vertical distribution of nitrite and ammonia at Station 2212 May 31, 1934. Depths measured in meters downward along the ordinate. Concentrations measured in milligrams nitrogen present as nitrite or as ammonia per cubic meter.

the assimilation of this substance by plankton. Evidently ammonia is similarly consumed. It is interesting, though not surprising, that there is no evidence that soluble organic phosphorus compounds are assimilated in a similar way—since they were found in as high concentration in the surface as at any depth.

Rakestraw remarks that the maximum for nitrite occurs between June and September. However, the nitrite does not appear to accumulate toward the end of summer to the extent to which ammonia and organic phosphorus compounds do. Nitrite is evidently a shorter-

lived link in the chain of nitrogen transformations than is ammonia for even in May the ammonia nitrogen concentration exceeds that of nitrite nitrogen by ten-fold.

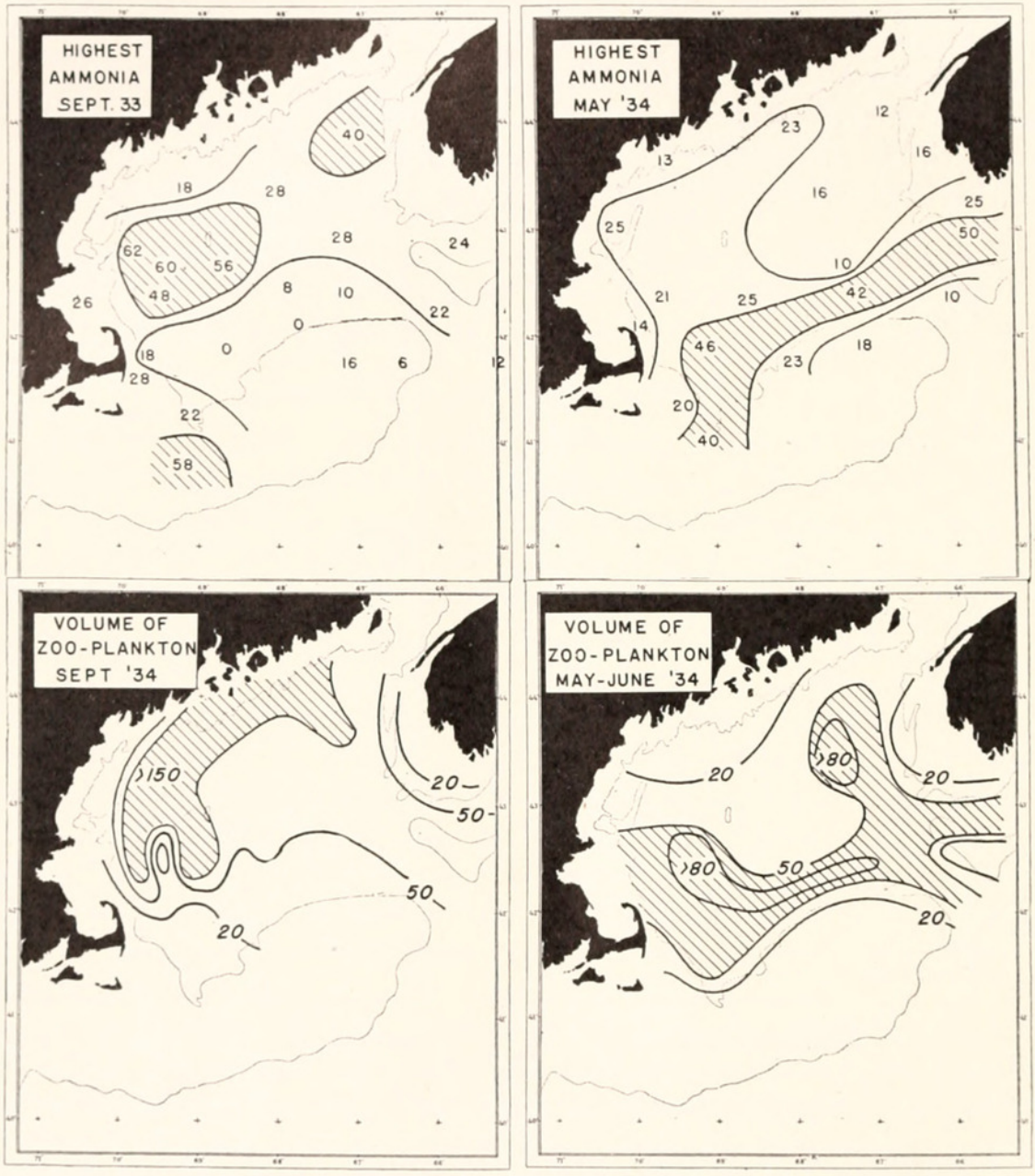


FIG. 6. The highest concentration of ammonia in the upper 80 meters of water in various parts of the Gulf of Maine in September, 1933 and May, 1934 compared with the quantitative distribution of zoöplankton. Ammonia concentrations expressed in milligrams ammonia nitrogen per cubic meter. Zoöplankton volumes expressed as cubic centimeters of dry plankton per square meter of surface area caught in a vertical haul from near the bottom.

RELATION TO PLANKTON

The quantity of ammonia observed during both cruises varied greatly from station to station. In September the greater quantities

were observed in the northern and western parts of the Gulf; in May in the southern and eastern regions. These facts did not assume significance until the plankton catches made at the time had been analyzed.

During each cruise a standard vertical zoöplankton haul was made at each station occupied (a number far exceeding those at which the ammonia was investigated). A 1.5-meter silk net was hauled from near the bottom to the surface. The total catch at each station was freed of excess moisture on a filter and its volume measured by displacement. The results of these measurements expressed as the volume of "dry" plankton per square meter surface have been plotted in Fig. 6 to show the general distribution of animal plankton. For comparison, the highest value of ammonia observed at each station in the upper 80 meters is also shown. While the correlation is not perfect, it is evident that the highest concentrations of ammonia at both periods of observation occur in regions in which the zoöplankton are densely distributed.

This correlation suggests that the animal plankton may be in some way responsible for the appearance of ammonia. While specific observations on plankton animals are lacking, ammonia appears to be the principal nitrogenous waste product of many invertebrate animals (Delauney, 1931). Harvey (1934) has pointed out that the phytoplankton community is continuously being grazed down by the zooplankton. These considerations point to the probability that zoöplankton, through their metabolic products and through their own decay, are an important intermediary in the liberation and distribution of ammonia in sea water.

Summary

1. In the deeper basins of the Gulf of Maine in May ammonia occurred in minimal concentrations at the surface and at all depths below sixty meters; maximal concentrations varying up to 45 mg. N per cubic meter occurred in a definite stratum between 30 and 60 meters.

2. In September the concentration of ammonia was rather uniform at all depths and increased as the distance from the open sea increased, concentrations exceeding 50 mg. N per cubic meter occurring in the western basin.

3. In the tideways of the North and South Channels, ammonia is distributed uniformly with depth in both May and September.

4. In shallow waters its occurrence showed no regularity.

5. The occurrence of ammonia may be correlated in part with the distribution of organic phosphorus compounds, of nitrite, and of

zoöplankton, so as to support the view that its distribution marks the place and the intensity of organic decomposition.

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