UNUSUAL PHOSPHORUS CONCENTRATIONS IN THE FLORIDA "RED TIDE" SEA WATER

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Beginning in late November 1946, and continuing at sporadic intervals until July 1947, a flowering of *Gymnodinium* sp. caused discolored water off the west coast of Florida. Millions of fish were killed along the coastline and this mortality was always directly associated with the presence of *Gymnodinium* (Gunter, Smith and Williams, 1947). The phenomenon has been popularly called the "Red Tide."

Under normal conditions in the sea, phytoplankton production is limited by the supply of phosphorus and nitrogen compounds. It was thought pertinent to inquire whether the tremendous populations of *Gymnodinium* observed were able to exist with the normal nutrient supply of the sea or whether additional supplies of nutrients had become available in some way to support this flowering.

Between July 22 and 24, when an intense flowering was under way near Sarasota, Florida, various water samples were obtained by Mr. William Anderson for Dr. Paul Galtsoff, U. S. Fish and Wildlife Service. These samples were preserved with chloroform and were made available for determination of total phosphorus content. Similar samples taken one month later, during a period when there was no evidence of the plankton bloom, were also analyzed for comparison.

The total phosphorus was determined by the method described by Redfield, Smith and Ketchum (1937). The results include the organic phosphorus combined in particulate matter and plankton, the organic phosphorus in solution in the water, and inorganic phosphate-phosphorus. In different stages of the cycle of synthesis and decomposition of organic matter in the sea the proportion of phosphorus in each of these fractions will differ greatly (Ketchum, 1947). The inorganic phosphorus, which is available for assimilation by the plankton, was found by Dr. R. H. Williams[2] to be undetectable in an area NE. of Key West shortly after a heavy outbreak of the Red Tide. Apparently it was all combined in one or the other of the organic fractions.

[1] Contribution No. 419 from the Woods Hole Oceanographic Institution.

[2] Personal communication.

Since our analyses include all organic and inorganic phosphorus compounds in the water, they indicate the total amount of phosphorus which had been available for synthesis into organic matter. The maximum concentration of phosphorus to be expected in the sea is about 2.0 microgram atoms per liter (Sverdrup, Johnson and Fleming, 1942).

TABLE I.—TOTAL PHOSPHORUS CONTENT OF WATER

SAMPLES TAKEN OFF FLORIDA COAST DURING AND AFTER THE FLOWERING OF *Gymnodinium* SP. (RED TIDE).

Location and Condition of Water in July	*July, 1947* Salinity °/oo	*July, 1947* Total P. µg. at./L.	*August 22, 1947* Salinity °/oo	*August 22, 1947* Total P. µg. at./L.
A. 5 mi. off Sarasota Point; 50 yards outside amber water.	32.9	2.48	33.4	0.81
In water of deep amber color.	33.2	20.4	—	—
B. 3½ mi. off Sarasota Point; water, deep amber color.	32.5	8.80	33.6	1.00
C. 1 mi. south of Sarasota Point; water, light amber color.	33.2	4.92	32.9	1.22
D. 1½ mi. off Sarasota Beach and 1½ mi. above Pt. O'Rocks; water, deep amber color.	32.5	14.6	33.2	1.08
E. 3 mi. off Musketeer's Pass; water, deep amber color.	33.2	5.96	33.6	0.62
F. 3 mi. up from Venice Inlet ½ mi. off beach, in clear blue water.	33.2	1.15	—	—

The locations of the collections are shown in Fig. 2 and the results of the analyses in Table I. In July the samples of water taken outside the discolored area contained normal phosphorus concentrations. Within the discolored area, however, the total phosphorus content varied from 4.9 to 20.4 microgram atoms per liter. This is approximately 2½ to 10 times the normal expected concentration. The samples taken in the same places in August contained between 0.62 and 1.22 microgram atoms per liter and were, consequently, all within the range to be expected in sea water. The salinity data indicate that there was little difference in the amount of fresh water present at the times of sampling. According to Parr (1935) the salinity of the offshore water in this area is about 36°/oo. These water samples, therefore, contained no more than 10% fresh water derived from rain and drainage.

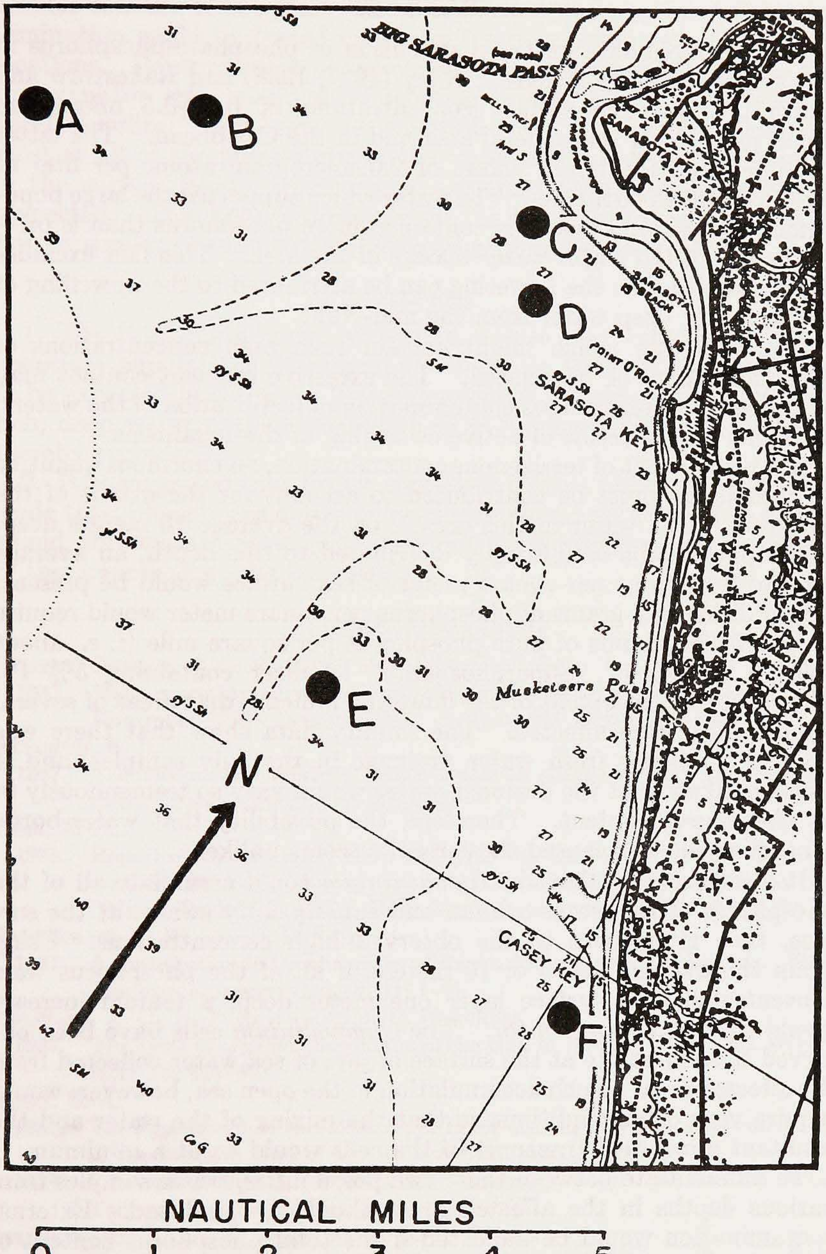

Figure 2. Section of chart off Sarasota, Florida, showing locations where water samples were taken. The depths are in feet at mean low water.

Discussion

The available data on the distribution of phosphate-phosphorus in this general area are meagre. Riley (1937, 1938) and Rakestraw and Smith (1937) found surface concentrations of 0.02–0.5 microgram atoms per liter in this general area and in the Caribbean. The latter authors found maximum values of 2.0 microgram atoms per liter at depths of 500–2000 meters. The water which supported the large populations of *Gymnodinium* thus contained more phosphorus than is present in any of the major water masses of the area. This fact excludes the possibility that the flowering can be attributed to the upwelling of nutrient-rich, deep water from the mid-Gulf.

Two processes which might explain such high concentrations of phosphorus may be postulated. The excessive nutrient content may be the result of terrigenous contamination or fertilization of the waters, or it may be the result of active swarming of the organisms.

If it is the result of terrigenous contamination, an enormous quantity of phosphorus must be contributed to account for the extent of the flowering. The water in this area is on the average 10 meters deep. If the phosphorus is uniformly distributed to this depth, an average total of 3–6 grams per square meter of sea surface would be present. The addition of 3 grams of phosphorus per square meter would require about 17,000 pounds of pure phosphorus per square mile (*i. e.*, about 340,000 pounds of "Superphosphate" fertilizer containing 5% P). The reports of the extent of the flowering indicate that areas of several square miles were affected. The salinity data show that there was little or no excess fresh water drainage in the July samples, and it seems unlikely that the drainage water would vary so tremendously in its phosphorus content. Therefore, the possibility that water-borne contamination has caused these results seems unlikely.

It is conceivable that the *Gymnodinium* could assimilate all of the phosphorus of the water column and subsequently swarm at the surface, thus giving rise to the observed high concentrations. Using again the average depth of 10 meters, if all of the phosphorus were concentrated in a surface layer one meter deep, a tenfold increase would thus be accounted for. The *Gymnodinium* cells have been observed to accumulate at the surface of jars of sea water collected from the affected area. Such accumulation in the open sea, however, would require very calm conditions so that the mixing of the water and the resultant downward transport of the cells would be at a minimum.

To differentiate between these two possibilities, water samples from various depths in the affected areas should be analyzed. External contamination would be indicated if the total phosphorus content of the water column were greater than would be expected from the normal content of the sea. The distribution and source of this contamination could be traced easily by the proper spacing of sampling locations. Determination of the carbon: nitrogen: phosphorus ratios of the plankton cells would show whether phosphorus alone or a "balanced fertilizer" had been the contaminant. On the other hand, if most or all of the phosphorus of the water column were concentrated in the surface layers, swarming of the *Gymnodinium* cells would be suspected. This note is presented in the hope that future investigation of similar phenomena will give an answer to this problem.

Summary

1. The total phosphorus content of waters containing dense *Gymnodinium* populations was found to be 2½ to 10 times the maximum to be expected in the sea. The possibility that upwelling of nutrient-rich, deep water is the explanation of this intense plankton bloom is thereby excluded.

2. It is suggested that future studies of intense plankton blooms include total phosphorus determinations at various depths. The results would differentiate between terrigenous contamination and swarming of the organisms at the sea surface.

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