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VOLUME XV

OCEANOGRAPHY OF
LONG ISLAND SOUND, 1952-1954

By

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GEORGIANA B. DEEVEY
ROBERT J. CONOVER
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HOWARD L. SANDERS

Issued February, 1956
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OCEANOGRAPHY OF LONG ISLAND SOUND, 1952-1954

VIII. CHEMICAL COMPOSITION OF THE PLANKTON

By

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ABSTRACT

Net plankton samples, collected occasionally during 1953 from the central part of Long Island Sound, were analyzed for wet and dry weight, ash, chlorophyll, total phosphorus and total nitrogen. The phytoplankton samples showed seasonal variations in ash which are explained by changes in the relative abundance of certain species; they also showed variations in chlorophyll, which may be explained as an adaptation of the phytoplankton to seasonal changes in illumination. In contrast to ash and chlorophyll, the nitrogen and phosphorus remained relatively constant throughout the year, although the average N:P ratios for the two groups were different. These ratios are discussed in relation to the inorganic nutrient supply of the Sound.

INTRODUCTION

Routine plankton observations, comprising counts, chlorophyll analyses, and zooplankton displacement volumes, have provided the main basis for the description of plankton distribution and seasonal variation in Long Island Sound. However, it was decided that additional measurements of wet and dry weight, ash, chlorophyll, total phosphorus, and total nitrogen on a few plankton samples would facilitate studies on the dynamic aspects of production and utilization of plankton and on the transformation of nutrients in the Sound. Samples were collected periodically during 1953 at the locations and dates listed in Table I. While only a few samples were taken, it was hoped that they would reveal any large seasonal fluctuations in chemical composition, which, if they existed, would affect the dynamic studies just mentioned.

In addition to the weights and chemical measurements, the species composition of the phytoplankton samples was determined, since it seemed likely that species variations might have some effect on the results. The counts were made by Shirley M. Conover, and her help is gratefully acknowledged.

METHODS

Sampling. All samples, phytoplankton and zooplankton, were obtained by surface tows. The phytoplankton samples were collected in a net of bolting silk, 30 cm in diameter, which had a pore size of 75μ and which retained the larger members of the phytoplankton population. A second net with a larger pore size of 415μ was suspended inside the phytoplankton net, and this served to screen and thus eliminate the larger zooplankton from the phytoplankton sample. In order to catch the smaller phytoplankton as well, it would have been necessary to use a net with a pore size smaller than 75μ , but this was impossible since such a net would have retained large quantities of detritus. The zooplankton samples that were used for the analyses were collected in another net, 40 cm in diameter, with a pore size of 415μ which retained only the larger members of the zooplankton population. Unfortunately, it was practically impossible to obtain a quantitative separation of the two plankton groups because of their overlap in size, especially in summer. It was also difficult to obtain a phytoplankton sample of workable size except in the spring flowering period.

Contamination of the June 1 phytoplankton samples by zooplankton and detritus explains the high phosphorus and nitrogen and the low ash and chlorophyll relative to those values obtained for other phytoplankton samples. This sample had a zooplankton count which was 15% that of the phytoplankton count; and, since the zooplankton were the larger organisms, the percentage of zooplankton organic matter in the sample was probably much greater than 15%.

Analytical. The zooplankton samples were filtered under suction on No. 10 bolting silk, the phytoplankton samples on No. 20 bolting silk. The sample was washed with a small volume of distilled water and suction was reapplied to remove as much water as possible before determining the wet weight. The dry weights were determined after the samples had been dried in an oven at 95° C. Since there was considerable error in the wet weight determinations, especially for phytoplankton, all chemical analyses are referred to the dry weights.

The percentage of organic matter, which is assumed to equal the loss in weight upon ignition, was determined on a fraction of each sample. Suspensions of fresh phytoplankton catches were used to determine the chlorophyll content, as described in this volume by Riley and Conover.

Nitrogen and phosphorus analyses were carried out on 10–15 mg fractions of the dried samples. For nitrogen, samples were digested with 0.2 ml H_2SO_4 and 4–5 drops H_2O_2 , the amount of ammonia then being determined by the standard micro-Kjeldahl method as described by Pregl (1930: 109–118).

At first, phosphorus samples were digested with nitric and perchloric acids, followed by 3 ml HCl so as to volatilize arsenic prior to the determination of phosphorus by the modified Denigés-Atkins method. Because the phosphorus content of the samples appeared low, the digestion method was checked against the sulfuric acid-hydrogen peroxide method that was used for the nitrogen determinations. The latter method gave higher values. Cooper (1934) attributed the low results obtained in certain oxidation methods to interference in color development by oxidizing agents remaining in the mixture. An investigation of the nitric-perchloric method revealed that it could give values for phosphorus that were equal to those obtained by the sulfuric acid-hydrogen peroxide method provided greater care was taken to prevent loss of perchloric acid fumes from the digesting mixture, to get rid of *all* nitric acid after digestion was

TABLE I. CHEMICAL COMPOSITION OF PHYTOPLANKTON AND ZOOPLANKTON

Phytoplankton		Percent Dry Weight					Percent Organic Matter				
Sts.*	Date	Dry Wt. (% Wet Wt.)	Org. matter	Ash	Chlor.	P	N	Chlor.	P	N	N:P
8	Jan. 27	19.0	29.6	70.4	0.35	0.33	2.25	1.19	1.11	7.6	6.8:1
2	Feb. 18	14.6	27.3	72.7	0.40	0.26	2.33	1.47	0.95	8.5	9.1:1
1, 2	Mar. 9	16.2	27.2	72.8	0.40	0.36	2.87	1.47	1.32	10.5	8.0:1
1, 2	Mar. 23	10.2	38.2	61.8	0.55	0.27	2.09	1.44	0.71	5.5	7.9:1
5	June 1	29.0	57.3	42.7	0.15	0.73	4.77	0.26	1.27	8.3	6.6:1
N.H.H.	July 7(a)	17.3	71.6	28.4	0.31	0.57	4.15	0.43	0.80	5.8	7.3:1
N.H.H.	July 7(b)	19.3	49.1	50.9	0.30	0.64	4.43	0.60	1.30	9.0	7.0:1
2, 8	Aug. 4	8.0	38.6	61.4	0.16	0.48	2.73	0.41	1.24	7.1	5.9:1
8	Feb. 1	10.5	30.9	69.1	0.33	0.32	2.24	1.07	1.03	7.0	7.0:1
	Average	16.0	41.1	58.9	0.33	0.44	3.10	0.93	1.08	7.7	7.3:1
Zooplankton											
5	Jan. 19	9.4	—	—	—	0.97	10.80	—	—	—	11.1:1
8	Jan. 27	12.1	85.9	14.1	—	0.87	9.96	—	1.04	11.0	10.6:1
8	Apr. 15	10.9	78.6	21.4	—	0.70	9.25	—	0.89	11.7	13.1:1
8	Apr. 15	8.9	72.0	28.0	—	0.69	8.37	—	0.96	11.6	12.1:1
2	July 7	12.6	87.3	12.7	—	1.05	9.78	—	1.20	11.2	9.3:1
5	Nov. 23	8.0	74.5	25.5	—	0.59	5.56	—	0.79	7.5	9.5:1
	Average	10.3	79.7	20.3	—	0.82	8.91	—	0.98	10.6	10.9:1

* Numbered stations are routine stations shown in Fig. 1 of Riley's INTRODUCTION to this volume. N.H.H. refers to New Haven Harbor.

completed, and to wash the precipitate in the digested sample three or four times. The results in Table I were obtained with the sulfuric acid-hydrogen peroxide method, with an additional step of volatilizing arsenic with HCl.

RESULTS

The results of chemical analyses are summarized in Table I.

Phytoplankton. The ash averages 58.9% of the dry weight, with a slightly higher average of 69.4% for the five winter samples. This indication of a seasonal trend agrees with the findings of other investigators. For example, Moberg (1928) reported that the average ash content of net phytoplankton in California waters was 75% of the dry weight between October and February and 25.5% from May to June. Table II shows that: the seasonal trend results from changes in species composition of the samples; the winter phytoplankton samples are almost solely diatoms, of which a single species, *Skeletonema costatum*, makes up 72%, 82.7%, 96.6% and 72.2% of the total cell count in the Jan. 27, Feb. 18, Mar. 9 and Mar. 23 samples respectively; the summer samples contain large proportions of other

TABLE II. SPECIES COMPOSITION OF THE PHYTOPLANKTON SAMPLES IN PERCENTAGES OF THE TOTAL CELL COUNT

	Collection dates							
	I/27	II/18	III/9	III/23	VI/1	VII/7	VII/7	VIII/4
<i>Skeletonema costatum</i>	72.1	82.7	96.6	72.2	1.8	—	—	—
<i>Thalassiosira decipiens</i>	8.1	4.6	0.7	—	3.1	—	—	—
<i>T. nordenskiöldii</i>	2.3	2.4	—	8.7	—	—	—	—
<i>Thalassiosira nitzschoides</i>	9.5	5.2	0.3	1.0	1.1	—	—	0.5
<i>Lauderia borealis</i>	—	—	—	8.9	—	—	—	—
<i>Melosira sulcata</i>	4.5	1.8	0.6	1.3	1.3	—	—	—
<i>Nitzschia closterium</i>	—	—	—	—	—	26.6	14.3	—
<i>N. pungens</i> var. <i>atlantica</i>	—	—	—	—	6.0	—	—	—
<i>Asterionella japonica</i>	0.3	—	—	3.3	—	8.7	0.6	—
<i>Chaetoceros affinis</i>	0.2	—	—	—	—	—	—	8.6
<i>C. curvisetus</i>	0.3	—	—	—	—	—	—	5.9
<i>C. compressus</i>	0.8	0.7	—	—	—	—	—	1.1
<i>C. danicus</i>	—	—	—	1.3	2.7	—	—	—
<i>C. decipiens</i>	—	—	—	0.6	18.0	—	2.8	64.0
<i>C. radicans</i>	—	—	—	0.6	—	—	—	—
<i>Coscinodiscus radiatus</i>	—	—	—	—	—	—	—	2.7
<i>C. perforatus</i> var. <i>cellulosa</i>	—	—	—	—	—	—	—	3.6
<i>C. centralis</i> var. <i>pacifica</i>	—	—	—	—	—	3.1	34.5	2.6
<i>Rhizosolenia delicatula</i>	0.2	—	—	—	4.5	—	—	—
<i>Prorocentrum scutellum</i>	—	—	—	—	—	—	—	8.7
<i>Thalassiosira gravida</i>	—	—	—	—	—	—	—	1.4
<i>T. rotula</i>	—	—	—	—	1.1	—	1.0	—
<i>Peridinium trochoideum</i>	—	—	—	—	53.3	—	—	—
<i>Goniaulax africana</i> (?)	—	—	—	—	1.1	43.8	32.1	—
<i>G. cochlea</i>	—	—	—	—	—	6.1	10.8	—
<i>Ezuriella</i> spp.	—	—	—	—	—	2.0	1.6	—
Unidentified pennate diatoms	—	—	—	—	—	8.7	0.6	—
Total	98.3	97.4	98.2	97.9	94.0	99.0	98.3	99.1

phytoplankton, especially dinoflagellates, of which *Goniaulax* spp. make up about half the cell count in the two July samples. A larger percentage of ash from diatoms accounts for the higher ash content in the winter samples.

It would be interesting to know the relative proportions of the various constituents of diatoms and dinoflagellates that coexist in nature, since most data are acquired from pure cultures of single species. Table III represents a rough approximation of the composition of *Goniaulax* and *Coscinodiscus* as calculated from the July 7(a) and 7(b) samples. These genera make up the greater percentage of the total cell count of these two samples and, since they are the only large forms present in appreciable numbers, it may be assumed that they represent the entire volumes of the samples. An equation is set up for each sample, using the number of cells of each genus in the sample as coefficients for the chemical component to be solved; these are then equated to the total weight of that component in the

sample. The two equations are solved simultaneously. For example:

$$(a) 0.12x + 5.42y = 244.5$$

$$(b) 4.99x + 6.27y = 895.5,$$

where x = weight in mg of 10^6 *Coscinodiscus* cells, y = weight in mg of 10^6 *Goniaulax* cells and where 244.5 and 895.5 are the wet weights in milligrams of the July 7(a) and 7(b) samples respectively. As a check on the algebraic method, the wet weight per million cells is converted to an estimate of volume by assuming a specific gravity of 1.03 which is then compared with observed volumes. While calculated and observed dimensions vary slightly, the correction

TABLE III. COMPOSITION OF *Goniaulax* AND *Coscinodiscus*

	Mg/10 ⁶ cells		Percent Dry Weight		Percent Organic Matter	
	Gon.	Cosc.	Gon.	Cosc.	Gon.	Cosc.
Wet weight	42.3	126.3	—	—	—	—
Dry weight	7.2	25.7	—	—	—	—
Organic matter	5.3	10.6	73.6	41.2	—	—
Ash	1.9	15.1	26.4	58.8	—	—
Chlorophyll	0.022	0.075	0.31	0.29	0.41	0.65
Nitrogen	0.298	1.166	4.14	4.53	5.62	11.00
Phosphorus	0.041	0.171	0.57	0.66	0.77	1.61

	<i>Goniaulax</i>	<i>Coscinodiscus</i>
Calculated diameter μ	46 x 36	85
Observed diameter μ	35 x 28	50 — 160 mean about 110 μ

for which would decrease the weight of *Goniaulax* and increase that of *Coscinodiscus*, the results are sufficiently accurate to give some indication of the differences between diatoms and dinoflagellates. The data in Table III support the conclusion that seasonal variations in ash are due to changes in relative abundance of certain species, since *Goniaulax* has only half as much ash as *Coscinodiscus*.

That there is some seasonal variation in chemical composition is borne out by the chlorophyll values. When the chlorophyll percentages for the five winter and four summer samples are averaged separately, chlorophyll comprises 1.33% of the organic content in winter and 0.43% in summer. If we assume that 4.4 Harvey Units of plant pigment are equivalent to 1 μ g chlorophyll (see Riley and Conover's paper), then the winter samples average 5850 HU/mg P, the summer samples 1850 HU/mg P. These values are considerably

lower than the 12500 HU/mg P reported by Harvey, *et al.* (1935) for the spring flowering period in the English Channel.

In contrast to chlorophyll, phosphorus and nitrogen do not show a regular seasonal variation. Variations from sample to sample may be as great as 100%, but this is much less than the 300% difference between summer and winter chlorophyll. However, Table III indicates that there are variations between species and that summer diatoms may be richer in nitrogen and phosphorus than winter diatoms. The ratio of nitrogen to phosphorus averages 7.3:1 by weight or 16.7:1 by atoms, with relatively small deviations. This average agrees well with Fleming's average of 7:1 (Fleming, 1939).

Zooplankton. Table I reveals that zooplankton have a more nearly uniform composition throughout the year than phytoplankton. The April 15 and November 23 samples are undoubtedly contaminated with phytoplankton, since both contain precipitates which must be centrifuged out after digestion of the samples. Copepods made up about 95% of the zooplankton in the samples, and contamination by phytoplankton may explain why the average ash content was higher and the phosphorus and nitrogen values lower than one would expect for copepods, considering values quoted by Vinogradov (1953: 381-387). Vinogradov's figures¹ for *Calanus finmarchicus* are 9.0-10.2% N and 1.02% P as percentage dry weight, while the Long Island Sound samples are 8.91% N and 0.82% P. The difference is accentuated by the higher ash content of the Sound samples, but both give a N:P ratio of 11:1. When the November sample is omitted from consideration, the percentage of nitrogen in the organic matter is very constant.

Fleming's average N:P ratio of 7.4:1 for zooplankton is much lower than that of the Long Island Sound zooplankton. Fleming points out that there is no reason why the ratio should be the same in phytoplankton and zooplankton, since the latter are physiologically much more complicated than single cell organisms, yet it is shown in the following discussion that the phytoplankton are able to maintain a fairly constant ratio under quite different environmental conditions. Average N:P ratios are calculated from only a few analyses which vary from author to author and species to species, hence such over-all averages probably have no validity when applied to a particular area.

¹ Recalculated from Vinogradov's P_2O_5 values.

DISCUSSION

Redfield (1934) was the first to point out that the ratio of inorganic N:P in ocean water is nearly constant and is identical to the ratio of these elements in plankton. He also pointed out that limited bodies of water may have lower N:P ratios than average ocean water, and he has presented data that show a ratio of 10:1 by atoms for the English Channel. In the Sound a still more extreme condition has been noted (see Riley and Conover's paper). The maximum N:P ratio in winter is about 8:1, and for several months following the spring phytoplankton flowering, nitrate is almost entirely depleted² while considerable phosphate remains. However, the data show that the ratio of N:P in Long Island Sound phytoplankton is almost constant within analytical error and that this ratio is strikingly close to that of open ocean water in spite of the dissimilar N:P ratios of these two types of water.

In the laboratory, Ketchum (1939, 1949) found that pure cultures of phytoplankton grown in a nitrogen-deficient medium showed a decrease below the normal nitrogen content; *Chlorella pyrenoidosa* contained as little as 2.25–2.72% N in their ash free dry weight; when the deficient cultures were returned to media containing adequate nitrogen, the nitrogen content reverted back to about 7.7%, which is normal for *Chlorella pyrenoidosa* in cultures as well as nature. Moreover, this deficiency can be made up in the dark as well as in light, and this led Harvey (1945) to suggest that while phytoplankton may become nutrient deficient during the day, such deficiency may be made up at night. This would enable populations to absorb nutrients continuously from media with low concentrations while carbon fixation would proceed only in daylight, thus maintaining the required nitrogen and phosphorus concentrations in the organic matter. Such a mechanism, coupled with rapid replenishment of nutrients in a shallow basin like the Sound where there is continuous mixing of bottom water and considerable land drainage, may explain how the phytoplankton maintain a nitrogen content which is the same as that of ocean plankton where the N:P ratio in the water is greater.

Recent physiological experiments (Harvey, 1953) may also explain why chlorophyll, as opposed to nitrogen and phosphorus, undergoes a marked seasonal variation. The data in Table III show that seasonal changes in dominant species do not explain this variation, since both diatoms and dinoflagellates contain about the same amount

² Preliminary analyses show that some nitrogen is available in the form of ammonia.

of chlorophyll. Working on pure cultures of *Nitzschia closterium*, Harvey demonstrated that the amount of chlorophyll synthesized was a function of the amount of illumination, only half of the chlorophyll being produced when the illumination was increased six times. This situation is apparently a complex one, since nitrogen deficiency in addition to increased illumination will also decrease chlorophyll synthesis; Harvey emphasizes that both factors together do not completely explain the problem. However, on the basis of these experiments, it is logical to expect a threefold decrease in the chlorophyll content of summer phytoplankton in an area like Long Island Sound where there is approximately a ninefold increase in summer illumination over winter illumination.

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