The Cycles of Phosphorus and Nitrogen in Tokyo Bay

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Theoretical treatment of the distribution and seasonal changes in the contents of nitrogen and phosphorus have generally been limited to the case of oceanic water. The similar treatment, however, is difficult in the case of coastal water. The difficulties may probably be due to the facts that the coastal water is rich in organic matter and that a considerable part of it is in the form of dissolved organic substances.

Some explanations on the seasonal changes in the contents of nutrient salts in Tokyo Bay have been forwarded from the results that the nitrogen phosphorus ratio in such waters was found to be the same as that in oceanic water.

Results and Discussions

According to Suda (1929), Tokyo Bay is divided into two regions from hydrography and geography; The inner part, north of Kannonsaki—Futtusaki line, and the outer part, called Uraga Suido, the region within the two lines Zyogashima—Sunosaki and Kannonsaki—Futtusaki (Fig.1). The area, volume, and average depth of the former are 1,187 km², 16.6 km³, and 13.9 m., respectively, and those of the latter are 467 km², 71 km³, and 152 m., respectively. From Fig.2, prepared from the data obtained by monthly observations (Central Fisheries Station of Japan 1948—49), the hydrographical division of the Bay was ascertained and the mixing of coastal and oceanic waters was recognized at the junction of the two regions. The surface currents in Tokyo Bay are shown in Fig.1 (Suda, 1929), and the distribution of average chlorinity of monthly observed data suggests the possibilities of the presence of these currents (Fig.3).

From the vertical stability calculated and the isopleth diagram of chlorinity, it was estimated that the water of the inner part was thoroughly mixed from surface to bottom in winter. Annual variations in temperature at different depths in the station 29 is shown in Fig.4. In winter the water from surface to 50 m. was thoroughly mixed and in summer the water below 100 m. showed the lowest temperature. The latter fact may be due to the upwelling of cold deep water. The remarkable increase of phosphate content may be assumed to support the presence of the upwelling.

The seasonal change in the average amount of phytoplankton collected at various

Fig. 1 Surface currents in Tokyo Bay. ○ and number denote the observed station and station number, respectively.

Fig. 2 T-Cl diagram of 5 m layer in Tokyo Bay. Solid line denotes the inner part. Dotted line denotes the Uragsuido.

points in the inner part of the Bay is shown in Fig. 5. There should be some interrelation between the seasonal changes in the amounts of plankton and that in the contents of nutrient salts. In the following paragraph, qualitative interpretations will be given on the seasonal changes and on cycles of nutrient elements.

1. On the ratio of nitrogen and phosphorus.

In the deep water of ocean the atomic ratio of nitrate nitrogen and phosphate phosphorus is 16:1 and the ratio of nitrogen and phosphorus in plankton is the same (Sverdrup, Johnson, and Fleming, 1942). Since in deep water almost all of nitrogen and phosphorus are in the forms of nitrate, and phosphate, it may be considered that the ratio of nitrogen and phosphorus in oceanic water would be 16:1.

The sum of nitrogen content in various forms and total phosphorus content in the water of the Bay were determined, because the coastal water contains abundant organic compounds. Some of which are containing nutrient elements. Some examples are shown in Tables 1 and 2. The results indicated that the mean ratio of nitrogen and phosphorus in the Bay is 7.4 (in weight), or 16 (in atom number), the confidence

Fig. 3 The average distribution of chlorinity for all year round. Unbroken line denotes the isochlorinity line of surface. Broken line denotes the contour line of Tokyo Bay.

limits of the value being 8.5 and 6.3 in weight ($\alpha=0.05$). In the case represented in Table 1 organic nitrogen was not detected but, on the other hand, 90% of phosphorus was found in organic matter.

2. The cycles of phosphorus and nitrogen in the inner part of Tokyo Bay.

At. station Nos. 2, 5, 10, 14, and 19, the annual changes in nitrogen, phosphate phosphorus, the atomic ratio of total inorganic nitrogen* and phosphate phosphorus, and the atomic ratio of nitrate nitrogen and phosphate phosphorus are shown (Fig. 6). The values concern the quantities in a water column under 100 cm². surface**.

* Sum of nitrogen in nitrate, nitrite, and ammonium. Represented by ΣN .

** Analytical methods used in the present study were in accord with the ordinary methods (MIYAKE, 1949).

Fig. 4 Annual variation in temperature at different depths in Uraga Suido.

Fig. 5 Seasonal change in the amount of phytoplankton.

Table 1. Contents of nitrogen and phosphorus. ¹⁾
Unit: γ/l . Station: No. 14. Date: Oct. 1949.

Depth m.	$\text{NO}_3^- \text{-N}$	$\text{NO}_2^- \text{-N}$	$\text{NH}_4^+ \text{-N}$	Org. N	$\text{PO}_4^{\equiv} \text{-P}$	Org. p ²⁾	ΣN	Total P	N/P ³⁾
0	195	6.0	150	0	4.0	66.0	351	70.0	5.0
5	189	8.8	355	0	14.0	66.0	554	80.0	6.9
10	290	14.7	299	0	9.8	67.2	600	77.0	7.8
20	348	12.9	325	0	6.0	72.0	690	78.0	8.9
32	410	10.8	105	0	14.4	60.6	530	75.0	7.1

1) Mean of duplicate analysis.

2) Total phosphorus minus phosphate phosphorus.

3) $\text{N}/(\text{Total phosphorus})$.

Table 2. Contents of various types phosphorus.
Unit: γ/l . Station: No. 14. Date: Oct. 1949.

Depth m.	I	II	III	N $\text{PO}_4^{\equiv} \text{-P}$	V	VI	VII
0	70.0	70.0	70.0	4.0	66.0	0.0	0.0
5	80.0	80.0	67.5	14.0	53.5	12.5	0.0
10	77.0	77.0	69.1	9.8	59.3	7.9	0.0
20	78.0	76.3	72.5	6.0	66.5	3.8	1.7
32	75.0	75.0	75.0	14.4	60.6	0.0	0.0

I: Untreated sample.

II: Filtered through Toyo 5C filter paper.

III: Filtered through a sintered glass filter, inside coated with 3% collodion.

V: Total-P (III) minus $\text{PO}_4^{\equiv} \text{-P}$.

VI: Total-P (II) minus Total-P (III).

VII: Total-P (I) minus Total-P (II).

From Fig. 6, the following phenomena were observed: (1) The contents of nitrate and phosphate reached a minimum in spring on the contrary the maximum growth of phytoplankton was shown in spring. The station No. 2, located near the mouths of rivers, was exceptional. (2) The ratio of nitrate nitrogen and phosphate phosphorus showed a minimum in spring. (3) The ratio of total inorganic nitrogen and phosphate phosphorus showed a maximum in spring.

If the ratio of the absorption velocities of nitrogen and phosphorus by phytoplankton is 16:1 in atom number, and if the velocity of the regeneration of phosphate is slower than that of inorganic nitrogen, ΣN , the ratio of ΣN and phosphate phosphorus may become maximum in spring. If it is also assumed that nitrate nitrogen is selectively consumed by phytoplankton, and further, that the oxidation of nitrogen decrease during winter to early spring, the minimum in the ratio of nitrate nitrogen and phosphate phosphorus in spring may be explainable.

3. Some remarks on the distributions of nitrate and phosphate in summer.

The contents of nitrate, nitrite, ammonium, and phosphate at each station were

Fig. 6 Annual changes in the contents of nutrient salts.

determined in July 1948. The results are shown in Fig. 7. The lines A and B are expressed by the following equation:

$$\log(\text{NO}_3\text{-N})/(\text{PO}_4\text{-P}) = a + b \times \log(\Sigma\text{N})/(\text{PO}_4\text{-P}),$$

where a and b represent constants.

The fact that nearly all of open circles (○) in Fig. 7 located on the light side of the line

Fig. 7. The relation between $\text{NO}_3\text{-N}/\text{PO}_4\text{-P}$ and $\Sigma\text{N}/\text{PO}_4\text{-P}$ of surface and bottom layers in summer.

D which represents the relation $\Sigma\text{N}/\text{PC}^{\text{II}}\text{-P}=16$ indicates that in the surface layer inorganic nitrogen phosphate phosphorus ratio is larger than 16 in atom number at every station. Distribution of nearly all of the solid circles (●) along the C line which represents the relation $\Sigma\text{N}=\text{NO}_3\text{-N}$, and on the light side of the line D indicates that in bottom layer (1) nearly all nitrogen exists as nitrate and (2) ΣN is larger than the value calculated by using the relation $\text{N}/\text{P}=16$. This fact may be explained by assuming that only decomposition or oxidation of the matter containing nitrogen and phosphorus takes place in the bottom layer and by assuming that the regeneration velocity of inorganic nitrogen is larger than that of phosphate*.

In the surface layer, the ratio of nitrate nitrogen and phosphate phosphorus was less than 16, while the ratio of ΣN and phosphate phosphorus was larger than 16. It may be reasonable to consider that the former fact suggests the selective consumption

* In the coastal region, precipitation of phosphorus with mud should be considered.

of nitrate and the latter, the regeneration velocity of nitrogen is higher than that of phosphate.

The tangent of line B in Fig. 7 is larger than that of line A. This may be due to higher oxidation velocity of nitrogen in the surface layer than in the bottom layer.

The term $(\text{PO}_4^{\text{■}} - \text{P})$ in the equation of line B could not be cancelled, because the tangent b was not equal to unity. This may suggest that phosphate is necessary in the assimilation of nitrogen by phytoplankton. Then, in the study of the assimilation of nitrogen by phytoplankton, the interaction of nitrogen and phosphorus should be taken into consideration. The writer wishes to express his heartfelt thanks to Dr. M. Migita, Dr. Y. Miyake, and Dr. T. Hanaoka for their valuable criticisms and suggestions. Especially must the writer express his gratitude to Prof. M. Tauchi and Prof. H. Goto for their encouragements in the course of this work.

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