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<td>レッドタインの研究: 長崎湾の夏季における藻類の分布と生態系の影響</td>
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Red Tides in Nagasaki Bay during Summer Season
of 1979

Tengku Dahril and Shoji IIZUKA

Almost every year during the summer season, red tides have occurred in Nagasaki Bay. Red tides are caused by various kinds of phytoplankton and bay waters discolor like coffee by the exclusive growth of a single organism or mixed growth of two or three organisms. However, very little is known about red tide in this bay. In this paper the authors dealt with red tides in Nagasaki Bay during the summer season of 1979.

The innermost part of this bay was divided into 3 areas. Five water sampling stations were fixed in each area and water samplings were done of a water column 4.5 m in depth at each station with transparent Akryl synthetic resin tubes (18 mm in inner diameter; 1.5 x 3 m in length). Collected sea water subsample was put in a plastic vessel and mixed with the other sea water subsamples of the same area. Then, sea water sample of a fixed volume was taken randomly from the mixed sea water subsample. These samplings were continued for 79 days from June 12 to August 29 at interval of twice a week, generally, and a total 21 samples per area were collected. The dominant organisms during this season were Skeletonema costatum and Olisthodiscus sp. and the accompanying organisms were Prorocentrum minimum, Prorocentrum obtusidens and Thalassiosira sp. The concentration of chlorophyll-a and cell density in this layer were 108.3 mg m⁻³ and 5.8 x 10⁷ cells l⁻¹ in maximum, respectively. During the period of survey red tides were observed for about one month and especially, the bay waters were discolored densely every day in August. Those dense discolorations of this bay are close to that of the highly polluted innermost part of Tokyo Bay and Osaka Bay. To understand completely the causative factors of the occurrence of red tide is difficult. However, it is possible to imagine that high concentration of pollutants which were supplied by river water and polluted water discharged from an urban waste treatment plant might accelerate the growth of red tide organisms.

Nagasaki Bay is one of the most important fishing ports situated in the western coastal area of Kyushu, Japan. Nagasaki City, of 440,000 people, is located on the coast of the innermost parts of the bay. Area and mean depth of the bay are about 11.03 km² and 19.96 m and tidal ranges are 2.32 m at spring tide and 1.12 m at neap tide. From those values, exchanged volumes during a half tidal period are estimated 11.17 % and 5.61 % to total volume of the bay, respectively. In innermost parts, there are two rivers, Urakami R. and Nakashima R. and the pollutant influx loads by both rivers are 21.15 ppm and 11.88 ppm in BOD with reference to the published data in 1976 by Department of Environment Protection, Nagasaki Prefecture. Meanwhile, near the mouth of the Urakami R. there is an urban waste water treatment plant for Nagasaki City which discharges the treated waste water of 35,000 tons a day toward Urakami R.. Concentrations of nitrogen and phosphorus in the discharged water are about 44.0 µg-atom l⁻¹ and about 5.8 µg-atom l⁻¹, respectively, according to Nagata's personal data. Inflow of such nutritiously rich water may play an important role on eutrophication of Nagasaki Bay. Perhaps, from this reason, almost every year, red tides have occurred.
in this bay when warm season comes. Red tides are caused by various kinds of phytoplankton. Bay water discolors like coffee because of the exclusive growth of a single organism or mixed growth of two or three organisms. However, very little is known about red tide in this bay with exception of incomplete reports of Iizuka and Irie (1966 and 1968). In this paper, the authors dealt with red tide in Nagasaki Bay during the summer season of 1979.

Methods and materials

Survey were conducted in innermost parts of the bay within an area of 3.05 km². Survey Stations were distributed in a north-east direction line reaching from Megami to its opposite coast, Kanzaki. The parts were divided into three areas, Area I, the nearest to Urakami R., Area II, the middle part, and Area III, the farthest most part. Five water sampling stations were fixed in each area (Fig. 1). Water samplings were done with transparent Akryl synthetic resin tubes (18 mm in inner diameter; 1.5×3 m in length) which were lowered gradually but vertically until 4.5 m in depth and elevated again to the boat after upper mouth of the tube was fixed tightly by a rubber stopper. By means of this procedure, subsample sea water was collected as a water column till 4.5 m in depth at each station. Collected subsample sea water was put in a plastic vessel and mixed with the other subsample sea water of the same area. Then, sample sea water of a fixed volume was taken randomly from the mixed subsample sea water. Such samplings were carried out principally twice a week from June 12 to August 15 and once a week after August 15 to the end of August. A total of 21 samples per area were collected for 79 days during the surveys. After measuring water temperature on the boat, samples were brought to the laboratory to determine chlorophyll-a salinity, inorganic nutrients and to observe species composition of phytoplankton and to count cell numbers. Cell counting was done three times by 0.1 ml of concentrated plankton suspending sea water by naturally dropping a millipore filter (1.2 μ). Chlorophyll-a determination was done by fluorometric method (Strickland and Parsons, 1972). Determination of nutrients followed by mean of the method stated in Kaiyo-kansoku-shishin (1970) published by the Oceanographic Society of Japan.

Results

Changes of temperature and salinity, inorganic nutrients, chlorophyll-a and cell number of phytoplankton in each area during the survey are shown in Figs. 2, 3, 4 and 5, respectively.

Temperature varied from 22.2 °C at the beginning of the survey to a maximum of 30.3 °C in early August and Salinity ranged from 21.2 to 33.4 ‰. Variable patterns of
both elements between each area were almost the same. Maximum, minimum and mean concentration of inorganic nitrogen and phosphorus in each area are shown in table 1. Maximum values of nitrate-N, nitrite-N and ammonia-N in the whole area were 5.52, 1.60 and 15.49 $\mu$g-atom l$^{-1}$, and were found concentrically in area I on June 22. Occurrences of such high value corresponded with the dropping of salinity caused by heavy rainfall on the preceding day. It seems to indicate that inflow of river water plays an important role on supply of nitrogen in this area. Maximum concentration of phosphate-P had been found in area I on June 25 with 3.84 $\mu$g-atom l$^{-1}$ and then, concentration decreased gradually to 0.53 $\mu$g-atom l$^{-1}$ on July 16. The next highest concentrations were found in area II together with area I on July 19. In general, concentrations of inorganic nutrients were high in area I compared with the other two areas. This fact suggested that nutrients were supplied mainly by river water including waste water discharged from an urban waste water treatment plant.

Several peaks were found in the variation

![Fig. 2. Changes in temperature and salinity of the strata above 4.5 m in the three areas of Nagasaki Bay, (from June 12 to August 29, 1979). Area I (●), area II (▲) and area III (■).](image)

![Fig. 3. Mean concentrations of inorganic nutrients in the three areas of Nagasaki Bay, (from June 14 to August 10, 1979). Area I (●), area II (▲) and area III (■).](image)

Table 1. Mean concentrations of inorganic nutrients in the three areas of Nagasaki Bay (from June 14 to August 10, 1979), and maximum and minimum concentrations of them in the respective areas.

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<th>AREA I</th>
<th>AREA II</th>
<th>AREA III</th>
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<td></td>
<td>MEAN MAX MIN</td>
<td>MEAN MAX MIN</td>
<td>MEAN MAX MIN</td>
</tr>
<tr>
<td>$\text{NO}_3^-$</td>
<td>1.63 5.52 0.40</td>
<td>1.08 4.88 0.04</td>
<td>0.81 3.22 0.00</td>
</tr>
<tr>
<td>$\text{NO}_2^-$</td>
<td>0.87 1.60 0.35</td>
<td>0.55 1.20 0.08</td>
<td>0.42 0.86 0.07</td>
</tr>
<tr>
<td>$\text{NH}_4^+$</td>
<td>5.87 15.49 0.45</td>
<td>2.64 10.88 0.08</td>
<td>2.25 6.56 0.37</td>
</tr>
<tr>
<td>$\text{PO}_4^-$</td>
<td>1.97 3.84 0.53</td>
<td>1.27 3.77 0.05</td>
<td>0.90 1.88 0.28</td>
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[Unit : $\mu$g-atom l$^{-1}$]
of chlorophyll-a. The first peak was on June 12 and the values were 108.3 mg m⁻³ in area I, 73.7 mg m⁻³ in area II and 52.2 mg m⁻³ in area III. Almost the whole area of Nagasaki Bay was covered with a brown-red colored water. The causative organism was Olistodiscus sp. and cell densities were $7.9 \times 10^6$ cells l⁻¹ in area I, $11.1 \times 10^6$ cells l⁻¹ in area II and $6.1 \times 10^6$ cells l⁻¹ in area III. The second peak was not so high as the first peak, but discoloration appeared also during this time. Causative

![Fig. 4. Mean concentration of chlorophyll-a in the strata above 4.5 m in the three areas of Nagasaki Bay, (from June 12 to August 29, 1979). Area I (●), area II (▲) and area III (■).](image)

![Fig. 5. Mean cell density of diatoms (●) and dinoflagellates (▲) in the strata above 4.5 m in the area I of Nagasaki Bay, (from June 12 to August 29, 1979).](image)

![Fig. 6. Species composition and cell density of phytoplankton in the area I, Nagasaki Bay, from June to August 1979. (△) Skeletonema costatum, (○) Olistodiscus sp., (■) Prorocentrum minimum, (★) Thalassiosira sp., (●) microflagellates, (▲) Prorocentrum obtusidens, (▼) Eutreptiella sp., (□) Fibrocapsa japonica, (▲) Mesodinium rubrum, (▼) Silicoflagellates, (■) other diatoms, (▲) other dinoflagellates.](image)
organisms were micro-diatom (Thalassiosira sp.) and Olisthodiscus sp. and the cell densities were $5.6 \times 10^7$ cells l$^{-1}$ and $2.1 \times 10^6$ cells l$^{-1}$, respectively. Other species were Prorocentrum obtusidens Schiller ($4.1 \times 10^5$ cells l$^{-1}$), Ebria tripartica (Schumann) Lemmermann ($5.7 \times 10^4$ cells l$^{-1}$) and other dinoflagellates ($8.3 \times 10^4$ cells l$^{-1}$). The next discoloration continued for 10 days from July 6 to 16. On July 9, chlorophyll-a was 29.25 mg m$^{-3}$ in area III and was 25.85 mg m$^{-3}$ in area II on July 16. This causative organism was Skeletonema costatum and the maximum cell density was $4.3 \times 10^7$ cells l$^{-1}$ in area I on July 9. Then, the population of Skeletonema costatum (Greville) Cleve began to decrease and on the contrary, Olisthodiscus sp. began to grow, which reached cell density of $1.5 \times 10^6$ cells l$^{-1}$ on July 16. Inverse relationship between both species was similar as that of Pratt (1966) in Narragansett Bay. Next bloom began on July 23 and continued for 7 days. Dominant organisms were Skeletonema costatum and the other microdiatom (Thalassiosira sp.) and the maximum cell density and chlorophyll-a were $2.0 \times 10^7$ cells l$^{-1}$ and 31.9 mg m$^{-3}$. In early August, water temperature increased slowly to 29.7 °C in maximum and salinity was sustained in 31.0 % and the dominant organisms were Prorocentrum minimum (Pavillard) Schiller and Glenodinium sp.. Their cell densities reached, respectively, $2.4 \times 10^6$ and $2.2 \times 10^5$ cells l$^{-1}$ in maximum and chlorophyll-a was 47.6 mg m$^{-3}$. After heavy rainfall on August 6, salinity decreased and red tide disappeared temporarily but after that, red tide organisms began to growth.

Fig. 7. Species composition and cell density of phytoplankton in the area II, Nagasaki Bay, from June to August 1979. (△) Skeletonema costatum, (○) Olisthodiscus sp., (□) Prorocentrum minimum, (●) Thalassiosira sp., (●) microflagellates, (△) Prorocentrum obtusidens, (◇) Eutreptiella sp., ( khủng) Fibrocapsa japonica, (▲) Mesodinium rubrum, (◇) Silicoflagellates, (■) other diatoms, (▲) other dinoflagellates.
immediately. This bloom continued from August 10th to 22nd with *Skeletonema costatum* and micro-diatom (*Thalassiosira* sp.) as dominant organisms. Maximum chlorophyll-a was 52.7 mg m\(^{-3}\) in area I on August 10. Such continuous occurrences, like this, of mixed diatom red tide which were mainly composed of *Skeletonema costatum*, were certified for about one month from the end of July to the end of August in this bay. This became one of the characteristics of red tide in Nagasaki Bay together with *Skeletonema* and *Olisthodiscus* red tides occurrence in the rainy season.

Changes of species composition and cell densities of main organisms in each area shown in Figs. 6, 7 and 8. Changenable patterns were not considerably different between each area.

![Graph](image)

**Fig. 8.** Species composition and cell density of phytoplankton in the area III, Nagasaki Bay, from June to August 1979. (△) *Skeletonema costatum*, (○) *Olisthodiscus* sp., (□) *Prorocentrum minimum*, (●) *Thalassiosira* sp., (●) microflagellates, (▲) *Prorocentrum obtusidens*, (▼) *Eutreptiella* sp., (●) *Fibrocapsa japonica*, (▲) *Mesodinium rubrum*, (▼) Silicoflagellates, (□) other diatoms, (△) other dinoflagellates.

**Discussion**

1. Dense red tides in Nagasaki Bay

The sampling method accepted in this survey is "water-boring method". By means of this method, fifteen water samples were collected for a short time within one hour in a water column of 4.5 m in depth. This is a method devised to estimate more accurately the movements of phytoplankton communities containing the motile red tide flagellates which are believed to migrate vertically through the strata of this depth unconcern with sampling time. Another feature of this sampling method was to mix together subsampling sea water collected in
a vessel. This procedure was effective to deal with numbers of subsamples for counting cell numbers of red tide organisms involved the feeble organisms against fixation before dark. However, numerals obtained by this method show only the mixed mean value in intra-area and intra-strata to 4.5 m in depth. This is the reason why chlorophyll-α amounts as well as cell densities were not so high in spite of the dense red tide.

In the present survey, a chlorophyll-α amount over 100 mg m⁻³ was recorded only one time and in many red tides chlorophyll-α amounts were between 40 to 60 mg m⁻³. It was also scanty that cell densities over 10⁷ cells l⁻¹ were recorded. Considering that flagellate red tides are biological phenomena which make the cell density concentrically increase in superficial strata within one or two meters in depth by floating up and make the water discolored, true values of superficial strata would be two to four times of previously mentioned values. Therefore, it was presumed that chlorophyll-α over 100 mg m⁻³ and cell density reaching 10⁸ cells l⁻¹ would appear often. Cell densities over 10⁸ cells l⁻¹ are maximum status which has been observed in coastal and inbayment waters. Such dense discoloration of Nagasaki Bay, which continued almost every day during midsummer season, is close to that of the highly polluted innermost part of Tokyo Bay and Osaka Bay.

2. Nutritional factors of red tide in Nagasaki Bay

By the statistical examination, there are no significant differences in cell production among the areas. However, concentrations of ammonia-N and phosphate-P in area I were significantly high compared with the other two areas. It was supposed that high concentration of such nutrients in this area would be influenced by inflow of river water including treated waste water discharged from an urban waste treatment plant. Nutritional loads of treated waste water are estimated about 22 kg in nitrogen and about 6 kg in phosphorus a day (analytical values were cited from Nagata's personal data). The total nitrogen and phosphorus in the whole innermost bay water is about 157 kg and about 32 kg respectively (values were cited from Sato's unpublished annual data). It can be understood that influx of such treated waste water towards Urakami R. has an important effect upon the sea water of Nagasaki Bay.

To understand completely the causative factors of the occurrence of the red tide is difficult. However, it is possible to imagine that high concentration of pollutants might accelerate the growth of red tide organisms. Growth promoting substances of red tide organisms have been reported by many authors. For instance, soil extract and river water (Wilson and Collier, 1955), humic substances in river water, soil and sea mud (Prakash and Rashid, 1968), sulfide pulp wastes from a paper-mill (Okaichi and Yagiu, 1969), decomposed matters of pearls oyster's faeces (under the aerobic condition) (Iwasaki, 1969), hot extract of bottom mud (Hirayama and Numaguchi, 1972), cold extract of bottom mud (Uyeno and Nagai, 1973), suspending matters of bottom mud (Honjo and Hanaoka, 1973) and decomposed matters of diatoms (Prakash et al., 1973) were summarized by Iwasaki (1978). Doig and Martin (1974) described that low concentration of sewage and urban waste water support the growth of Gymnodinium breve Davis. Therefore, further study on influence of land drainage including urban waste water upon the growth of red tide organisms need to be done also in Nagasaki Bay.

3. Causative organisms of red tide in Nagasaki Bay

Nagasaki Bay

In such nutritional environments which have inflow of river water and urban waste water, the sea water of Nagasaki Bay promote dominantly the growths of Skeletonema costatum and Olisthodiscus sp. Both species grow well usually in such an eutrophicated bay which has been influenced by river water and high degree of pollution like that of the innermost parts of Isé Bay (Adachi and Kawai, 1979), Osaka Bay (Joh et al., 1971), Tokuyama Bay (Otsuka, 1971), Hakata Bay (Honjo et al., 1978a and 1978b), Nagagansett Bay (Pratt, 1965) and Nagasaki Bay is no exception from such kinds of bays. Proocentrum minimum, Proocentrum obtusidens and Thalassiosira sp. caused red tides by their growth in this bay but in other times they occurred with moderate density in Skeletonema costatum and Olisthodiscus sp. red tides as accompanying organisms. Another species like as Proocentrum micans Ehrenberg, Proocentrum compressum (Ostenfeld) Abé, Gonyaulax diacantha (Meunier) Schiller, Gymnodinium sp (type' 65), Gymnodinium breve, Ceratium furca (Ehrenberg) Clapared and Lachmann, Ceratium fusus (Ehrenberg) Dujardin, Noctiluca miliaris Suriray, Fibrocapsa japonica Toriumi and Takano, Eutreptiella sp., Dicytola fibula Ehrenberg, Ebria tripartica, Distephanus sp. of phytoplankton and Mesodinium rubrum (Lohmann) Hamburger and Buddenbrock of zooplankton were not causative organisms of red tide but they occurred in moderate densities. Among those organisms, we could not find the specific species which are found only in Nagasaki Bay. No occurrence of Gymnodinium sp. (type' 65) red tide was the other characteristics of the red tide in Nagasaki Bay.

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Literature Cited


1979年夏季における長崎湾の赤潮

テンタ ダハリル・飯塚昭二

長崎湾では毎年夏になると赤潮がおこる。赤潮はいろいろの種類によって起こるが、夏季の長崎湾はいつも何かの種か、二つか三つの種の混合した大増殖で湾の海水はコーヒー色に着色する。ここでは1979年夏季の観察から長崎湾の赤潮について報告した。湾奥部（女満町浦上川口まで）を3水域に分け、各区に5地点の採水点を設け観察の対象とした。採水は透明アクリル・パイプ（内径18mm、長さ1.5m、3本接続）による水柱採水法で、これにより表面から4.5mの深さの海水を水柱として採取した。採取した海水は各区ごとに一つの容器に入れ、これを各区の標本海水とした。このようなサンプリングを6月12日から8月29日まで夏季の79日間のうち21回行なった。標本海水は顕微鏡下の種別の計数と、クロロフィル-aの測定、塩分および栄養塩類の定量をおこなった。

長崎湾の赤潮の原因種は Skeletonema costatum と Olisthodiscus sp. の二種が優占種であった。ほかに Prorocentrum minimum と Prorocentrum obtusidenis および Thalassiosira sp. などが出現した、最高値
はクロロフィル-aで108.3 mg m^{-3}、細胞密度は5.8×10^{7} Cells l^{-1} であった。観察期間中1ヶ月間以上は赤潮状態であり、8月に入ると毎日のように海水が着色する長崎湾の状況は原因種の類似性においても東京湾、大阪湾と似ている。これは湾奥部に川口をもつ二河川の存在と下水・し尿処理排水など都市排水の流入の影響のためと思われる。このため湾水は強く富栄養化し、これが赤潮発生を促進しているのではないかと思われる。