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Phytoplankton distribution in Mikawa Bay of Japan in relation to temperature and salinity variables

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Abstract. *Djumanto, Rasul E, InoueT, Aoki S. 2017. Phytoplankton distribution in Mikawa Bay of Japan in relation to temperature and salinity variables.Bonorowo Wetlands 1: 16-25.* Species composition and horizontal distribution of phytoplankton in relation to temperature and salinity variables were investigated in Mikawa Bay of Japan. Surface seawater was filtered with a 30 cm diameter conical plankton net with a mesh size of 53 µm weekly from mid-August to late September 2011. Surface layer temperature and salinity were measured with a CTD sensor. Phytoplankton samples were observed with an inverted microscope with phase contrast at 100-400 magnification. The salinity and surface temperature data and the density of the phytoplankton horizontally were made contour maps by connecting the location of each sampling station having the same value. Contour maps were created using surfer software. The result showed that the average temperature at the 1 m surface layer ranged from 22.7 to 28.7ºC. Meanwhile, salinity was ranged from 11.8 psu to 30.0 psu. Phytoplankton was abundant in the area with high temperatures and low salinity. The most abundant species among sampling stations in Bacillariophyceae was *Chaetoceros* sp(p). (52.2%) followed by *Pseudo-Nitzschia* sp(p) (27,7%), and then *Coscinodiscus* sp(p). (6.3%). On the other hand, the most abundant in Dinophyceae was *Dinophysis* sp(p). (1.1%) followed by *Ceratium fusus* (0.9%) and then *Ceratium furca* (0.8%), which was most dominant in the off-river mouth area. The phytoplankton population's density center and contour lines were changed and moved depending on salinity or temperature profiles.

Keywords: Abundance, phytoplankton, Mikawa Bay, Japan

INTRODUCTION

In aquatic ecosystems, phytoplankton plays an important role in the biogeochemical cycles of elements due to their role as primary producers and a major supplier of organic matter for heterotrophic organisms. It is a fundamental biological property and governs productivity, carbon transformation within the food webs, nutrient utilization, and a quality element for determining the ecological status of water ecosystems. Phytoplankton is responsible for about 40% of global primary production and forms the aquatic food web base. They are essential mediators of carbon and energy (Falkowski 1994). Quantitative measures of phytoplankton biomass, size distribution, and community composition are important indicators of the trophic state of aquatic systems and provide insight into the environmental forcing that affects phytoplankton dynamics. Phytoplankton growth is affected by the availability of nutrients and other limiting factors such as light and temperature. In many estuarine systems, primary production is considered high (Mann 2000) due to increased nutrient input from adjacent land or river runoff. It hence often serves as nursery grounds for commercially important finfish and shellfish species.

Mikawa Bay is a coastal water system in which freshwater runoff from some rivers supplies nutrient influx, and circulation in the bay induces nutrient transport off wards and backward into the water system. This affects the nutrient level, phytoplankton growth, and biomass distribution. Mikawa Bay is characterized by fluctuations in hydrographic and chemical conditions within the water system, driven by the wind, freshwater input, tides, and hurricanes. Wind strength and direction, precipitation, and waves may vary substantially quickly and affect the hydrographic conditions. Such bay can, therefore, often be considered as highly dynamic systems. Periodically, increases and decreases in primary production may be triggered by alternating periods of mixing and changing nutrient cycling. Phytoplankton distribution in the bay systems is affected either directly through alternating periods of mixing and stratification or indirectly through subsequent variability in nutrient concentrations and forms of nutrients.

Previous researchers have conducted several studies regarding plankton bloom in Mikawa Bay. The characteristic features of the bay ecosystem, such as the distribution of salinity, dissolved total nitrogen, and dissolved oxygen during the stratified period, were studied by Suzuki and Matsukawa (1987). There were two layers of circulation, and the upper layer of the river mouth region has higher production of particulate organic nitrogen due to strong upwelling and river inflow. In contrast, the lower layer of the bay mouth region has a higher deposition of particulate organic nitrogen caused by weak upwelling and downwelling. On the one hand, a study about a massive coccolithophorid bloom found that blooming initiated by the poorer standing crops during spring resulted in relatively rich nutrients through the bay. The influx of oceanic water into Mikawa Bay with higher salinity and temperature leads to bloom (Kai et al. 1999). Yamamoto and Okai (2000) found that diatoms with a low growth rate cannot form red tides in a heavily diffusive environment, while species with a high growth rate can form red tides even in a robust and diffusive environment. However, the flagellates will develop red tides in severe diffusive conditions through their swimming ability. In contrast, diatoms form red waves through their high growth rates with vertical diffusion and upwelling movement of water.

However, no one has studied the phytoplankton distribution in the Mikawa Bay in relation to temperature and salinity variables. It is interesting to investigate the phytoplankton distribution and occurrence of nutrient concentration in environmental conditions. Nutrient levels in Mikawa Bay are stirred by water discharged from the river; sediment absorption and nutrient uptake ultimately affect increased phytoplankton distribution.

Although the intensive use of the bay and its ecological importance for much marine living, relatively little is known about basic features, such as hydrographic conditions, phytoplankton distribution, primary production, and processes in the estuary environment, this knowledge is essential in the sustainable use of the bay systems, maintaining optimal water quality conditions, and the welfare of farmed fish. This study investigates the variable environmental influences on a typical bay's phytoplankton distribution, dynamics, and processes.

MATERIALS AND METHODS

Study site

Mikawa Bay is a partially mixed estuary composed of Kinu-ura Bay, the estuary of the Yahagi River (37 m^3s^{-1} the annual mean) in the northwest, and Atsumi Bay, the estuary of Toyo River (35 m^3s^{-1}) in the east (Suzuki and Matsukawa 1987). The Bay is a semi-enclosed estuary located in mid-Japan, has a surface area of 604 km^2 with an average depth of 9.2 m. The Yahagi and Toyo Rivers are two major rivers empty into the bay from the northwest and northeast, respectively. Mikawa Bay is a rich fishery area because of inorganic and organic loadings from these rivers. This bay is the most eutrophicated in Japan because of high economic growth during the last two decades (Yamamoto and Okai 2000).

Field survey

Field sampling was conducted in 18 stations once a week from mid-August to last September 2011, as shown in Figure 1. The position of stations 1 to 8 formed a straight line west-east towards Toyo rivers, while stations 9 to 15 formed a straight line north-south towards Tahara bays, the distance between the station was approximately 1 km. The position of each sampling station was set with GPS (geo-positioning system). At each phytoplankton sampling station, vertical temperature and salinity profiles were determined with a conductivity temperature depth (CTD) system.

Phytoplankton was sampled at each site by collecting the sea surface water using a plastic bucket of 10 liters as much as 10 times and filtered using a 30 cm diameter conical plankton net (mesh size of 53 µm). The filtered water was collected in the collecting bottle of 50 ml, then transferred to a polyethylene bottle of 30 ml. Macro-zooplankton were removed from phytoplankton water samples using 115 µm mesh nets (Havens et al. 1996).

The phytoplankton samples were preserved in 5% neutral formaldehyde (final concentration) in polyethylene bottles. Concentrated formalin (37-40%), buffered by borax (sodium tetraborate, $Na_2B4O_7.10H_2O$), and was added to a sample to the fixative ratio of 9: 1, using a graduated cylinder or a dosing feeder (i.e., 90 ml sample, 10 ml formaldehyde). Buffering of fixative was prepared a day before sampling takes place by adding 2 g of borax to 98 ml of 40% formaldehyde. The jar was gently rotated to mix the contents repeated several times within 1 h. The samples were stored in a cool room for later phytoplankton identification and counting.

Phytoplankton abundances

Phytoplankton samples were observed with an inverted microscope with phase contrast at 100, 200, or 400 magnifications. Each preserved phytoplankton sample bottle was shaken by flipping through the bottle, taking 1 ml using a pipette, and then gently pouring evenly into Sedgwick-Rafter Slide. About 50 to 100 fields (or more than 100 fields if the abundance was low) were observed, the phytoplankton was identified to species level where possible using taxonomic keys (Yamaji 1991; Tomas 1997) and counted. Cells counting was started from the most abundance then followed the less. Population densities were estimated from the counts as numbers per liter, based on the volume of water sampled by the net and assuming 100% sampling efficiency.

Horizontal distribution of temperature, salinity, and phytoplankton abundances

The salinity and surface temperature data and the density of the phytoplankton horizontally were made contour maps by connecting the location of each sampling station having the same value—the contour patterns were drawn using surfer software with the kriging method. The value of the contours was adjusted to the range of the highest value with the lowest.

RESULTS AND DISCUSSION

Hydrographic conditions

During this investigation, the average temperature at the 1 m surface layer ranged from 23.8oC to 28.1oC; the surface temperature ranged from 22.7ºC (26^{th} September) to 28.7ºC (29^{th} August). The horizontal distribution of temperatures at the surface layer on 22^{nd} August showed the highest temperatures were located on the southeast side of the bay, while the lowest was on the northwest side of the bay (Figure 2). The surface temperature is affected by the weather, the season, offshore input driver runoff from the mainland. The weather condition a few days before sampling was very hot and cloudy. Those conditions indicated a high temperature of the water from the river was distributed to the bay's east side.

On the 29th of August, the surface temperature showed the highest temperature was located in the middle of the bay. Water mass with high temperature shifted to the southwest, while the temperature was gradually decreased on the northwest side of the bay. The weather before the measurement date showed cloudy on 23rd and 24th August, and then rainy on 25th August with accumulated rainfall reaching 50 mm in Toyo and over 150 mm in the upstream area, meanwhile from 26th to 28th August mainly was sunny.

Meanwhile, at the beginning of September, the water mass with high temperature continued to move towards the southwest, so the highest temperature of the surface layer was located on the southwest side of the bay. The surface temperature was gradually decreased toward the river mouth off on the northeast side of the bay. The weather before sampling was sunny on 30th August, then cloudy with a shower on 31st August and 1st September. The influence of typhoon No. 12 was seen from 1st September with increasing wind speed. As the typhoon approached Shikoku Island on 2nd September, the easterly wind started to blow out. Because the typhoon moved very slowly, the strong easterly wind lasted until 5th September. In the Typhoon period, the rainfalls accumulated about 100mm in the middle and lower, and 300mm in the upper Toyo River watershed. The typhoon pushed the surface layer moved to the northeast, so the river runoffs took effect around Toyo River.

The surface water temperature was horizontally homogeneous during sampling on 12 th September. Water conditions were seen turbid up to station 7 off Toyo River, and stations 16 to 18 were observed very turbidly, which was affected by the inflow from Umeda River waters.

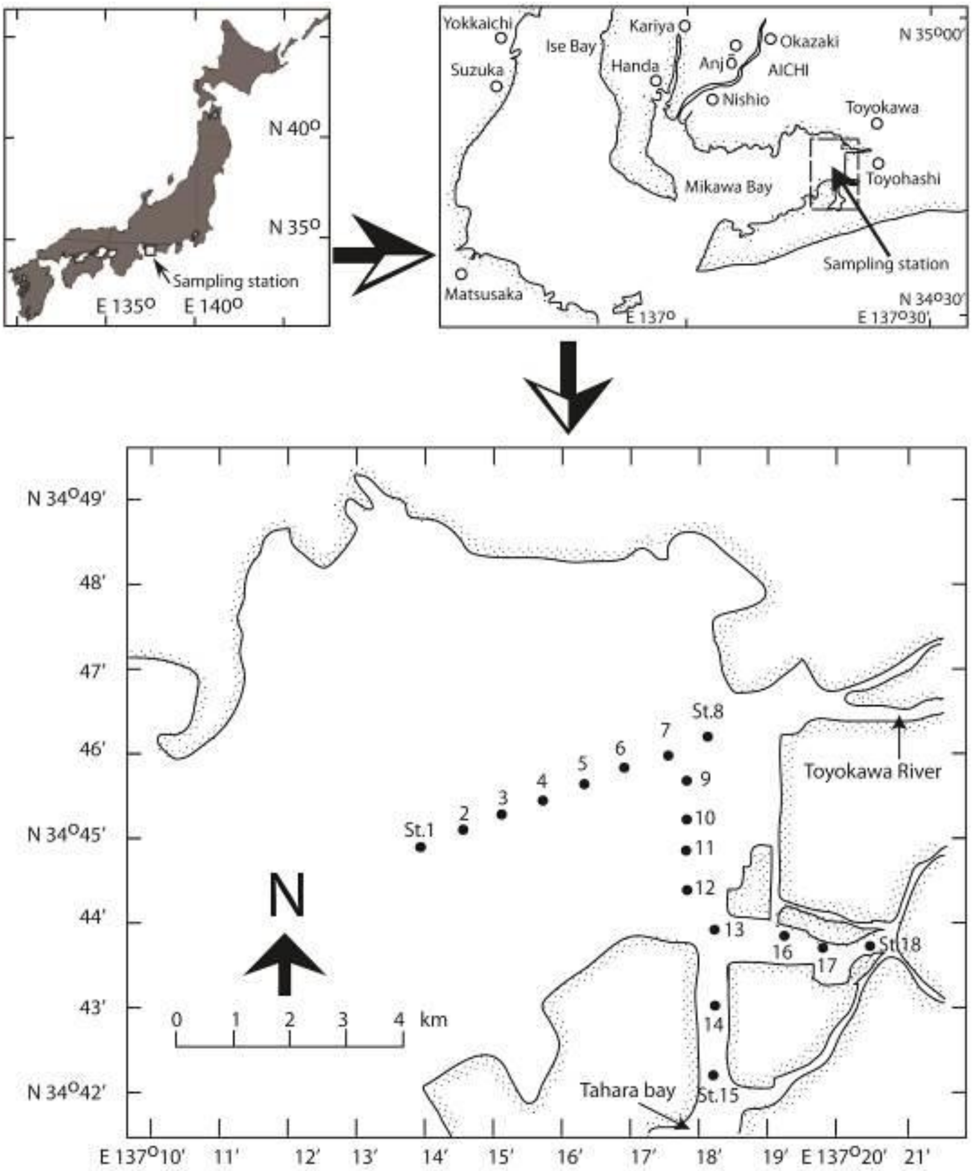

Figure 1. The map showing phytoplankton sampling station from station 1 to st. 18 (dark circle) in Mikawa Bay of Japan

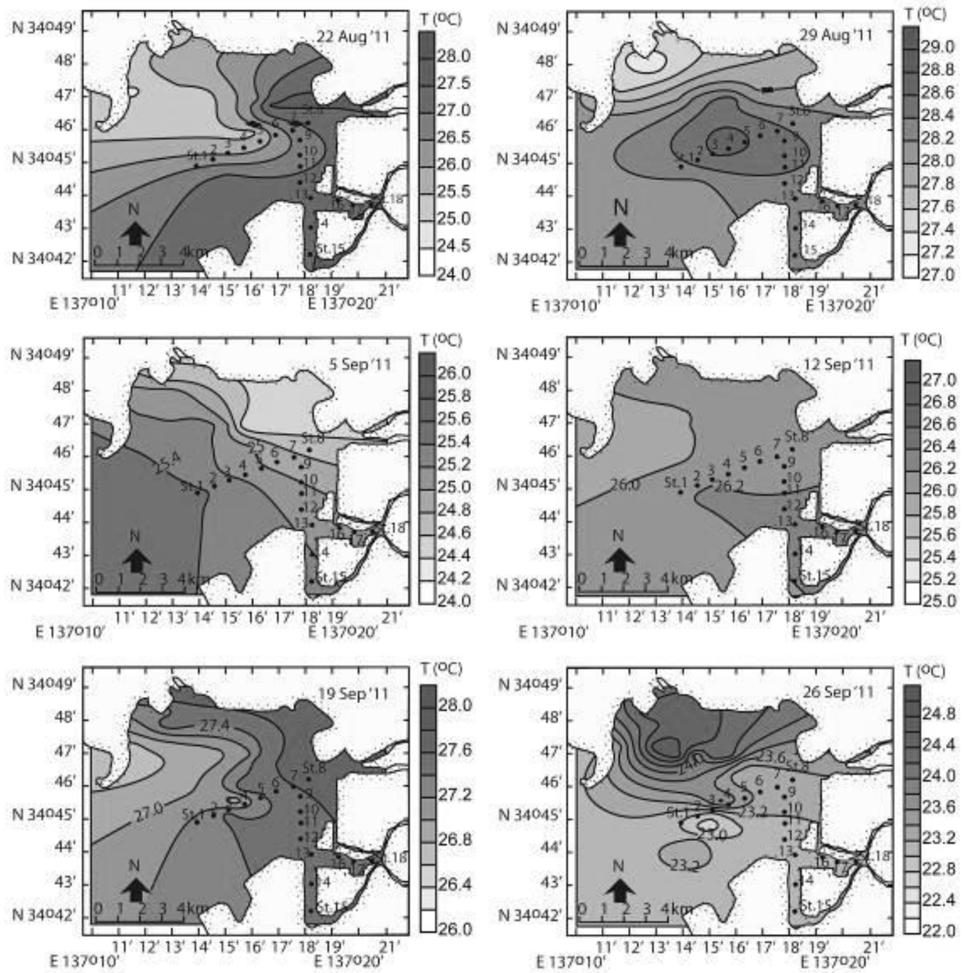

Figure 2. Horizontal structures of temperature (°C) among stations of sampling. Isotherm showed by contour lines.

The surface temperature profile on the 19th of September was relatively almost similar to the temperature on the 22nd of August. The highest temperature was located on the east side, while the lowest was on the west side of the bay. The surface temperature at the off Toyo River mouthwash around 27.8°C, and then to the westward direction was gradually decreased to26.8°C. Higher temperature carried by freshwater river runoff was depressed by the southwest offshore current to the northeast. Meanwhile, the surface temperature profile on 26 September showed the highest on the north side and the lowest on the bay's south side.

The average salinity at the 1 m surface layer ranged from 24.9psu to 28.3psu; the surface salinity ranged from 11.8psu (5th September) to 30.0psu (19th August). The horizontal distribution of salinity at the surface layer on 22nd August showed the highest salinity was located in the southwest, while the lowest was in the northeast, close to the Toyo River mouth (Figure 3). Freshwater from Toyo River was distributed to the narrow area at a northern part of the bay caused by the offshore current. On the other hand, the higher salinity from offshore pushed the freshwater approach to inshore. Hence salinity was drastically decreased in the inshore area.

The surface salinity profile on 29th August showed the highest was 30.0 psu, and the lowest was 23.8 psu. The highest salinity was concentrated in the narrow area in the center of the bay. The salinity from offshore was gradually decreased to the river mouth.

The surface salinity profile on 5th September showed the highest was 31.3psu, and the lowest was 11.8psu, with an average salinity of 28.3psu. The highest salinity was concentrated in the southwestern part of the bay, while the lowest was found in the northeastern part of the bay. The salinity profile showed the salinity was gradually decreased with the narrower isohaline area in the eastern part.

The surface salinity profile on 12 September showed the highest was 29.5psu, the lowest was 26.1psu, and the average salinity was 28.3psu. The difference between the highest and the lowest was 3.4psu. The surface salinity was gradually decreased from the center to the edge of the bay.

The horizontal distribution of salinity profiles on 19 September showed the lowest salinity was 26.8psu, and the highest was 30.5psu, while an average was 29.2psu. The most elevated salinity was located on the north side of the bay, while the lowest was located on the south-eastern side of the bay. High salinity in the north was gradually decreased to the south with the rate of decline of about 0.5psu in each km of distance.

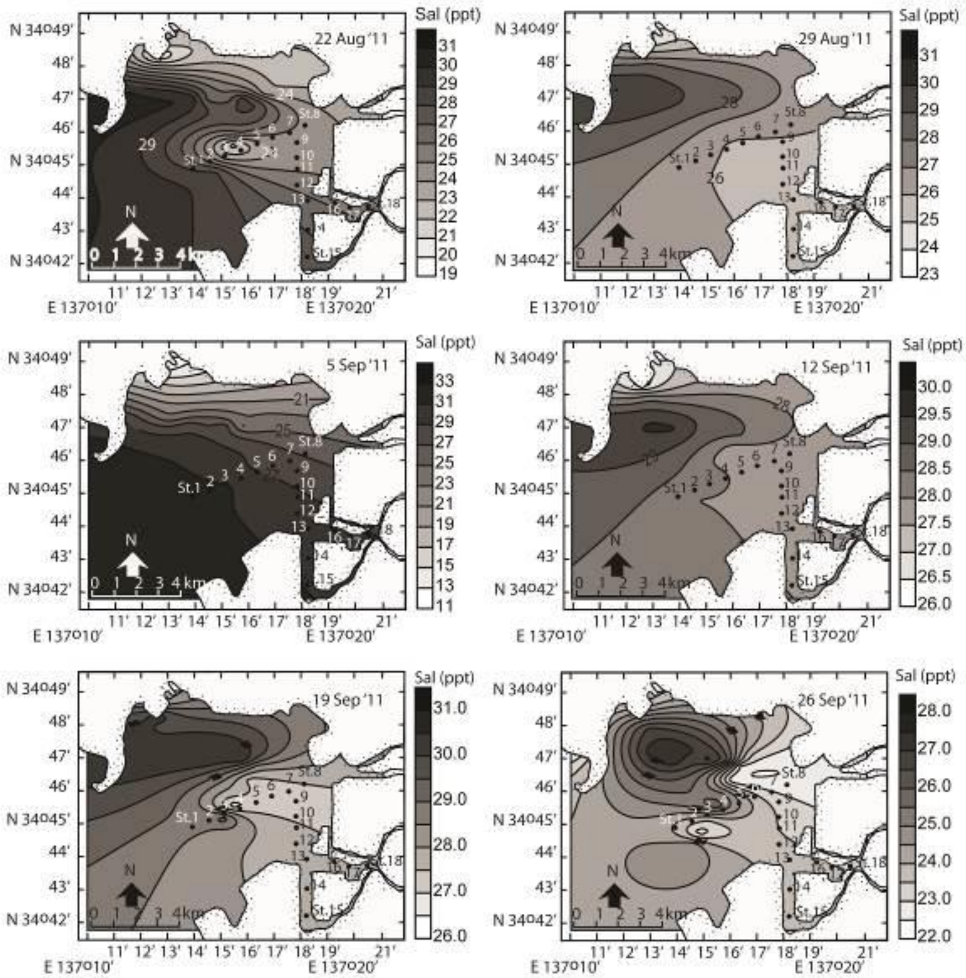

Figure 3. Horizontal profile of salinity (psu) among station of sampling during the study period and contour lines showed isohaline

Phytoplankton abundance

A total of 19 species of Dinophyceae and 12 species of Bacillariophyceae were identified in all samples from Mikawa Bay (Table 1). The most abundant species in Bacillariophyceae was *Chaetoceros* sp(p). (52.2%) followed by *Pseudo-Nitzschia* sp(p). (27,7%), and then *Coscinodiscus* sp (p). (6.3%) of total phytoplankton. Those species were most abundant among the station of sampling. On the other hand, the most abundant in Dinophyceae was *Dinophysis* sp(p). (1.1%) followed by *Ceratium fusus* (0.9%) and then *Ceratium furca* (0.8%), which are most dominant in the off-river mouth.

Phytoplankton distribution

Figure 4 indicates weekly changes in cell densities of phytoplankton at the surface layer in Mikawa Bay from late August to September 2011. During sampling, the phytoplankton population showed the most density occurred on 29th August, followed on 12 September, and the least density occurred on 5th September. The phytoplankton population's density center and contour lines were changed and moved depending on the salinity or temperature profiles or both combinations.

The most density of phytoplankton population on 22nd August was located in the center of the bay, while the least density was found in the northern side of the bay. The phytoplankton density was decreased drastically from the south to the north side of the bay. The contour pattern of phytoplankton population was relatively similar to those of temperature contour pattern, which was decreasing of temperature from station 1 to 5 followed by decreasing of phytoplankton density, and increasing of temperature from station 5 to 7 followed by rising of phytoplankton density, and then dropped afterward both for temperature and phytoplankton density.

The highest phytoplankton density was found in the middle of the bay and then declined in all directions. The most rapid decrease in density was from the middle of the bay to the mouth of the Toyo River, increasing phytoplankton density from station 1 to 7 and decreasing phytoplankton density from station 13 to 18, similar to those for temperature in the same station. However, it was a contrasting condition for the rest stations.

Table 1. The average density of phytoplankton (cell/L) in Mikawa Bay during weekly sampling from mid-August to September. The station number refers to Figure 1.

Species name/ Station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	(%)
Dinophyceae																			
Alexandrium sp(p).	0	1	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0,0
A. affine	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0,0
A. tamarensa	0	0	0	0	0	6	0	29	0	0	0	0	0	0	0	0	0	0	0,0
Ceratium sp(p).	188	146	268	147	151	142	140	198	92	79	19	72	38	48	4	6	14	5	0,3
C. furca	295	428	731	503	691	432	186	140	277	124	106	7	6	1	0	0	0	0	0,8
C. fusus	46	42	125	119	219	167	580	1813	378	306	131	441	122	94	72	39	18	10	0,9
Dinophysis sp(p).	40	54	185	302	439	980	414	136	1901	369	149	646	55	8	10	10	0	0	1,1
D. acuminate	0	0	0	0	0	0	0	0	13	19	2	7	1	0	0	0	0	0	0,0
D. caudata	0	0	2	1	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0,0
D. fortii	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0,0
Gymnodinium sp(p).	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,0
Noctiluca scintillans	2	1	2	1	4	3	5	15	13	5	9	9	18	8	17	23	19	10	0,0
Oxytoxum sp(p).	0	0	0	0	0	0	0	1	0	0	0	7	4	0	0	1	0	0	0,0
Prorocentrum sp(p).	1	0	0	0	0	0	0	0	7	2	0	0	2	0	0	0	0	0	0,0
P. triestinum	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0,0
Protoperidinium sp(p).	16	12	110	22	38	24	77	100	71	59	20	8	6	5	3	8	13	2	0,1
P. depressum	9	5	8	3	1	11	1	2	11	1	1	21	0	1	0	0	0	0	0,0
Pyrophacus steinii	2	2	1	2	2	3	12	13	5	1	1	4	1	2	2	4	0	0	0,0
Scrippsiella sp(p).	1	1	1	2	1	0	0	0	0	1	1	1	0	0	0	0	0	0	0,0
Bacillariophyceae																			
Actinoptychus senaris	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,0
Chaetoceros sp(p).	26120	35824	14114	34044	40405	36512	1755	1517	1520	3070	3546	2259	13612	22184	21016	6681	942	1101	52,2
Coscinodiscus sp(p).	2180	1916	1657	3271	3104	6108	1335	2107	2654	2180	1207	1577	973	364	321	314	252	92	6,3
Ditylum brightwellii	0	0	0	0	0	0	0	0	19	0	0	0	0	0	0	0	0	0	0,0
Pseudo-Nitzschia sp(p).	12135	16475	1337	26991	26713	29516	594	166	657	946	906	642	5572	10731	5565	1810	258	211	27,7
Rhizosolenia sp(p).	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0,0
R. setigera	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0,0
Skeletonema costatum	2223	63	687	8896	11774	10600	467	398	186	112	278	389	695	6945	2778	459	183	75	9,3
Stephnopyxis palmeriana	6	34	46	4	0	3056	107	53	33	46	16	28	12	2	2	0	1	1	0,7
Thalassionema nitzschioides	55	10	116	57	75	56	3	16	23	185	0	70	1	56	2	1	0	0	0,1
Thalassiosira sp(p).	15	1	1	1	0	0	0	0	0	2	0	0	0	0	0	0	12	9	0,0
Thalassiothrix sp(p).	42	40	63	117	54	49	21	71	122	205	192	253	212	180	93	72	144	126	0,4
Total density	43372	55054	19457	74482	83673	87665	5701	6774	7986	8019	6582	6468	21330	40629	29884	9427	1858	1642	

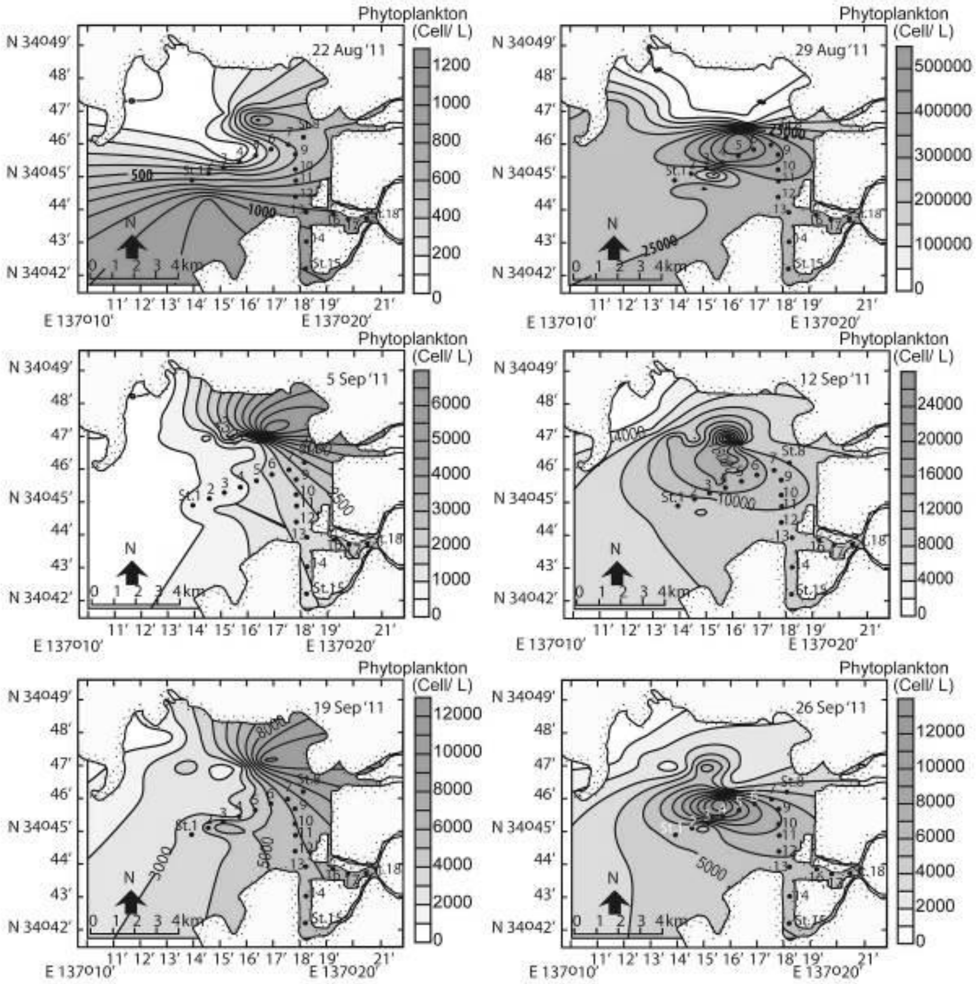

Figure 4. The contour showing the horizontal distribution of phytoplankton during sampling in Mikawa Bay from late Augustus to September

The horizontal distribution of phytoplankton density profile on the 5th of September contrasted with the distribution of phytoplankton in the previous weeks. The higher phytoplankton density was found in the Toyo River mouth and then decreased gradually to offshore. That pattern profile was opposite with the horizontal distribution profile of salinity, which was progressively increased from the river mouth to the offshore direction.

On 12 September, the highest phytoplankton population was concentrated in the center of the bay, and then phytoplankton density gradually decreased in all directions. That distribution profile was similar to the salinity distribution profile but not with temperature profiles because the temperature among stations was relatively the same.

The horizontal distribution of phytoplankton on 19 th September was relatively similar to that on 5th September, the highest population located close to the Toyo River mouth and then decreased to offshore direction. That profile pattern was relatively the same with the temperature distribution; however, rather different with salinity pattern distribution.

The highest population of phytoplankton on 26 th September was located in the center of the bay and then decreased in all directions. That profile pattern was relatively similar to the salinity distribution pattern. However, it was very different with temperature distribution.

The distribution of the dominant species of phytoplankton, namely *Chaetoceros* sp(p), *Pseudo-Nitzschia* sp(p) (27,7%), and *Coscinodiscus* sp(p), was similar to those with the distribution profile of the total phytoplankton. Most of the dominant species were the highest density in the center of the bay and then gradually decreased to all directions.

Discussion

Phytoplankton distribution

Mikawa Bay comprises two bays, namely Atsumi Bay (eastern part) and Chita Bay (northwestern part. It extends to Ise Bay through the Nakayama and Morozaki channels.

Ise Bay is connected to the Pacific Ocean through the Irago channel. These waters are stratified to make two layers of circulation, i.e., outflow in the upper layer and inflow in the lower layer, usually occur from June to September (Matsukawa and Suzuki 1985; Suzuki et al. 1987). Marine water flows into Ise Bay through the bottom layer of the Irago channel. It mixes with the middle-layer water of Ise Bay at the mouth of Mikawa Bay and with inflow to Chita Bay through the lower layer of the Morozaki channel. In contrast, the influx to Atsumi Bay through the Nakayama channel is intercepted in the head region of the Atsumi Peninsula. Therefore, the influence of marine water in Mikawa Bay appears first in Chita Bay, then followed by Atsumi Bay (Suzuki and Hirasawa 1985; Suzuki and Terasawa 1997).

Mikawa Bay is a semi-enclosed bay with a narrow mouth in the west tip and a wide central part restricting the exchange of bay waters. Moreover, the hinterland of Mikawa Bay, a large city, has over 1.5 million. Eutrophication in the inner bay, which has deteriorated due to contamination by pollutants from domestic and industrial wastes, has continued since the1980s (Suzuki and Matsukawa 1987). Since then, harmful algal blooms were frequently occurred in the bay from spring to summer, particularly domination of small diatoms and microflagellates in phytoplankton communities. A massive algal bloom of *Gephyrocapsa oceanica* was firstly developed in Mikawa Bay in April 1996. The bloom was preceded by deviated oceanographic conditions combined with other factors. The water temperatures of the upper and bottom layers before the algae bloom were lower by about 2°C compared to the average of the last five years and almost constant at about 11°C. The concentration of dissolved inorganic nutrient (DIN) was relatively high (3.5-14 µg-at N/l), whereas the concentration of PO_4^-P was very low (0.15 < µg-at P/L). The salinity of the upper layer was higher by about 1 psu compared to the average of the last five years. The saltiness of the bottom layer ranged from 31 to 32 psu, which was almost constant and almost the same compared to the average of the last five years (Kai et al. 1999).

Those anomalies in oceanographic conditions were not found during this study. Therefore, the chance of phytoplankton blooming can be ignored. However, the density distribution population of phytoplankton in Mikawa Bay was affected by the distribution of salinity, temperature, and other factors, such as the number of nutrients in the bay and nutrient input from the river runoff (Takahashi et al. 1992; Kai et al. 1999). However, each phytoplankton species requires a specific environmental condition to increase density. In the Yodo River estuary of Osaka Bay, the salinity was played as an ecological factor that controlled the abundance of *Alexandrium tamarense*. The population of *A. tamarense* was the most abundant when salinities were relatively higher than 15 psu, river discharge was low, and the water column was stable (Yamamoto et al., 2013).

Relationship between the phytoplankton distribution and marine environments

Many factors affect algal density, e.g., nutrients, light, wave action, physical and hydrographic conditions, etc. Dinoflagellates usually represent a minor component of microplankton. However, when conditions were right, they could replicate quickly and became the dominant species within 7-10 days (Siu et al. 1997). In this study, the density contour pattern of the phytoplankton population was relatively similar or contrasting against those of temperature or salinity contour pattern, depending on the distribution of temperature and salinity, the combination of both temperature and salinity, or other factors. In the range salinity of 25-28 psu and temperature of 23-27^{o}C, the increase of both temperature and salinity will be followed by increasing phytoplankton density, while decreasing temperature combines with increasing salinity caused by decreasing of phytoplankton density. At a constant salinity condition among stations, then when the temperature increase will lead to phytoplankton density decreases; otherwise, when the temperature decreases will be followed by increasing in phytoplankton density, vice versa with salinity contour pattern. However, on the temperature and salinity above 25, a stable temperature and salinities were not affected to phytoplankton fluctuated among stations. It appears that when the salinity is more than 28psu and the temperature is less than 25°C, the increasing or decreasing temperature will positively influence the density distribution of phytoplankton.

Temperature and nutrient input from the land appeared to affect population growth in *Chaetoceros*sp(p), *Pseudo-Nitzschia* sp(p), and *Coscinodiscus*; their population was the most dominant among station and sampling. A water temperature of 27-28 ^{o}C promoted the highest density. At the high optimal temperature, the mean maximal phytoplankton reached a cell density of more than 400.000 cells ml L^{-1}, shown for *Alexandrium catenella* (Siu et al. 1997). However, the too high temperature was also unfavorable for population growth. At 30^{o}C, the maximal capacity, population growth rate, and the mean doubling time of *Alexandrium catenella* were decreased significantly (Siu et al. 1997).

In conclusion, Bacillariophyceae was the most abundant among phytoplankton groups, and the most abundant species in Bacillariophyceae was *Chaetoceros* sp(p), then *Pseudo*-Nitzschiasp(p). and*Coscinodiscus* sp(p). Their density population and distribution was affected by the distribution of salinity, temperature, and other factors, such as the quantity of nutrient in the bay and nutrient input from the river runoff. A water temperature of 27-28 ^{o}C promoted the highest density. Population numbers of *Chaetoceros*sp(p), *Pseudo-Nitzschia* sp(p), and *Coscinodiscus* were the most dominant among station and sampling period, temperature, and nutrient input from the land was the significant effects of population growth of those species.

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