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Influence of river discharge on seasonal and interannual variability of remotely sensed chlorophyll-*a* concentration in Toyama Bay, the Sea of Japan

Genki TERAUCHI[1,2*], Ryo TSUJIMOTO[1,3], Joji ISHIZAKA[4], Hideaki NAKATA[5]

Abstract : It is often reported that increase of phytoplankton biomass in Toyama Bay coastal area in summer is a cause of water quality degradation as measured by Chemical Oxygen Demand. Satellite chlorophyll-*a* concentration (Chl-*a*) and river discharge from 1998 to 2009 were compared to study the influence of land-based sources of nutrients on seasonal and interannual variability of Chl-*a* in Toyama Bay. Toyama Bay was divided into three sub-areas (A, B and C, from innermost to outermost) by taking level, trend and peak timing of satellite Chl-*a* into consideration. In sub-area A, satellite Chl-*a* increased towards summer and its increasing interannual trend was detected. From the comparison of variability in satellite Chl-*a* with river discharge and nutrient data in Toyama Bay, it was suggested that a high concentration of total nitrogen from the Jinzu River was a compelling cause of potential eutrophication in sub-area A. In both sub-areas B and C, a positive correlation was found between satellite Chl-*a* and river discharge from May to July ($p < 0.01$, $r = 0.47$ in sub-area B; $p < 0.01$, $r = 0.47$ in sub-area C) and August to October ($p < 0.01$, $r = 0.51$ in sub-area B; $p < 0.01$, $r = 0.47$ in sub-area C). It was considered that there were excessive nutrients not used by phytoplankton in sub-area A, and they were delivered to sub-areas B and C from May to October then contributed to increase in phytoplankton biomass. The influence of river discharge on satellite Chl-*a* was obvious in the sub-area A throughout the year, but it also occasionally extends to sub-areas B and C from May to October. Monitoring the peak pattern and level of seasonal variability in Chl-*a* was suggested for assessment and management of water quality, because a single and long summer peak pattern is correlated with symptoms of eutrophication.

Keywords : *phytoplankton; river discharge; ocean color radiometry; chlorophyll-a; coastal environment*

1) Northwest Pacific Region Environmental Cooperation Center, 5–5, Ushijimashin-machi, Toyama City, Toyama 930–0856, Japan
2) Graduate School of Science and Technology, Nagasaki University
3) Fisheries and Fishing Port Division, Agriculture, Forestry & Fisheries Department, Toyama Prefectural Government
4) Hydrospheric Atmospheric Research Center, Nagoya University
5) Graduate School of Fisheries Science and Environmental Studies, Nagasaki University
* Corresponding author:
Tel: 076–445–1571
Fax: 076–445–1581
E-mail: terauchi@npec.or.jp

1. Introduction

Rivers that supply nutrients and sediments to coastal waters are essential to maintaining high productivity and biodiversity in coastal ecosystems. While rivers provide nutrients that are essential for primary production of phytoplankton, excessive nutrients cause eutrophication and often result in degradation of water quality, occurrence of red tides, hypoxia and anoxia, and benthic mortality (RABALIS *et al.,* 1996). As coastal waters tend to be influenced by anthropogenic sources, it is necessary to understand seasonal changes in phytoplankton biomass in order to conserve the coastal

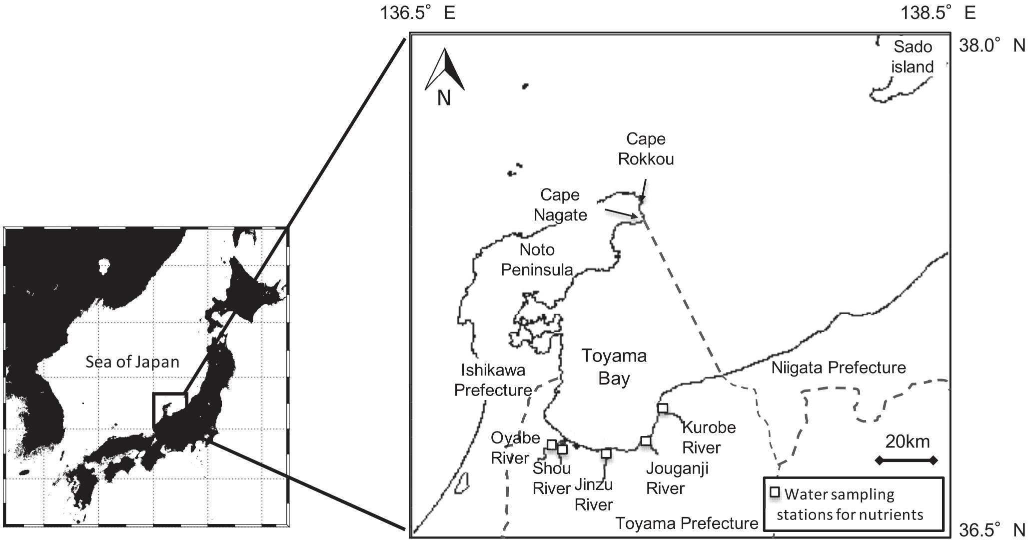

Fig. 1. Location of Toyama Bay.

environment.

The environment of Toyama Bay (Fig. 1), a semi-enclosed bay in the Sea of Japan, is strongly influenced by nutrients provided from fresh water discharged from surrounding rivers (NAGATA *et al.,* 1988; NAGATA and N AKURA 1993; TSUJIMOTO 2009). The TOYAMA BAY WATER QUALITY CONSERVATION RESEARCH COMMITTEE (2001) reported that riverine input of nutrients contribute to an increase of phytoplankton biomass in the summer in Toyama Bay, and results in degradation of water quality measured by Chemical Oxygen Demand (COD) in coastal area.

River discharge influence on the variability of chlorophyll-a concentration (Chl-*a*, a proxy for phytoplankton biomass) in Toyama Bay was first reported by NAGATA and NAKURA (1993). They observed a remarkable increase of Chl-*a* after spring in the region that is most affected by river discharge. OHNISHI *et al.* (2007) observed high satellite Chl-*a* in summer at the Jinzu River estuary and detected a correlation between high satellite Chl-*a* and lower sea-surface salinity, whereas spring and fall peaks of satellite Chl-*a* were associated with thermal stratification in the Sea of Japan as reported by YAMADA *et al.* (2004). TERAUCHI *et al.* (2014) illustrated potential eutrophic zones in the Toyama Bay coastal area by combining 12 years satellite Chl-*a* level and trend data and suggested that a long term increasing trend in total nitrogen input from the Jinzu River from 1986 to 2008 is the greatest contributor to high and increasing Chl-*a* in the detected potential eutrophic zone. The detected potential eutrophic zone by TERAUCHI *et al.* (2014) includes the Jinzu River mouth, where TSUJIMOTO (2012) reported that nutrients were not limiting phytoplankton growth from analysis of monthly observation data of dissolved inorganic nitrogen (DIN), dissolved inorganic phosporus (DIP) and dissolved silica (DSi) from April 2006 to February 2008. Tsujimoto (2012) also reported that nutrient limitation was altered from nitrogen limitation in 2006 to phosphorus limitation in 2007 at a water sampling station located outside of the potential eutrophic zone detected by TERAUCHI *et al.* (2014). Nevertheless, there is no study illustrating the effect of land-based sources of nutrients from rivers on the variability of Chl-*a* in Toyama Bay utilizing long term spatial and temporal scales of data.

Wider spatial coverage and higher temporal frequency in monitoring of sea surface Chl-*a* by ocean color satellite have been utilized in many studies. ACKER *et al.* (2005) observed significantly higher satellite Chl-*a* in 2003 than in 2002 at the Chesapeake Bay mouth that was consistent with strong forcing by freshwater flow and nutrient loading in the nutrient-limited region. WALKER and RABALAIS (2006) found positive correlations between satellite Chl-*a* and river discharge at the west of the Mississippi Delta with 0 to 1 month time lags. YAMAGUCHI *et al.* (2012) detected high satellite Chl-*a* in summer in the Yellow and East China Seas associated with movement of Changjiang diluted water with a 0–2 month time lag. TERAUCHI and ISHIZAKA (2007) detected radical changes in satellite Chl-*a* in several days in Toyama Bay coastal area that monthly based shipboard measurements were not able to detect.

Objective of this paper is to analyze the influence of river discharge on seasonal and interannual variability of Chl-*a* in Toyama Bay using long-term ocean-color satellite data. Causes of potential eutrophication in the Toyama Bay coastal area will then be discussed.

2. Data and methods

2.1 Location of study area

Toyama Bay is located to the east of Noto Peninsula, at the center of the eastern part of the Sea of Japan (Fig. 1). Toyama Bay's surface area is approximately 2,120 km^2, with a maximum depth of 1,250 m and volume of approximately 1,280 km^3 following the boundary definition by IMAMURA *et al.* (1985) - east of an imaginary line running between Cape Nagate in Ishikawa Prefecture and the border of Toyama-Niigata Prefectures. Toyama Bay consists of three layers of water masses; Japan Sea Proper Water flows in areas deeper than 300 m, Tsushima Warm Current in areas of depth less than 300 m and coastal waters mixed with fresh waters provided from five Class-A rivers (the Oyabe, Shou, Jinzu, Jouganji and Kurobe River) and 29 Class-B rivers that flow into the bay (UCHIYAMA, 2005). Annual average runoff from the five Class-A rivers are 60.37, 33.05, 172.77, 19.31, and 86.48 m^3 s^{-1} in Oyabe, Shou, Jinzu, Joganji, and Kurobe Rivers, respectively (JAPAN RIVER ASSOCIATION, 2004), and contribute significantly to nutrient loads in Toyama Bay (TSUJIMOTO, 2009).

2.2 Satellite Chl-*a* data

Satellite Chl-*a* data of two ocean color sensors were obtained for this study: 2,700 images of the Sea-viewing Wide Field-of-view Sensor on board the Orbview-2 satellite (SeaWiFS) and 3,766 images of the Moderate Resolution Imaging Spectroradiometer on board the Aqua satellite (MODIS-A). Data were obtained for the area defined by 36.5 to 38.0° N and 136.5 to 138.5° E from 1998 to 2009. Daily composite data were computed after a quality screening process conducted by TERAUCHI *et al.* (2014). TERAUCHI *et al.* (2014) evaluated a set of variables called level 2 flags that report various potential errors at each pixel in comparison with *in situ* and satellite Chl-*a*, and showed more than 300% overestimation of *in situ* Chl-*a* was observed in 7 of 42 match ups flagged with both COASTZ and STRAYLIGHT flags. SeaWiFS Chl-*a* data so flagged was then excluded when computing the daily composite of SeaWiFS Chl-*a*. The daily composite of MODIS-A Chl-*a* was computed without level 2 flag screening per good agreement between *in situ* and MODIS-A Chl-*a* data; 32 out of 34 match ups were within the range of 33–300%.

TERAUCHI *et al.* (2014) also demonstrated pixel-to-pixel consistency in daily composite data between the quality screened SeaWiFS and MODIS-A Chl-*a* data during the observation-overlapping period, July 2002 to December 2004. With the quality screening of SeaWiFS, a comparison of SeaWiFS and MODIS-A data showed high correlation with a slope close to one described by the following formula:

$$\text{Log (MODIS-A Chl-}a) = -0.900 + 0.932 \log \text{(SeaWiFS Chl-a), with } r^2 = 0.81,\ N = 137{,}173.$$

Taking into account the pixel to pixel consistency between the quality screened SeaWiFS and MODIS-A, daily composites of SeaWiFS and MODIS-A Chl-*a* data in the overlapping period (from July 2002 to December 2004) were composited by averaging. Monthly mean data were then computed by Windows Image

Manager software (http://www.wimsoft.com/) from the daily composite data; SeaWiFS daily composite from January 1998 to June 2002, SeaWiFS and MODIS-A averaged daily composite from July 2002 to December 2004 and MODIS-A daily composite data from January 2005 to December 2009.

2.3 Defining sub-areas in Toyama Bay according to satellite Chl-*a* peak timing

Since past studies showed an increase of Chl-*a* after spring to summer in Toyama Bay coastal area, possibly due to the influence of land based sources of nutrients from rivers (NAGATA and NAKURA 1993; OHNISHI *et al.* 2007), the Julian day of annual Chl-*a* maximum was calculated during the period 1998 to 2009 (Fig. 2(a)). The earliest day of annual Chl-*a* maximum was day 58 and latest was day 230. The bay was then divided into two sub-areas: that area where the peak appears before the end of Julian day 121 (end of April; a spring peak) and that area where the peak appears later (a summer peak) (Fig. 2(b)).

Additionally, the summer peak area was divided into two sub-areas; the potential eutrophic zone detected by TERAUCHI *et al.* (2014), and outside this zone (Fig. 2(c)). Finally, Toyama Bay was divided into three sub-areas (sub-areas A, B and C; Fig. 2(d)). The coastal area along Noto Peninsula and Nanao Bay in Ishikawa Prefecture were excluded due to lack of *in-situ* Chl-*a* for validation of satellite Chl-*a* data. That area of the bay outside defined by a line from Cape Nagate in Ishikawa Prefecture to the border between Toyama Prefecture and Niigata Prefecture was also excluded for statistical analysis. Sub-area A is the potential eutrophic zone detected by TERAUCHI *et al.* (2014) located at the innermost part of Toyama Bay, where the satellite Chl-*a* value is higher than 5 mg m^{-3} in average and an increasing trend was observed in some spots during the study period. Sub-area B is located in between sub-area A and C, but a possible influence from land-based sources of nutrients from rivers is suspected. Sub-area C is located at the outermost part of Toyama Bay and satellite Chl-*a* is expected to increase with nutrients provided from deeper waters due to mixing and thermal stratification. Furthermore, satellite Chl-*a* data at 5 x 5 pixels around an offshore point located between Cape Rokkou in Ishikawa Prefecture and Sado Island in Nigata Prefecture were extracted as a reference site with negligible impact from land based sources of nutrient from rivers

2.4 River discharge data

Daily river discharges of five Class-A rivers (Oyabe, Sho, Jinzu, Jouganji and Kurobe Rivers) from 1998 to 2009 were obtained from the Water Information System of the Ministry of Land, Infrastructure and Transport, Japan. The sum of monthly means from these five Class-A rivers was then calculated for comparison with satellite Chl-*a* variability. Since the river discharge data of the Kurobe River was not available from January 1 to March 3, 2003 and November 4 to May 4, 2004, river discharge data during these periods was excluded from analysis.

2.5 Nutrients data

Total nitrogen (TN) and total phosphate (TP) concentrations have been monitored on a monthly basis from April 1985 to March 2006 and quarterly (February/May/August/November) since May 2006 at major river inflow points of Toyama Bay. These TN and TP data in the five Class-A rivers from 1998 to 2009 were obtained from the database of the National Institute for Environmental Studies, Japan.

3. Results

3.1 Seasonal variability of satellite Chl-*a* and river discharge

To visualize the typical seasonal variation of satellite Chl-*a* in Toyama Bay, monthly means from 12 years of satellite data were computed (Fig. 3). The monthly means clearly illustrated high satellite Chl-*a* from spring to fall in innermost part, and spring and fall peaks of satellite Chl-*a* in outermost part of Toyama Bay.

Monthly means of satellite Chl-*a* in each sub-area as well as the reference site were then computed from 1998 to 2009. To ensure the reliability of monthly means data in each sub-area, data with less than 80% valid values in

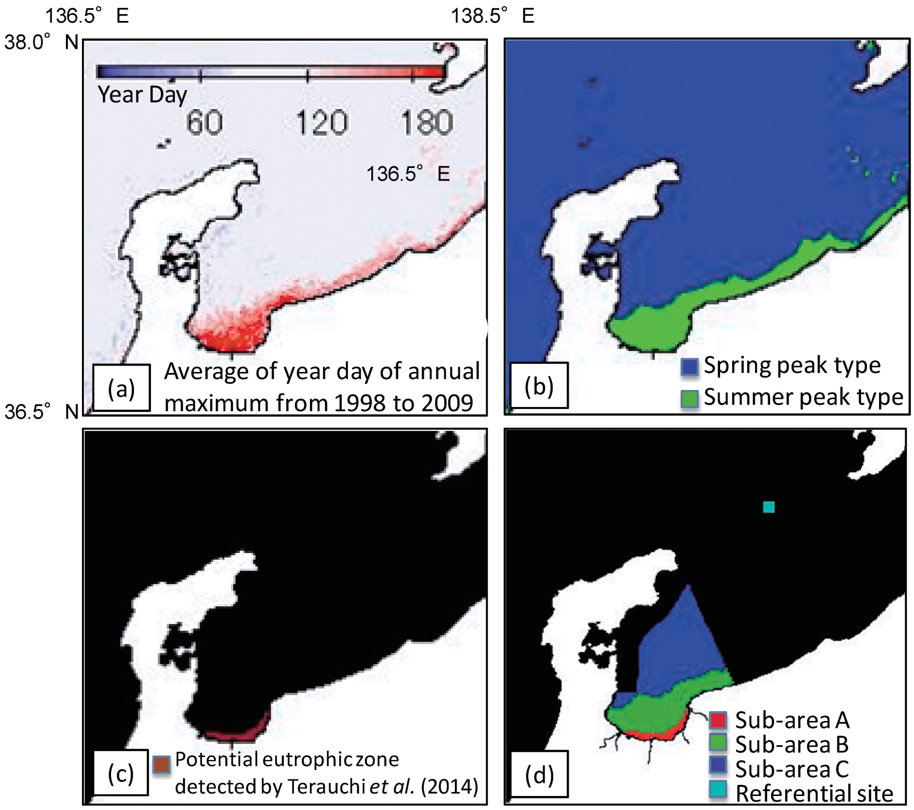

Fig. 2. Three sub-areas divided by the peak timing of satellite Chl-*a*.
(a) Average of year day of annual maximum from 1998 to 2009. (b) Spring peak and summer peak types in satellite Chl-*a*. (c) Potential eutrophication zone detected by Terauchi *et al.* (2014) using ocean color satellite data. (d) Sub-areas set by b and c, and location of referential site.

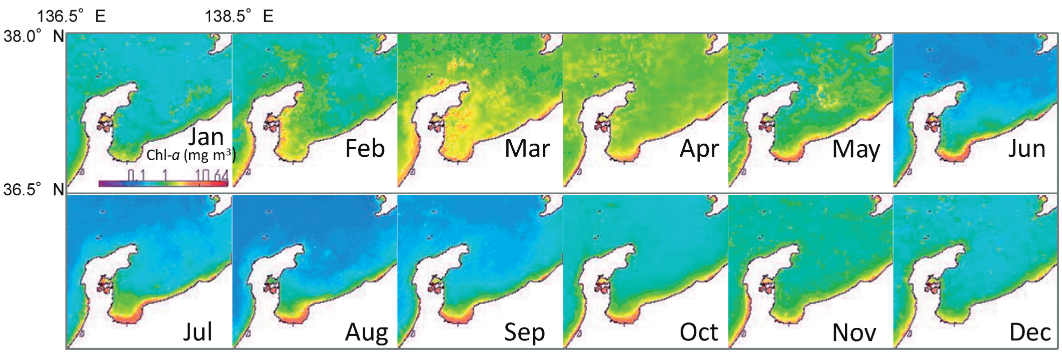

Fig. 3. Twelve years overall mean of monthly satellite Chl-*a* in Toyama Bay

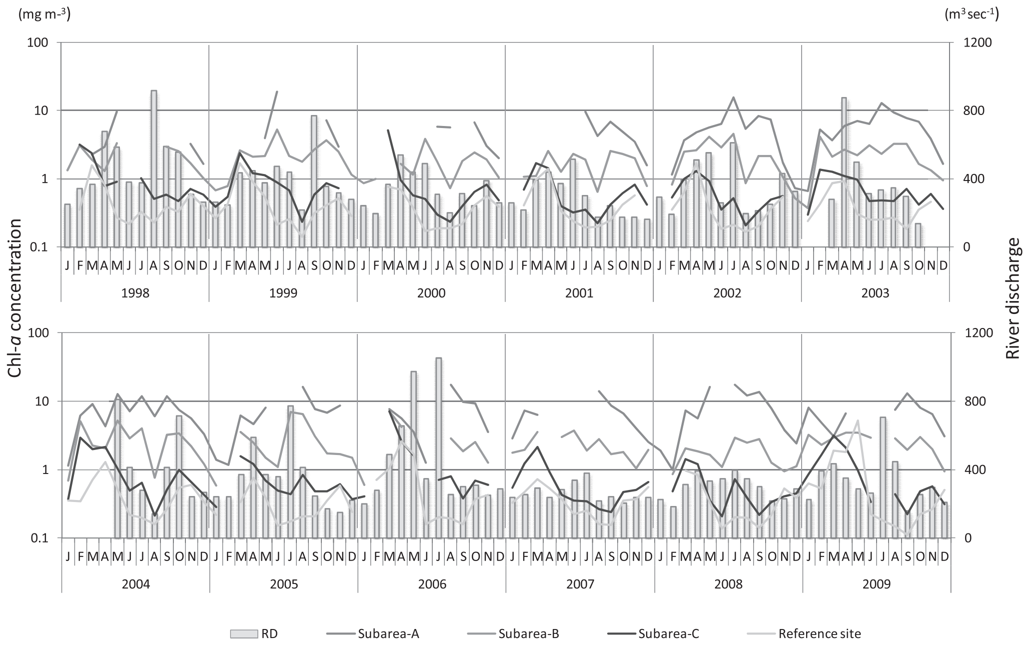

Fig. 4. Monthly means of satellite Chl-*a* in each sub-area and the reference site, and sum of monthly mean river discharge in the five Class-A rivers from 1998 to 2009.

each sub-area were excluded.

Satellite Chl-*a* in sub-area A were relatively higher than other sub-areas, and increased from spring to summer before decreasing in November (Fig. 4). A single and long summer peak pattern appeared in 2002, 2003 and 2008, but this pattern was not able to be detected due to lack of reliable data in other years such as 1998, 1999, 2000, 2001, 2005, 2006, 2007 and 2009. In contrast, satellite Chl-*a* in sub-area C was low in summer, there were spring and fall peaks almost every year, and its variation was similar to that of the reference site. In sub-area B, located in between sub-areas A and C, satellite Chl-*a* increased in spring, then did plateau in 2001, 2003, 2004, 2007 and 2009 or increased occasionally from May to October in 1999, 2000, 2002, 2005 and 2008 until it decreased every winter. As would be expected, river discharge was low in winter and increased towards spring every year. There were also increases of river discharge from summer to fall; however these increases appeared in different months each year.

To understand the extent of river discharge on Chl-*a* variation in Toyama Bay, monthly satellite Chl-*a* in each sub-area was compared with the sum of the five Class-A river monthly mean discharges from 1998 to 2009 (Fig. 5). Correlations between monthly satellite Chl-*a* and river discharge in sub-areas A, B and C were then derived. Correlated data were then sorted into four seasons (February to April, May to July, August to October and November to January) to see if there was any seasonal characteristic in the relationship between satellite Chl-*a* and river discharge (Fig. 5 (a) – (d)). There were positive significant correlations between satellite Chl-*a* and river discharge in sub-areas B and C in May to July and August to October (Table 1). Satellite Chl-*a* in sub-area A was often higher than 10 mg m^{-3} from May to October, but did plateau at river discharge amounts greater than 500 m^3 sec^{-1}. Although there were no significant correlations between satellite Chl-*a* and river discharge in sub-area A in all seasons, a positive correlation ($p < 0.05$) was found from August to October

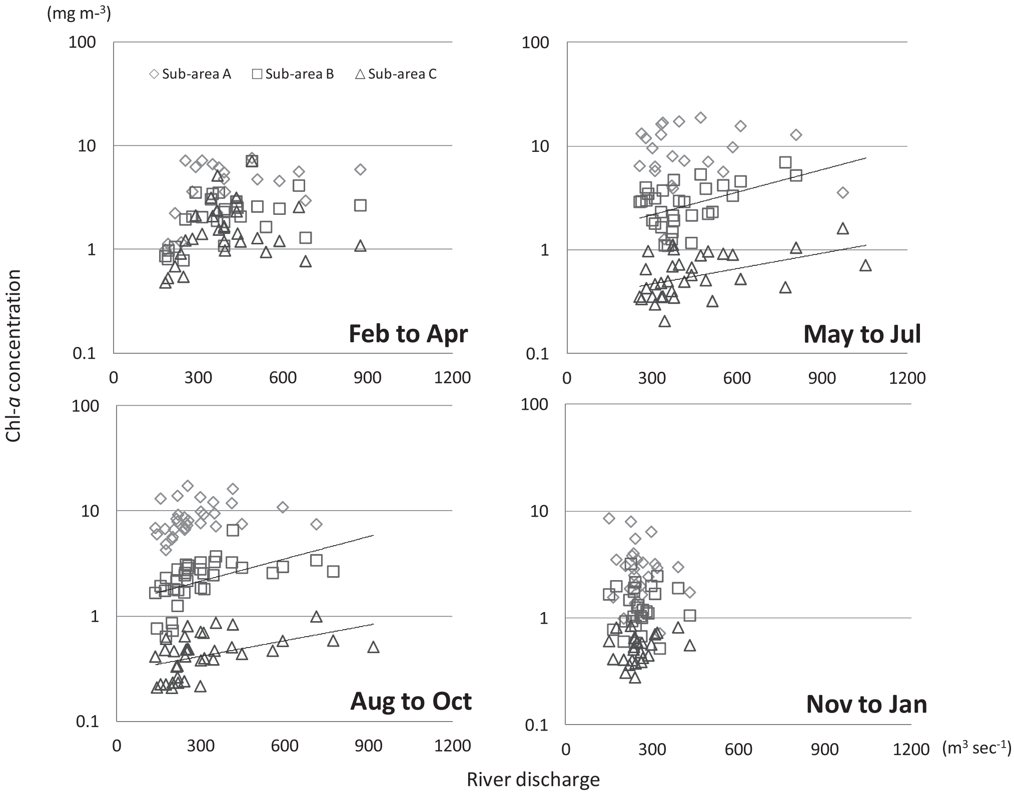

Fig. 5. Comparison of monthly means of satellite Chl-*a* and sum of monthly mean river discharge in the five Class-A rivers from 1998 to 2009. Matched data were sorted into four seasons (February to April, May to July: August to October, and November to January).

Table 1. Correlations between satellite Chl-*a* and river discharge in all sub-areas. Liner regression model was applied to logarithmically transformed satellite Chl-*a* value and river discharge to see significant relationship between them. Italic letters at column of sub-area A from August to October are *p* and *r* values when excluding two plots that have more than 500 m^3 sec^{-1} in sum of monthly river discharge.

Sub-area	Feb to Apr		May to Jul		Aug to Oct		Nov to Jan	
	p value	r	p value	r	p value	r	p value	r
A	0.06	0.42	0.78	0.06	0.09 *<0.05*	0.30 *0.45*	0.31	0.21
B	0.17	0.45	<0.01	0.47	<0.01	0.51	0.83	0.04
C	0.27	0.21	<0.01	0.47	<0.01	0.47	0.20	0.27

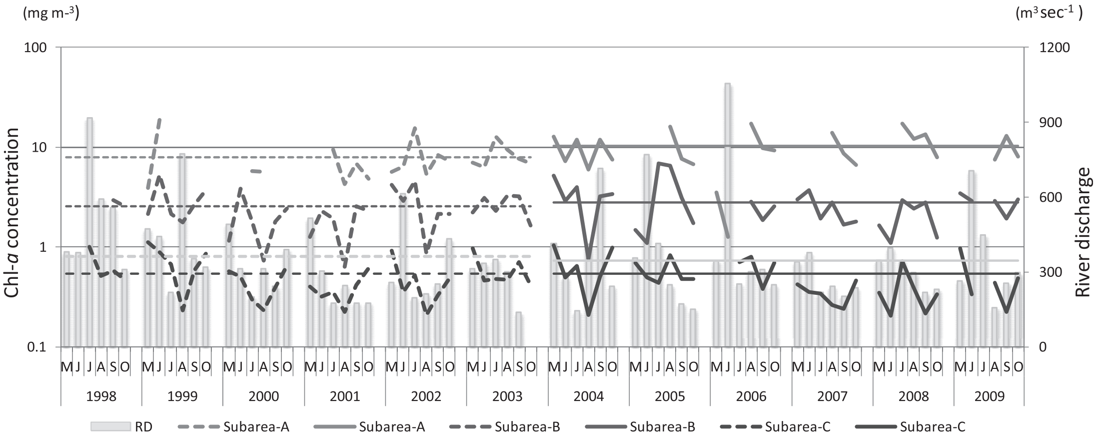

Fig. 6. Interannual variability of satellite Chl-a in each sub-area and sum of monthly mean in river discharge at the five Class-A rivers in May to October from 1998 to 2009. Dashed and solid lines indicate data in earlier years (1998 to 2003) and later years (2004 to 2009), respectively. Horizontal lines indicate mean values in each sub-area in earlier and late years.

when excluding two plots that have more than 500 $m^3\ sec^{-1}$ amount of river discharge.

3.2 Interannual variability of satellite Chl-*a* and river discharge from 1998 to 2009

Since positive significant correlation between satellite Chl-a and river discharge was found in sub-areas B and C in two seasons (May to July and August to October), their interannual variability from 1998 to 2009 in each season were investigated (Fig. 6). In May to July, no significant trend was detected in satellite Chl-a in all sub-areas and river discharge amounts from 1998 to 2009. On the other hand, a increasing trend (Spearman's rank correlation, r_s = 0.44, $p < 0.05$) in satellite Chl-a was detected in sub-area A in August to October, whereas no significant trend was detected in satellite Chl-a in other sub-areas and river discharge amounts.

Since high Chl-a values more than 10 mg m^{-3} appeared more frequently in sub-area A in later years (2004 to 2009) than earlier years (1998 to 2003), averages of Chl-a in each sub-area and river discharge amount in earlier and later years were compared. Only in sub-area A, was the level of satellite Chl-a in the later years found to be higher (t-test, $p < 0.05$) on average than that of the earlier years, while no

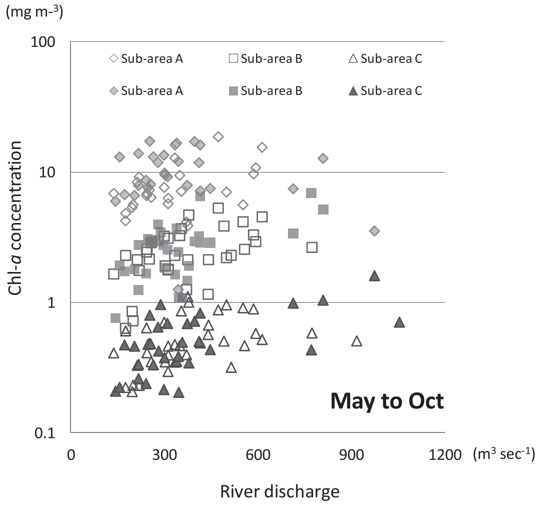

Fig. 7. Comparison of monthly means of satellite Chl-a and sum of monthly mean river discharge in the five Class-A rivers in May to October from 1998 to 2009. Open and filled plots indicate data in earlier years (1998 to 2003) and later years (2004 to 2009), respectively.

difference was detected in sub-areas B ($p > 0.05$) and C ($p > 0.05$). There were no difference in river discharge amounts between the earlier and the later years ($p > 0.05$). To see if there was any bias in the relationship between satellite Chl-*a* and river discharge amounts depending on earlier vs. later years, monthly means of satellite Chl-*a* in each sub-area from May to October in the earlier and later years were compared with the sum of monthly means of river discharge (Fig. 7). Satellite Chl-*a* in sub-area A was relatively higher in the later years than that of the earlier years for the same amount of river discharge in its range of 150–400 m^{-3} sec^{-1}.

We therefore conclude that the detected increasing trend of satellite Chl-*a* in sub-area A is not related to an increase in river discharge.

3.3 Interannual change of nutrients in May and August

We also investigated the interannual change of TN and TP concentrations observed in May and August at the five Class-A rivers from 1998 to 2009 (Fig. 8(a) – (d)).

There was a decreasing trend in TN in the Oyabe River both in May (Spearman's rank correlation, $r_s = -0.79$, $p < 0.01$) and August ($r_s = -0.77$, $p < 0.01$) from 1998 to 2009. In contrast, TN concentration in the Jinzu River was higher than other rivers in August, and remained constant from 1998 to 2009.

There were decreasing trends in TP in the Oyabe River ($r_s = -0.78$, $p < 0.01$), Jinzu River ($r_s = -0.74$, $p < 0.01$) and Jouganji River ($r_s = -0.70$, $p < 0.01$) in August. No significant trend was detected for other TN and TP data in May and August.

4. Discussions

This study revealed seasonal and interannual variability of satellite Chl-*a* in three sub-areas (A, B and C) in Toyama Bay and evaluated the possible influence of river discharge and nutrients from 1998 to 2009. There were spring peak and fall peaks of satellite Chl-*a* in sub-area C every year, while satellite Chl-*a* in sub-area A peaked in summer. Significant positive correlations between satellite Chl-*a* and river discharge were found in sub-areas B and C from May to October, and also in sub-area A from August to October at river discharge amounts of less than 500 m^3 sec^{-1}. An increasing trend of satellite Chl-*a* was detected in sub-area A in August to October from 1998 to 2009, but no increasing trend was detected in river discharge and nutrients data.

It is known that there are spring and fall blooms of phytoplankton in the temperate zones (Parsons *et al.,* 1984) and that they often begin with the development of thermal stratification of the water column (spring bloom) or decay of thermal stratification in the surface layer (fall bloom). On the other hand, Sze (1993) reported a single and long summer peak appears if eutrophication develops in oligotrophic lakes in the temperate zone, where spring and fall peaks of phytoplankton biomass is a typical seasonal pattern. It is also known that changes of these patterns in seasonal variation of phytoplankton biomass have been observed not only in fresh water but also in estuary barrages and enclosed bays (Murakami, 1996; Yamada and Kaziwara, 2004).

A single and long summer peak pattern and interannaul increasing trend of satellite Chl-*a* observed in sub-area A from 1998 to 2009 were considered as a sign of potential eutrophication. This result was consistent with Terauchi *et al.* (2014) that annual maximum in monthly mean Chl-*a* showed high and increasing trend in some spots of sub-area A. River discharge data from May to July and August to October did not show any trend. Nutrient concentration in May and August presented in this study did not show any increasing trend from 1998 to 2009. In fact, TN concentration in the Oyabe River showed a significant decreasing trend in May and August, as did TP concentrations in the Oyabe, Jinzu and Jouganji Rivers in August. On the other hand, in Jinzu River that account for 46% of the discharge from the five Class A River (Japan River Association, 2004), TN concentration was significantly higher than other rivers and it remained constant from 1998 to 2009. Tsujimoto (2012) conducted monthly observation of nutrient and phytoplankton biomass at three water sampling stations near the Jinzu River mouth from April 2006 to February 2008 that corresponds to the later years of this study, and reported that both TN and TP concentration were always higher than the thresholds that limit phytoplankton growth at the

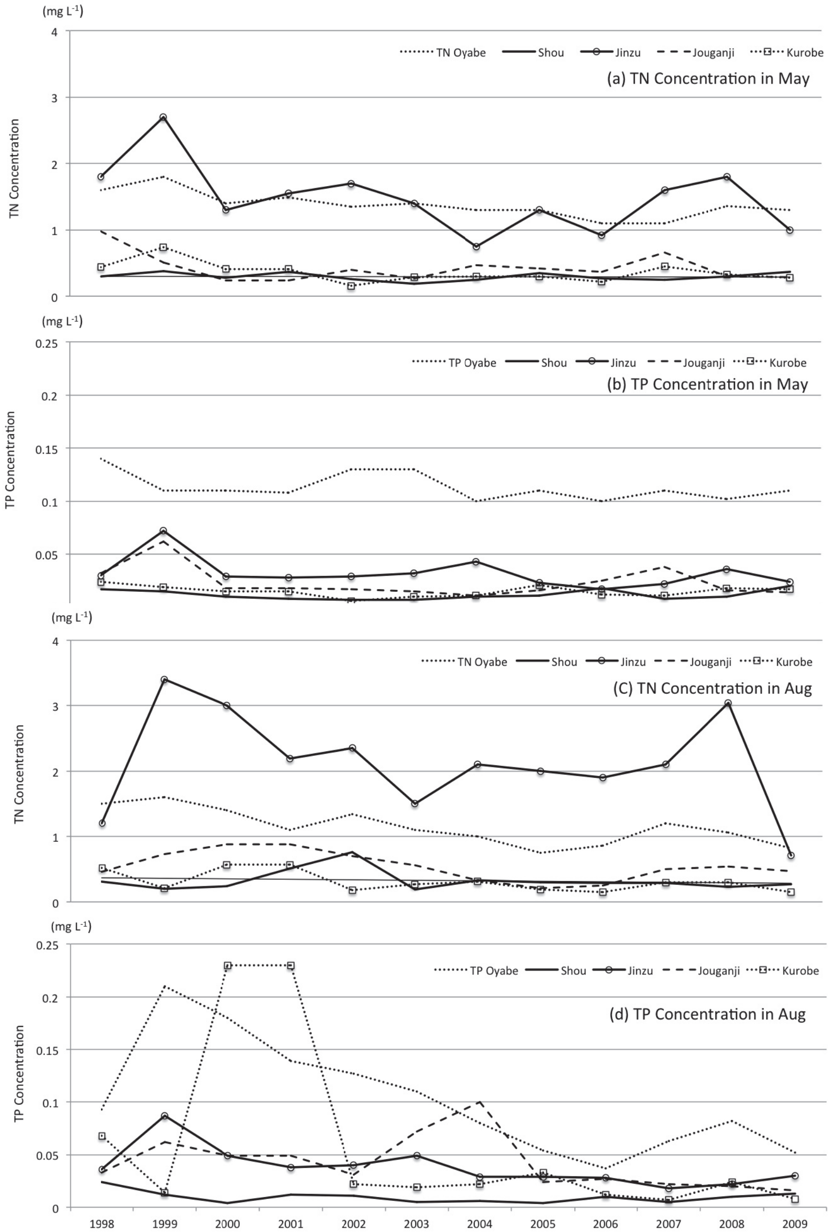

Fig. 8. Interannual change of TN and TP data observed in May and August at downstream points of the five Class-A rivers from 1998 to 2009. (a) TN concentration in May. (b) TP concentration in May. (c) TN concentration in August. (d) TP concentration in August.

water sampling station nearest the Jinzu River mouth (located in sub-area A of this study). Thus, the high concentration of TN in the Jinzu River was suspected as a compelling cause of potential eutrophication in sub-area A. Although this hypothesis was not proved by the TN and TP data used in this study, it is possible that the May and August nutrient data may have not been sufficient to manifest a link with satellite Chl-*a*.

Spring and fall peaks of satellite Chl-*a* observed in sub-area C indicated that sub-area C belongs to the typical temperate zone as reported by PARSONS *et al.* (1984), and phytoplankton growth is mainly controlled by nutrients provided from deeper layer by mixing. These peaks were also consistent with the spring and fall peaks of satellite Chl-*a* in the Sea of Japan observed by YAMADA *et al.* (2004). Nevertheless, it was suggested that river discharge does influence Chl-*a* variability in sub-areas B and C, because there was a significant positive correlation between satellite Chl-*a* and river discharge in these sub-areas from May to October. Satellite Chl-*a* in sub-area B increased towards summer after spring in some years, but the summer peak was shorter than sub-area A. NAGATA and NAKURA (1993) reported that there was a positive correlation between river discharge amount and the distribution of lower salinity water at the sea surface in Toyama Bay. As TSUJIMOTO (2012) reported that TN and TP concentration were higher than the thresholds that limit phytoplankton growth at the water sampling station in sub-area A, it was considered that excessive nutrients were occasionally delivered to sub-area B and C from May to October and contribute to increase in phytoplankton biomass. TSUJIMOTO (2012) also suggested that nutrients could possibly be transported to outer area before they were used through the process of phytoplankton photosynthesis in coastal area when radical increase in river discharge was recorded. TSUJIMOTO (2012) then indicated that those transported nutrients could contribute to increase phytoplankton in outer area, where river discharge flow slows down. This theory was consistent with our result that satellite Chl-*a* in sub-area A did not increase further once river discharge exceeded 500 m^{-3} sec^{-1}.

TSUJIMOTO (2012) suggested that reduction of both nitrogen and phosphorus is necessary to conserve water quality in Toyama Bay, because the nutrient limitation was altered from nitrogen in 2006 to phosphorus in 2007 at the water sampling station away from the Jinzu River mouth (located in sub-area B in this study). Our result also showed that land based sources of nutrients are possibly transported to sub-are B and C in Toyama Bay from May to October, it is therefore possible that a reduction of both nitrogen and phosphorus can contribute to controlling or limiting growth of phytoplankton not just in sub-area A, but also in sub-areas B and C. Since the seasonal variability of satellite Chl-*a* in sub-are A showed the single and long summer peak that indicates potential eutrophication almost every year, close attention must be paid in this sub-area to conserve water quality. Attention also needs to be paid to sub-area B, where satellite Chl-*a* increased occasionally from May to October in some years with probable excessive nutrients delivered from rivers, although the single and long summer peak pattern in satellite Chl-*a* is not yet observed.

5. Conclusion

Past studies in Toyama Bay indicated influence of river discharge on variability of phytoplankton biomass, but in a qualitative manner or with spatially and temporally limited ship observation data. This study used spatially and temporally intensive satellite Chl-*a* for long-term to measure the influence of river discharge on seasonal and interannual variability of phytoplankton biomass in Toyama Bay, and identified extent of land-based sources of nutrients from rivers. The influence of river discharge on satellite Chl-*a* was obvious in the sub-area A throughout the year, but it also occasionally extends to sub-areas B and C from May to October. Monitoring the peak pattern and level of seasonal variability in Chl-*a* was suggested for assessment and management of water quality, because a single and long summer peak pattern is correlated with symptoms of eutrophication.

It is therefore revealed from this study that monitoring of satellite Chl-*a* will be a promising environmental assessment tool for conservation of water quality in Toyama Bay and other coastal waters.

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