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NUTRIENT DISTRIBUTIONS IN THE HIGHLY TURBID CHIKUGO RIVER ESTUARY AND THE DIFFERENCE BETWEEN THE EARLY SPRING AND THE SUMMER OF 2010

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ABSTRACT

The influence of salinity, turbidity, and phytoplankton on the nutrient distribution in the Chikugo River estuary was investigated in the early spring and summer of 2010. Multiple regression analysis showed that the dominant factors influencing the variation of the dissolved nutrient concentrations were salinity and the suspended sediment concentration. It is suggested that dissolved inorganic nitrogen and dissolved inorganic phosphorus were supplied from the pore water of the bottom sediment, and they were also affected by dilution with seawater. Particulate nitrogen was supplied by the resuspension of sediment, and particulate phosphorus was supplied by the sediment and seawater. The variation of nutrient concentrations in the Chikugo River estuary results from not only an exchange between the fresh water and seawater but also possibly the resuspension of bottom sediment. In particular, in the summer, nutrient concentration decreased as a result of an increase in the chlorophyll a concentration.

1. INTRODUCTION

Red tide occurs in the Ariake Bay of Japan in recent years, and it causes lack of nutrient in the seawater (Beltrão et al., 2011). Since the Chikugo River is the greatest inflow river in the Ariake Bay, the fresh water discharge from the river will have remarkable impact on the sea. Generally, the fresh water stagnates in a river mouth estuary, and is mixed with sea water. Therefore, nutrient is not directly released to a sea from a river, but the concentration and constituent of nutrient also change in a river mouth estuary.

For example, nutrient in estuary commonly varies by an exchange between the fresh water and seawater in the estuaries in the Gulf of Papua as Davies (2004) showed. Santos et al. (2009) indicated a large variability in nutrient concentrations over tidal and seasonal time scales in a Gulf

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of Mexico subterranean estuary. Domingues et al. (2011) showed the relevance of phytoplankton and nutrient: phytoplankton growth seemed to be nitrogen-limited throughout the productive period, especially green algae in 2005 and diatoms in 2008 in the fresh water tidal zone of a turbid, Mediterranean estuary. Rozan et al. (2002) conducted a study to determine the seasonal relationship between phosphorus in the upper sediments and pore waters of a shallow intercoastal bay. And they found that the reactive solid phase phosphorus pool and sharp increases in soluble phosphorus in pore waters and overlying waters, as the conditions became more reducing throughout the summer months. However, salinity intrusion in estuary moves with semi diurnal tidal cycle and semi lunar tidal cycle, and furthermore, there is the feature on the highly turbid water from the flood mud in the Chikugo River. An insufficient number of studies investigated nutrient spatial distribution in the scale on these tidal cycles in which have been considered of turbidity.

In this paper, the influence of salinity, turbidity, and phytoplankton on the nutrient distribution in the Chikugo River estuary was investigated in the early spring and summer of 2010, and its spatial distribution and the feature of temporal variation was discussed.

2. STUDY AREA

The Chikugo River is located in the northern region of Kyushu district, Japan (Figure 1). The River is approximately 150 km long and has a catchment area of 2,860 km^2. Freshwater discharge at the gauge station located 25.5 km upstream of the river mouth shows a seasonal variation—from 40 m^3/s in January to 3,000 m^3/s in June. The river mouth barrage is located 23 km upstream and salinity intrusion is observed up to a distance of 17 km upstream.

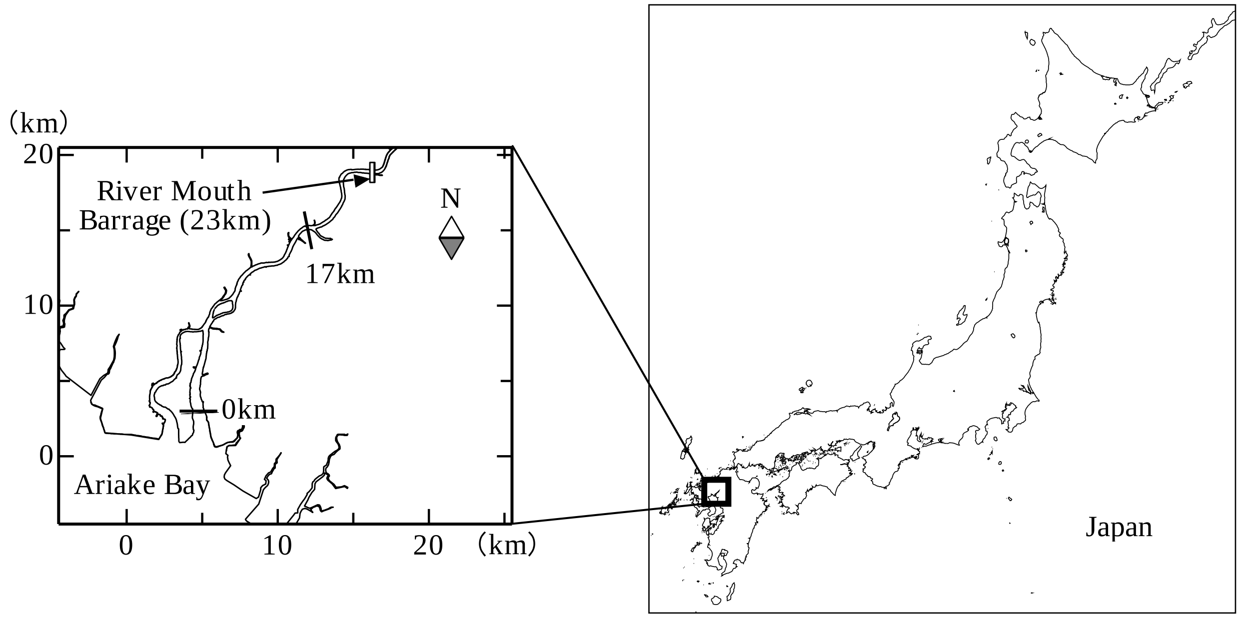

Figure 1 Location map of the Chikugo River Estuary, Japan.

The River flows into the Ariake Sea, whose tidal current reaches a maximum velocity of 1.0 m/s. Its tidal range is approximately 5 m; this large tidal range is responsible for the change from a highly stratified state during neap tides to a well mixed state during spring tides. The estuarine turbidity maximum (ETM) is most apparent at 14 km station, and the suspended sediment concentration (SSC) is ranging between 2,000 mg/l and 8000 mg/l during the spring tide. It is known that the typical salinity intrusion limit is 17 km station.

3. MEASUREMENTS

Field observations were conducted in early spring (March 16 and April 9) and summer (from September 11 to Sept. 22). Vertical profiles of salinity and turbidity were obtained by using CTD with a nephelometric backscatter sensor and fluorescence chlorophyll sensor (AAQ-1183, JFE Advantech, Japan). At each station, the profiles were obtained every ninety minutes for twelve hours during both spring tides and neap tides. SSC is calculated from turbidity (*TB*) by using equation 1. Salinity, turbidity and water level have been measured every ten minutes near the stream bed at 14.6 km station by using a nephelometric backscatter sensor (ATU-75W-USB, JFE Advantech, Japan). Discharge was measured at the barrage by Chikugo Regional Bureau, Japan Water Agency.

$$SSC = 1.05 \times TB + 4.0 \cdot 10^{-4} \times TB^2 + 6.0 \cdot 10^{-14} \times TB^5 \tag{1}$$

Water samples were collected from the surface and bottom layers at the eighteen stations. The nutrient concentration and phytoplankton concentration were measured at the laboratory. Chlorophyll *a* (Chl) and pheophytin *a* (Pheo) were analyzed by a fluorometer (10AU Field Fluorometer, Turner Designs, USA). The concentrations of dissolved inorganic nitrogen (DIN) and total nitrogen (TN) were measured by using a nutrient autoanalyzer (QuAAtro 2-HR, BLTEC, Japan). Figure 2 shows the rate of NO_2-N+NO_3-N in total dissolved nitrogen (TDN). Since NO_2-N+NO_3-N occupies a major part to TDN, NO_2-N+NO_3-N is considered to be DIN for convenience. Particulate nitrogen (PN) was calculated as the difference between TN and DIN. Dissolved inorganic phosphorus (DIP) and total phosphorus (TP) were also measured by using a nutrient autoanalyzer. Particulate phosphorus (PP) was calculated as the difference between total phosphorus and DIP.

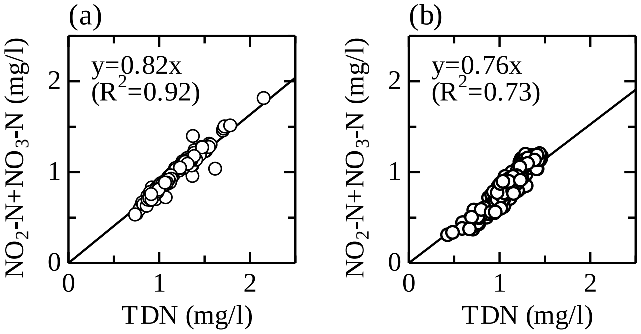

Figure 2 Relationship between of TDN and NO_2-N+NO_3-N in (a)the early spring and (b)the summer in the Chikugo River Estuary, 2010.

4. RESULTS

4.1 Fresh Water Discharge and Salinity Movement of the Chikugo River Estuary

General condition of the estuary is shown in Figure 3. The dry season discharge of the Chikugo River calculated as the average of 2008, 2009 and 2010 was 59.77m^3/s. The maximum discharge in the three years was 2914.5m^3/s on June 30, 2009. There were comparatively high discharges in observation periods in the early spring (Figure 3a). The discharge changed 107.67 m^3/s in September 13 through 38.23 m^3/s in September 18 (Figure 3e). The water level varies in response to the tide level change. Here we classify March 16 in the early spring and September 11, 13 and 22 in the summer as spring tides. April 9 in the early spring and September 17 and 18 in the summer are also classified as neap tides.

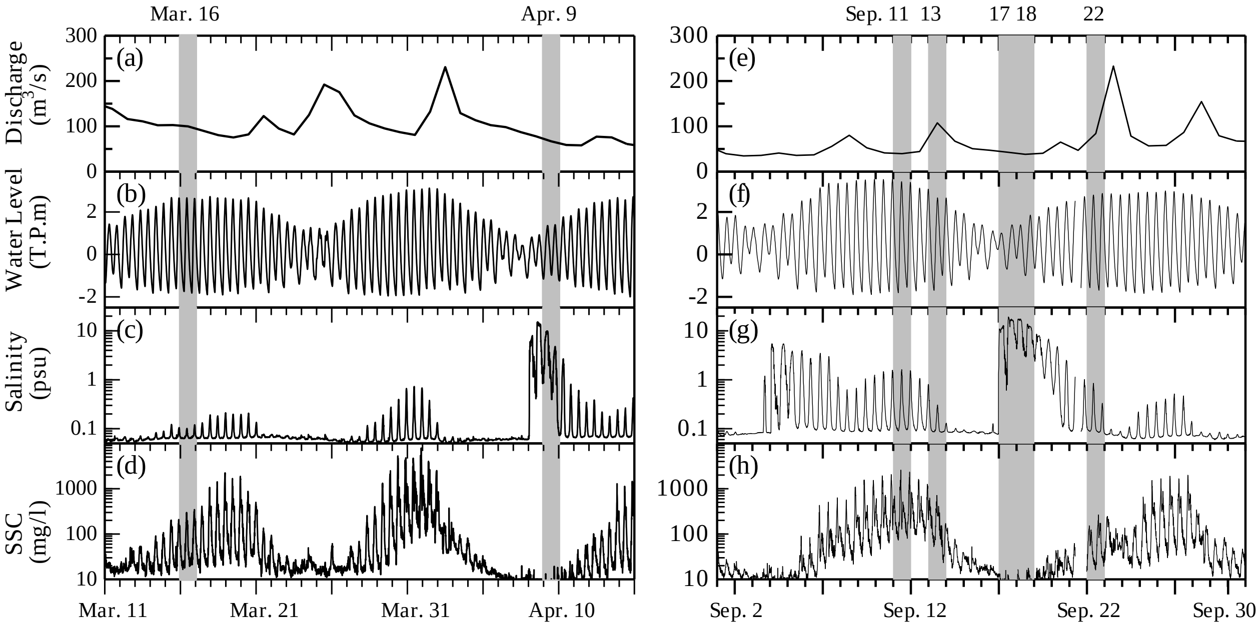

Figure 3 (a) Discharge at 23km from the river mouth and (b) water level, (c) salinity and (d) turbidity at 14.6km station from March 11 to April 14 as the early spring; (e) the discharge, (f) water level, (g) salinity, (h) turbidity from September 1 to September 30 as the summer. The dates which observations were conducted are represented in gray lines.

In spring tides, the water level changes greatly (Figure 3b, 3f). Maximum tidal range was 5.238 m on September 11. Salinity varied between 0 and 1 psu because the estuary was well mixed. The front of sea water reached near the monitoring station (14.6 km) in spring tide (Figure 3c, 3g). SSC was high in the spring tide (Figure 3d, 3h); it reached the maximum concentration of 2,594 mg/l on September 11.

In neap tides, change of the water level was small (Figure 3b, 3f): 2.857 m of the maximum tidal range on September 18. Salinity increased rapidly and it reached over 10 psu, because salt wedge appears and becomes strongly stratified (Figure 3c, 3g). SSC was very low compared to spring tides (Figure 3d, 3h). The maximum SSC was 17.7 mg/l on September 17 during the neap tide.

4.2 Longitudinal Distribution of Water Quality

Figure 4 shows longitudinal distributions of water quality at the spring tide in the summer. In the high tide, salinity in the river channel (0-10 km) reached near the sea level; it exceeded 1 psu at 13km station (Figure 4a). This shows that the front between fresh water and salt water (0.1-0.5 psu) was appeared at 15 km station. ETM zone was also found at the same area (Figure 4b). It is shown that the ETM occurred into the point. The maximum of Chl and Pheo was observed in the upstream (32.3 μg/l in Chl, 84.0 μg/l in Pheo). It was suggested that these might have moved together with the ETM (Figure 4c). TN and DIN reached measured maximum in the upstream at the same area of Chl and Pheo peak (Figure 4d). Then they decreased gently as it went to the sea: 2.465 mg/l through 1.180 mg/l in TN and 1.143 mg/l through 0.356 mg/l in DIN. TP at the high tide in the estuary were approximately 0.6 mg/l and it was observed about 0.1 mg/l in DIP (Figure 4e).

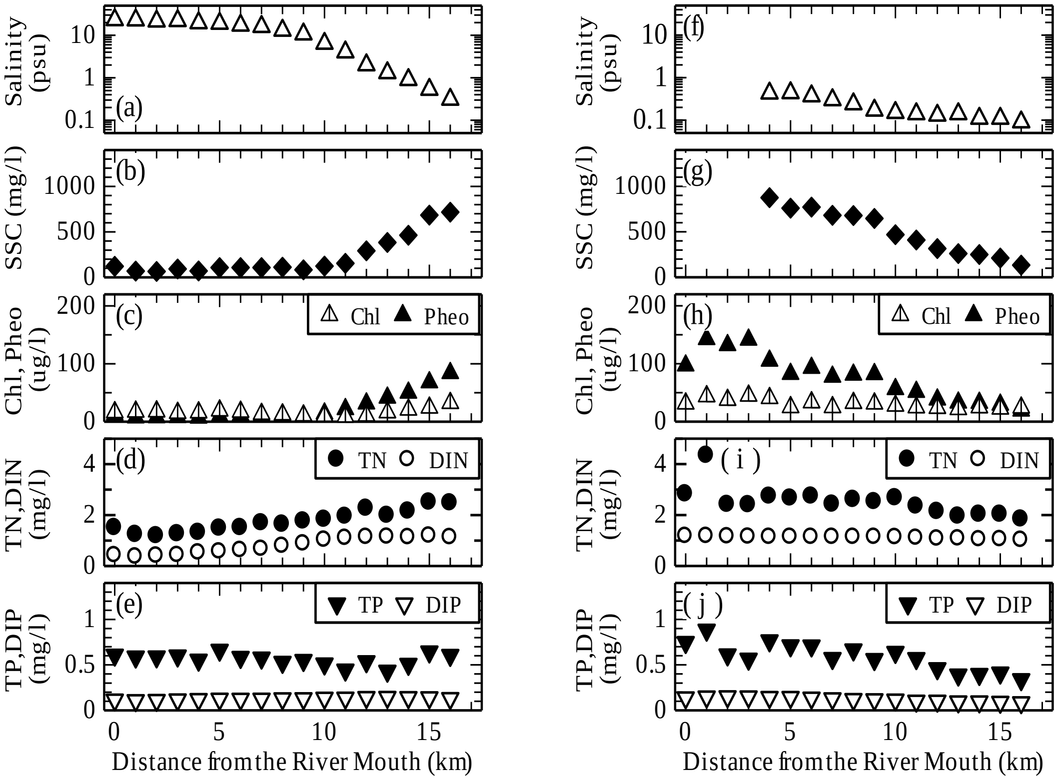

Figure 4 Longitudinal distributions of each parameter on water surface in the summer, September 11. (a) Salinity, (b) SSC, (c) Chl, Pheo, (d) TN, DIN, (e) TP and DIP in water surface on the high tide; and that of (f) salinity, (g) SSC, (h) Chl, Pheo, (i) TN, DIN, (j) TP and DIP on the low tide

In the low tide, salinity did not exceed 1 psu in the river channel (Figure 4f). Salt water was flushed away from the estuary. The highest SSC was measured near the sea: 876 mg/l at 4 km station (Figure 4g). ETM had moved back to the downstream during ebb tide. The maximum concentration of Chl was 44.8 μg/l at 3 km station, and Pheo was 142.6 μg/l at 1 km station (Figure 4h). TN and TP were highest at 1km station: 4.332 mg/l in TN and 0.883 mg/l in TP (Figure 4i, 4j). The longitudinal distributions of DIN and DIP concentration were constant during low tide (Figure 4i, 4j). The same tendency as the summer was shown also in the early spring.

4.3 Relationship between Nutrient and the Other Water Quality Parameters

Figure 5 shows the relationship between DIN and the other water quality parameters: salinity and SSC in the early spring and the summer. A negative correlation was observed between salinity and DIN during neap tides while there was no relationship between them during spring tides in the early spring (Figure 5a), however, a negative correlation was observed during both spring tides and neap tides and it was seen that there are two linear tendencies in the summer (Figure 5c). In contrast, there are no clear relationship between SSC and DIN in the early spring (Figure 5b) and the summer (Figure 5d). Nitrogen and phosphorus were shown as the same tendency, so only nitrogen is shown as a representative in the following figures.

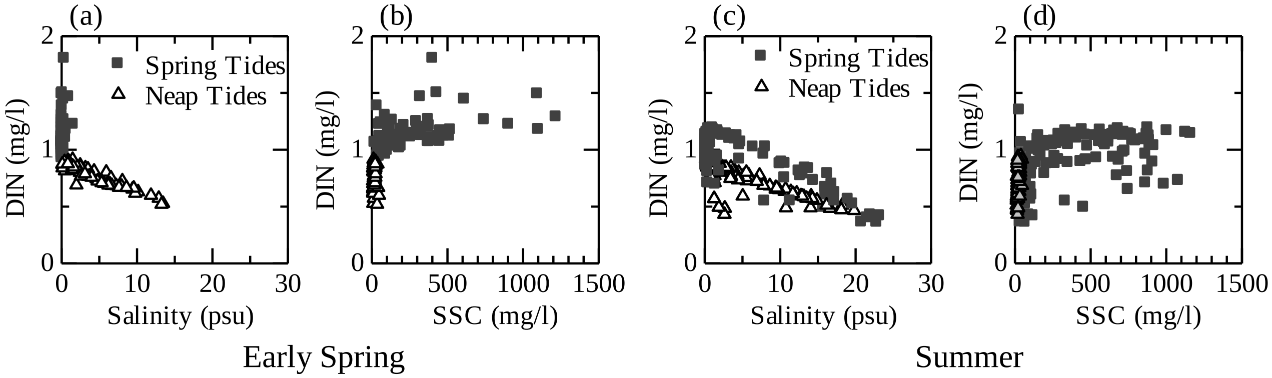

Figure 5 Relationships between (a) Salinity and DIN in the early spring, (b) SSC and DIN in the early spring, (c) Salinity and DIN in the summer, and (d) SSC and DIN in the summer.

The relationship between PN and salinity, and the relationship between PN and SSC in the early spring and the summer are shown in Figure 6. PN concentrations increased almost linearly with SSC during spring tides in the early spring (Figure 6b, 6d), but the correlation is not so good during the summer (Figure 6d). The clear relation was not found in other combination: salinity and PN (Figure 6a, Figure 6c), and SSC and PN (Figure 6b, Figure 6d) in neap tides. There are no relation between chlorophyll a and DIN for both spring and summer (Figure 7).

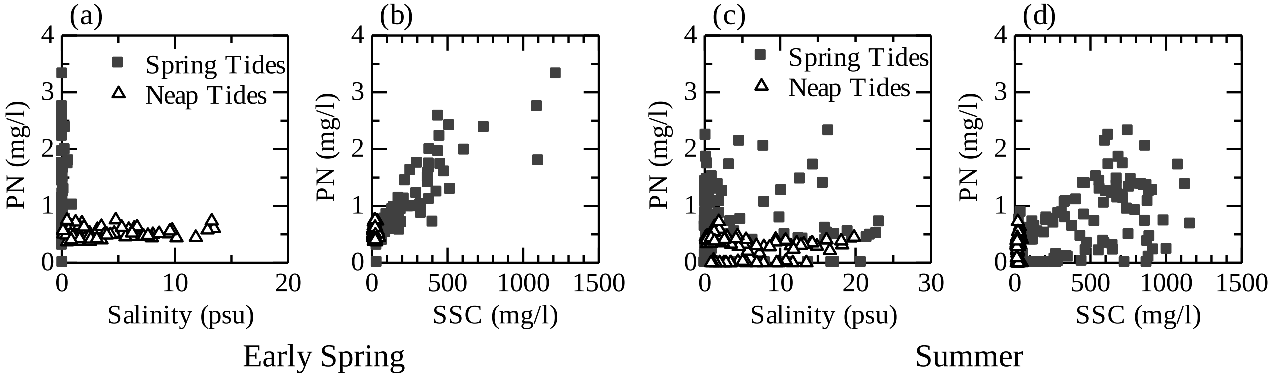

Figure 6 Relationships between (a)Salinity and PN in the early spring, (b)SSC and PN in the early spring, (c)Salinity and PN in the summer, and (d)SSC and PN in the summer.

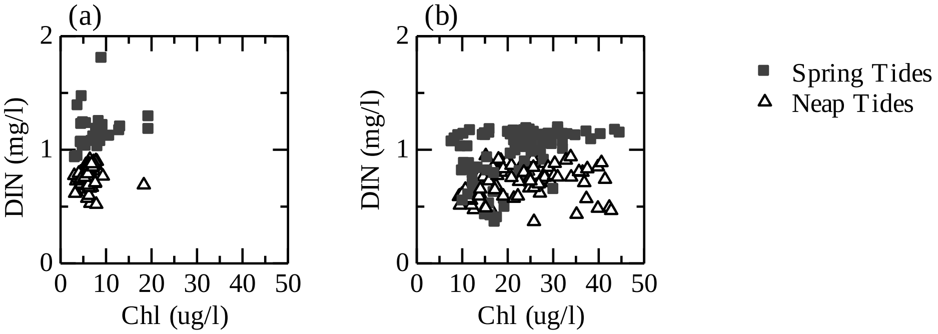

Figure 7 Relationships between the Chlorophyll *a* and DIN in (a)the early spring and (b)the summer.

5. DISCUSSION

The dominant factors influencing nutrient concentration was investigated by multiple regression analysis. DIN, PN, DIP and PP were chosen as response variables, and salinity, SSC, Chl, were chosen as explanatory variables. Pheo was treated as an exception since it had high correlation with SSC: The correlation coefficients were 0.98 in the early spring and 0.96 in the summer.

5.1 Multiple Regression Analysis of Dissolved Nutrients

It was shown that the dominant factors influencing the variation of the dissolved nutrient concentrations were salinity and SSC in the early spring. Eq. 2 and eq. 3 are multiple regression models for the concentration of DIN (C_{DIN}) and DIP (C_{DIP}):

$$C_{DIN} = 0.994 - 4.112 \cdot 10^{-2} \times Sal + 4.266 \cdot 10^{-4} \times SS \quad (2)$$

$$C_{DIP} = 0.044 - 1.468 \cdot 10^{-2} \times Sal + 2.268 \cdot 10^{-4} \times SS \quad (3)$$

where Sal is salinity and SS is SSC. Intercept means the dissolved nutrient concentration of fresh water. Basically nutrient concentration of seawater was low level (Figure. 5a, 5c). A negative term of salinity means that DIN and DIP decreased when seawater intruded into the river channel. Generally the suspended sediment hardly adsorbs DIN and DIP. However, there are relationship between SSC and dissolved nutrient (eq. 2, eq. 3). It is suggested that DIN and DIP were supplied from erosion of the bottom sediment and that they were affected by dilution with seawater in the spring.

Multiple regression models for the concentration of DIN (C_{DIN}) and DIP (C_{DIP}) in the summer are shown in eq. 4 and eq. 5:

$$C_{DIN} = 0.985 - 2.398 \cdot 10^{-2} \times Sal + 2.596 \cdot 10^{-4} \times SS - 3.316 \cdot 10^{-3} \times Chl \quad (4)$$

$$C_{DIP} = 0.106 + 7.238 \cdot 10^{-5} \times SS - 9.126 \cdot 10^{-4} \times Chl \quad (5)$$

where *Chl* is the analyzed chlorophyll a concentration. In addition to a negative term of salinity and a positive term of SSC, a negative term of chlorophyll a also existed. These models indicated that DIN and DIP were supplied from the pore water of the bottom sediment. It is also found that they were both consumed by phytoplankton. DIN was diluted with the seawater, but DIP was not influenced by the seawater in the summer.

5.2 Multiple Regression Analysis of Particulate Nutrients

Multiple regression models for the concentration of PN (C_{PN}) and PP (C_{PP}) in the early spring are shown as eq. 6 and eq. 7.

$$C_{PN} = 0.464 + 2.481 \cdot 10^{-3} \times SS \tag{6}$$

$$C_{PP} = 0.124 + 2.511 \cdot 10^{-2} \times Sal + 9.363 \cdot 10^{-4} \times SS \tag{7}$$

It was shown that PN concentration was described by simple linear regression of SSC; it was suggested that PN adhered to the suspended sediment. The model for PP consists of an intercept, a positive term of salinity and a positive term of SSC. It is suggested that PP was supplied by the fresh water, the suspended sediment from both river and sea. The sediments from each area must be distinguished. In the summer data, the significant formulas on PN and PP were not obtained statistically.

6. CONCLUSION

We measured salinity, SSC, phytoplankton concentration and nutrient concentration of the Chikugo River Estuary in the early spring and summer of 2010. Then we investigated the longitudinal distributions of water qualities, and discussed the influence of salinity, SSC and Chl on nutrient concentration. As a result, there was a difference of tendency in a correlation between salinity and nutrient, and that shows the existence on changes of nutrient concentration which is not affected by the influence of sea water. Moreover, the multiple regression analysis showed that dissolved nutrient in the estuary was affected by the following factors: supply from fresh water, dilution with seawater, supply from the pore water of the bottom sediment, and consumption by phytoplankton.

Nutrient in estuary commonly varies by an exchange between the fresh water and seawater (Davies, 2004). However, this study showed that the resuspension of bottom sediment and the presence of phytoplankton also influence nutrient concentration.

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