Spatial distribution and its temporal variation of hypoxic water mass and phytoplankton bloom around Sumida river estuary, Odaiba, Tokyo Bay

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1. Introduction

Estuaries are of immense importance to many communities. It has been estimated that 60 to 70% of the commercial marine fishery resources depend on estuaries for part of or all of their life cycle (Klen, 2006). The characteristics of estuarine flow and transport process are important as they play a critical role in the functionality and health of this system. Coastal waters and estuaries present the world with a bounty of tangible and intangible benefits. People rely on the coastal waters and estuaries for recreation, livelihoods, and social and economic wellbeing. Estuaries represent only a tiny proportion of the world's surface waters, but they are among the most productive ecosystems in nature. However, oxygen-depleted waters in stratified season are a serious environmental problem in Sumida river estuaries, Tokyo Bay. The development of this water is due to the substantial oxygen consumption to decompose large amount of organic materials that are internally produced and received from the surroundings of Tokyo Metropolitan and nearby cities associated with the stratification of the water column (e.g. Horiguchi et al., 2001; Koibuchi and Isobe, 2007; Sohma et al., 2008). Thus, water quality deterioration often causes hypoxia and phytoplankton bloom in estuarine system but the mechanisms that controls hypoxic events and phytoplankton bloom vary among estuaries are often difficult to distinguish. Extensive researches have been carried out in the Tokyo Bay including the general biogeochemical properties in terms of phytoplankton activities (Koibuchi & Isobe, 2007) as well as the hypoxic water behavior (Yagi et al.2007; Sohma et al., 2008).

1.1 Background and purpose of the study

Sumida river estuary (Odaiba) is located on the west side of Tokyo Bay and is a healthy natural ecosystem which is among the limited natural ecosystem left in the Bay. However, the highly fluctuating mechanism on the development and fate of hypoxic water and phytoplankton bloom associated with stratification in response to environmental factors around this estuary has not yet been adequately addressed by continuous time series observation. Currently, available information on this area is limited and therefore little is known about the mechanism on the occurrence of hypoxia and phytoplankton bloom and their interaction in response to different environmental factors. This study focused on the occurrence and extent of hypoxic water and phytoplankton bloom around the estuary to determine the regulating factors which most influence hypoxia and phytoplankton blooms.

Hence, the present study is aimed to understand water quality characteristics as a basis to mitigate the adverse ecological effect to the estuary's ecosystems. To achieve the goal, series of intensive field observation coupled with spatial and temporal dimension were used to investigate the occurrence of hypoxia and phytoplankton bloom around Sumida river estuary in summer 2011. The findings from the study would better serve scientists, decision makers and managers in their attempts to address the cause of hypoxia and bloom in estuary for its better management. The main objectives of the study are as follows:

- To provide a detailed description of the patterns and mechanism on the occurrence of the hypoxic events and phytoplankton bloom in response to physical forcing and environmental factors.
- To describe the spatial distribution and its temporal variation of the hypoxic events and phytoplankton blooms.
- To characterize the flow velocity with correspond to water quality processes in the estuary.

2. Materials and Methods

2.1 Study site

The field observation stations at Odaiba are a narrow channel with two openings to canals at the mouth of the Sumida River. The depth is generally shallower than 5m except in a single narrow shipping lane and around the openings to the canals where the depth is about 8-9m. The observation stations are at station.1 located in the outer part of Odaiba and the station 2 and 3 are at the inner part of Odaiba. The study site is the upper area of Tokyo Bay (Figure.1).

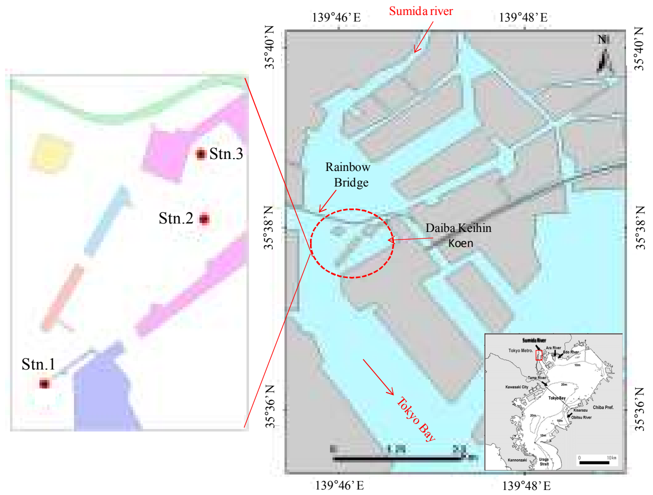

Fig.1 Study site and layout of observation stations, map of Sumida river estuary, the uppermost part of Tokyo Bay, Odaiba

2.2 Field observations

Intensive field observations were carried out at the three stations at Odaiba from June to September in summer, 2011. The hydrographic conditions (e.g. water level, flow velocity, water temperature, salinity), water quality condition (e.g. chlorophyll-a and DO concentration) were monitored in every 10 minutes interval by two Yellow spring Incorporated(YSI-6600) sensors and Work Horse HADCP at station 1 while instrumented buoys were moored at other two stations (Figure 1). The automatic data logging sensors (YSI, ADCP, Alec- CLW, Alec CTW and Alec DOW) were inspected, checked for drift or biofouling and recalibrated bi-monthly. Schematic diagram of survey methodologies are shown in Figure.2. During the observation period, daily and hourly climatological data such as precipitation, wind speed/direction and solar radiation at the Tokyo Meteorological Observatory station were obtained from the website of Japan Meteorological Agency. Daily flow rates of Sumida river estuary (Sugama observation point) were obtained from the tables of river discharge (Ministry of Land, Infrastructure and Transport, River Bureau).

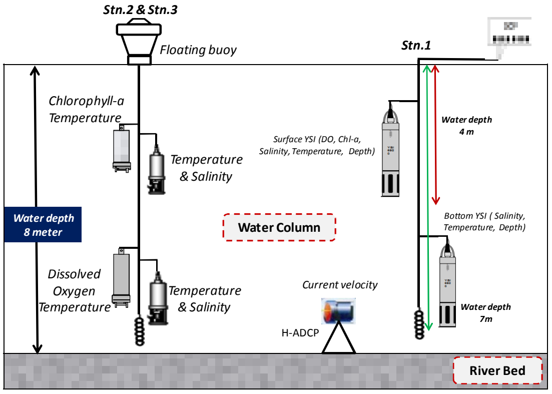

Fig.2 Schematic illustration showing the overall field observation techniques during the field surveys.

3. Result and Discussion

3.1. Meteorological & hydrographic conditions

Time series of wind speed, solar radiation, precipitation and river discharge from June-September, 2011 are shown in Figure. 3 and 4.

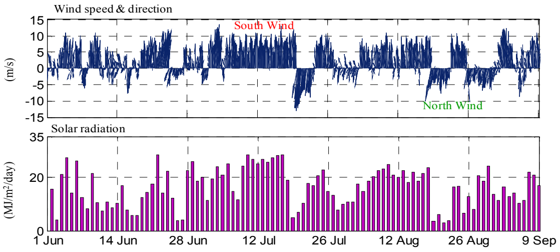

Fig.3 Time series of solar radiation and wind condition

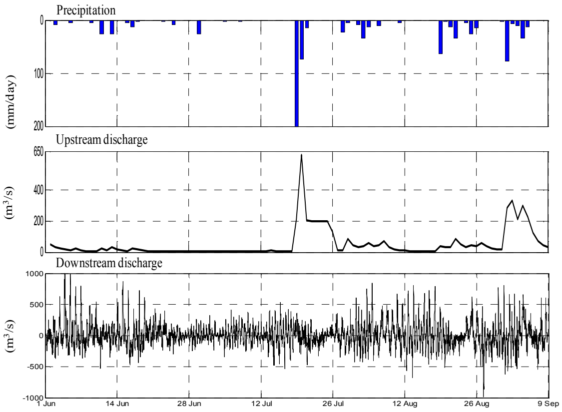

Fig.4 Time series of precipitation and river discharge

The Figures show that the onset of high discharge (200-630 m^3/s) on 18th July to 28th July and 31st August to 9th September suggesting a fresh water origin during peak and moderate discharges. The seasonal discharge structure shows this period with the greatest haline stratification. Salinity influenced stratification more than temperature indicating pronounced haline stratification and this stratification was persistent until early September and it exhibited prompt responses to discharge which further regulated density stratification. The prevailing winds were southerly from June to early September with a daily mean velocity of 3 m/s. There was a strong northerly wind with a daily mean velocity of 6 m/s (maximum 14 m/s) associated with a rainfall and discharge front on August and September. The solar radiation was found high during south wind and low at north wind. River discharge at downstream point was more tidally affected than the upstream point.

3.2. Stratification and dissolved oxygen

Surface to bottom density differences and surface and bottom dissolved oxygen at the three stations (June 1, 2011 to September 9, 2011) are shown in Figure 5. The variations in surface to bottom density differences at the three sites reveal episodic stratification events. The density differences are primarily driven by changes in salinity at station 1 and by temperature changes at other two stations. The surfaces to bottom density differences at station 2 and 3 were greater than at the station 1. The difference between surface and bottom sigma-T, which is also an index of water column stratification, was highest at the inner part of estuary and decreased at outer part of the estuary. Salinity influenced water column stratification more than temperature indicating that thermal stratification was low at the sea ward end of estuary. In contrast, the surface and bottom temperature were high in the inner part of estuary, indicating pronounced thermal stratification than the halocline stratification. Stratification at the inner part of estuary was strong and persistent; it did not exhibit prompt responses to physical factors such as fresh water runoff/or tidal flows immediately, which regulated stratification down-estuary where the influence of environmental factors on stratification was greater.

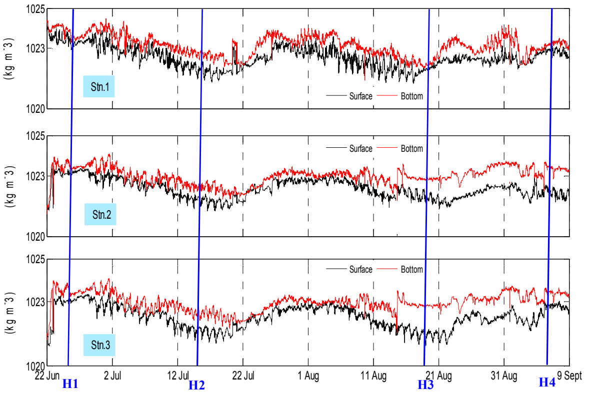

Fig.5 The difference between the bottom and surface Sigma-T at the outer part of Odaiba (Station 1), inner part of Odaiba (Station2 and 3). Blue vertical lines indicate the beginning of four hypoxic events starting on 25th June (H1), 17th July (H2), 19th August (H3) and 5th September (H4).

3.3. Spatial distribution of hypoxic water

Figure 6 shows the observation results in terms of temporal changes of near surface and near bed dissolved oxygen concentration from station 1, 2 and 3 indicated by H1(25 June-3 July), H2(17-25 July), H3(19 August-1 September) and H4(5-9 September). High DO in the surface layer were observed at station 1, where chlorophyll-a concentration coverage was high during entire observed period. Inner part of the estuary (station 2 and 3), the difference between surface and bottom layers dissolved oxygen concentrations were more prominent and evident. Photosynthetic oxygen production in well-illuminated surface layers resulted in DO > 7-12 mg/l for all the three locations. In contrast, DO in bottom layer for station 2 and 3 was lower which was approximately <2-3 mg/l. DO in the bottom layer at the station 2 was comparable with DO observed at the station 3 and at the seaward location of the estuary (station 1), excluding several periods of pronounced hypoxia. After recovering every hypoxic events, dissolved oxygen concentration abruptly increased to around 10-15 mg/l and this increasing of dissolved oxygen corresponding to the sudden increasing and decreasing of near bottom salinity and water temperature. Moreover the changes pronounce also with the wind speed and direction as can be seen in Figure 4. The overall dissolved oxygen concentrations at the outer part of Odaiba (station 1) were higher than those of the station 2 and station 3 in terms surface level oxygen concentration. Dissolved oxygen concentration in the bottom layer of station 2 and station 3 were always above the anoxic level at about <1 mg/l. Neap tidal flow (Figure.8) transported waters from inner part that were sometimes oxygen rich (daytime) and sometimes oxygen poor (nighttime) towards outer part of estuary resulting in subsurface hypoxic condition at the outer part (station 1).

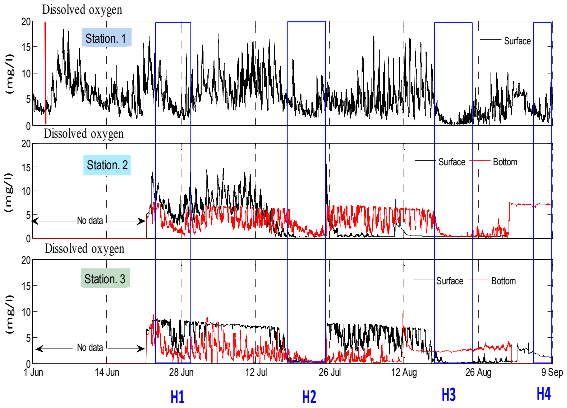

Fig.6 Dissolved oxygen concentration in surface layer (black line) and in bottom layer (red line) at station 1, 2 and 3. Blue rectangles indicate four hypoxic events (H1, H2, H3 and H4).

3.4. Spatial distribution of chlorophyll-a

Observed spatial distribution of surface layer chlorophyll-a concentration indicated by B1(19-24 June), B2(16-20 July), B3(4-10 August) and B4(15-20 August) as phytoplankton bloom and dissolved oxygen concentration are given in Figure 7. Observed chlorophyll-a concentration showed that the phytoplankton biomass was concentrated more at the station 1 than those of station 2 and 3. Thus the highest concentration of chlorophyll-a was found at the outer part (station 1) and second highest concentration was observed at station 2 and the lowest concentration of chlorophyll-a was found at the station 3. It is mentionable that the station 1 is located at seaward position which is directly influenced by the incoming bay water as well as outgoing river water and as a result concentration of chlorophyll-a was much higher than those of station 2 and station 3. In contrast, station 2 and 3 were located at the innermost part of Odaiba which are enclosed by land and less influenced by river water and sea water. Furthermore significant differences in chlorophyll-a concentration between station 2 and station 3 was observed although the distance between these two locations is not more than 100 m. This significant differences were due a floating fence which was positioned in the surface layer to limit the transport of phytoplankton. Dissolved oxygen concentration also displayed strong temporal and spatial variations with the variations of phytoplankton biomass. Higher concentration of dissolved oxygen could be found only at the near surface water corresponding well with the distribution of chlorophyll-a distribution (Figure 6).

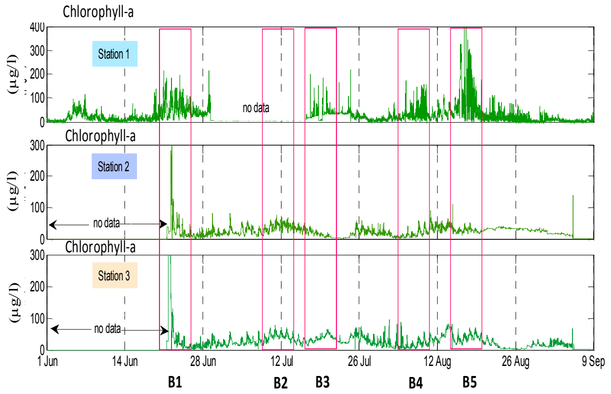

Fig.7 Chlorophyll-a concentration in surface layer (green line) at station 1, 2 and 3. Red rectangles indicate five phytoplankton bloom events (B1, B2, B3, B4 and B5).

Spring-neap tidal modulation controlled the surface and bottom layers of water column and influenced the distribution of chlorophyll-a. During spring tides, salinity intrusion occurred by strong horizontal transport of saline water from the bay as a result chlorophyll-a concentration declined from the reverine source. During neap tide, the estuarine water column stratified, with maximum horizontal transport from river and vertical mixing to surface and bottom layer were restricted and as a result in the surface layer chlorophyll-a concentration increased (Figure 8). But this evidence was more prominent at the station 1 rather than station 2 and 3.

3.5 Tidal circulation

Figure 4.34 shows the current cycles for the observation period throughout the cross section by along channel velocity components. The tidal cycle of ebb and flood phases is evident from the measured north-south components of velocities and water elevation. Thus, Odaiba area appears to be an active tributary, maintained by river discharge and tidal flows, with characteristics features of tide dominated areas.

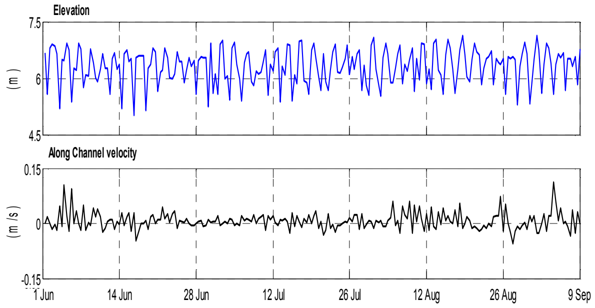

Fig.8 Time series of tidal elevation and along river velocity.

4. Conclusion

Understanding physical process of water properties is essential for successful management of water quality in estuaries. The study demonstrates that the hydrographic and water quality characteristics around this area were likely affected by wind and the combined effect of wind and tidal circulation associated with river discharge. This study also suggests that under the summer condition, the tidal circulation and river discharge were the dominant factors influencing circulation in the estuary. In addition comparative analysis of these hydrographic and water quality parameters considering the local environmental factors in several estuarine systems in Tokyo Bay and other regions nationwide and worldwide should help environmental scientists and decision makers in organizing estuarine monitoring, research and management.