FIELD OBSERVATION ON BLUE CARBON DYNAMICS IN THE YATSUSHIRO SEA CONSIDERING INFLUENCE OF STRATIFICATION

NAOKI SAITO
Kyushu University, Fukuoka, Japan, saito.naoki.926@s.kyushu-u.ac.jp

XION BING
Kyushu University, Fukuoka, Japan, xiong.bing.788@s.kyushu-u.ac.jp

HIROTO KOMORI
Kyushu University, Fukuoka, Japan, komori.hiroto.977@s.kyushu-u.ac.jp

SHINICHIRO YANO
Kyushu University, Fukuoka, Japan, yano@civil.kyushu-u.ac.jp

KEISUKE NAKAYAMA
Kobe University, Kobe, Japan, nakayama@phoenix.kobe-u.ac.jp

KATSUAKI KOMAI
Kitami Institute of Technology, Kitami, Japan, komai@mail.kitami-it.ac.jp

KEI YAJIMA
Shimane University, Matsue, Japan, yajima@soc.shimane-u.ac.jp

ABSTRACT

Recently, *blue carbon*, which is the carbon fixed by marine living organism has attracted attention as a new measure to mitigate climate change. In order to estimate the fixed amount of blue carbon, the partial pressure of CO2 (pCO2) in seawater is important. In this study, we carried out field observation in the Yatsushiro Sea and tried to reveal the actual dynamics of pCO2 in a coastal region. In addition, from observation in the conditions with different mixing condition, that is, strong stratification, weak one, and well-mixed, we tried to reveal the effects of stratification on pCO2 in seawater. As a result, it was confirmed that the effects of photosynthesis by flora and calcification by corals on the fluctuation of pCO2. Moreover, we revealed that the effect of photosynthesis of phytoplankton was concentrated in the surface layer. Furthermore, in the strong stratification period, it was suggested that pCO2 in seawater was able to be fluctuated due to the inflow of seawater from a coral habitats area.

Keywords: blue carbon, the partial pressure of CO2, stratification, the Yatsushiro Sea

1. INTRODUCTION

In recent years, "*blue carbon*", which is the carbon fixed into marine ecosystems, has been attracted attention to as a new climate change mitigation measure. It is known that about 55% of the carbon fixed by global ecosystem is blue carbon (UNEP, 2004). Especially, the coastal area where vegetation such as seagrass beds exists is considered to be important places for carbon absorption and fixation functions (Mcleod *et al*., 2001; Watanabe *et al*., 2015). In estimating the fixed amount of blue carbon, understanding a mechanism of fluctuating of the partial pressure of CO2 (pCO2) in seawater is one of the most important issue.

However, there are few studies on pCO2 in seawater in coastal areas. In addition, pCO2 in seawater can greatly fluctuate in space and time in a coastal area, and can be affected by physical processes such as flow and mixing, and biological processes such as the photosynthesis by marine flora and the calcification by corals. Therefore, it is necessary to accumulate data based on various conditions of geography, topography, ecosystems, *etc*. in order to improve the estimation accuracy related to the dynamics of pCO2 in seawater in a coastal area.

Furthermore, in past studies, it has been reported that when stratification develops, the dissolved inorganic carbon concentration (DIC) in the surface layer decreases and also pCO2 decreases (Fujii *et al*., 2011; Fujii *et al*., 2012; Fujii *et al*., 2013; Tada *et al*., 2018).

This study, following Saito *et al*. (2019), we carried out field survey to measure pCO2 in seawater in the Yatsushiro Sea, and tried to reveal it under an actual situation. In addition, the details of the effect of stratification on pCO2 dynamics in seawater was investigated by observations under three stratification conditions, such as strong stratification, weak one, and well-mixed. Yatsushiro Sea is one of the largest semi-enclosed inner bay in Japan, and also can be characterized by both seagrass (especially eelgrass) and coral inhabit.

2. METHODOLOGY OF THE STUDY

2.1 Survey area

The survey site is the point *a* in the Yatsushiro Sea shown in Figure 1 (32° 27' 30” N, 130° 27' 37” E, about 20 m deep). The Yatsushiro Sea is extremely closed compared to other semi-enclosed bays in Japan, and is characterized by the high river inflow load (Ministry of the Environment, 2017). In addition, the existence of seagrass beds of about 1,141 ha has been confirmed (Ministry of the Environment, 1997). Moreover, there are many reef-building corals near the Amakusa Islands surrounding the Yatsushiro Sea and the southern area including Minamata Bay (Ministry of the Environment and The Japanese Coral Reef Society, 2004).

The survey site is selected near the mouth of the Kuma River, which accounts for about 60% of the river basin area flowing into the bay, because the strong freshwater-seawater stratification can be generated by freshwater inflow from the river.

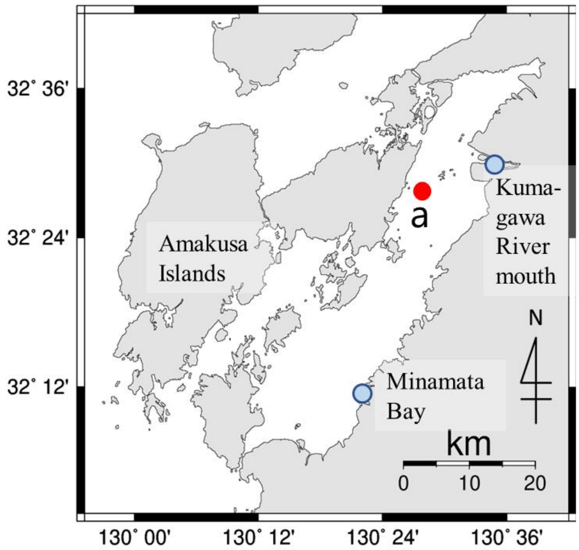

Figure 1. The survey site.

2.2 Survey method

The three survey dates were selected as August 26, 2018 for the weak stratification condition, December 7, 2018 for the well-mixed one, and August 2, 2019 or the strong stratification. All days are during the spring tide period. Weather of two days for stratified condition were fine, on the other hand, the day for well-mixing was cloudy throughout the day according to the AMeDAS Yatsushiro station. During a half cycle of semi-diurnal tide from about 9:00 (high tide) to about 15:00 (low tide), water quality measurement and water sampling were conducted. Measured items were vertical distribution of water temperature, salinity, chlorophyll-*a*, *etc*. from water quality measurement, and DIC, total alkalinity (TA), and nutrients from water samples. Water quality profile was measured every 20 minutes using a multiple water quality meter (ProDSS, YSI Co., Ltd.). Water was sampled a total of 30 samples from 5 times, that is, high tide, 1.5 hours after high tide, maximum ebb tide, 1.5 hours before low tide, and low tide, from 6 layers at depths of 0 m, 3 m, 6 m, 9 m, 12 m, and 15 m from sea surface. Seawater samples were collected in 250 mL Duran bottles, and DIC was fixed by injecting mercuric chloride solution. DIC and TA were measured using a flow-through type carbonic acid analyzer (MDO-02, Kimoto Denshi Co., Ltd.) and a total alkalinity titrator (ATT-15, Kimoto Denshi Co., Ltd.). In addition, raw water and filtered water (using 0.45 mm filter) were separately collected for the measurement of nutrients. PCO2 in seawater was calculated from water temperature, salinity, DIC, and TA from the chemical equilibrium relation of carbon system (Zeebe and Wolf-Glandrow, 2001). ΔDIC which is the fluctuating value due to photosynthesis and ΔTA due to calcification were calculated as the differences between the observed DIC and TA and the estimated values, which were calculated from the mixing ratio of the river water (freshwater) from the Kuma River and the seawater in the Kuroshio Current in the outer sea area, East China Sea (Qu *et al*., 2018).

3. RESULTS AND DISCUSSION

Using the observed values, multiple regression analysis was performed using pCO2 in seawater as the objective variable. The explanatory variables were water temperature, salinity, ΔDIC, and ΔTA. DIC and TA were excluded from the explanatory variables, because they showed a strong positive correlation (multicollinearity) with salinity (correlation coefficients were 0.95 and 0.98, respectively). The *t* values indicating the degree of influence on the objective variable were 85.51, -1.77, 103.44, and -47.94, respectively.

Figure 2 shows the contour figures of σ_t, ΔDIC, ΔTA, chlorophyll-*a*, and pCO2 in seawater in the strong stratification period. We omit figures for the weak stratification period and the well-mixing one. Regarding ΔDIC, large negative values was observed near the sea surface. Moreover, the distributions of the maximum values of ΔDIC generally corresponded to chlorophyll-*a*. As a result, it was confirmed that the effects of photosynthesis by phytoplankton were concentrated in the surface layer. In the weak stratification period, at the less than about 8 m, ΔDIC was uniformly about 120 μmol/kg, and in the well-mixing period, it kept a constant of about 70 μmol/kg.

ΔTA showed different values vertically in the strong stratification period. In contrast, it was approximately −60 μmol/kg in both of the weak stratification period and the well-mixing one. From investigation of the structure of the water mass using the TS-diagram, it was shown that the distribution of ΔTA generally corresponded to the water mass in the strong stratification period. From the above, it was suggested that the water mass affected by the coral flowed into the observation site.

From the distribution of pCO2 in seawater, it was confirmed that in the strong stratification period, although water temperature of the surface was high, pCO2 decreased due to strength of photosynthesis caused by stratification, and CO2 absorption from the atmosphere into the sea was promoted.

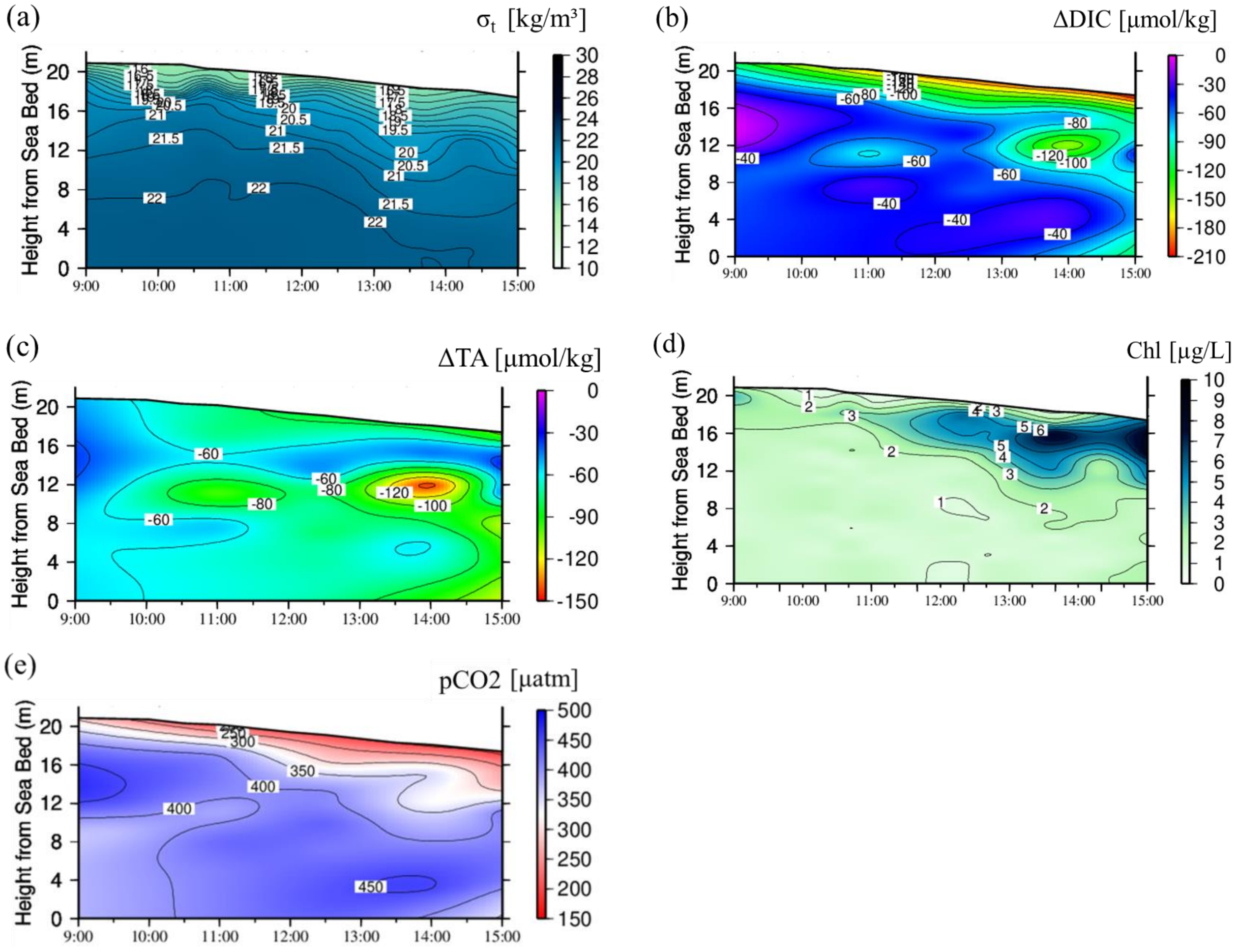

Figure 2. Isopleths of σ_t (a), ΔDIC (b), ΔTA (c), chlorophyll-*a* (d), and pCO2 in seawater (e) in the strong stratification period (2019/Aug./2).

4. CONCLUSIONS

Field surveys of pCO2 in seawater was conducted in the Yatsushiro Sea, and its fluctuation factors were considered. The effects of photosynthesis and calcification on the fluctuation of pCO2 in seawater were confirmed. In addition, it was confirmed that the effect of phytoplankton photosynthesis was concentrated in the surface layer. In strong stratification period, pCO2 in seawater fluctuated due to inflow from coral habitats. In a further research, we plan to investigate on a relationship between flow pattern from coral habitat area in the bay to the observation area and pCO2 dynamics using a numerical model.

ACKNOWLEDGMENTS

This research was carried out by JSPS KAKENHI Grant-in-Aid for Scientific Research (B) (18H01545). The winter survey was conducted using the training ship *Kakuyo-Maru* owned by the Faculty of Fisheries, Nagasaki University in association with Prof. Akihide Tada, Nagasaki University. Here, we express our gratitude.

REFERENCES

UNEP. (2009). Blue Carbon, A rapid response assessment.

Mcleod, E., Chmura, G. L., Bouillon, S., Salm, R., Björk, M., Duarte, C. M., Lovelock, C. E., Schlesinger, W. H., and Silliman, B. R. (2011). A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO2. *Frontiers in Ecology and the Environment*, 9:552-560.

Watanabe, K., and Kuwae, T. (2015). How organic carbon derived from multiple sources contributes to carbon sequestration processes in a shallow coastal system?. *Global Change Biology*, 21:2612-2623.

Fujii, T., Komai, Y., and Fujiwara, T. (2011). Carbon Dioxide Dynamics in Coastal Regions of Osaka Bay. *Journal of JSCE*, B2, 68(2): I_1061-I_1065.

Fujii, T. and Fujiwara, T. (2012). Continuous Measurement of Carbon Dioxide Concentration in the Surface Seawater of Osaka Bay. *Journal of JSCE*, B2, 67(2):I_911-I_915.

Fujii, T., Fujiwara, T., and Nakayama, K. (2013). Fluxes of Carbon Dioxide in the Eastern Regions of Osaka Bay. *Journal of JSCE*, B2, 69(2):I_1111-I_1115.

Tada, K., Nakayama, K., Komai, K., Tsai, J., Sato, N., and Kuwae, A. (2018). Fluctuation analysis of dissolved inorganic carbon concentration in eelgrass beds considering stratification. *Journal of JSCE*, B3, 74(2):I_444-I_449.

Saito, N., Xion, B., Yano, S., Nakayama, K., Komai, K., and Yajima, K. (2019). Field survey on blue carbon dynamics in the Yatsushiro Sea considering stratification. *Abstracts of Annual Meeting of JSCE*. 74:II-191.

Ministry of the Environment. (2017). 2017 the Ariake Sea and the Yatsushiro Sea Comprehensive Survey Evaluation Committee Report.

Ministry of the Environment. (1997). 5th Basic Survey on Natural Environment Conservation.

Ministry of the Environment. and The Japanese Coral Reef Society. (2004). Coral Reefs of Japan.

Zeebe, R., E. and Wolf-Gladrow, D. (2001). CO2 in Seawater: Equilibrium, Kinetics, Isotopes. Elsevier Science.

Qu, B., Song, J., Yuan, H., Li, X., and Li, N. (2018). Carbon Chemistry in the Mainstream of Kuroshio Current in Taiwan and Its Transport of Carbon into the East China Sea Shelf. *Sustainability*, 10(3):791.