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# BEHAVIOR OF ANOXIC WATER IN THE BANGPAKONG ESTUARY

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## ABSTRACT

We carried out hydrographic observations in the Bangpakong estuary during transient period from rainy season to dry season in 2011 and 2012. The main objective of the hydrographic observations was to elucidate the behavior of anoxic water mass in the Bangpakong estuary, which was the possible cause of mass mortality of cultured shellfishes in the study area. We had succeeded the CTD and mooring observations in both years, and we had obtained time–series data of DO, salinity, and current velocity for approximately 2 months, which were the first long-term continuous records in terms of water quality in the Bangpakong estuary. From mooring data, it was revealed that DO and salinity at the bottom layer in aquaculture area oscillated with large amplitude, and the period of the oscillation corresponded to tidal variation. Amplitude of the oscillation was large in September and became small in October, and anoxic condition lasted for several days in October in 2011 and 2012. Current direction at station M1 in 2011 was opposite to that of in 2012 throughout the mooring period southward in 2011 and northward in 2012. Wind conditions in Chonburi in both years were almost the same, but river discharge in 2011 was much higer than that of in 2012. Therefore, it was possible that the difference of current direction at station M1 occurred due to change of buoyancy flux, and persistent period of anoxic condition was different between 2 observed years associated with circulation change. It was suggested that mass mortality of cultured shellfishes in Bangpakong estuary was caused by anoxic water because timing of mass mortality corresponded to that of anoxic water appearance qualitatively. It was also suggested that the anoxic water mass in aquaculture area was transported from off shore area by residual currents.

**Keywords:** anoxic water mass, residual current, salinity, Bangpakong estuary.

## INTRODUCTION

The Bangpakong estuary is located in the northeastern corner of the Upper Gulf of Thailand (UGoT) (Fig. 1). Water depth in the estuary is mostly less than 10 m but 20 m in the southwestern part of the estuary. Bangpakong River supplies enormous amount of freshwater into the estuary during rainy season; the maximum river discharge is approximately 1000 $m^3 s^{-1}$ in August. Circulation in the estuary varies due to various in buoyancy flux from rivers such as Bangpakong and Chao-phraya and Asian monsoon (Buranapratheprat and Yanagi, 2003; Aschariyaphotha and Wongwises, 2012). According to 3-dimensional numerical model result of Buranapratheprat and Yanagi (2003), a strong eastward current comes into the estuary in surface layer in June, and then the current bifurcates; one flows directly into the inner estuary reaching the east coast, while the other flows out from southern part. Southward density driven currents become the strongest in surface layer in September due to large river discharge. Current pattern at the surface layer in December has a trend to flow out from western part of the

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estuary. In September and December, intrusion from the southern part occurs at the bottom layer.

Since enormous nutrients and organic matters are supplied from Bangpakong River, the Bangpakong estuary becomes eutrophic. In addition, because the whole UGoT has also eutrophicated due to supplying materials from other rivers (Chongprasith and Srinetr, 1998; Cheevaporn and Menasveta, 2003), massive amount of nutrients might be transported from outside of the estuary by a clockwise circulation within the UGoT (Buranapratheprat et al., 2002). Although the eutrophication leads to a variety of problems such as red tide, primary productivity becomes high due to the large nutrient load. Therefore, the Bangpakong estuary is suitable for aquaculture, especially shellfish farming (Chalermwat and Lutz, 1989). In fact, oyster, green mussel, and red clam have been cultivated in this estuary taking advantage of shallow water and high productivity, and the aquaculture of shellfishes has been one of the main fishery industries around Chonburi, Thailand. However, mass mortality of the cultured shellfish takes place every year in the Bangpakong estuary from the late September to early October. The mass mortality causes financial damage to local fishermen.

The causes of the mass mortality of cultured shellfish are either red tide, fish disease, or anoxic water but it has not been confirmed yet. Phytoplankton blooming occurs throughout the year in the UGoT but the blooming occurs during only northeast monsoon season (May – August) in the eastern part of the UGoT including the Bangpakong estuary (Buranapratheprat et al., 2006; Buranapratheprat et al., 2008; Buranapratheprat et al., 2009). The timing of phytoplankton blooming is a little different from that of mass mortality. There has no report on shellfish disease so far. We hypothesize that anoxic water might be the main cause of shellfish mass mortality. This is because the mass mortality occurs during the same period every year and the timing of mass mortality coincides with that of northeast monsoon onset which changes circulation in the UGoT (Aschariyaphotha et al., 2008). In general, anoxic water is developed at the bottom layer in the tropical waters because solubility of oxygen is lower due to high water temperature, and density stratification develops due to large river discharge. It is possible that variations in circulation in relation to variability in monsoon and river discharge give influence to behavior of anoxic water. Namely, physical processes are supposed to be cause of the mass mortality of cultured shellfish.

Although field observations on water temperature and salinity were conducted in this area before, there are few time-series data for water quality especially dissolved oxygen (DO). Hence, we do not know the marine environment in the Bangpakong estuary when mass mortality occurs. In the present study, we investigate temporal and spatial variations in DO concentration, salinity, and current velocity in the Bangpakong estuary based on hydrographic observation data.

## MATERIAL AND METHODS

### Hydrographic observation

Hydrographic observations were carried out from early September to end of October in 2011, and from end of August to end of October in 2012 (Table 1). We conducted 3 times CTD measurement to capture horizontal and vertical distribution within each year. We set up 21 stations in the Bangpakong estuary (Fig. 1), and observed vertical distribution of water temperature, salinity, DO, and fluorescence at each station using RINKO Profiler (JFE Advantech Co., Ltd.). In order to obtain time–series data, we conducted mooring for about 2 months at station M1 in 2011 and at stations M1 and M2 in 2012 (Fig. 1). We moored DO meter, current meters, temperature and salinity meters, sea level meter at 1-m above the sea bottom. Water depth at stations M1 and M2 were 2.4 (low tide) – 4.4 m (high tide) and 3.7 (low tide) – 5.7 m (high tide), respectively. Mooring period, data interval, specifications of moored instruments were shown in Table 1.

**Table 1.** CTD observation dates, mooring periods, mooring locations, data intervals, used instruments.

| Year | Date | Instrument |
|---|---|---|
| **2011** | **September 5-6** | **RINKO Profiler** (JFE Advantech Co., Ltd) |
| **2011** | **October 4-5** | **RINKO Profiler** (JFE Advantech Co., Ltd) |
| **2011** | **October 24-25** | **RINKO Profiler** (JFE Advantech Co., Ltd) |
| | | |
| **2012** | **August 30-31** | **RINKO Profiler** (JFE Advantech Co., Ltd) |
| **2012** | **September 21-22** | **RINKO Profiler** (JFE Advantech Co., Ltd) |
| **2012** | **October 21-22** | **RINKO Profiler** (JFE Advantech Co., Ltd) |

**Mooring Observation**

Location: M1 (13°22.503’N, 100°56.700’E)
Period: 2011 September 5 - October 24

| Measurement Item | Data interval | Mooring Depth | Instrument |
|---|---|---|---|
| Dissolved Oxygen | 20 min. | 1 m above bottom | COMPACT-DOW (JFE Advantech Co., Ltd) |
| Current Meter | 10 min. | 1 m above bottom | COMPACT-EM (JFE Advantech Co., Ltd) |
| Temperature and Salinity Meter | 20 min. | 1 m above bottom | COMPACT-CTW (JFE Advantech Co., Ltd) |

Location: M1 (13°22.518’N, 100°56.689’E)
Period: 2012 August 30 - October 21

| Measurement Item | Data interval | Mooring Depth | Instrument |
|---|---|---|---|
| Dissolved Oxygen | 10 min. | 1 m above bottom | COMPACT-DOW (JFE Advantech Co., Ltd) |
| Current Meter | 10 min. | 1 m above bottom | COMPACT-EM (JFE Advantech Co., Ltd) |
| Temperature and Salinity Meter | 20 min. | 1 m above bottom | COMPACT-CTW (JFE Advantech Co., Ltd) |
| Sea Level Meter | 2 min. | 1 m above bottom | Level TROLL 500 (In-Situ Inc.) |

Location: M2 (13°22.409’N, 100°55.681’E)
Period: 2012 August 30 - October 21

| Measurement Item | Data interval | Mooring Depth | Instrument |
|---|---|---|---|
| Dissolved Oxygen | 10 min. | 1 m above bottom | COMPACT-DOW (JFE Advantech Co., Ltd) |
| Current Meter | 10 min. | 1 m above bottom | COMPACT-EM (JFE Advantech Co., Ltd) |
| Temperature and Salinity Meter | 10 min. | 1 m above bottom | COMPACT-CT (JFE Advantech Co., Ltd) |
| Sea Level Meter | 2 min. | 1 m above bottom | Level TROLL 100 (In-Situ Inc.) |

## RESULTS

### Horizontal and vertical distributions of salinity and DO

Surface salinity distributions in 2011 and 2012 were shown in Fig. 2. Surface salinity around river mouth was less than 5 psu and increased to the south. The surface salinity increased from early September to end of October in 2011 and from end of August to end of October in 2012. High salinity water masses of more than 28 psu emerged in the southern part of the estuary at the sea surface in end of October. Surface salinities in 2012 were higher than those in 2011 in each month. Bottom salinity (1 m above the bottom) distribution in 2011 and 2012 were shown in Fig. 3. Bottom salinity around the river mouth was quite low and there were large gradients of bottom salinity from river mouth to southwestern part of the estuary until early

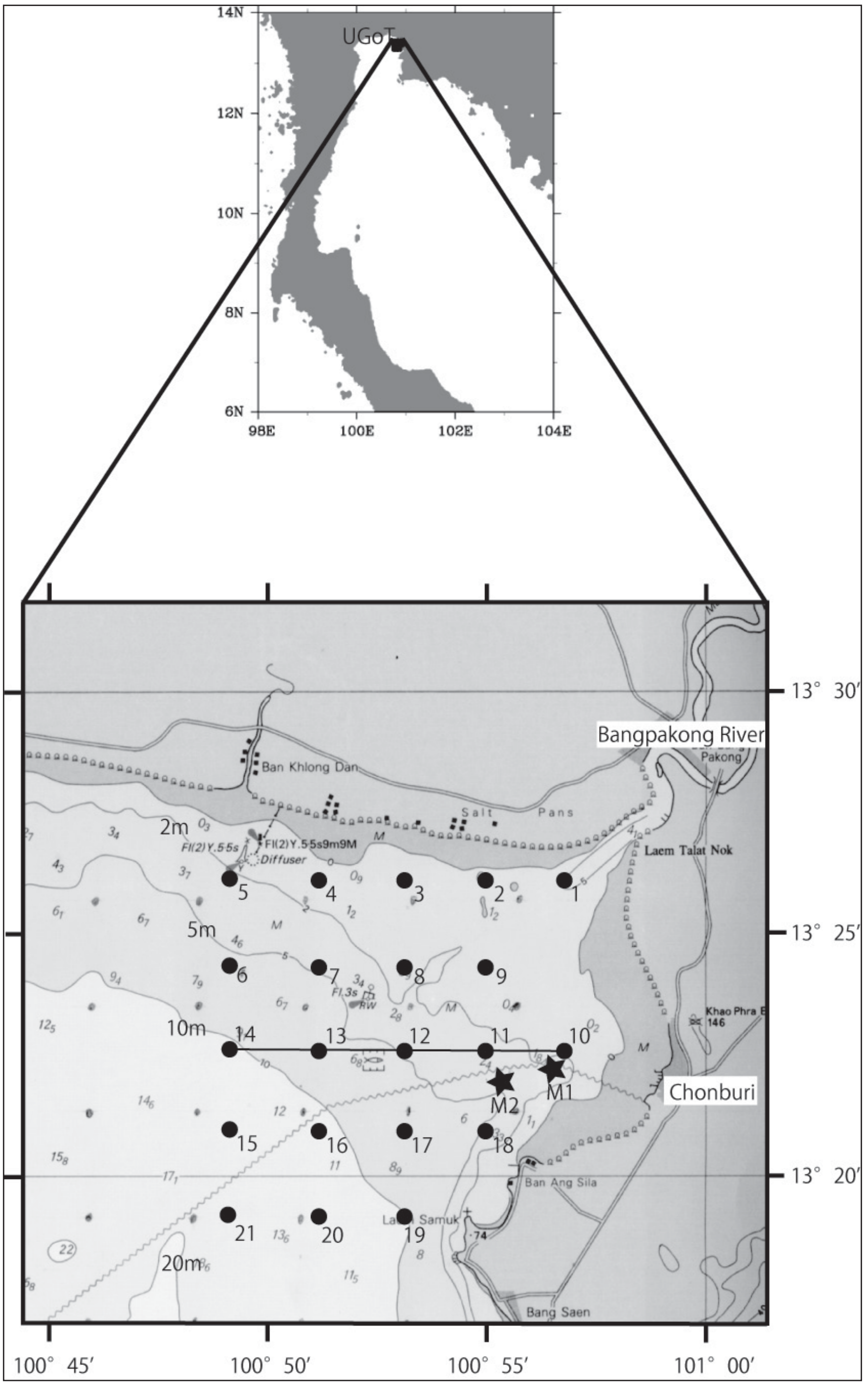

**Figure 1.** Bathymetry and hydrographic observation points. Black circles represent CTD observations, and stars represent mooring points. A line from station 10 to 14 indicates position of cross section used in Figs. 5 and 6.

October. The salinity gradient pattern at the bottom layer coincided with bottom topography because surface layer is occupied by low salinity water and water depth near river mouth was shallow (Fig. 1). In end of October, bottom salinity in the estuary became constant of 32 psu in both years.

Fig. 4 showed horizontal distribution of DO at 1 m above the bottom in each month in 2011 and 2012. Temporal change and distribution patterns were different in 2011 and 2012. In early September 2011, low DO water mass of less than 2 mg $l^{-1}$ occupied the southwestern part where water depth was more than 10 m but DO was more

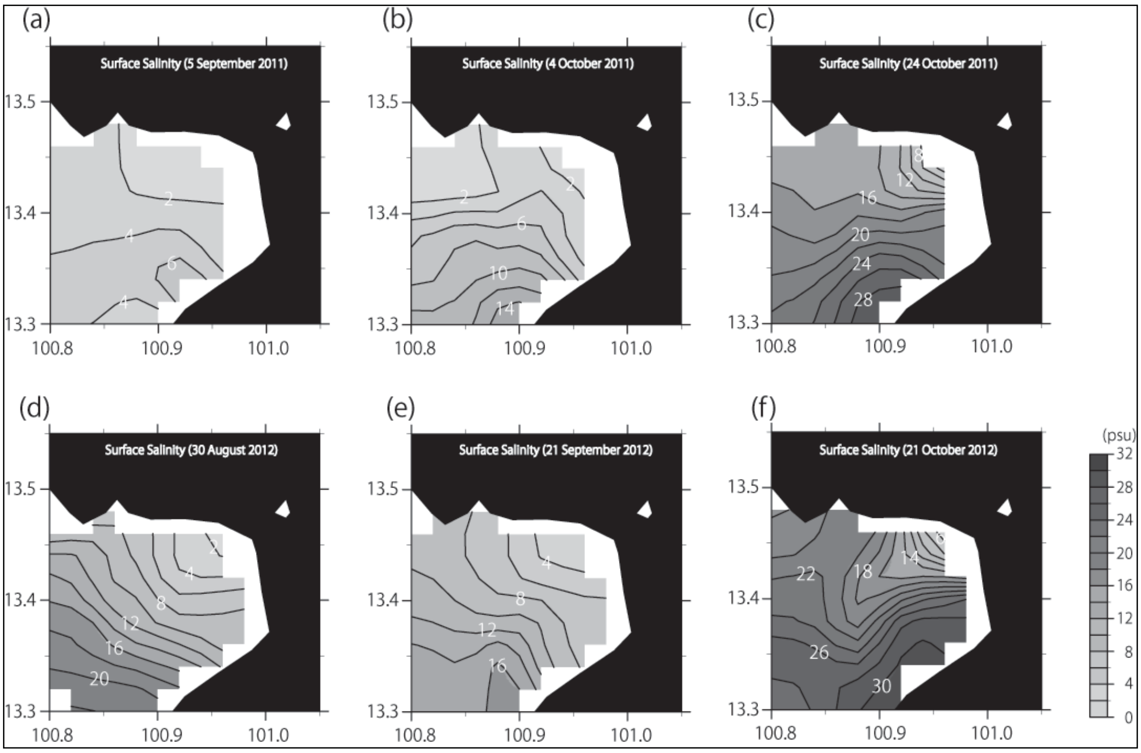

**Figure 2.** Horizontal distributions of surface salinity (a) early September 2011, (b) early October 2011, (c) late October 2011, (d) late August 2012, (e) late September, and (f) late October. Contours and monochrome tones indicate salinity, and contour interval is 2 psu.

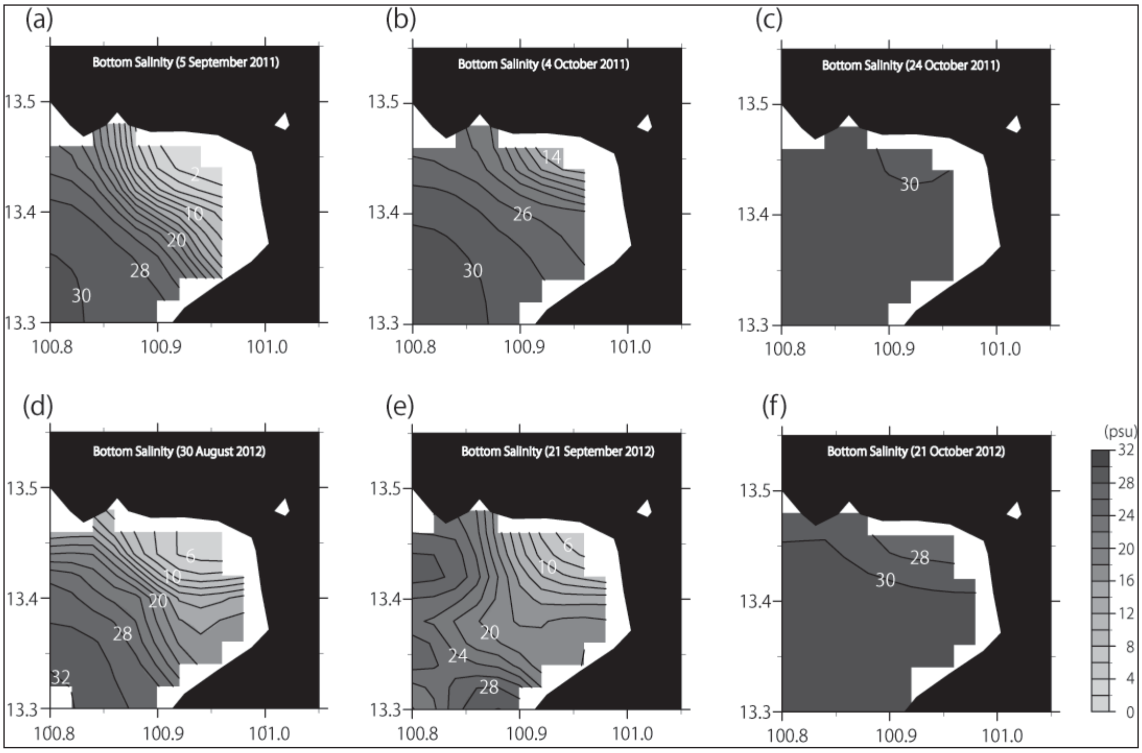

**Figure 3.** Horizontal distributions of bottom salinity (1 m above sea bottom) (a) early September 2011, (b) early October 2011, (c) late October 2011, (d) late August 2012, (e) late September, and (f) late October. Contours and monochrome tones indicate salinity, and contour interval is 2 psu.

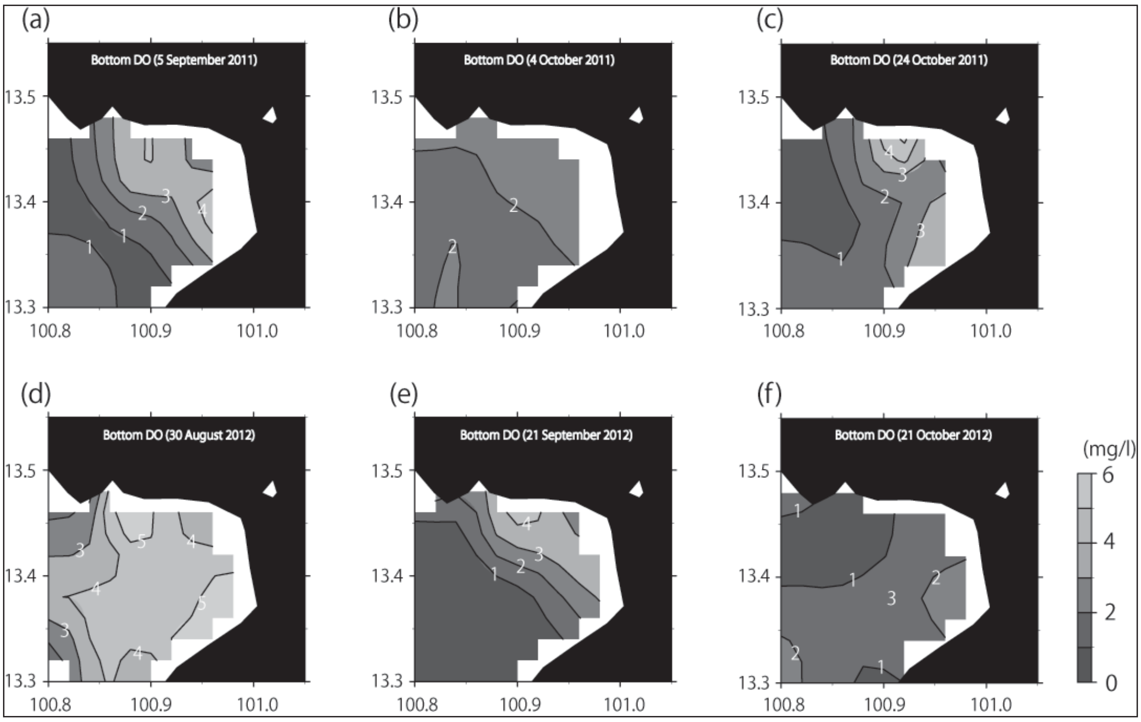

**Figure 4.** Horizontal distributions of bottom dissolved oxygen (DO) (1 m above sea bottom) (a) early September in 2011, (b) early October in 2011, (c) late October in 2011, (d) late August in 2012, (e) late September 2012, and (f) late October 2012. Contours and monochrome tones indicate DO concentration, and contour interval is 1 mg/l.

than 3 mg $l^{-1}$ in the shallower area. In early and end of October 2011, DO was also low in deeper area, especially in the western part of estuary in end of October where DO was less than 1 mg $l^{-1}$. On the other hand, DO was high in whole area in end of August 2012, but low DO water mass of less than 1 mg $l^{-1}$ occupied deeper area in end of September. DO in whole area became low in end of October 2012.

Fig. 5 and 6 showed east – west cross sections of salinity and DO in 2011 and 2012, respectively. Halocline developed in all months, but depth of the halocline became shallower from early September to end of October 2011. DO was quite low below 3 m. Although halocline developed in end of August 2012 as well, DO in the bottom layer was not low. Bottom salinity in end of August 2012 is about 6 psu lower than that in early September 2011. In end of September and October 2012, DO were quite low below 3 m as seen in 2011. Salinity in September 2012 looked strange. During the cruise this time, we observed low salinity water mass at the bottom and middle layer. The low salinity water might be ground water.

## Temporal variations of salinity, DO, and current velocity

Fig. 7 showed temporal variation in salinity and DO at station M1 in 2011 and at stations M1 and M2 in 2012. Both salinity and DO oscillated at all stations. The period of oscillation was about 12 hours which corresponded to tidal variation. Variation ranges of salinity and DO were 2 – 28 psu and 0 – 9 mg $l^{-1}$, respectively. Low salinity water mass contained high DO while DO in relatively high salinity water mass was quite low. Since water depth of M1 station at low tide was about 2.4 m, mooring instruments might be located in water mass strongly influenced by river water. Therefore, it was suggested that river water came to mooring station at low tide and offshore water mass came at high tide. It was found that DO in aquaculture area had large variability associated with tidal variation. At station M1, amplitudes of both salinity and DO in September were larger than those of in October. At station M2, amplitudes of both salinity and DO were smaller than those of at station M1, and DO was basically lower than that of at station M1. As water depth in low tide at station M2 (3.7 m) was deeper than that of in low tide at station M1 (2.4

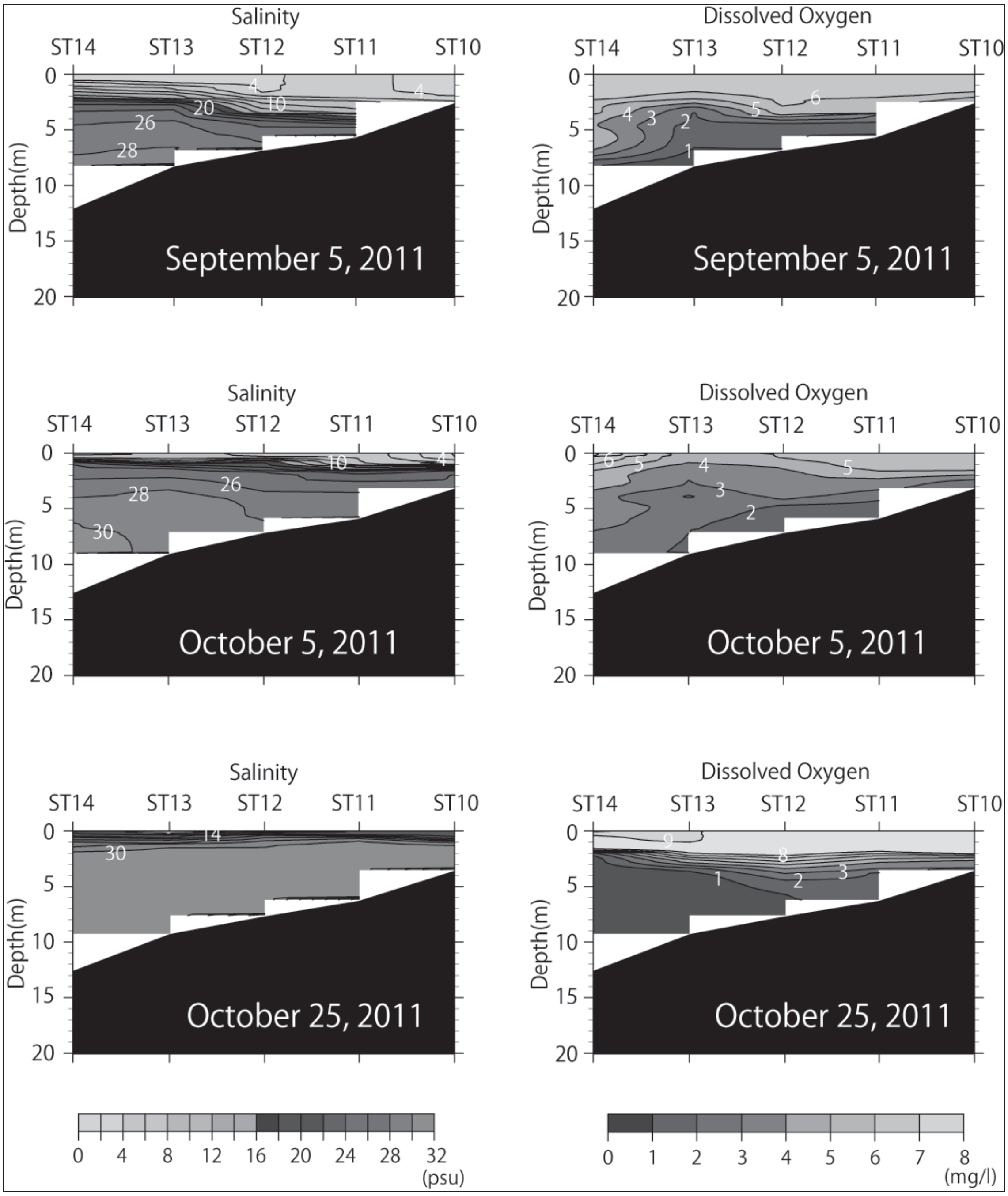

**Figure 5.** Cross sections of salinity and dissolved oxygen along east-west line shown in Fig. 1 in 2011. Contour interval is 2 psu.

m), influence of river water in low tide at station M2 might be smaller than that of at station M1. Hence, amplitudes of DO and salinity at station M2 were less than those of at station M1. Salinity at station M2 in October was lower than that of in station M1 and continuously decreased from mid–October. Since salinity meter at station M2 did not have wiper to prevent biofouling, salinity sensor might not measure correct values.

We applied tide-killer filter, which removes variation of less than 48 hours, to salinity and DO data in order to see variations longer than tidal variation (Fig. 8). Negative correlation between salinity and DO was clearly seen. DO and salinity had about 5 days variations. At station M1,

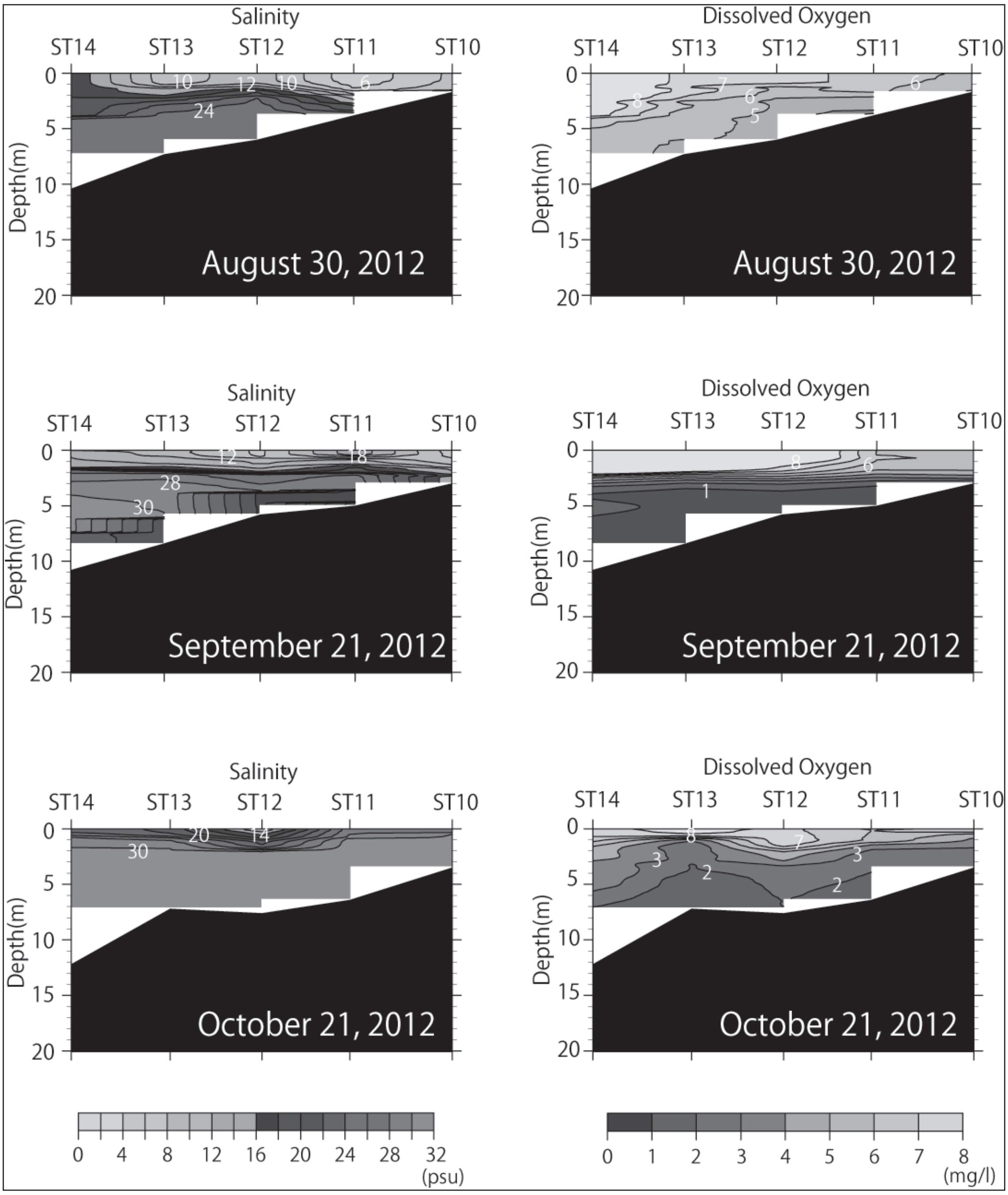

**Figure 6.** Cross sections of salinity and dissolved oxygen along east-west line shown in Fig. 1 in 2012. Contour interval is 2 psu.

salinity increased from end of September in both year, and low DO less than 1 mg $l^{-1}$ continued for several days. At station M2, low DO appeared in mid–September and anoxic condition was maintained about 20 days.

Tidal currents dominated within all mooring stations. Tidal current amplitudes of $M_2$, $S_2$, $O_1$, and $K_1$ were 10 cm $s^{-1}$, 4cm $s^{-1}$, 3 cm $s^{-1}$, 7 cm $s^{-1}$, respectively. Current direction to each constituent was east–westward. Residual flows of tidal currents removed by the tide-killer filter are shown in Fig. 9. Residual flows varied among several days period in all data. The current velocities were less than 5 cm $s^{-1}$. Although current direction at M1 and M2 in 2012 was slightly different, variation pattern was almost the same in both stations. The current direction in 2011 was opposite to that of in 2012; southeast flow dominated in 2011, and northeast flow dominated in 2012.

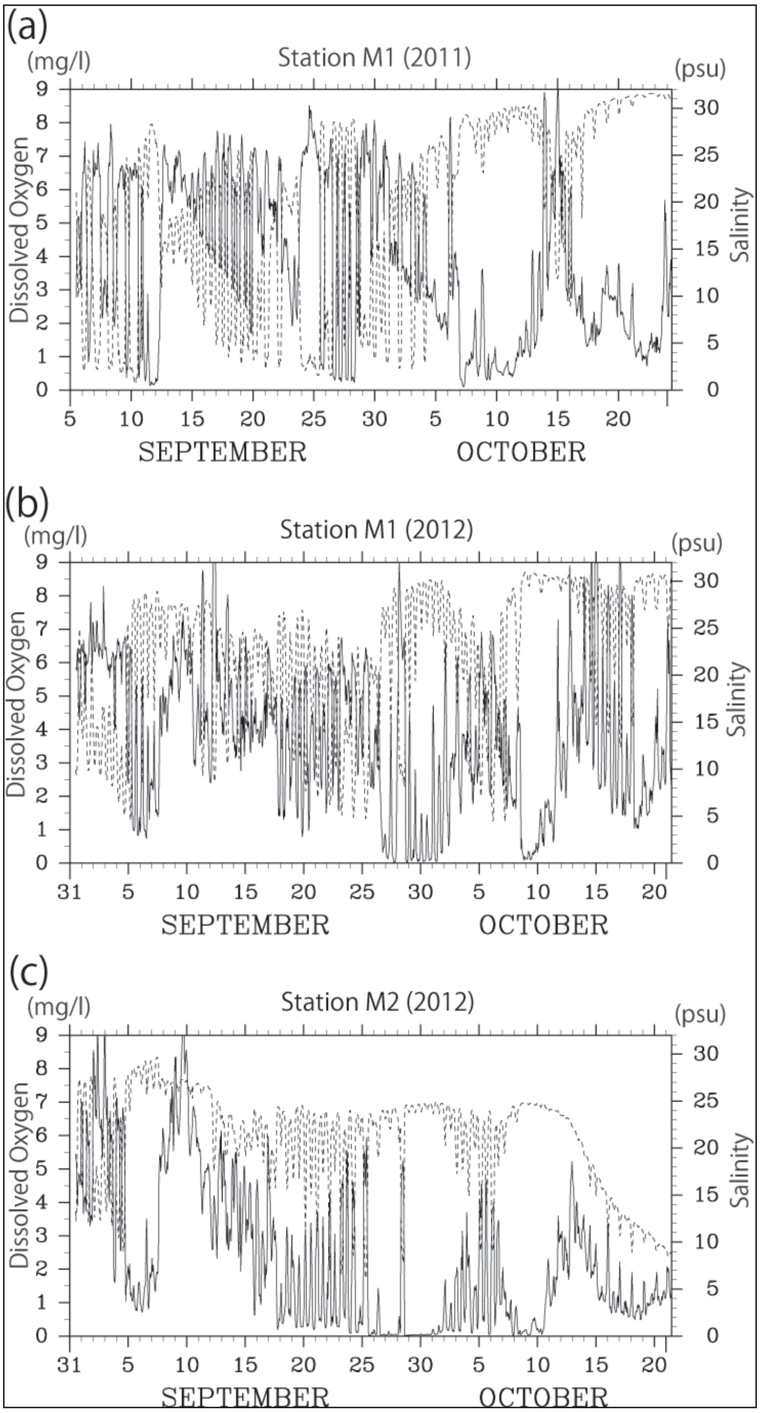

**Figure 7.** Time–series of dissolved oxygen (DO) and salinity (a) at station M1 in 2011, (b) at station M1 in 2012, and (c) at station M2 in 2012. Blue and red lines represents DO concentration and salinity, respectively.

## DISCUSSION

We discuss the origin of anoxic water mass in the Bangpakong estuary. High salinity water mass was low in DO as shown in Figs. 3, 4, and 8. Looking at horizontal distribution of bottom DO and salinity in 2012, DO in late August was high in whole estuary (Fig. 4d) while DO in mid–September was less than 1 mg $l^{-1}$ within the half of estuary (Fig. 4e) although bottom salinity distribution pattern was almost the same in both months (Fig. 3). River discharge of the Bangpakong River drastically increased in September 2012; monthly mean of river discharges were 248 $m^3$ $s^{-1}$

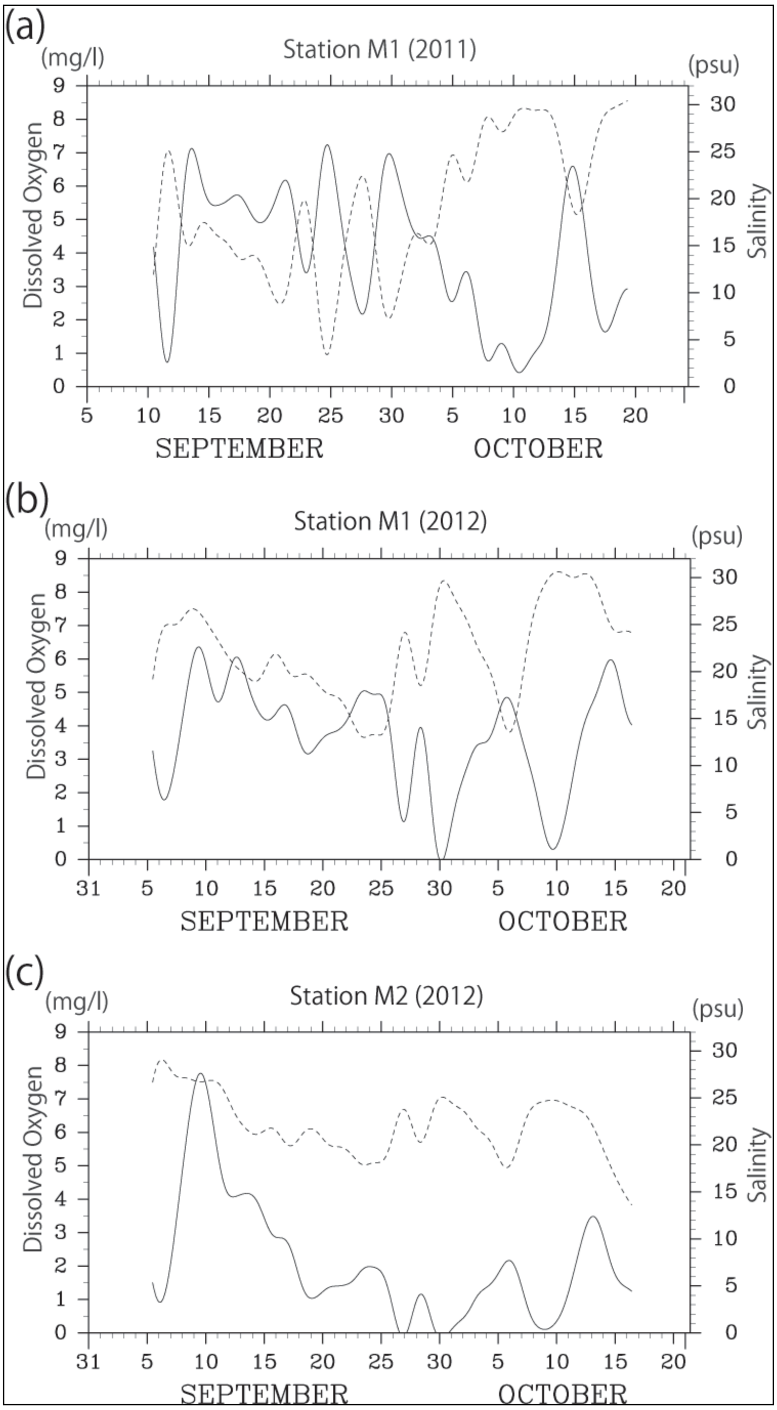

**Figure 8.** Same as Fig. 7 but high frequency variations in dissolved oxygen and salinity less than 48 hours are removed by the tide-kill filter.

in August and 641 m$^3$ s$^{-1}$ in September. This fact suggested that DO was consumed locally due to salinity stratification during rainy season. High salinity water mass of about 32 psu emerged in late October at the bottom layer (Fig. 3f), which was not seen in late August and mid–September. DO in late October 2012 was quite low in the whole estuary. Residual current of tidal current removed by tide-killer filter at station M1 in 2012 indicated northeast – northward flow, and the current velocity strengthened in mid and late September (Fig. 9b). At the sea surface, high salinity water mass with more than 28 psu distributed southeastern part of the estuary in late October (Fig. 2f). In addition, Buranapratheprat et al. (2006) have reported that circulation in UGoT changes from clockwise to

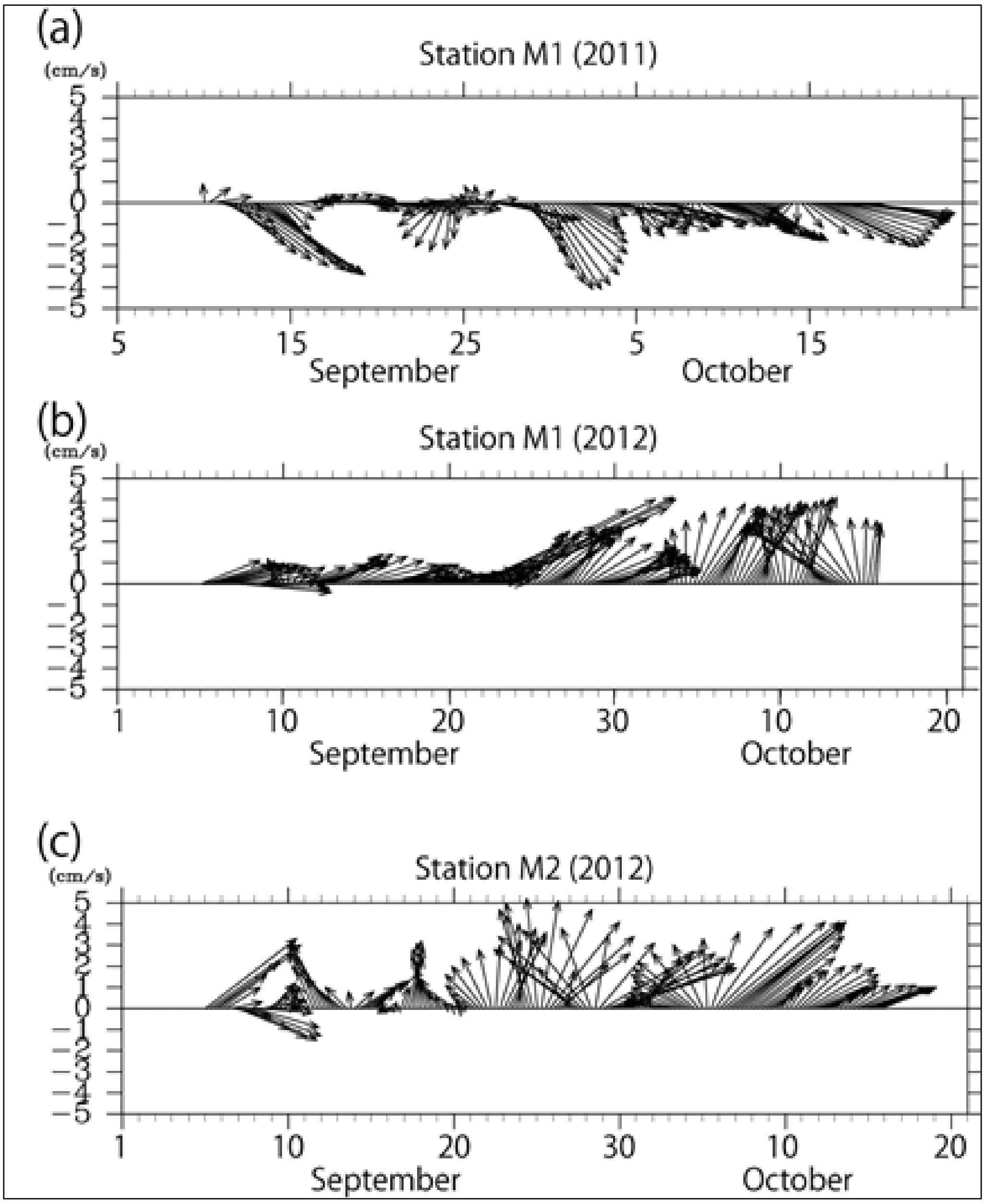

**Figure 9.** Time series of current velocity 1 m above sea bottom (a) at station M1 in 2011, (b) at station M1 in 2012, and (c) at station M2 in 2012. Vertical axis indicates magnitude of vector, and upward (downward) and rightward (leftward) of arrows show northward (southward) and eastward (westward) currents, respectively. High frequency variations less than 48 hours are removed by the tide-kill filter.

anticlockwise when northeast monsoon period starts. It is suggested that high salinity with low DO water mass was transported from south. From the above discussion, we can conclude that anoxic water mass might be generated in large area not only in Bangpakong estuary but also in UGoT due to the increase of river discharge in September, and also the anoxic water mass transported into the Bangpakong estuary by residual current.

We compared data between 2011 and 2012. Salinity increased gradually from end of September 2011 and from late September 2012 at station M1. In both years, amplitude of salinity drastically decreased when salinity increased. Low DO water mass less than 2 mg $l^{-1}$ was observed for 6 days during October 2011, and for 2.5 days and 3 days during October 2012 (Fig. 8). Persistence time of anoxic condition in 2011 was longer than that of in 2012. Basically, DO seemed to be lower in October, but sometimes low salinity with high DO water mass intruded into the mooring station. When low salinity water mass intrusion occurred on 30 September and 15 October 2011, southeastward residual currents flowed; 3.4 cm $s^{-1}$ on 30 September and 2.2 cm $s^{-1}$ on 15 October. On the other hand, when low salinity water mass intrusion occurred on 24 and 28 September and 6 October 2012, northeastward residual currents at station M1 flowed; 3.2 cm $s^{-1}$ on 24 September, 3.4 cm $s^{-1}$ on 28 September, and 3.6 cm $s^{-1}$ on 6 October. We could not find common conditions for low salinity water mass intrusion.

Circulation pattern were different in both years throughout mooring period. Wind conditions in Chonburi in both years were almost the same; south wind dominated in September and northeast wind blew in mid–October. River discharge in Bangpakong in 2011 was much larger than that of in 2012. As found in Fig. 2, salinity distributions in both years were quite different. It is suggested that circulation in Bangpakong estuary was strongly controlled by buoyancy flux from rivers, and behavior of anoxic water mass might be changed.

Unfortunately, we do not have data in terms of mass mortality of shellfishes in the study area in 2011 and 2012. According to fishermen, mass mortality occurred in late September and in early October both year. As shown in Fig. 8, anoxic water mass appeared for several days at stations M1 and M2. The appearance of the anoxic water corresponded to the occurrence of mass mortality qualitatively. Shellfishes might not be able to survive under anoxic condition for several days. Therefore, anoxic water mass might relate to mass mortality in this area which has occurred in late September and early October every year.

## CONCLUSION

We have carried out CTD and mooring observations in the Bangpakong estuary during transient period from rainy season to dry season in 2011 and 2012. The main objectives of the hydrographic observations were to elucidate behavior of anoxic water mass in the Bangpakong estuary, which was the possible cause of mass mortality of cultured shellfishes in the study area. We have succeeded CTD and mooring observations in both years, and we have obtained time–series data of DO, salinity, and current velocity for approximately 2 months, which were the first long–term continuous records in terms of that of water quality in the Bangpakong estuary.

From the CTD and mooring data, it was found that salinity correlated to DO concentration; DO concentration in high salinity water mass was quite low. From mooring data, it was revealed that DO and salinity at the bottom layer in aquaculture area oscillated with large amplitude, and the period of the oscillation corresponded to tidal variation. Amplitude of the oscillation was large in September and became small in October, and anoxic condition persisted for several days in October 2011 and 2012. However, persistent period of anoxic condition in 2011 was longer than that of in 2012. Current direction at station M1 in both years were opposite throughout the mooring period; southward in 2011 and northward in 2012. Wind conditions in Chonburi in both years were almost the same, but river discharge in 2011 was much larger than that of in 2012. Therefore, it is possible that difference to current direction at station M1 was taken place due to change of buoyancy flux, and persistent period of anoxic condition different between 2 years associated with circulation change.

It was suggested that mass mortality of cultured shellfishes in Bangpakong estuary was caused by anoxic water because timing of mass mortality corresponds to that of anoxic water appearance qualitatively. It was also suggested that the anoxic water mass in aquaculture area was transported from offshore area by currents. However, we do not know the origin of the anoxic water mass from our observed data in the Bangpakong estuary. Anoxic water mass might distribute within large area of UGoT. Therefore, we have to expand the field survey area in near future. Our mooring data suggested that residual flow pattern were varied by buoyancy flux change. Since the change of residual current might influence behavior of anoxic water mass, we should investigate variation of circulation in the UGoT associated with buoyancy flux change using numerical models in near future.

## ACKNOWLEDGMENTS

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