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Seasonal variation in fresh water residence time and its impact on the water quality at Hurun Bay, South Sumatera, Indonesia

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Abstract: To understand the characteristics and control mechanism of water quality at Hurun Bay, a seasonal variation in freshwater residence time was investigated based on a series of temperature, salinity, DIN (Dissolved Inorganic Nitrogen), TOM (Total Organic Matter), DIP (Dissolved Inorganic Phosphorus), DO (Dissolved Oxygen) and phytoplankton data observed during the period of 2004. The residence time of freshwater as indicator of the water exchange played an important role to control the water quality at Hurun Bay. Long freshwater residence time in both transition periods of Wet-Dry and Dry-Wet seasons has increased the DIN and TOM accumulation in the water column, and it stimulated phytoplankton bloom at Hurun Bay. This situation has caused the DO decrease due to fast decomposition of organic matter. The results recommend that in both transition periods, the aquaculture activity should be limited at minimum level to reduce the risk of fish mass mortality caused by the DO depletion due to the phytoplankton bloom and diseases appearance.

Keywords: *seasonal variation, fresh water residence time, water quality, Hurun Bay*

I. Introduction

Hurun Bay is a semi enclosed estuary situated at the western coastal area of Lampung Bay, southern coastal area of Sumatera and faces to the Sunda Strait (Fig.1). The environment within this area seems to be strongly influenced by monsoonal wind system that affects the variability of the meteorological and oceanographic conditions of Lampung Bay. There are two dominant monsoonal seasons, which drive the climate cycle in the study areas (as in all other Indonesian areas) named the dry and rainy seasons that occur during December to March and June to September, respectively. The rainy season is related to the northwest (NW) monsoon, while the dry season is related to the southeast (SE) monsoon. Among these seasons, there are two transition periods that also influence the circulation of the water mass within the study area; one is the period between wet and dry seasons (Trans. W-D) in April-May and another between dry and wet season (Trans. D-W) occurs in October to November. During the wet season, high air pressure over Asia and low air pressure over Australia are observed, allowing wet air transport (northwesterly wind) from the South China Sea to the Pacific Ocean across the Indonesian archipelago. Inversely, low air pressure over Asia and high air pressure over Australia drive the wind blowing from the southeast to the northwest (southeasterly wind) carrying the dry air from Australia and resulting in the dry season (BÜHRING, 2001;

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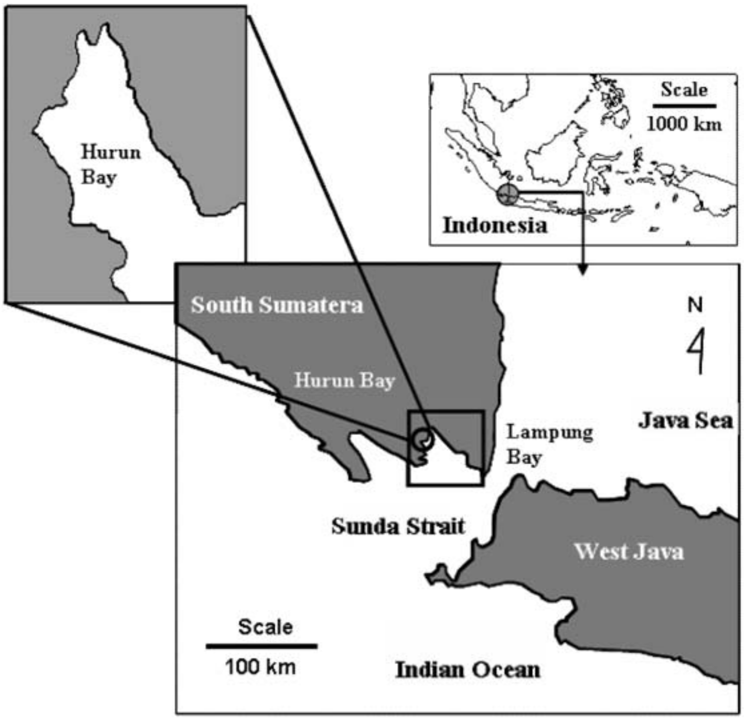

Fig.1. The location of Hurun Bay in the southern coastal area of Sumatera.

TOMASCIK *et al.,* 1997). Consequently, on the regional scale, the oceanic condition of Hurun Bay is highly influenced by water masses from the South China Sea, the Java Sea and the Indian Ocean that intrude through the Sunda Strait and spread in Lampung Bay (SACHOEMAR *et al.,* 2006; DAMAR, 2003; WIRYAWAN *et al.,* 1999).

GUO *et al.,* (2004) defines the residence time as the flushing time that determines the time where a pollutant moves through the bay (by action of freshwater discharge and tidal exchange). Information of the freshwater residence time in the bay is important to understand the mechanism of water exchange in reducing the water pollution in the bay (YANAGI, 1999a). Since Hurun Bay is considered to be an important water source to supply hatchery near the coast and the water body is utilized for growing of fish in the cage system, understanding the exchange process of the water mass that influences the water quality is important. Practical aquaculture will be easier to be managed if the information on the characteristics and behavior of marine ecosystem is available, though such information is very limited now at Hurun Bay. Hence, in the present study, the water exchange that is represented by the freshwater residence time will be evaluated to understand the mechanism of physical process that is considered to play an important role in the water quality variation at Hurun Bay as well as the monsoon, terrestrial and the anthropogenic activities.

2. Methods

2.1. Data Collections and Analysis

A series of temperature, salinity, DIN (Dissolved Inorganic Nitrogen), TOM (Total Organic Matter), DIP (Dissolved Inorganic Phosphorus), DO (Dissolved Oxygen) and phytoplankton parameters in wet season (mid-January and March), transition period of wet to dry season (Trans. W-D) of mid-April and May, dry season (mid-June, July, August and September) and transition period of dry to wet season (Trans. D-W) of mid-October and November were collected during the period of

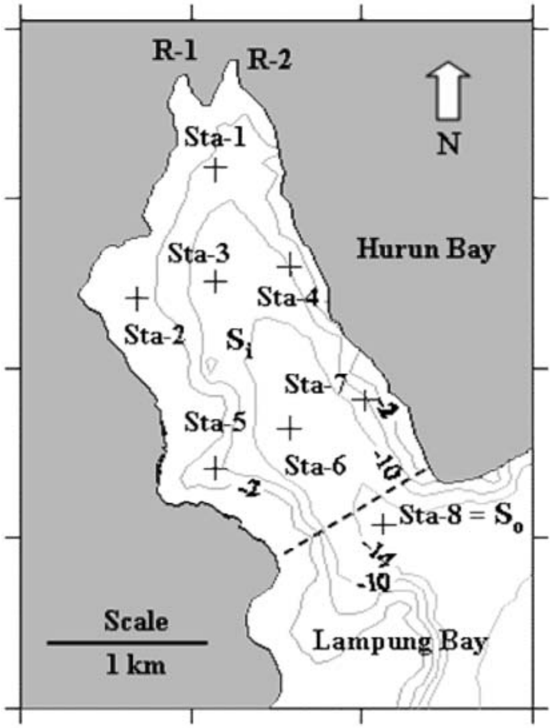

Fig.2. Sampling stations inside the bay (Stas.1–7) and outside the bay (Sta.8). Dashed line shows the boundary of the box. Numbers show the depth in meters.

2004. Water samples were taken by a Nansen bottle from the surface and 1 m above the bottom at eight stations of Hurun Bay (Fig.2). The water samples were then analyzed in the laboratory to measure TOM, DIN (nitrate, nitrite and ammonia) and DIP according to APHA (1979) standard method. Water temperature was measured directly in the field by using a water quality checker (YSI 55 Yellow Springs Instrument), dissolved oxygen (DO) by YSI 550 (Yellow Springs Instrument) and salinity by WTW 340i (Wissenschaftlich Technische Werkstatten, Germany), the nutrients were analyzed by using spectrophotometers (Spectronic 21D Milton and Spectro 2000 RS, Labomed). The phytoplankton was collected by filtering 50 l of the water sample of the surface layer using plankton net with the diameter of 30 cm and mesh size of 35 μm. Their abundance was then calculated by using Sedgwick Rafter Counting Cell, while the phytoplankton species was identified by YAMAZI (1982) identification guide.

In addition, the river discharge data from the two small rivers around Hurun Bay (R–1 and R–2 in Fig.2) were collected by measuring the speed of water flow, the depth and width of the rivers during the observation. The calculation results of the rivers discharge were then included in calculation of freshwater residence time in a box model analysis. To support this analysis, the meteorological data (precipitation and evaporation) for the period of 2004 were collected from the Indonesian Meteorological Agency for the Lampung region covering Hurun Bay. The depths of Hurun Bay are within a range of 2 to 21 m. All the data were then applied to analyze seasonal variation in freshwater residence time and its impact on the water quality of Hurun Bay

2.2. Box Model Analysis and Freshwater Residence Time

The analysis of freshwater residence time at Hurun Bay can be calculated by using box model analysis. Hurun Bay has a volume V of 35.2×10^6 m^3, sea surface area A_s of 3.4 km^2, cross sectional area at the sea boundary A_b of 12×10 m^2 and average depth H of 10.3 m (Fig.2). In this study, we assumed that the average of the water depth within the bay can represent the mean depth condition of the bay because the water masses from the inner and outer parts of the bay were exchanged only through the small area of the box boundary (dashed line) as shown in Fig.2.

Spatially averaged data at stations 1–7 are the representative value inside the box, and the averaged data at Stas.R–1 and R–2 and that at Sta.8 represent the rivers and the sea, respectively. The box model analysis (GORDON *et al.*, 1996; YANAGI, 1999a) is applied to the bounded area of Hurun Bay (Fig. 2) using the average data observed during the wet season (January and March), the transition period of W-D (April and May), the dry season (June, July, August, September) and the transition period of D-W (October and November) in 2004.

The freshwater entering the bay mainly comes from the discharge of two rivers (R–1 and R–2) with the annual average of 2.68×10^6 m^3/month (Fig.3). The highest river discharge

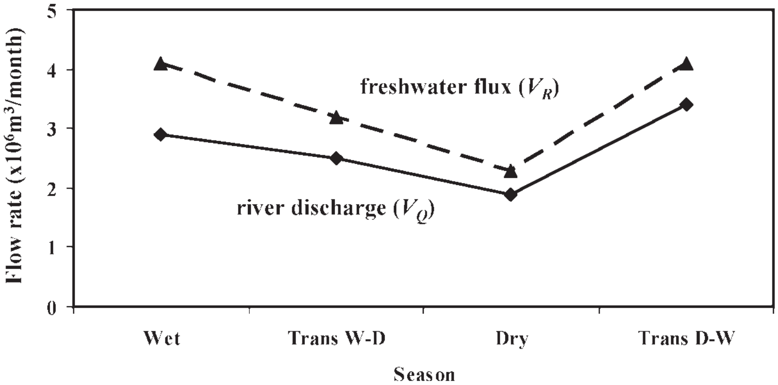

Fig.3. Seasonal variations in river discharge (V_Q) and freshwater flux (V_R) from the box.

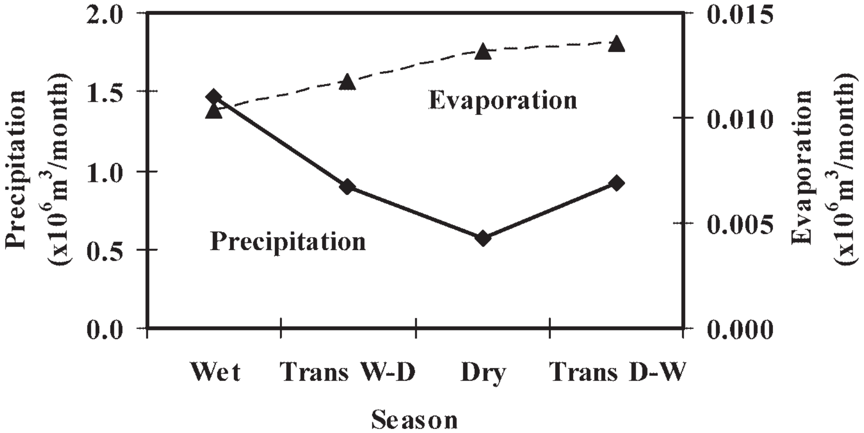

Fig.4. Seasonal variations in precipitation and evaporation in 2003–2005 at Hurun Bay (Source : Indonesian Meteorological Agency).

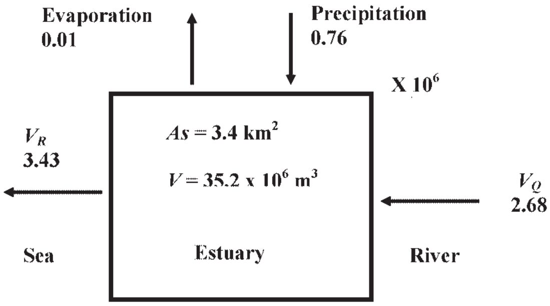

Fig. 5. Annually averaged freshwater budget at Hurun Bay.

was in the transition period of D-W (3.4×10^6 m^3/month) and the lowest was in the dry season (1.9×10^6 m^3/month). If the ground water discharge and variation of the mean sea level may be assumed to be zero and the atmospheric budget (precipitation-evaporation) is considered, the freshwater flux through the open boundary of Hurun Bay V_R is calculated. According to the meteorological data in 2004, precipitation and evaporation are estimated to be 1.5 and 0.010×10^6 m^3/month for the wet season, 0.9 and 0.012×10^6 m^3/month for Trans. W-D, 0.6 and 0.013×10^6 m^3/month for the dry season, 0.9 and 0.014×10^6 m^3/month for Trans. D-W, respectively (Fig.4). Hence, the freshwater export (V_R) from the box to the outside of the bay was largest in the wet season and smallest in the dry season (Fig.3). Because the evaporation level was insignificant, the amount of the freshwater flux to the bay was mainly governed by precipitation (Fig.4). The annual average of freshwater budget at Hurun Bay (Fig.5) with V_R is 3.43×10^6 m^3/month.

Temporal variability of salinity in the box (S_i) and outside the box (S_o) (Fig. 6), indicates

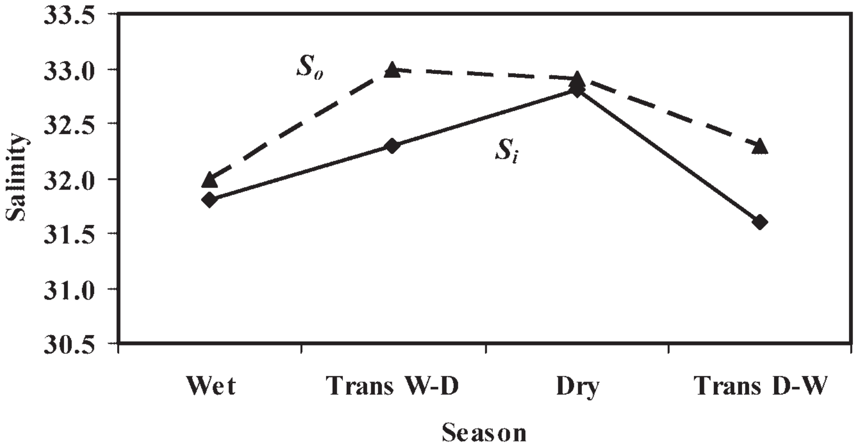

Fig. 6. Seasonal variations of salinity inside of the bay (S_i) and these outside of the bay (S_o).

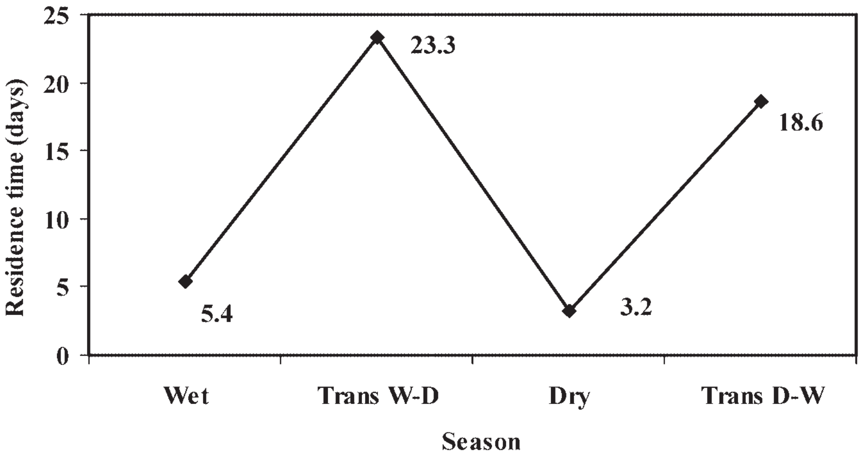

Fig. 7. Seasonal variations in freshwater residence time at Hurun Bay.

the strong monsoonal effect of the river discharge, precipitation and the water mass exchange within and around the bay. Large river discharge (Fig. 3) and precipitation (Fig.4) in the wet season results in low salinity in the box S_i (31.8) and low salinity gradient between S_i and S_o (0.2), while in the dry season the strong intrusion of water mass from the open sea and low river discharge are responsible for high salinity in the box of S_i (32.8) and low salinity gradient between S_i and S_o (0.1). On the other hand, the combined effect of moderate river discharge and intrusion of water mass from the open ocean in both transition periods of W-D and D-W resulted in high salinity gradient between S_i and S_o (0.7). This situation indicates that the water exchange was large in both wet and dry seasons compared to that during the transition periods of W-D and D-W. To confirm these phenomena, the residence time of freshwater in the bay was estimated by using the calculation method of YANAGI (1999b) and BURANAPRATHEPRAT *et al.,*. (2002) as follows :

$$\tau_f = V_f / V_R, \quad (1)$$

$$V_f = (S_o - S_i) V / S_o, \quad (2)$$

where τ_f is the residence time of freshwater, V_f is the standing stock of freshwater in Hurun Bay.

3. Results and Discussion

The calculation result shows that the residence time of freshwater in Hurun Bay was

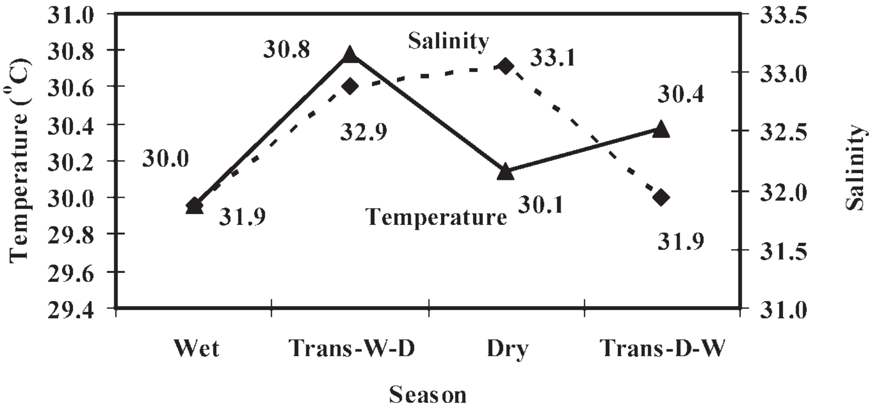

Fig. 8. Seasonal variations in water temperature and salinity observed at Sta. 8 in Hurun Bay.

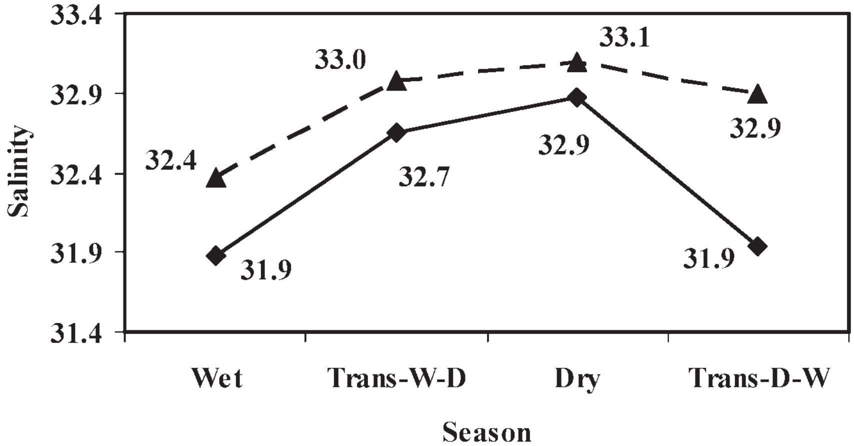

Fig.9. Seasonal variations of vertical distribution in water salinity at the surface and bottom layer in Hurun Bay.

within the range of 3.2 to 23.3 days (Fig. 7). In the wet and dry seasons, the residence time of freshwater was shorter than that in the transition periods of W-D and D-W, that is, 5.4 days in the wet season and 3.2 days in the dry season. While in the transition periods of W-D and D-W they are 23.3 days and 18.6 days, respectively. This means the water exchange in Hurun Bay is weak during the monsoon transition period. Since the water circulation is low, the water quality within the bay might be disturbed. The monsoonal system as driving force of meteorological and oceanographic variability seems to have played an important role in the water exchange within this area. During the wet (northwest monsoon) and dry (southeast monsoon) seasons, the northwesterly and southeasterly winds were steady and strong compared to those in both transition periods of W-D and D-W. Such local wind variability seems to influence the water circulation in Hurun Bay and Lampung Bay. In the southeast monsoon (Dry season), the upwelling occurrence in the coastal area of south Java penetrates the cold and high salinity water mass into Hurun Bay, as recorded at Sta. 8 (Fig. 8). While in the northwest monsoon (Wet season), the cold and low salinity water mass of the Java Sea and the South China Sea.

This situation suggests that the different wind direction in the wet and dry seasons has influenced the water exchange through the different mechanism of the water circulation. In both wet and dry seasons, the water column was well stratified and promoted the gravitational forces in classic estuarine circulation in

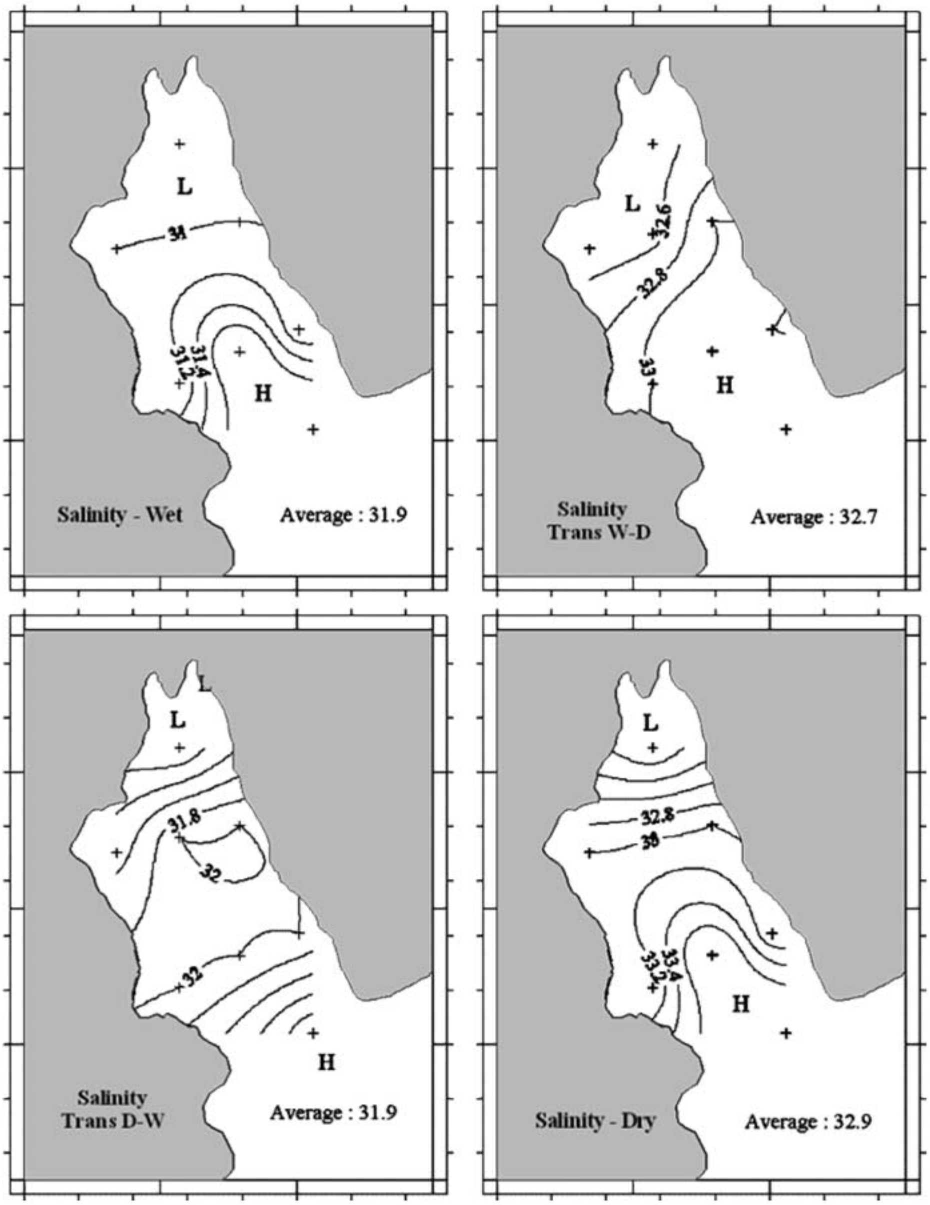

Fig.10. Seasonal and spatial variations in sea surface salinity at Hurun Bay.

Hurun Bay, where the upwelling and precipitation play important roles in generating water exchange and their circulation. These phenomena were also supported by vertical salinity distribution at the surface and bottom layers, and their horizontal distribution as shown in Fig 9 and 10. Variability of sea surface salinity indicates the strong correlation with the precipitation as shown in Fig.4, where high precipitation has caused decreasing salinity in the bay. Large river discharge during the period of wet, transition period of W-D and D-W has influenced on the salinity distribution in the bay. Low salinity water in the upper part of the bay during these periods was wider than that in the dry season, while high salinity

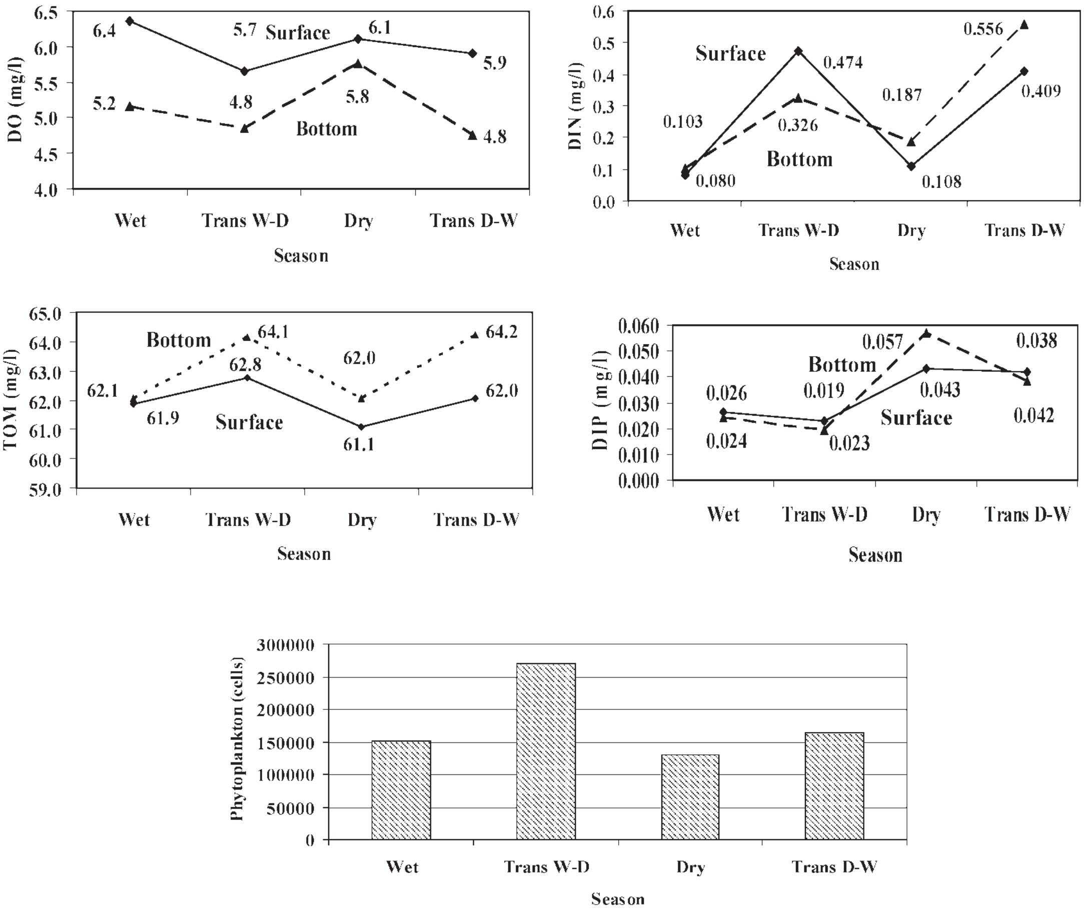

Fig.11. Seasonal variations in DO,DIN, TOM, DIP and Phytoplankton at Hurun Bay.

water was intruded into the bay during the period of dry season.

3.2. DO, DIN, TOM, DIP and Phytoplankton

The impact of the seasonal variability of the fresh water residence time on the water quality was seen on the DO, DIN, TOM and phytoplankton abundance. In the wet and dry seasons, DO in the surface and bottom layers were higher than those in the transition periods of W-D and D-W. DO at the surface layer in the wet and dry seasons were 6.4 and 6.1 mg/l, respectively (Fig.11), while in the bottom layer, DO was 5.2 mg/l in the wet season and 5.8 mg/l in the dry season. In the transition periods of W-D and D-W, DO at the surface layer was 5.7 and 5.9 mg/l, respectively, and that in the bottom layer was 4.8 mg/l. Low DO in the transition periods of W-D and D-W seems to be associated with the weak of water exchange during these periods in response to the long freshwater residence time. On the contrary, when the freshwater residence time, is short in the wet and dry seasons, the DO is high (Figs.7 and 11). Since DO concentration depends on temperature and salinity, we calculate DO saturation using observed temperature and salinity. The results are shown in Table 1, where DO concentration and DO saturation were low in transition seasons. These suggest that the long residence time in transition seasons results in high water temperature and low dissolved oxygen concentration, and low DO saturation due to large and long consumption of DO by organic matter in transition seasons. The variability of the ocean dynamics and the

Table 1. Seasonal variations of mean average water temperature (oC), salinity, DO concentration (mg/l) and DO saturation (%) derived from sea surface and bottom layer in Hurun Bay during period of 2004.

Season	Temperature (oC)	Salinity	DO concentration (mg/l)	DO saturation (%)
Wet	30.0	32.2	5.8	91.6
TransW-D	30.5	32.9	5.3	83.9
Dry	30.0	33.0	6.0	94.4
TransD-W	30.5	32.4	5.4	85.1

water circulation in Hurun Bay associated with the monsoonal system seem to have influenced on the DO variability. Hence, during the monsoon transition periods, the aquaculture activity should be limited to minimize the risk of fish mass mortality due to the depletion of the DO within this region.

The influence of the freshwater residence time on the water quality was also seen in the variability of DIN and TOM as shown in Fig. 11. Unlike the DO variability that has a negative correlation with the freshwater residence time, the DIN and TOM variabilities have positive correlations with the freshwater residence time. When the freshwater residence time was long, i.e. in the transition periods of W-D and D-W, DIN and TOM were high and the opposite in the wet and dry seasons. This means that the long freshwater residence time increases DIN and TOM in the water body of the bay, particularly in the area where the aquaculture activity is high at Hurun Bay. The spatial variability of DIN (Fig. 12) shows that DIN concentrations near Stas. 2 (outlet hatchery) and 8 (fish cage) were relatively high in all seasons and their concentrations increase in the transition periods of W-D and D-W. Increasing DIN concentration in both transition periods might be due to low water exchange as response to long freshwater residence time. DIN was released from the reservoir of hatchery and fish cage, being accumulated in the stagnant water mass of the bay, and conversely for the short freshwater residence time, the pollutant will be pushed away soon. Increased DIN in both transition periods of W-D and D-W seems to have stimulated phytoplankton bloom as shown in Fig.11. The population of phytoplankton species in Hurun Bay for the period of 2004 was dominated by *Alexandrium, Chaetoceros, Dinophysis, Nitzschia, Pseudo-nitzschia, Pyrodinium, Protoperidinium and Noctiluca* with more than 20% from total phytoplankton population identified.

Moreover, the temporal variability of DIP shown in Fig. 11 shows an insignificant seasonal variation in Hurun Bay. This means that DIP was not the main factor of the environmental loading at Hurun Bay and not critical for eutrophication. Since the water body in Hurun Bay is used for the aquaculture activity, nitrogen is a dominant factor for the environmental loading in the coastal area of Hurun Bay. This is consistent with results by previous researchers (DUFF, 1987; HAMMO, 1987; WALDICHUK, 1987; WILDISH *et al.,* 1990; SOLEY *et al.,* 1994; WU *et al.,* 1994; WU, 1995; LUPATSCH and KISSIL, 1998).

4. Conclusion

The monsoonal system has strongly affected on the water exchange in Hurun Bay and influenced the water quality. Long freshwater residence time during both transition periods of W-D and D-W has increased the DIN and TOM accumulation in the water body. Consequently it stimulated phytoplankton bloom and caused the decrease of DO concentration. At least there are two factors that influence the variability of freshwater residence time at Hurun Bay, being associated with the monsoonal system. The first is the precipitation and the water circulation in the Java and South China Seas in the wet season (northwest monsoon), and the second is the water mass penetration from the southern coastal area of Java due to the upwelling occurrence in the dry season (southeast monsoon). During these seasons, the water circulation was more active being stimulated by relatively strong northwesterly

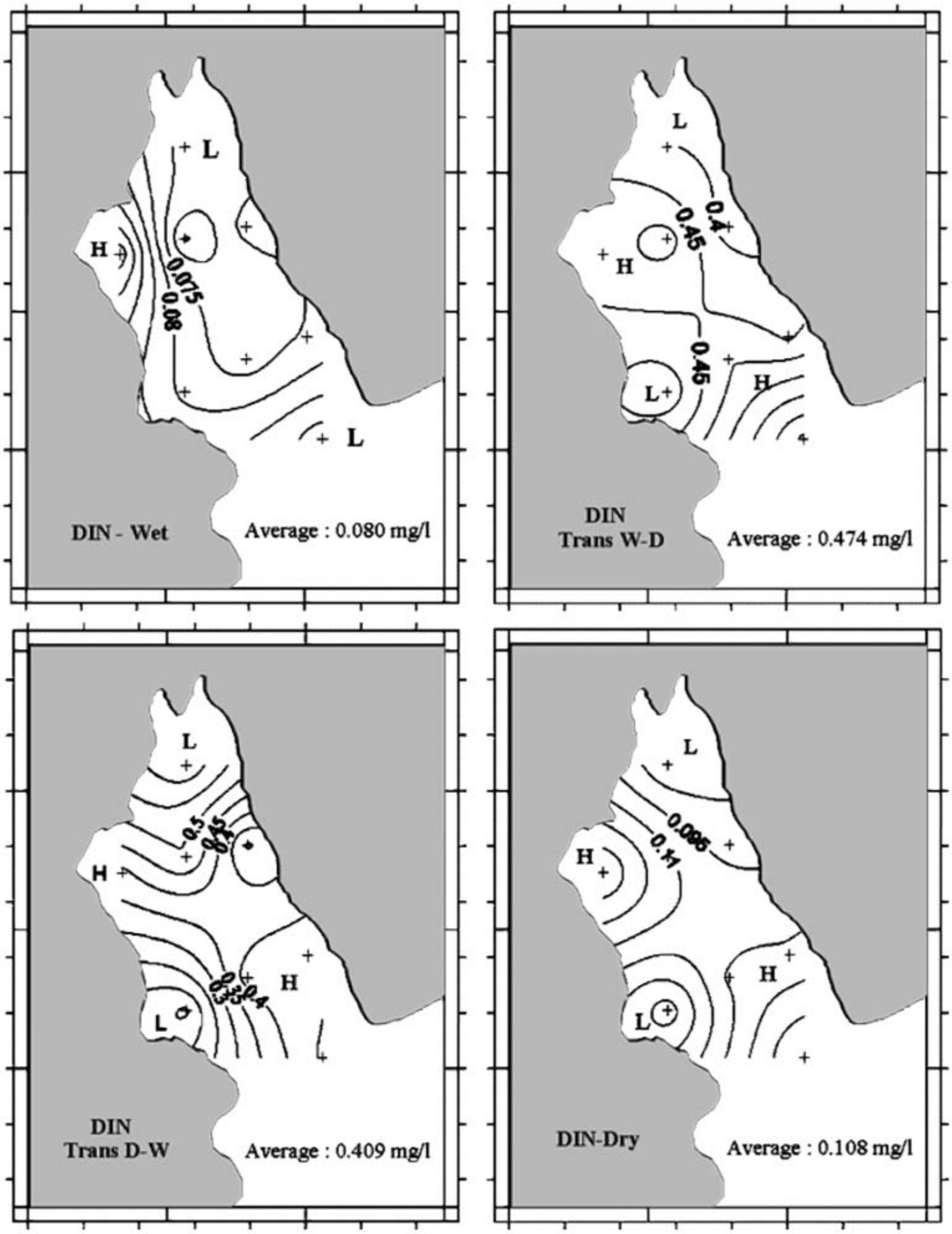

Fig.12. Seasonal and spatial variations in sea surface DIN at Hurun Bay.

and southeasterly winds over the ocean surface, but in both transition periods the wind was weak and so was the water circulation.

By understanding the characteristic variability of freshwater residence time in relation to the water quality in Hurun Bay, the aquaculture activity within this region could be managed properly toward sustainable utilization. In both monsoonal transition periods, the aquaculture activity should be limited to reduce the risk of fish mass mortality caused by the DO depletion and fish diseases due to the blooming of undesired phytoplankton.

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