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Occurrence Mechanism of Hypoxic Water in the Western Interior Parts of the Ariake Sea

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Summary

Vertical diffusion coefficients, which were calculated from the vertical velocities measured in the interior western parts of the Ariake Sea in summer of 2006, decreased rapidly near the lower end of density pycnocline. Oxygen consumption in the bottom layer of sea-water column was mainly caused by aerobic decomposition of organic mutter suspended in that layer. The seasonal variations of vertical diffusion coefficient and oxygen consumption rate in the study area, where located in the interior western parts of this sea, were analyzed by a two-layer box model. As a result, vertical diffusion coefficient tended to increase in summer and to decrease in winter, and its monthly variation was closely related to that of density stratification parameter. On the other hand, oxygen consumption rate tended to be positive (O_2 consumption) in summer and to be negative (O_2 production) in winter.

Keywords: Ariake Sea, hypoxic water, density pycnocline, oxygen consumption rate, two-layer box model

Introduction

Recently, degradation of environment and deterioration of ecosystem such as decrease of turbidity, sedimentation of mud on the sea-bottom, frequent occurrence of red tide and hypoxic water, and rapid decrease of bivalve become serious problems in the interior parts of the Ariake Sea[1),2)]. In those problems, large-scale outbreaks of hypoxic water in summer are one of the most critical environmental problems in this sea. It is considered that such a hypoxic water is generated basically when the quantity of oxygen consumption in the bottom layer of sea-water column is more than that of oxygen transfer from the surface layer of sea-water column to the bottom one. However, the knowledge of formation processes of density stratification which brings the fall of quantity of oxygen transfer from the surface layer to the bottom one, distribution of vertical diffusion coefficient near the density pycnocline which controls the oxygen flux from the surface layer to the bottom one and properties of oxygen consumption rate in the bottom layer is not yet accumulated sufficiently. Particularly, there are very few research reports about these issues in the western interior parts of the Ariake Sea.

In the present study, firstly the occurrence conditions of hypoxic water in the western interior parts of the Ariake Sea will be clarified based on the in situ measured data of current, dissolved oxygen, water temperature, salinity and so on. Next, the properties of vertical diffusion coefficient near the density pycnocline calculated from the vertical component of velocity measured during the formation of density stratification, and the relations between oxygen consumption rates of the bottom water of sea-water column and bottom sediment obtained experimentally and water quality in the bottom layer are discussed. Lastly, the oxygen consumption rates in the bottom layer and the vertical diffusion coefficients between the surface and bottom layers are calculated by applying a two-layer box model to the study area installed in the western interior parts of this sea, and the properties of their monthly changes are investigated based on the calculation results.

In situ measurements and experiments

In situ measurement points and analysis area (surrounded by broken lines) in the western interior parts of the Ariake Sea are shown in Fig. 1. In situ measurements were carried out at two points St. 1 and St. 2 in the western interiors parts of this sea, where fine particle soil and organic matter sediment largely, on August 24 and September 2, 2006. The ratio of mud (clay and silt: soil particle size less than 0.074 mm) content in the bottom sediment at St. 1 and St. 2 are 96% and 94%, respectively. First, to clarify the properties of water quality and flow at the two points, temporal variations of vertical profiles of velocity, velocity direction, sea-water temperature, salinity, dissolved oxygen (DO) concentration, turbidity, chlorophyll-a (Chl.a) and photon were measured using a multi-items water meter (AAQ 118, ALEC Electronics Inc.) and an electromagnetic current meter (VP-2400, KENEK Inc.). Next, to estimate the consumption rates in the bottom layer of the sea-water column under density pycnocline and the bottom sediment, seawater was collected every 0.5 m or 1.0 m from the sea-bottom to the sea-surface at St. 1 and St. 2 using a water sampler (C-type, Rigo Inc.), and undisturbed bottom sediment of 80 mm thickness was obtained using a sediment sampler (Rigo Inc.). Then, the samples were used to measure their DO consumption rate in the laboratory. These experiments for DO consumption rates of seawater and bottom sediment were carried out according to the manual for research of coastal environment[3] and a measurement method used by Ministry of the Environment[4]. Moreover, to clarify the turbulent structure of velocity during the formation of density pycnocline, the horizontal and vertical components of velocity were measured every 0.5 m depth at St. 1 and every 1.0 m depth at St. 2 using 3-dimentional exact current meter (NORTEC AS). Suspended particle organic matter (POC) which affects largely DO consumption rate in the bottom layer of sea-water column was also measured using CHN corder (JM-10, J-Science LAB), and inorganic nutrient (PO_4^--P, NH_4^+-N, NO_3^--N and NO_2^--N) concentrations were analyzed by auto-water analyzer (SWAAT, BLTEC).

Results and Discussion

1. Outbreak situation of hypoxic water

Fig. 2 and Fig. 3 show the spatial distributions of DO (day mean) concentration at 50 cm height above the sea-bottom in the interior parts of the Ariake Sea at spring and neap tides which

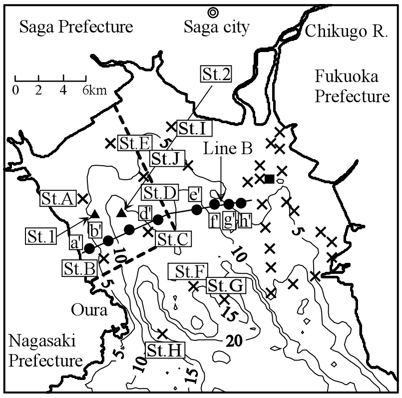

Fig. 1 Measurement points and analysis area (surrounded by broken lines) in the western interior parts of the Ariake Sea. ×indicates the measurement points of Saga and Fukuoka Prefectures, and St. A～H are the measurement points used in the present study. ● (a'～h') on Line B is the measurement points of the present study. ▲ (St. 1, St. 2) and ■ show the installed locations of multi-items water meters and an observation tower of Saga University, respectively. Numbers also present the water depth (m).

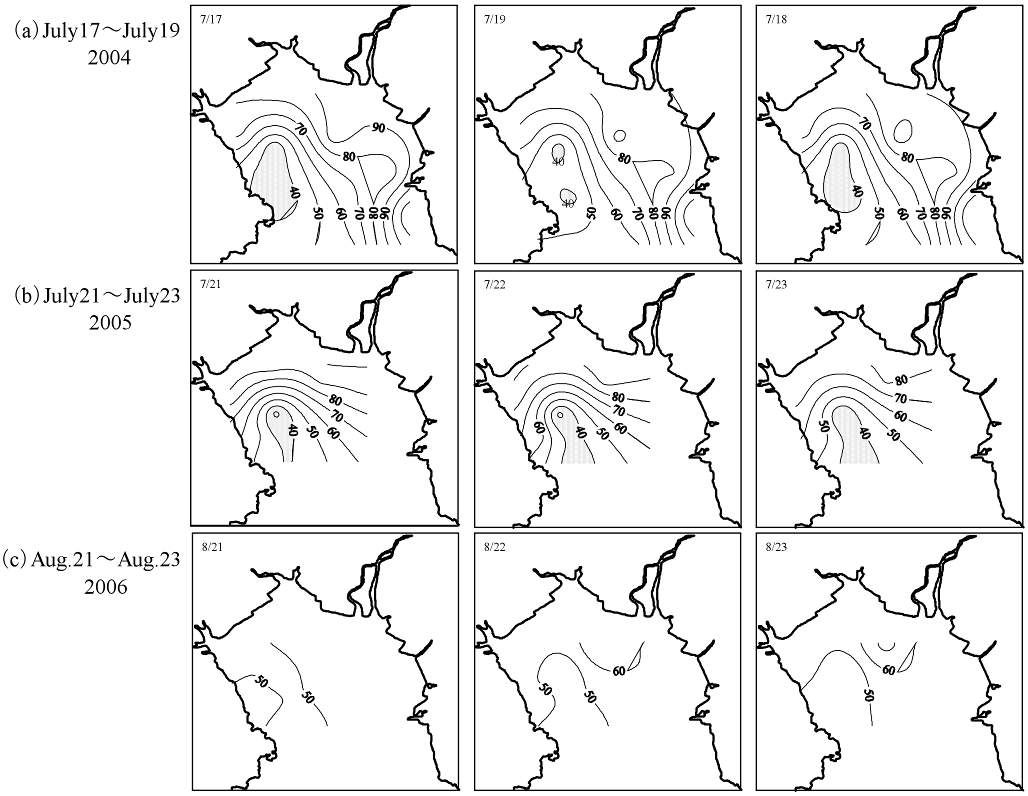

Fig. 2 Distributions of DO concentration (%) near the sea-bottom in the interior parts of the Ariake Sea at spring tide.

were obtained from Environmental Information and Research Networks of the Araike Sea[5]. As shown in these figures, the sea areas where DO saturation is less than 40% are seen partially at

(a) Aug.12～Aug.14 2004

(b) Aug.13～Aug.15 2005

(c) July17～July19 2006

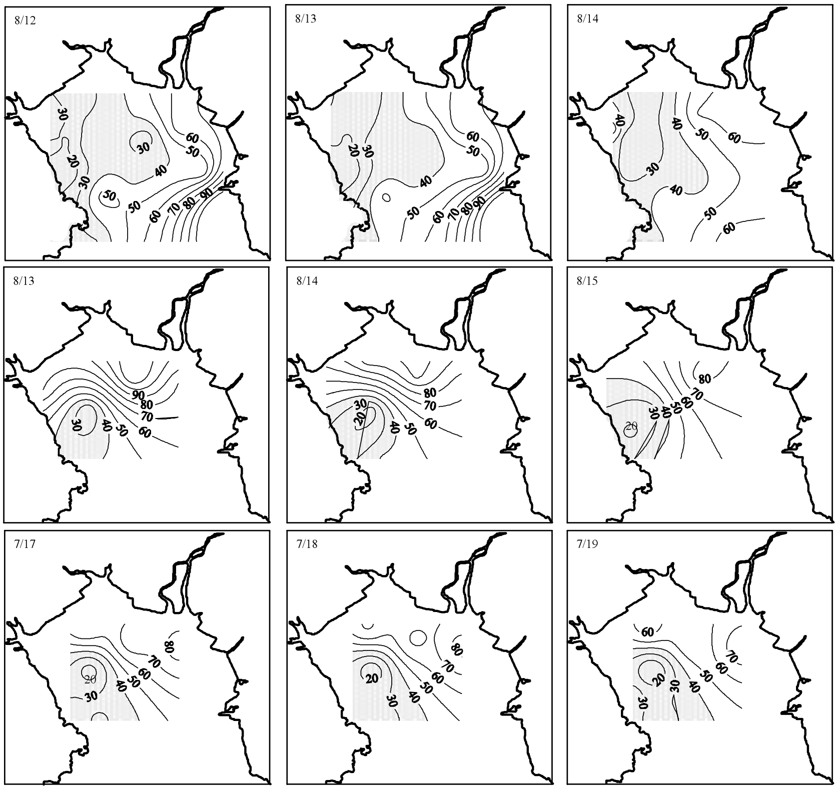

Fig. 3 Distributions of DO concentration (%) near the sea-bottom in the interior parts of the Ariake Sea at neap tide.

spring tide, but largely at neap tide. This fact indicates that hypoxic water is generated on a large-scale in the western interior parts of this sea at neap tide in summer. Fig. 4 presents the temporal variations of DO concentration, water level, velocity at 30 cm height above the sea-bottom, field-density difference between the surface and bottom layers of sea-water column (σ_{tb}-σ_{ts}) and wave height at St. 1 in summer, 2006. As can be seen in this figure, DO concentration at St. 1 decreases at neap tide and increases at sprig tide basically, and temporal variations of DO concentration are in inverse relation to that of σ_{tb}-σ_{ts}. Therefore, σ_{tb}-σ_{ts} increases at neap tide and density stratification develops, so that hypoxic water takes place, but vertical mixing between surface and bottom layers becomes active at spring tide and σ_{tb}-σ_{ts} decreases, so that hypoxic water does not appear. Incidentally, DO concentration increases rapidly on August 18 to 19 and August 31 to September 1, and conversely, σ_{tb}-σ_{ts} decreases suddenly on these days. Such a variation of DO concentration is considered to be caused by the increase of vertical mixing of sea-water with the rise of wave height due to the approach of typhoon T 0610 and strong south wind.

Fig. 5 presents vertical profiles of DO concentration and field-density of sea-water (σ_t) along Line B on September 1, 2006. As illustrated in this figure, σ_t in the surface layer of sea-water column is almost uniform in the vertical direction and well mixed except measurement points d'～e'. Such a situation is considered to be made by vigorous vertical mixing due to high wind-wave on this day. However, clear pycnocline is formed in the 3～6 m depth from the sea-surface, and hy-

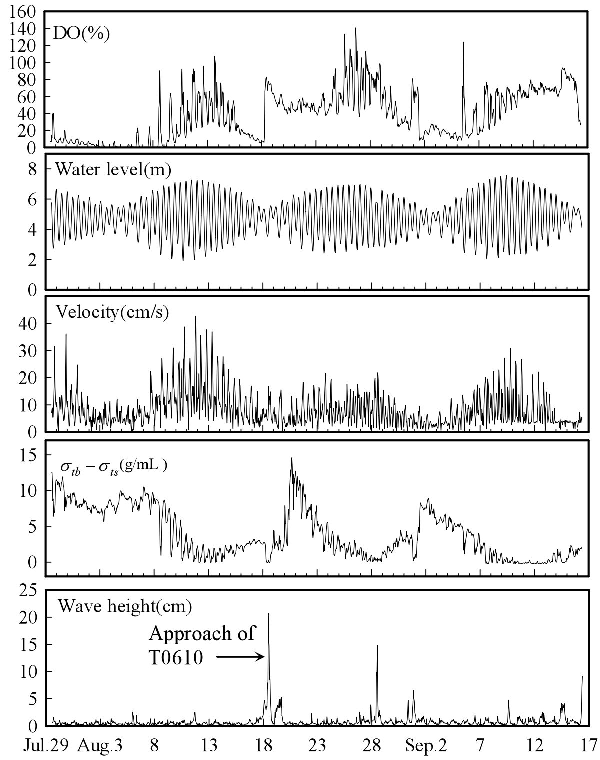

Fig. 4 Temporal variations of DO concentration near the sea-bottom, water level, velocity near the sea-bottom, σ_{tb}-σ_{ts} and wave height in summer, 2006.

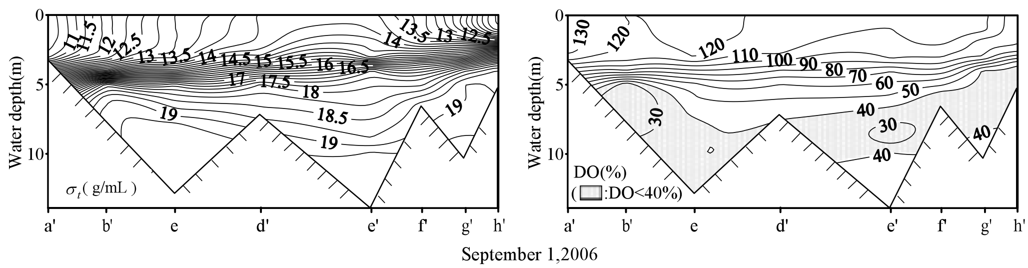

Fig. 5 Vertical profiles of σ_t and DO concentration along Line B.

poxic water less than DO saturation of 40% is found. Fig. 6 shows temporal variations of σ_t and vertical profiles of DO concentration and Chl. a at St. 1 and St. 2 on September 2, 2006. As can be seen from this figure, a remarkable density stratification is formed near the 2〜3 m and 4〜6 m depth from the sea-surface during the observation time at St. 1 and St. 2, respectively, and hypoxic water is existed under the density stratifications. Particularly, DO concentration is low value less than 2 mg/l near the sea-bottom at the both points, but conversely, it is high value over 10 mg/l in the surface layer above the density pycnocline. In other words, there coexist hypoxic water and supersaturated one of DO in the sea-water column. This supersaturated sea-water is considered to be generated by photosynthesis of phytoplankton.

As a result of consideration based on the above in situ measured data, the occurrence mecha-

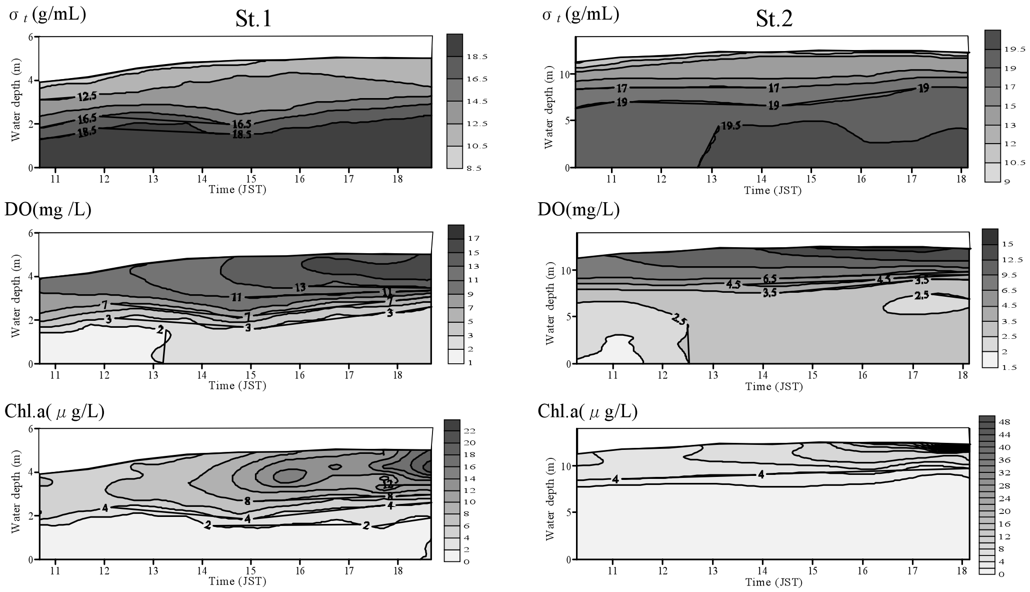

Fig. 6 Temporal changes in vertical profiles of σ_t, DO concentration and Chl.a at neap tide (September 2, 2006).

nism of hypoxic water in the western interior parts of this sea is conceptualized as shown in Fig.7. Namely, the increase of rainfall amount and river discharge in summer, and heating of sea-surface by solar energy decrease the density of sea-water in the surface layer. On the other hand, in the neap tide with slow velocity and low wave height, the vertical mixing between surface and bottom layers of sea-water column becomes very weak. As a result, density stratification is formed in the sea-water column, and density pycnocline exists between the surface and bottom layers. Thus, the density pycnocline restrains the DO transfer from the surface layer to the bottom one. On the other hand, phytoplankton multiplies in the surface layer rich in nourishment salt, and its corpse subsides to the bottom layer and sea-bottom. Further, such an organic matter is suspended in the bottom layer by wind wave and tidal current, and decomposed by bacteria. Its decomposition also consumes much DO in the bottom layer. As a result, because the consumption rate of DO in the bottom layer becomes more than the transfer rate of that from the surface layer to the bottom one, DO concentration in the bottom layer decreases rapidly and hypoxic water takes place there.

2. Distributions of vertical diffusion coefficient near density pycnocline

As shown in Fig. 7, the formation of density pycnocline in the sea-water column affects strongly on the vertical diffusion coefficient near the density pycnocline which controls the mass transfer such as DO flux. Namely, the vertical diffusion coefficient near the density pycnocline is one of the most important factors which control the occurrence of hypoxic water in the bottom layer.

Fig. 8 presents the temporal changes in vertical profiles of vertical diffusion coefficient (K_z) calculated from Eq. (1) using the vertical turbulent velocity of St. 1 and St. 2 at the time of the outbreak of hypoxic water. The vertical turbulent velocity *w'* was defined as the difference be-

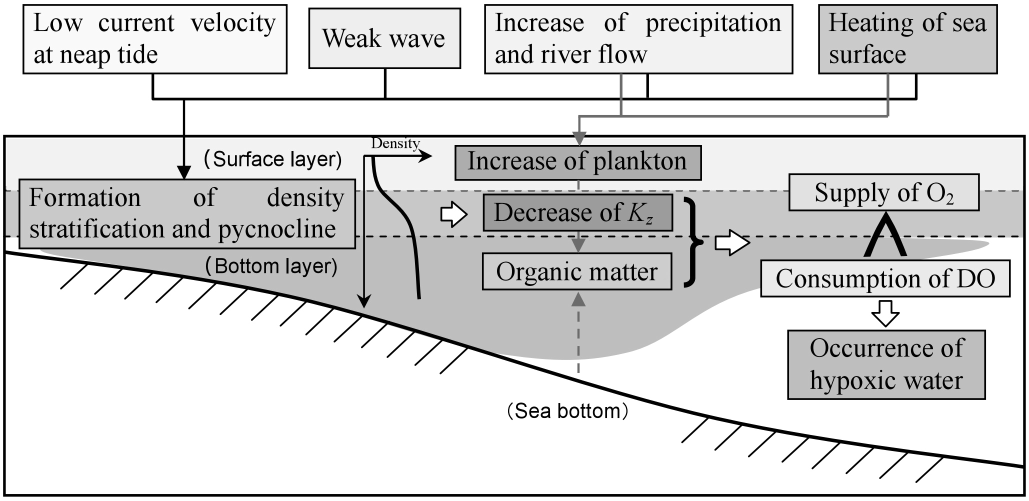

Fig. 7 Conceptual illustration of the occurrence of hypoxic water in the western interior parts of the Ariake Sea.

tween in situ measured vertical velocity and its moving average over 2 seconds, which is equal to the mean period of significant wave height in this sea area.

$$K_z = \beta \overline{w'^2} \int_0^{\tau c} R_w(\tau)\, d\tau \tag{1}$$

where β is a dimensionless parameter which connects Euler auto-correlation coefficient with Lagurange one, and β=1.0 was selected after Murakami[6), $\overline{w'^2}$ is the square mean of vertical turbulent velocity, $R(\tau)$ is the auto-correlation coefficient of vertical turbulent velocity, and τ_c is a elapsed time to when $R(\tau)$ becomes zero firstly. As illustrated in this figure, K_z values are big in the surface and bottom layers of sea-water column at both observation points, but its values decrease rapidly near the density pycnocline. Namely, K_z values in the surface and bottom layers range from 3.1 to 21.9 cm^{2}s^{-1} and from 11.4 to 60 cm^{2}s^{-1}, respectively. On the other hand, its values near the density pycnocline range from 3.6 to 7.5 cm^{2}s^{-1} and are small in comparison with those in the surface and bottom layers.

Now, K_z value during the formation of density stratification is also calculated by Munk-

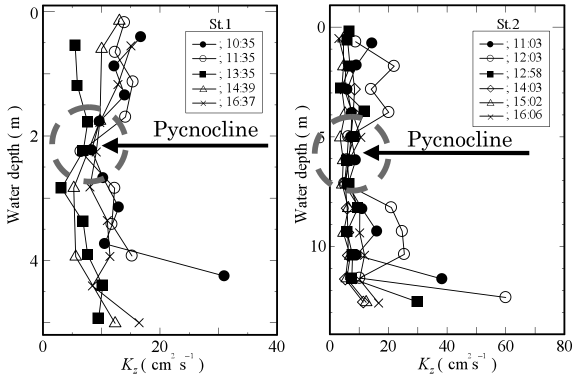

Fig. 8 Temporal changes in vertical profiles of K_z at St. 1 and St. 2 at the time of the outbreak of hypoxic water (September 2, 2006).

Anderson's equations as expressed by Eqs. (2) and (3)[7].

$$K_z = K_0(1+aR_i)^{-b} \tag{2}$$

$$R_i = -\frac{g}{\rho}\frac{\partial\rho/\partial z}{(\partial U/\partial z)^2} \tag{3}$$

where K_0 is the vertical diffusion coefficient under neutral condition (R_i=0), and K_0=1 cm^{2}s^{-1}, a= 3.33, b=3/2, R_i is a Richardson's number, ρ is the sea-water density, g is the gravity acceleration, z is the vertical axis and positive downward, and U is the mean horizontal velocity. K_z values at St. 1 and St. 2 calculated by both equations range from 7.3 to 38.8 cm^{2}s^{-1} and from 5.2 to 31.6 cm^{2}s^{-1}, respectively. These values are almost equal to those calculated by Eq. (1). From these results, it is considered that the DO flux from the surface layer to the bottom layer of sea-water column is compressed by forming of the density pycnocline.

3. DO consumption rate in the bottom layer

As above mentioned, DO consumption rate in the bottom layer of sea-water column during the outbreak of hypoxic water is an important factor as same as the vertical diffusion coefficient near the density pycnocline. Table 1 presents the results of oxygen consumption test for sea-water in the bottom layer and mud sediment collected at St. 1 and St. 2 on August 24 and September 9, 2006. DO consumption rates of bottom sediment (R_s) at the both points range from 1.09 to 1.49 gm^{-2}d^{-1}, and are almost the same order with those (0.84 to 1.04 gm^{-2}d^{-1}) obtained by Nakayama et al[8]. in the north west of this sea in July, 2002. On the other hand, the mean DO consumption rates in the bottom layer (R_w) at St.1 and St. 2 are 1.01 and 1.14 mgL^{-1}d^{-1}, respectively. Thus, assuming that the thickness of bottom layer, which is defined the depth from the lower end of density stratification to the sea-bottom, is 2 m at St. 1 and 7 m at St. 2 from the in situ measured data on September 2, 2006, the mean values of total DO consumption rates of sea-water column below the density pycnocline and bottom mud (R_{sw}) at both points are 1.64 and 1.33 mgL^{-1}d^{-1}, respectively. Thus, the mean ratios of R_w to R_{sw} are 0.63 at St. 1 and 0.79 at St. 2. From these results, it is considered that R_w contributes largely to DO consumption in the sea-water column below the density pycnocline. The values of R_{ws} obtained in the present study are almost same order to those (0.19 to 1.31 mgL^{-1}d^{-1}) measured by Nakayama et al[8]. and Tokunaga et al[9].

Fig. 9 illustrates the relations between R_w and POC in the bottom layer of sea-water column at St. 1 and St. 2. As shown in this figure, there are high relationships between those, and R_w increases with POC. In other words, R_w depends on the amount of suspended organic mutter in the sea-water column. Therefore, the organic mutter such as phytoplankton which subsides from the surface layer to the bottom one and detritus which is re-suspended by wave and current effects

Table 1 R_s, R_w and R_{sw} at St. 1 and St. 2.

	Observation stations	(gm^{-2}d^{-1}) R_s	(mgL^{-1}d^{-1}) R_w	(mgL^{-1}d^{-1}) R_{sw}
2006/8/24	St.1	1.25	1.08	1.70
	St.2	1.49	1.08	1.29
2006/9/2	St.1	1.25	0.95	1.58
	St.2	1.09	1.21	1.37

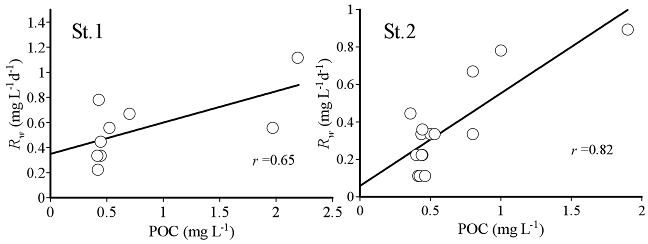

Fig. 9 Relations between R_w and POC in the bottom layer of sea-water column at St. 1 and St. 2 (August 24, 2006).

largely on DO consumption rate in the bottom layer.

4. Analysis of hypoxic water by a two-layer box model

(1) Used data

To investigate the outline of the occurrence mechanism of hypoxic water in the western interior parts of the Ariake Sea, in situ measured data were analyzed using a two-layer box model. The in situ measured data are those of water temperature (T), salinity (S), and DO concentration which were obtained by Saga Prefecture at St. A〜J in Fig. 1 from 1972 to 2002. These data measured at the 0, 5, 10, 20, 30 and 40 m depth from the sea-surface were interpolated linearly every 1 m depth. The sea-water density (ρ) was also calculated based on T and S data. On the other hand, the meteorological data were the monthly mean ones which were measured by Saga region meteorology observatory. Moreover, the river discharges were estimated from the watershed area and monthly precipitation.

(2) Analysis method

A two-layer box model was applied to the sea area surrounded by broken lines in Fig. 1, where hypoxic waters have taken place very often in recent years. The schematic of the two-layer box model is illustrated in Fig. 10. The thickness of upper layer box (H_1) is 4 m, which is the depth from the sea-surface to the center of density pycnocline, and that of lower layer box (H_2) is 5 m, which is the depth from the lower end of upper layer box to the sea-bottom. The mean salinity (S_1) and DO concentration (C_1) in the upper layer box, and the mean salinity (S_2) and DO con-

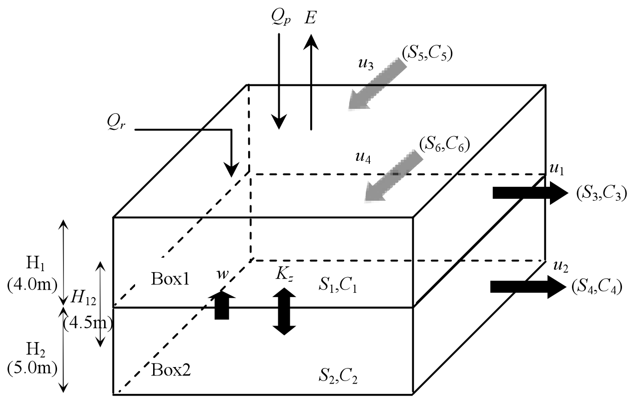

Fig. 10 Schematic of the two-layer box model for analysis area.

Table 2 Dimensions of the two-layer box model.

Volume (km^3)	V_1	0.426
	V_2	0.533
Interface Area (km^2)	A_{12}	106.56
Cross Section Area (km^2)	A_1	0.029
(East-West)	A_2	0.037
Cross Section Area (km^2)	B_1	0.058
(North-South)	B_2	0.072

centration (C_2) in the lower layer box were calculated from the data at St. A～E presented in Fig. 1. Moreover, The mean salinity (S_3) and DO concentration (C_3) in the north-south direction outside the upper layer box, and the mean salinity (S_4) and DO concentration (C_4) in north-south direction outside the lower layer box were calculated from the data at St. F～H. On the other hand, the mean salinity (S_5) and DO concentration (C_5) in the east-west direction outside the upper layer box, and the mean salinity (S_6) and DO concentration (C_6) in east-west direction outside the lower layer box were calculated from the data at St. I～J. The specifications of each box are listed in Table 2.

The sanity and water balances in each box are expressed by Eqs. (4)～(8) as follows:

<Upper layer box>

$$V_1 \frac{dS_1}{dt} = -u_1 A_1 S_{13} + w A_{12} S_{12} + u_3 B_1 S_{15} + \frac{K_z (S_2 - S_1) A_{12}}{H_{12}} \quad (4)$$

$$u_1 A_1 = Q + w A_{12} + u_3 B_1 \quad (5)$$

$$Q = Q_r + Q_p - E \quad (6)$$

<Lower layer box>

$$V_2 \frac{dS_2}{dt} = -u_2 A_2 S_{24} - w A_{12} S_{12} + u_4 B_2 S_{26} + \frac{K_z (S_1 - S_2) A_{12}}{H_{12}} \quad (7)$$

$$u_2 A_2 = -w A_{12} + u_4 B_2 \quad (8)$$

where V_1 and V_2 are the volumes of upper and lower layer boxes, respectively, A_{12} is the area of horizontal cross section between the upper and lower layer boxes, A_1 and A_2 are the areas of vertical cross section in the north-south direction of the upper and lower layer boxes, respectively, B_1 and B_2 are the areas of vertical cross section in the east-west direction of the upper and lower layer boxes, respectively, u_1 and u_2 are the mean velocities of vertical cross section in the north-south direction of the upper and lower layer boxes, respectively, u_3 and u_4 are the mean velocities of vertical cross section in the east-west direction of the upper and lower layer boxes, respectively, w is the mean velocity in the vertical direction at the horizontal cross section between the upper and lower layer boxes, H_{12} is the distance between the centers of the upper and lower layer boxes, $S_{ij} = (S_i + S_j)/2$, and Q is the inflow of fresh water into the upper layer box which consists of the river discharge (Q_r), precipitation (Q_p) and evaporation (E). E is estimated as follows[10]:

$$E = k\,(E_s - E_a)\,W \quad (9)$$

where k is the evaporation coefficient (=0.17 $mmd^{-1}hPa^{-1}sm^{-1}$), E_s is the saturation vapor pressure calculated from in situ measured sea-surface temperature, E_a and W are the monthly mean atmosphere vapor pressure and monthly mean wind velocity measured at Saga local meteorology station, respectively.

As indicated from Eqs. (4), (5), (7) and (8), there are six unknown quantities in these equations. Therefore, these unknown quantities can not be obtained by solving the above mentioned four equations. In the present study, these six unknown quantities in each month were calculated by the least squares method[11] using twenty nine data at each month for the past twenty nine years (1972 to 2000). On the other hand, the balance equation for DO concentration in the lower layer box is described as follows:

$$V_2\frac{dC_2}{dt}=-u_2A_2C_{24}-wA_{12}C_{12}+u_4B_2C_{26}+\frac{K_z(C_1-C_2)A_{12}}{H_{12}}-V_2R \tag{10}$$

where $C_{ij}=(C_i+C_j)/2$, and R is the oxygen consumption rate by biochemical action in the lower layer box.

(3) Analysis results

Fig. 11 shows the monthly changes of K_z and R obtained by the two-layer box model, and density stratification degree (P) calculated by Eqs. (11) and (12) as follows[12]:

$$p=\int_0^H|\rho(z)-\overline{\rho}|gdz \tag{11}$$

$$\overline{\rho}=\frac{1}{H}\int_0^H\rho(z)dz \tag{12}$$

where H is the mean water depth in the study area. As showed in this figure, the seasonal variations of K_z is reverse to that of P. Namely, K_z decreases in summer when P increases, and it increases in winter when P decreases. Particularly, the decrease of K_z in summer is considered to be caused by the formation of density pycnocline due to the increase of river discharge and heating on the sea-surface by solar energy. Hence, the development of density stratification compresses the oxygen flux from the surface layer of sea-water column to the bottom one. On the other hand, R increases and becomes a positive value, which means the consumption of DO in the bottom layer, in summer, and it decreases and becomes a negative value, which means the production of DO in that layer, in winter. It is considered that the increase of DO consumption in summer is due to the increases of organic matter and sea water temperature in the bottom layer,

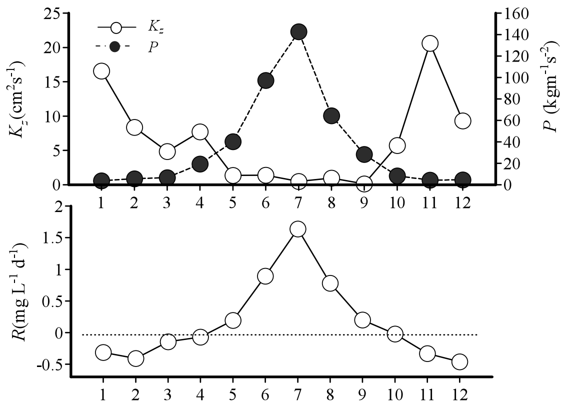

Fig. 11 Monthly variations of P, K_z and R of analysis area obtained by the two-layer box model.

and the production of DO in winter is due to the activation of the photosynthesis by phytoplankton in that layer. R values (1.0～1.5 $mgL^{-1}d^{-1}$) of summer calculated by this analysis are almost the same orders as those (1.29～1.64 $mgL^{-1}d^{-1}$) obtained by the oxygen consumption test. From above discussion, whether hypoxic water occurs or not is considered to depend on the balance between DO flux from the surface layer to the bottom one and DO consumption in the bottom layer.

Conclusions

From the investigation of the occurrence mechanism of hypoxic water in the western interior parts of the Ariake Sea based on the in situ measured data and the analysis results using a two-layer box model, the following can be concluded.

(1) Hypoxic waters in the western interior parts of this sea took place in the neap tide of summer when density pycnocline was formed. But, when strong waves owing to the approach of typhoon occurred, hypoxic water disappeared temporarily.

(2) Vertical diffusion coefficients, which were calculated from the in situ measured data of vertical velocity, decreased rapidly near the lower end of density pycnocline. Thus, it was considered that the density stratification compressed the DO flux from the surface layer of sea-water column to the bottom one.

(3) From the results of DO consumption test, the mean ratios of R_w to R_{sw} were 0.63 at St. 1 and 0.79 at St. 2. Moreover, R_w tended to increase with POC at both points.
Hence, it was considered that suspended organic matter such as the remains of phytoplankton subsided from the surface layer of sea-water column to the bottom one and the detritus re-suspended by current and wave affected largely DO assumption in the bottom layer.

(4) According to the analysis results of P, K_z and R by a two-layer box model, K_z decreased in summer when P increased, and increased in winter when P decreased. R was positive (DO consumption) in summer and negative (DO production) in winter.

(5) It was considered that the outbreaks of hypoxic water in the western interior parts of the Ariake Sea in summer were largely influenced by the oxygen balance between DO flux from the surface layer of the sea-water column to the bottom one and DO consumption in the bottom layer.

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有明海奥部西岸域における貧酸素水塊の発生機構について

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摘　　要

本研究では，有明海奥部西岸域における貧酸素水塊の発生機構を明らかにするために，まず現地観測や実験データに基づいて，密度成層期における鉛直拡散係数の分布性や底層の酸素消費速度の特性について検討した．次いで，29年間の浅海定線データを水平方向の移流効果を考慮した２層ボックスモデルで解析し，その解析結果に基づいて表底層間の鉛直拡散係数や底層での酸素消費速度の季節変動と密度成層強度の季節的推移との関連性について考察した．その結果，鉛直拡散係数は密度躍層の下端付近で急減すること，また底層の酸素消費は，ここに懸濁する有機物質の好気的分解によるものであることを示唆した．さらに，表底層間の鉛直拡散係数と密度成層強度とは相反する季節変動を示し，密度成層強度が増大する夏季において表底層間の鉛直拡散係数が大きく低下すること，一方，低層の酸素消費速度は，夏季に正の値（酸素消費）を，逆に冬季に負の値（酸素生産）となることを示した．これらの結果より，この海域における貧酸素水塊の発生は，夏季の密度躍層の形成に伴う表層から低層への酸素供給量の抑制と底層での酸素消費量の増大に起因するのと推察された．