Hypoxic water mass in Jakarta Bay, Indonesia

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[Introduction]
Jakarta Bay is an open bay located at the northern coast of West Java (Fig. 1). Its width is about 30 km and length is about 16 km. It is located in the equatorial area at the latitude of 6° S. Its mean depth is 15 m and there are 13 rivers flowing into Jakarta Bay (Wouthuyzen et al., 2011). Active commercial fishing is conducted in Jakarta Bay. However, recently massive fish kill often happened. It is supposed that the upwelling of oxygen depleted water (hypoxic water mass) would induced the massive fish kill (Sachoemar and Wahjono, 2007). However, it was not confirmed because of the lack of dissolved oxygen data. Not only Jakarta Bay, there are few information of hypoxic water mass in the coastal sea in the tropical zone especially equatorial area. The hypoxic water mass happened in many semi-enclosed bays in summer and became a big environmental problem in the temperate zone; e.g. in Chesapeake Bay, Tokyo Bay and Ise Bay. In these temperate bays, the surface heating and the increase of river discharge from spring to summer enhance the stratification and trigger the generation of hypoxic water mass. But the climate in the tropical zone is largely different from the temperate zone (e.g. the seasonal temperature variation is very small). Therefore, if the hypoxic water mass was formed in Jakarta Bay, its formation mechanism would be different from the temperate zone. So, in order to clarify the seasonal variation in dissolved oxygen (DO) in Jakarta Bay, field surveys were conducted in this study.
[Methods]
We made water quality survey in Jakarta Bay 6 times between December 2015 and February 2017 about every 3 months. In each survey, the casts of multi-parameter water quality profiler were conducted at 26 to 29 stations in Jakarta Bay. The dates of the survey were shown in Table 1. The survey was carried out during 5 to 6 hours beside in December 2015 when it took 2 days to make the survey. At each station, the vertical profiles of temperature, salinity, DO, chlorophyll fluorescence and turbidity were measured with a RINKO Profiler (JFE Advantech Co.) and the transparency was measured with a Secchi disk. Only in the survey in December 2015, an AAQ1183 Profiler (JFE Advantech Co.) was used instead of the RINKO Profiler.
[Results and discussions]
Hypoxic water mass was observed in all the 6 surveys in Jakarta Bay (Fig.2), the minimum DO was less than 2 mg/L in all the surveys. It suggests that the hypoxic water mass was formed throughout the year in Jakarta Bay. Seasonally, the hypoxic water mass was diminished in February when it was in the mid-rainy season (North West Monsoon). On the other hand, the hypoxic water mass most developed in November to December when it was the transition from the dry season to the rainy season. The hypoxic water mass often formed in the area with the bottom depth of 5 to 15 m especially in the eastern part of the bay head. In May 2016, the DO was less than 3 mg/L even in the surface layer in the eastern coastal area. It indicates that the upwelling of the hypoxic water mass really happened. The thermal stratification was not formed or weak throughout the year, the temperature difference between surface and bottom layers was less than 2 °C. The haline stratification was observed throughout the year. The stratification weakened in February when the hypoxia was reduced. In November to December, the stratification was relatively strong.
Since Jakarta bay is located in the equatorial area, surface heating tends to overwhelm the surface cooling. Therefore, the vertical convection reaching at the bottom unlikely happens. However, during the

mid-rainy season, the vertical mixing would be enhanced caused by the strong wind and high wave due to the North West Monsoon. As it would reduce the stratification and increase the oxygen transport to the bottom layer, the hypoxia would be reduced. In the deep tropical lakes and reservoirs which are not located at high altitude, the permanent thermocline was formed (oligomictic) (Hutchinson and Loffler, 1956). The water tends to become hypoxic below the thermocline in these lakes and reservoirs (e.g. Lehmusluoto and Machbub, 1995). However, in the case of Jakarta Bay, though the depth was shallow and the stable thermocline was not formed, the hypoxic water mass was formed throughout the year. It would be due to the 3 reasons. 1) This bay tends to be stratified because of the weak tidal mixing (tidal range is less than 1 m) and enough river discharge. 2) As it is difficult to occur the continuous vertical convection due to the surface cooling, the water column tends to keep stratification. 3) The oxygen consumption rate in this water may be high.

Keywords: hypoxic water mass, Jakarta Bay, Indonesia, tropical zone, dissolved oxygen

Table 1 Observation dates
8,9 Dec. 2015
9 Feb. 2016
29 May 2016
20 Sep. 2016
27 Nov. 2016
10 Feb. 2017

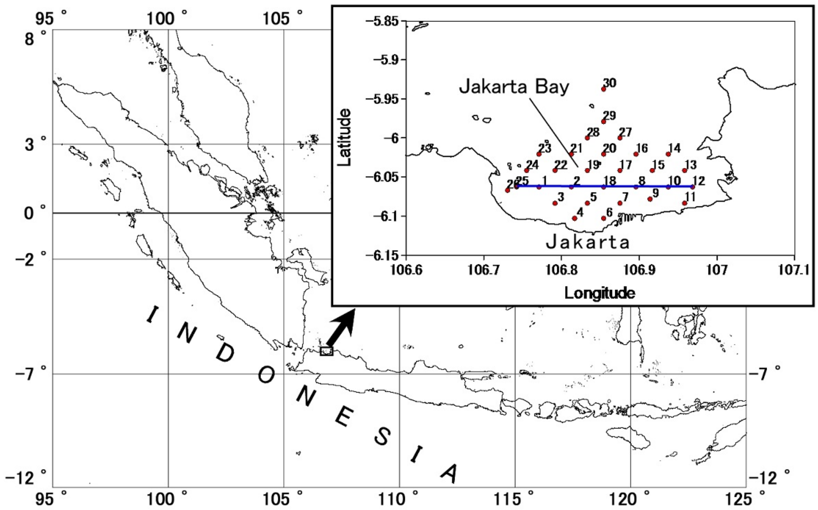

Fig.1 Map of Jakarta Bay and location of the observation stations

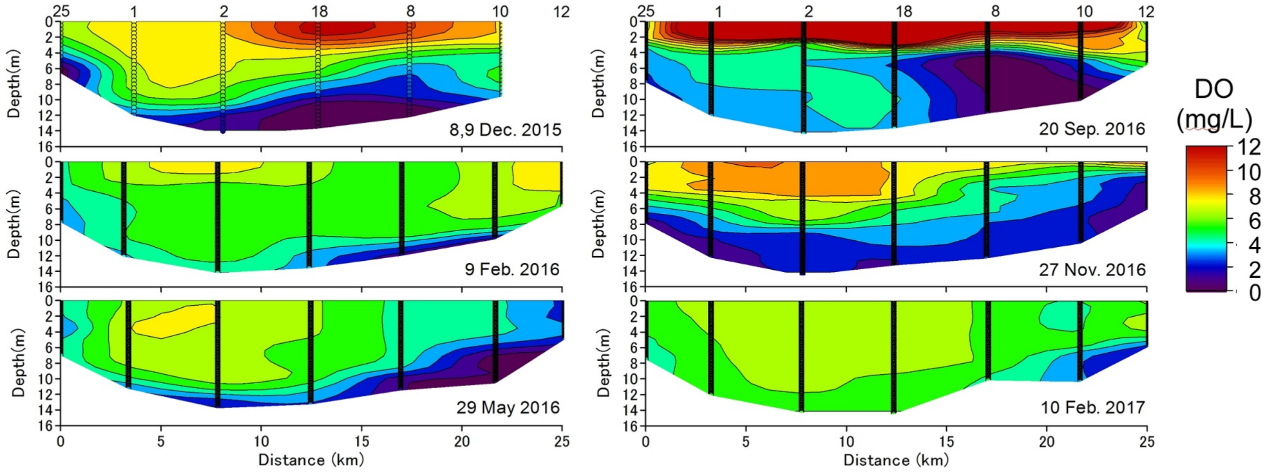

Fig.2 Distribution of Dissolved Oxygen along the longitudinal line in Jakarta Bay

Seasonal variation in hypoxia and its behavior in the Upper Gulf of Thailand

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Upper Gulf of Thailand (UGoT) faced to Bangkok of capital city of Thailand is one of the important coastal areas because of high fishery production. Recently, enormous organic matters and nutrients are supplied from land area through 4 large rivers. As the result, eutrophication, red tide, and hypoxia occur and marine environment in the UGoT becomes worse. In fact, cultured mass mortality of shellfishes happens every year at aquaculture farm in the eastern part of UGoT. Regardless of the circumstance, dissolved oxygen (DO) distribution and its seasonal variation are unclear due to limitation of observed data there. In the present study, we have conducted 7 times field survey from 2014 August to 2015 June at stations covered whole UGoT. It is found from our observation that hypoxia occurs from June to November and DO concentration in the bottom layer is less than 1 mg/l. As for distribution of hypoxia, hypoxia happens in the central part of bay head in June and then expands to northeastern part of the bay head. The hypoxia occurs in the half of UGoT in September and distributes in the northwestern part of the bay head. It is noteworthy that location of hypoxia changes from eastern side to western side of bay head through June to November. Since UGoT locates in tropical region, density stratification is formed by fresh water supply from rivers. Therefore, it is expected that distribution of hypoxia relates to that of surface salinity. However, we cannot see such relation. On the other hand, oxygen consumption rate in the water correlates surface chlorophyll-a concentration. Although we have compared DO concentration in the bottom layer with intensity of stratification, oxygen consumption rate, surface chlorophyll-a, and so on, we could not explain the movement of hypoxia area from east to west.

When location of hypoxia changes from east to west, monsoon direction also changes from southwest to northeast monsoon. It is expected that circulation in the UGoT is varied by variation in wind field and low DO water mass transports to the other area. We develop a 3-dimensional numerical model to reproduce current fields during our observation period. In the model, we consider tidal, density-driven, and wind-driven currents applying tidal variation at open boundary, river discharge from 4 large rivers, and wind and net heat flux at sea surface. The model well reproduces tide and distribution of water temperature and salinity. From the results of the model, it is found that bottom circulation changes when hypoxia area in eastern part of the bay head moves to west. We are developing lower trophic ecosystem model with 5 compartments, nutrient, phytoplankton, zooplankton, detritus, and DO. At the presentation, we will explain generation mechanism and cause of movement of hypoxia from the results of the coupled physical-ecosystem model.

Keywords: Hypoxia, Tropical region

Observation of Generation and Disappearance of Hypoxia in the Western Part of Nanao Bay

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In order to investigate the generation and disappearance of hypoxia in the western part of Nanao Bay located on Noto Peninsula, changes in water temperature, salinity, dissolved oxigen (DO) and current in Nanao Bay were observed from June to October, 2016.The generation and disappearance of hypoxia (DO less than 2mg/L) in the bottom layer (8.5 m depth) was repeated at several days interval. Hypoxia gradually appeared during several days and disappeared in hours. Hypoxia was observed from late June to early October and was the most frequent in August coinciding with high water temperature. In the case of hypoxia observed on June 24, DO did not changed significantly in the surface layer (1 m depth) but gradually decreased in the bottom layer from ca. 8 mg/L to ca. 2 mg/L during 3 days. Since salinity stratification was only found around estuary after precipitation on June 23, the salinity cannot be a main factor for hypoxia. Current velocity in the bottom layer was low from June 22 to 24. Therefore, stagnant flow and high water temperature were presumed to be the cause of hypoxia. On June 25 when strong southwestern wind blew in Nanao Bay, eastward flow occurred in the surface layer, whereas a strong westward flow exceeding 20 cm/s occurred in the bottom layer. DO in the bottom layer significantly recovered to ca. 8 mg/L with increasing current velocity. Water temperature in all layers decreased when the current in the bottom layer was strong. These results suggest that the wind-driven current in the surface layer to the leeward side had brought flow in the bottom layer toward the windward side as the compensation flow. As a result, vertical mixing was promoted and oxygen was supplied to the bottom layer.

Keywords: Nanao Bay, Hypoxia, meteorological factor

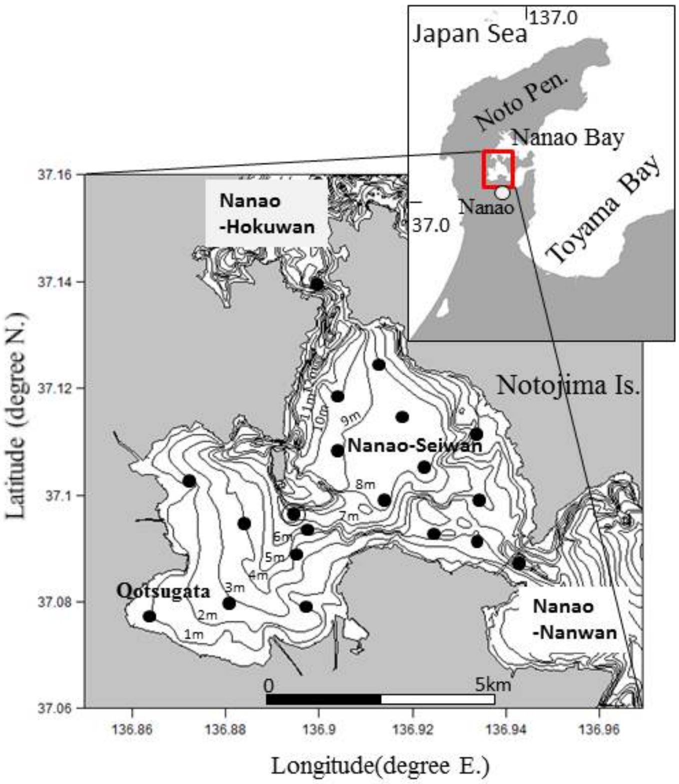

Fig.1. Location of observation stations in Nanao Bay (● indicates the CTD observation stations)、◉ indicates the temperature, current, and DO continuous mooring observation station).

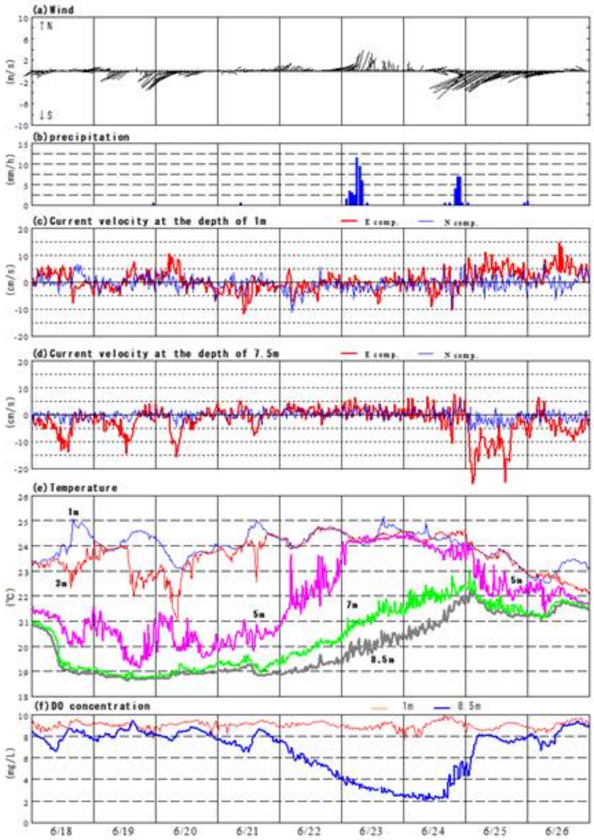

Fig.2. Temporal variations in (a)wind, (b)precipitation at Nanao, and (c)current velocity at the surface layer(1m), (d)current velocity at the bottom layer(7.5m), (e)Temperature at the depth of 1m, 3m, 5m, 7m, 8.5m, and (f)DO concentration at the surface and bottom layers from June 18 to 26 in 2016.

Monitoring for understanding marine condition in Wakasa Bay:Characteristics of seasonal variation in backscatter intensity measured by ADCP

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Wakasa bay is one of the bays facing the Japan Sea and its marine environment is strongly influenced by Tsushima Warm Current flowing near the shore. This area is known as a good fishing grounds for the set-net fishery and the trawl fishery. Recently, a monitoring system has been constructed to understand the fishing ground environment in Wakasa Bay. Water temperature, salinity and current are measured using moorings and real time buoys under this system, and the data collected by real time buoy are utilized for fishermen via web site. In this study, we focused on temporal variations of the backscatter intensity measured by an ADCP (Acoustic Doppler Current Profiler). To reveal the characteristics of variations, the ADCP data collected at a mooring point around the baymouth were analyzed. In addition, the characteristics of temporal variation of the backscatter intensity were compared with the temporal variation of physical and biological data such as water temperature, salinity, and fish catch. The data of water temperature and current collected by the monitoring system showed that the seasonal variation of the Tsushima Warm Current was closely related to the decrease of the backscatter intensity of the ADCP and the change of the fish catch in summer.

Keywords: monitoring system, Wakasa Bay , Tsushima Warm Curernt

Influence of Density Field on *Kyucho* and Bottom Intrusion in the Bungo Channel

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Occurrences of two density currents (*kyucho* and bottom intrusion) are known in the Bungo Channel, located between Kyushu and Shikoku, Japan (Takeoka et al., 2000). A *kyucho* is an intermittent intrusion of warmer water into the upper layer from the Kuroshio. A bottom intrusion is an intermittent intrusion of colder water into the lower layer from the bottom layer of continental slope. A *kyucho* in the channel is formed by the collision of a warm filament generated along Kuroshio front with the southwestern coast of Shikoku. The *kyucho* can flow into the central region of channel during a neap tide and warming period when vertical mixing is weak. A bottom intrusion is observed during a neap tide when the Kuroshio approaches the east coast of Kyushu (Kaneda et al., 2002a, b), however; its physical process is not fully understood. Strong bottom intrusions were observed five times during mid-November and mid-December 2013 in the southwestern coast of Shikoku (Fukuura Bay, Ehime) when temperature in the lower layer dramatically decreased (maximum: -4.0°C day^{-1}). In the present study, these bottom intrusions were analyzed using vertical temperature profiles along the coast of Shikoku measured by Ehime University and JF Ehime. Influence of density field inside the channel on *kyucho* and bottom intrusion was evaluated, using the observational data of Ehime Fisheries Research Center.

As the vertical temperature profiles were analyzed, we observed that both warmer and colder water alternately passed through the whole layer of Okinoshima Island, south of Bungo Channel. Strong bottom intrusions were seen when this colder water passed by Fukuura, the southernmost station in the channel. Temperature increases due to the *kyucho* were detected in the upper layer of Fukuura, after the warmer water passed through Okinoshima Island, however, the scale of increase was lower in Fukuura than in Okinoshima Island. As the bottom intrusions propagated into the central region, the strength dropped while the few *kyucho* propagated. The density field along the channel was analyzed to figure out a factor that only the bottom intrusions propagated into the central region. In the upper layer, the density was greater in the south than in the north in November 2013, and the water tended to move southward, thus the *kyucho* was interrupted. In the lower layer, the density was higher in the south than in the north, and the water tended to move northward, thus the bottom intrusions flowed into the central region. The previously observed data demonstrated that *kyucho* tended to be interrupted during October and November due to salinity increase in the upper layer of the south. Bottom intrusions tended to be interrupted between December and April of next year due to seasonal cooling in the north. Kaneda et al. (2002) only observed *kyucho* between December 1995 and April 1996 due to the density structure inside the Bungo Channel.

Keywords: Bottom intrusion, Kyucho, Bungo Channel, Kuroshio

Seasonal and interannual variations in the nutrient concentrations in the Bungo Channel, Japan

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The Bungo Channel is a channel connecting the Seto Inland Sea and the Pacific Ocean. The hydrographic condition in the Bungo Channel has been suggested to be strongly influenced by the intrusion of oceanic water from the Pacific Ocean. In this study, we focus on the spatial and temporal variations of the nutrients in the Bungo channel. We used field data of three nutrient elements (nitrate, phosphate and silicate), water temperature and salinity collected by the Ehime Research Institute of Agriculture, Forestry and Fisheries from 1991 to 2005 with an interval of one month. The nutrient concentrations were highest over the continental shelf slope in the southern area of the Bungo Channel during all seasons, and the interannual variations were also highest in the same area. In summer, water mass with relatively high concentration of nutrients was widely spread in the bottom layer of the channel. The nutrient concentrations in the middle and bottom layers in summer also showed large interannual variations. The large interannual variations of nutrient concentration from the shelf slope to the bottom layer of the channel are likely also associated with the bottom intrusion of oceanic water into the channel.

Keywords: Seto Inland Sea, field observations, nutrients, bottom intrusion

Marine Environmental Changes Caused by Destruction and Reconstruction of the Bay-mouth Breakwater

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Kamaishi Bay, a small bay on the Sanriku ria coast, is located in the northeastern part of Japan. Since the bay had been heavily damaged by a large tsunami associated with an earthquake off Chile in 1960, a bay-mouth breakwater was constructed in the bay by the Japanese government. The bay-mouth breakwater was very huge (about 2 km length) and the deepest in the world (63m depth). In 2011, surprisingly, it was destroyed by the giant tsunami following the Great East Japan Earthquake (hereafter referred to as Great Earthquake). The destroyed bay-mouth breakwater, however, is currently being reconstructed again. We have therefore investigated a sequence of marine environmental changes in the bay, using CTDO (temperature, salinity, depth and dissolved oxygen) data obtained by ship-board observations before the Great Earthquake, just after it, and at present (under the reconstruction of the breakwater). The results are summarized as follows.
Before the Great Earthquake (in 2009), the bay-mouth breakwater had a negative effect on the marine environment in the bay, although it provided a calm environment there. That is, oxygen deficiency occurred at the inner foot of the bay-mouth breakwater during the season of stratification, especially in the fall season, where a stagnant region formed. This is because water exchange between inside and outside the bay was prevented by the bay-mouth breakwater. Just after the Great Earthquake (in 2011), on the other hand, the oxygen deficiency is reduced, since the stagnant water tended to be removed by the water exchange between inside and outside the bay. At present (in and after 2015), however, the oxygen deficiency is reappearing, because the water exchange begins to be prevented again by the bay-mouth breakwater that is being reconstructed. In other words, the marine environment is getting worse again in the lower layer in Kamaishi bay.

Keywords: Water exchange, Bay-mouth breakwater, Kamaishi Bay, Great East Japan Earthquake

Nutrient Status of Otsuchi Bay and the major rivers flowing into it on the Sanriku Coast of Japan: 6 Years after the Great East Japan Earthquake

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The massive tsunami on 11 March 2011 severely damaged coastal fauna and the infrastructure of many coastal communities, including sewage treatment systems and fishery facilities. It also delivered massive amounts of debris and soil from landside into bays and heavily disturbed seaweed and seagrass beds. The disturbance has raised concerns about alterations in the nutrient status (the concentration and stoichiometry of major nutrients) of the affected bays. We will report time-series data on the nutrient status of Otsuchi Bay, an embayment located within the severely damaged region from March 2011 to March 2017. We compared data collected after the tsunami with those collected before the tsunami to evaluate possible tsunami-related impacts on nutrient status of the bay and the major rivers flowing into it. Anomalous features was noted in the first years after the tsunami: 1) remarkable accumulation of nitrite and silicic acid in summer of 2011; 2) remarkable accumulation of phosphate during the mixing period between November 2011 and January 2012 when the total inorganic nitrogen to phosphate (TIN/P) ratio was substantially reduced (ca. 6) relative to the typical ratio observed during the pre-tsunami period (ca. 10). This low TIN/P ratio was due to the high concentration of phosphate that was inferred to have originated from land-derived debris and sediment. In contrast, during the mixing period of the subsequent 2 years (2012–13 and 2013–14), the TIN/P ratio increased to reach a value of 12–13, which is greater than the typical value before the tsunami. Although the TIN/P ratio reduced slightly during the mixing period of the following 2 years (2014–15 and 2015–16), the average ratio was still higher than that before the tsunami. In this presentation we will report results obtained in the 6th year.

Keywords: the 2011 off the Pacific coast of Tohoku Earthquake, tsunami, Sanriku Coast, Nutrient status

A comparison between the 1D diffusion coefficient of beached litters in the cross-shore direction and surf zone diffusivity off Wadahama beach, Nii-jima Island, Japan

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Recently, marine litter is widely recognized as a global environmental problem. In addition to large marine debris, small plastic fragments are significant concern because they can be found anywhere in the ocean, coastal regions, and beaches. It is well known that marine debris gradually degrade into small plastic fragments on a beach because of exposure to ultraviolet radiation, heat of the sand, and mechanical erosion. Since long-term stranding on the beach enable marine debris to degrade into small plastic fragments, an understanding of the residence time of litters on a beach can widely applied to preventing the fragmentation of litters and mitigation of plastic pollution on the beach. In the previous studies by Kataoka et al. (2013), it is clarified that reduction of litter population on the beach can be approximated as an exponential function, because the backwash process obeys a diffusion process. The diffusion coefficient can be obtained by measuring their residence time on the beach. To estimate their residence time, Mark-recapture experiments (MREs) are often conducted. However, it is too hard to conduct these experiments on beaches in all part of the world because they consume enormous time and labor. Thus, the previous study proposed that the diffusion coefficient of marine debris is associated with that in the surf zone during storm events. These coefficients are connected with a constant determined by comparing two coefficients. In the present study, to estimate the constant, we conducted the MRE for diffusion coefficient of marine debris on Wadahama beach, Nii-jima Island and a Neutral Particle Experiment using video imaged of the surf zone. We will present these experiment results and relationship between two diffusion coefficients in detail.

Keywords: Beached marine debris, Diffusion coefficient, Mark-recapture experiment, Neutral particle experiment

Horizontal two-dimensional pattern formation of chlorophyll-a in ecosystem model with vertical mixing process

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In the Toyama Bay, chlorophyll-a in the surface layer of a few meters increases in the rainy season of Jun to July, while forming the counterclockwise pattern (cf. Fig.1). This characteristic distribution is considered to be found in the relationship between oceanic physical processes (advection and diffusion) and ecosystem in the Toyama Bay. However, the formation and development mechanism are not revealed in detail. Then, we investigate the mechanisms of pattern formation using a satellite image, ocean observation data, and physics-ecosystem modelling.
Especially, we focus on the vertical mixing process and the inflow of nutrient from the river.
In this study, we used the NPZ model as an ecosystem model, including the advection and diffusion terms as ocean physical processes. This three-dimensional system was solved by finite differential method. The horizontal oceanic area is 100 km x 100 km referring to extention of the Toyama Bay and the resolution is 2km x 2km. For the model calculation, we employed a horizontal diffusive coefficient of 10 (m^2/s) and performed a cyclonic circulation as flow fields. Also vertical diffusive coefficients are in the range of 10^{-5} to 10^{-2}(m^2/s).
The experiments are carried out for macro and micro plankton, and several values of grazing rate coefficient showing a relationship between the predictor-pray of planktons as the ecosystem parameters. In this numerical experiment, assuming the inflow of nutrient from rivers, we set up a situation where the concentration of nutrient increases from below the model area and analyse the transition.
We also analyzed by using COMS-GOCI satellite image to understand development of chlorophyll-a pattern in the actual situation in the Toyama Bay and to compare it with numerical experiment.
The data is from April to September of 2010 to 2014 and data from April to October 1, 2015 (lacking only for July 2012).
In the numerical experiment without vertical diffusion, the counter-clockwise spiral pattern was formed in all zooplankton parameter. This pattern gradually collapsed, and then the amount of phytoplankton in the model area changed uniformly(cf. Fig. 2). After that, a spiral pattern was appeared again only in micro zooplankton parameter.
The counterclockwise spiral pattern in the surface layer in the three-dimensional model with the vertical diffusion.
The concentration of phytoplankton was lower in the three-dimensioal case than that in the two-dimensional case, however, because the nutrient supplied on the surface layer was carried to the deep layer by the vertical mixing.
It was found there were cases where the spiral pattern was formed to the lowest layer and cases where it was not formed, depending on the zooplankton parameters and the magnitude of vertical diffusion.
From these experiments, the formation of the spiral pattern in Toyama Bay is assumed nutrient supplied from a river is transferred to a counterclockwise flow field, and then phytoplankton consume its nutrient. We found that for the abundant nutrient in the bay, the spiral pattern was formed with active interactions of predator-prey between plankton.
In satellite image analysis, chlorophyll-a concentration distribution in Toyama Bay was classified into 4 patterns. : firstly high concentration in the offshore area, secondly high concentration on the coast, thirdly high concentration part developed from near Kurobe river estuary toward Toyama Bay, fourthly spiral

pattern.
For the fourth spiral pattern, we showed the possibility to explain the mechanism of the formation in the numerical experiment.
Moreover, for the formation of a spiral pattern, we suggest that spring water in the Kurobe River with the rich nutrient are carried in counterclockwise circulation field in the Toyama Bay. Furthermore we plan to investigate the above described items in three-dimensional model research.

Keywords: chlorophyll-a, ecosystem model, Toyama Bay, two dimensional pattern, Vertical mixing

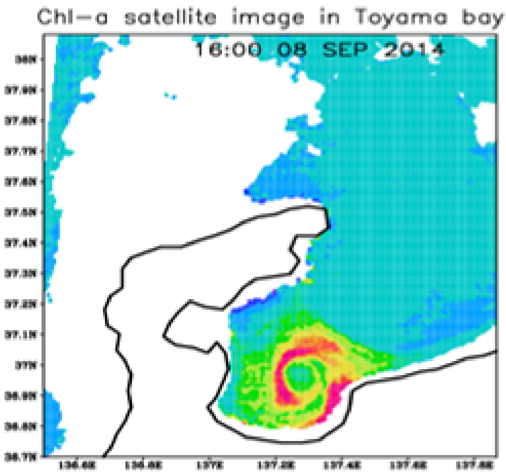

Figure.1
Chlorophyll-a concentration distribution in COMS-GOCI satellite.

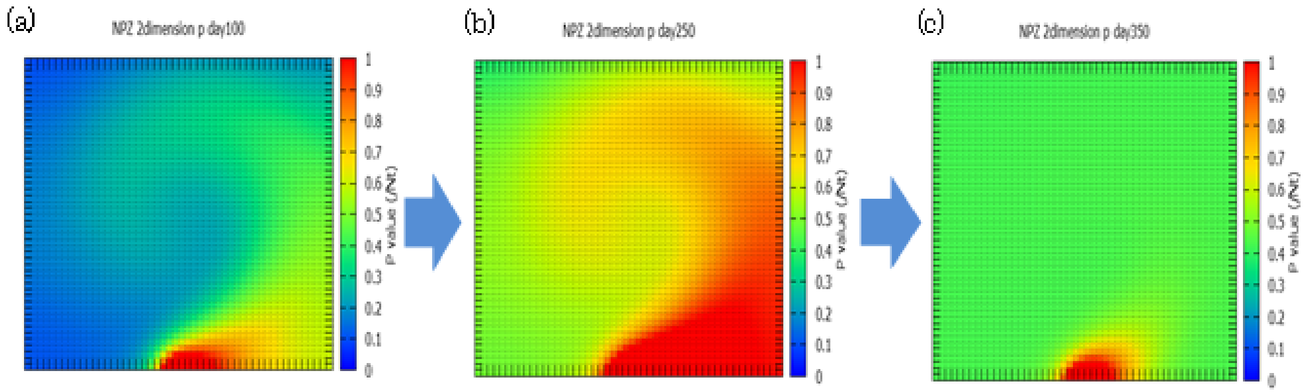

Figure.2
Transition of the phytoplankton concentration distribution in numerical experiment.
(a) Distribution of 100 days
(b) Distribution of 250 days
(c) Distribution of 350 days

