La mer 50 : 1-10, 2012
Société franco-japonaise d'océanographie, Tokyo

Benthic microalgal biomass in the estuarine tidal flat of the Mae Klong River, Thailand: Relationship with environmental factors at the sediment–water interface

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Abstract: The present study describes and quantifies the short–term variations of microphytobenthic biomass and associated limiting factors in the tidal mudflat of the Mae Klong River estuary. Surficial sediment (0–0.5 cm) was collected during exposure in September (wet monsoon) and November (post monsoon) 2006 at 25 stations, covering the entire tidal flat area in order to determine microphytobenthic biomass (benthic chlorophyll *a*), loss on ignition (LOI) and nutrients in pore water. The average microphytobenthic biomass of September (8.49 $\pm$2.86 mg m^{-2}) was 63% higher than that of November (5.21$\pm$2.58 mg m^{-2}), and statistically different between two–month observations ($P<0.0001$) due to the available irradiance during aerial exposure. The higher microphytobenthic productions in September have also contributed largely to the sedimentary composition in surficial sediments. Furthermore, the longer aerial exposure periods might allow the sediment–water interface to become oxic conditions, resulting in increasing $NO_2^- + NO_3^-$ concentration in pore water via nitrification processes, and contribution of $NO_2^- + NO_3^-$ was calculated as 52.5% to dissolved inorganic nitrogen (DIN; $NO_2^- + NO_3^-$–N$+NH_4^+$–N). These results suggested that variability of microphytobenthos have been regulated largely by the supplied irradiance during exposure, and may have great role on sedimentary composition in the estuarine tidal flat of the Mae Klong River.

Keywords: *microphytobenthos, chlorophyll a, nutrients, sediment–water interface, estuary, Mae Klong River.*

1. Introduction

The microphytobenthos play a great role in estuaries and shallow water ecosystems, where the available irradiance extends to the seafloor, and much attention has recently been paid to their potentially important production. The microphytobenthos are well documented, frequently referred to as the major primary carbon source for the shallow ecosystem food web, and also serve as an important component in nutrient cycles in tidal estuaries (MACINTYRE *et al.*, 1996 and references therein). According to the previous studies, the microphytobenthos may contribute up to 50% of the entire primary production, depending on environmental factors (FIELDING *et al.*, 1988; de JONGE and COLIJN, 1994; BLACKFORD, 2002). Furthermore, the microphytobenthos can regulate oxygen concentration, which can mediate nutrient transformations and fluxes between the sediment and overlying water via their photo-

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synthesis and also play an important role in sediment stability (SUNDBÄCK *et al.*, 1991; CAHOON and COOKE, 1992; BARRANGUET, 1997; WELKER *et al.*, 2002).

The production and biomass of microphytobenthos are largely influenced by several environmental factors including nutrients, substrate types, tidal rhythm and irradiance, and biological factors such as herbivore grazing (BARRANGUET *et al.*, 1998; LIGHT and BEARDALL, 1998; SMITH and UNDERWOOD, 2000; BLACKFORD, 2002; RIAUX–GOBIN and BOURGOIN, 2002; PERKINS *et al.*, 2004; CARTAXANA *et al.*, 2006; SKINNER *et al.*, 2006; KOH *et al.*, 2007; YAMAGUCHI *et al.*, 2007; DU *et al.*, 2009; JESUS *et al.*, 2009; LOASSACHAN *et al.*, 2009). There have been some reports that microphytobenthos and their primary production influenced sediment stability and nutrient fluxes in an estuarine area (GERBERSDORF *et al.*, 2004; WILSON and BRENNAN, 2004; CIBIC *et al.*, 2007). BARRANGUET (1997) found the production and biomass of microphytobenthos play a great role in regulating oxygen concentration at the sediment–water interface in a mussel cultured area. Moreover, the oxygenation of the organically enriched sediments by microphytobenthos may influence the abundance of the macrobenthic fauna in the western Seto Inland Sea (YAMAGUCHI *et al.*, 2007). A negative correlation among Chl *a* contents in surface sediments and measured silicic acid fluxes using core incubation technique was documented in a coastal shallow ecosystem (Shido Bay, the Seto Inland Sea), suggesting that the microphytobenthos greatly reduced the upward silicic acid flux of sediment–water interface during their nutrient uptake requirement (SRITHONGOUTHAI *et al.*, 2003). LOASSACHAN *et al.* (2009) also found that the microphytobenthos have a great effect on the nutrient availability, especially silicic acid at the sediment–water interface during the large supply of irradiance (winter periods) for their photosynthetic growth in a coastal shallow water, the Seto Inland Sea, Japan.

The present study aims to examine the temporal dynamics of microphytobenthic biomass at the estuarine intertidal flat and its relation to the environmental factors at the sediment–water interface. This study provides considerable information on microphytobenthos, a primary producer, in the Mae Klong River estuarine system, which is a highly productive area and important fishing ground in the upper Gulf of Thailand.

2. Materials and Methods

2.1 Study site

The Mae Klong is one of the most important large rivers, which discharge fresh water into the upper Gulf of Thailand, and is also considered as an important source of nutrients and materials loaded into the western part of the head of the Gulf of Thailand. This river is strongly influenced by the wet southwest monsoon from May to October, and the dry northeast monsoon from November to April.

The Mae Klong River estuary is one of the most important fishing grounds in the upper Gulf of Thailand with its high production of commercial aquatic species, such as razor clams (*Solen* spp.), blood clams (*Anadara granosa*), and green mussels (*Perna viridis*), and is the largest habitat of the razor clam in Thailand. Furthermore, the tidal flat of the Mae Klong River estuary (Don Hoi Lot) has been listed in the Ramsar Convention as an international important natural wetland (www.ramsar.org). The estuarine area consists of a large tidal flat and coastal wetland. The tidal flats are generally characterized as muddy fine sand (>50% of grain size fractions are 125–250 μm) and accumulated from the Mae Klong River, covering an area of 875 km^2 (87,500 ha).

2.2 Sampling strategies

Observations were carried out in September and November 2006 at 25 stations, covering the entire area of the tidal flat (Fig. 1). All the observation and sampling were performed during exposure. Duplicate undisturbed cores were collected carefully at each station using an acrylic pipe of 4 cm in diameter. The surficial sediment (0–0.5 cm) from one core sample was carefully sliced off into a glass vial for analysis of chlorophyll *a* (Chl *a*), and the surficial sediment from another core was also cut–off into a plastic bag for analysis of water content, loss on ignition (LOI) and extraction of pore water. All samples were stored in a cooler box for

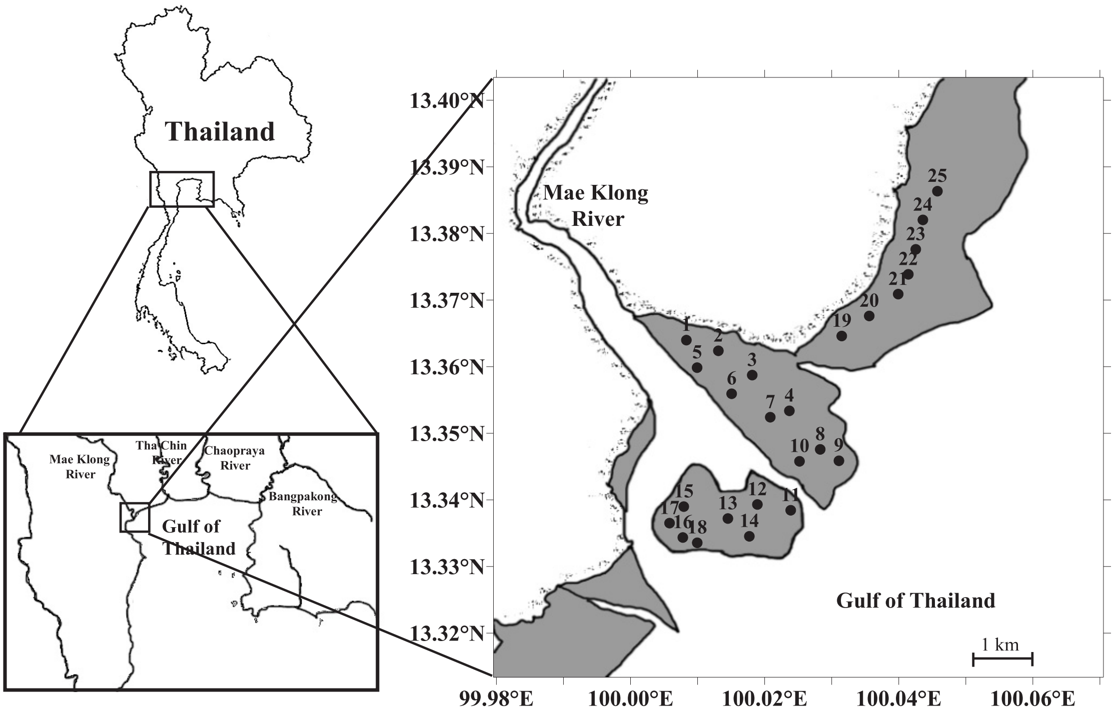

Fig. 1. Sampling stations in the tidal flat (gray zones) of Mae Klong River estuary.

several hours until further analysis in a laboratory.

Water content, LOI and Chl *a* concentrations were immediately determined on the fresh sediment samples. The residual sediments from water content analysis were homogenized and divided into two sub-samples for LOI determination and pore water extraction. Aliquots of the sediment samples were centrifuged to extract the pore water (3,000 rpm, 15 min at 4℃), and the supernatant was then filtered through a Whatman GF/F filter for inorganic nutrient analysis. The filtered pore water samples were kept at −20℃ until the nutrients were analyzed.

2.3 Analysis

The water content of the sediment was determined from the weight loss after drying the wet sediment at 105℃ until a constant weight was obtained (approximately 24 h). For LOI determination, sediment samples were dried to constant weight at 60℃ for 3 days, ignited in a muffle furnace at 550℃ for 3 h, and then LOI was calculated from the loss of weight after combusting the dried sediment samples. For Chl *a* determination, the sediment samples were extracted in 90% acetone and kept at *ca.* 4℃ in the dark for 24 h. The Chl *a* concentrations were analyzed following the spectrophotometric method of Lorenzen (1967) described in Parsons *et al.* (1984) using a spectrophotometer (Cecil, 1000 series). LOI and Chl *a* contents were expressed as mg m^{-2} DW, which was calculated from the sediment core area. The concentrations of inorganic nutrient in pore water, ammonium (NH_4^+–N), nitrite and nitrate (NO_2^- + NO_3^-–N), phosphate (PO_4^{3-}–P) and silicic acid ($Si(OH)_4$–Si) were analyzed using a nutrient auto analyzer (SKALAR, The SAN^{Plus} Segmented Flow Analyzer), and the nutrient concentrations were expressed as μmol l^{-1}. Microphytobenthos species were also roughly observed by a microscope. Moreover, the entire exposure periods in the present study were calculated from the tide table.

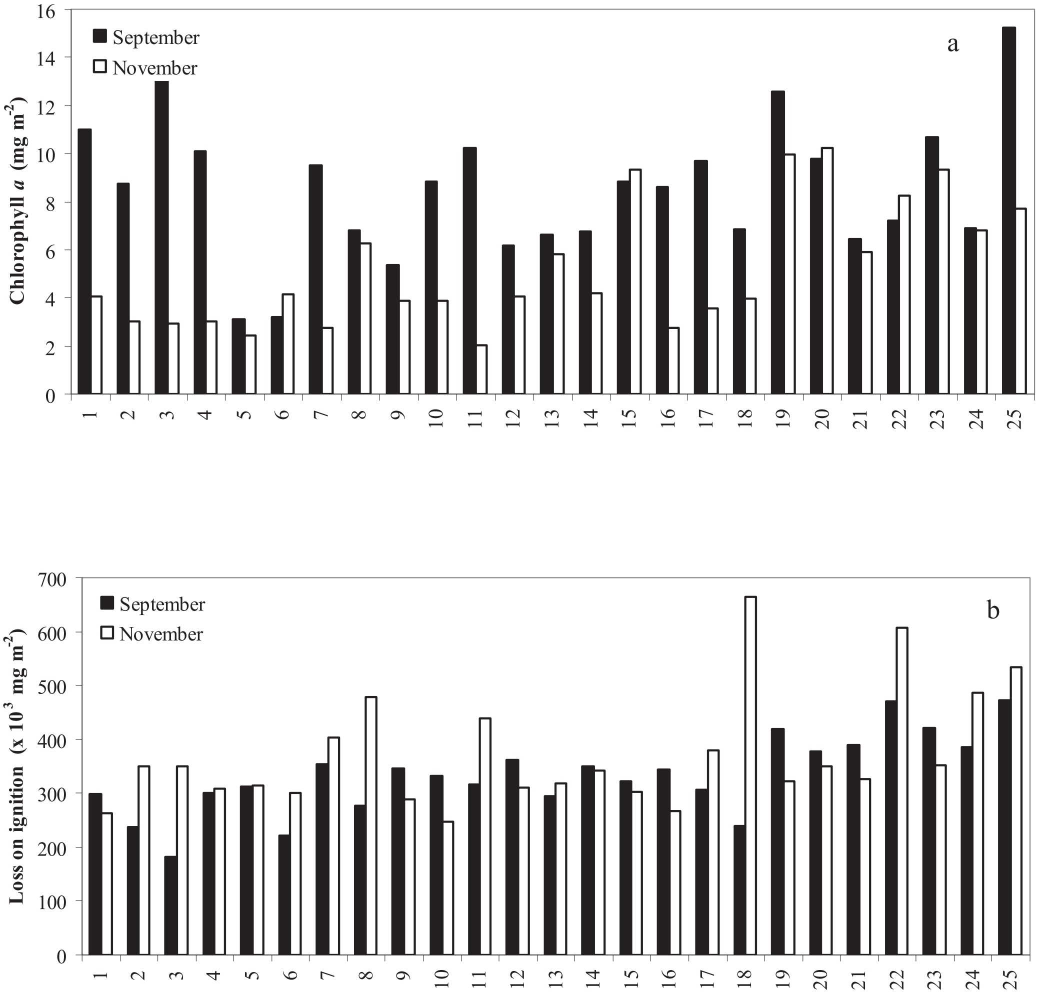

Fig. 2. Variability of (a) benthic Chl *a* content and (b) LOI in surficial sediment layer (0–0.5 cm).

2.4 Statistical methods

Differences in microphytobenthic biomass, LOI, Chl *a*/LOI ratio and nutrient concentrations in pore water during two–month observations were tested through non–parametric tests followed by Mann–Whitney *U* Test. The correlations between microphytobenthic biomass and other parameters were examined by Spearman's rank correlation coefficient. These analyses were performed using SPSS 16.0 for Microsoft Windows.

3. Results

3.1 Chlorophyll a concentration and loss on ignition in the surficial sediments

The variability of benthic Chl *a* concentration within the surficial sediments (0–0.5 cm) is shown in Fig. 2a. In September, the benthic Chl *a* ranged between 3.09 mg m^{-2} (at Stn. 5) and 15.2 mg m^{-2} (at Stn. 25), averaging 8.49 mg m^{-2}. While the benthic Chl *a* of November varied from 2.04 mg m^{-2} (at Stn. 11) to 10.2 mg m^{-2} (at Stn. 20) with an average of 5.21 mg m^{-2}; this was statistically lower than those of Chl *a* contents collected in September (*P*

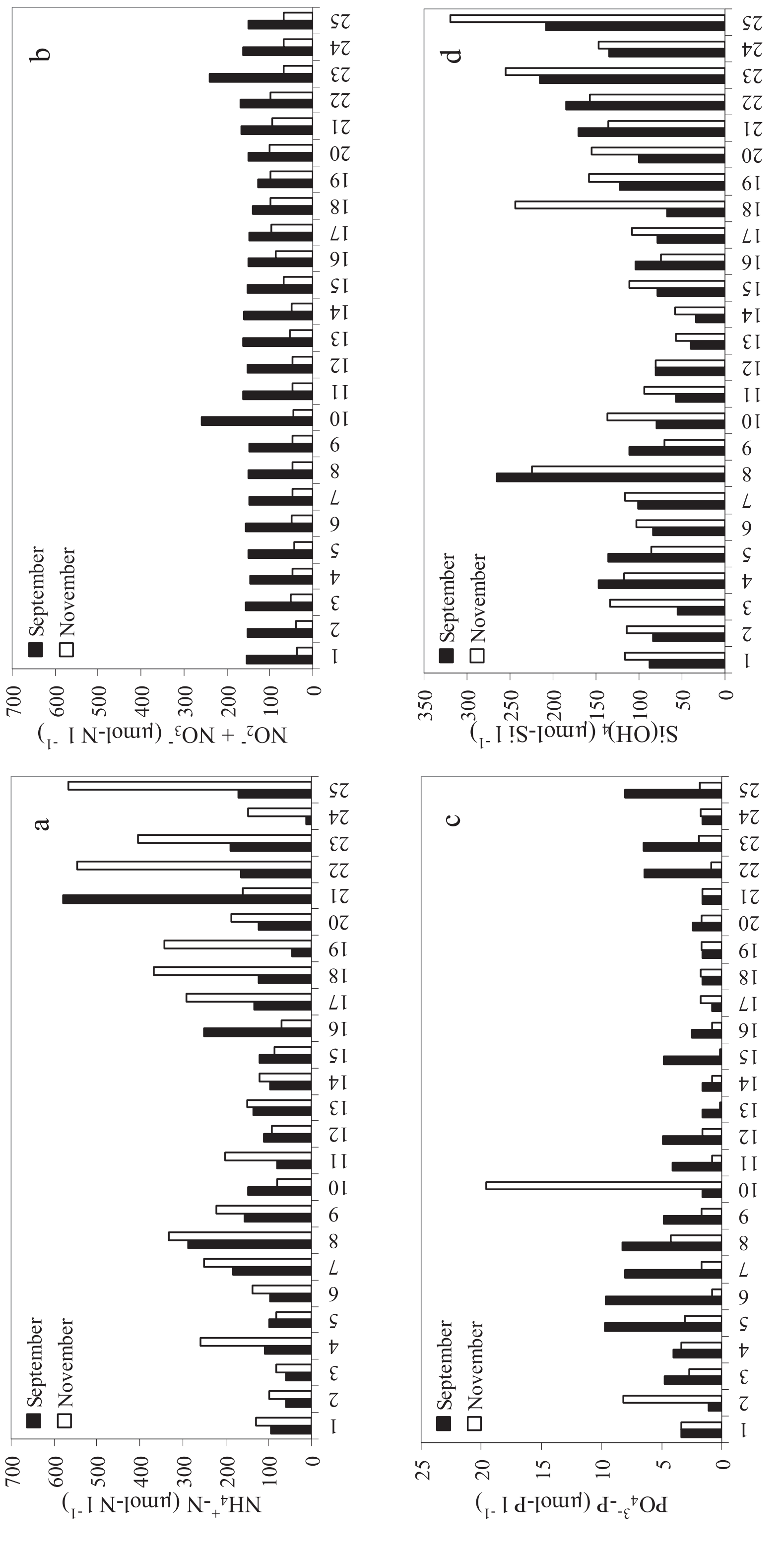

Fig. 3. Variability of (a) NH_4^+–N, (b) NO_{2^-} + NO_{3^-}–N, (c) PO_4^{3-}—P and Si (OH) $_4$–Si concentration in pore water.

< 0.0001, $n = 50$). The variability of LOI in surficial sediments is illustrated in Fig. 2b. The LOI of September ranged between 181,000 mg m^{-2} (at Stn. 3) and 472, 000 mg m^{-2} (at Stn. 25), averaging 333,000 mg m^{-2}. In November, the LOI ranged from 247,000 mg m^{-2} (at Stn. 10) to 664,000 mg m^{-2} at (Stn. 18) with an average of 372,000 mg m^{-2}. However, there was no significant difference in the sedimentary LOI in the surficial layer in the estuarine tidal flat between September and November observation.

3.2 Variability of inorganic nutrients in pore water

Concentrations of the inorganic nutrient in pore water are presented in Fig. 3. In September, NH_4^+–N concentration varied from 11.3 μmol–N l^{-1} (at Stn. 24) to 579 μmol–N l^{-1} (at Stn. 21), averaging 145 μmol–N l^{-1}. Concentration of $NO_2^- + NO_3^-$–N ranged from 128 μmol–N l^{-1} (at Stn. 19) to 258 μmol–N l^{-1} (at Stn. 10), with an average of 160 μmol–N l^{-1}. PO_4^{3-}–P concentration was between 0.806 μmol–P l^{-1} (at Stn. 17) and 9.75 μmol–P l^{-1} (at Stn. 5), with an average of 4.22 μmol–P l^{-1}. $Si(OH)_4$–Si concentration varied between 33.4 μmol–Si l^{-1} (at Stn. 14) and 265 μmol–Si l^{-1} (at Stn. 8), averaging 113 μmol–Si l^{-1}. In November, NH_4^+–N concentration varied from 68.9 μmol–N l^{-1} (at Stn. 16) to 566 μmol–N l^{-1} (at Stn. 25), with an average of 216 μmol–N l^{-1}. Concentration of $NO_2^- + NO_3^-$–N ranged from 36.1 μmol–N l^{-1} (at Stn. 1) to 100 μmol–N l^{-1} (at Stn. 20), averaging 63.9 μmol–N l^{-1}. PO_4^{3-}–P concentration was between 0.162 μmol–P l^{-1} (at Stn. 13) and 19.6 μmol–P l^{-1} (at Stn. 10), with an average of 2.72 μmol–P l^{-1}. $Si(OH)_4$–Si concentration varied between 57.1 μmol–Si l^{-1} (at Stn. 13) and 319 μmol–Si l^{-1} (at Stn. 25), averaging 135 μmol–Si l^{-1}. However, there was no significant difference in the nutrient concentrations in the pore water in the estuarine tidal flat between September and November, except the concentration of $NO_2^- + NO_3^-$–N. The higher $NO_2^- + NO_3^-$–N concentration was observed throughout September observations (Fig. 3b).

4. Discussion

4.1 Temporal variation of microphytobenthic biomass (Chl a) in the surficial sediments

Benthic Chl *a* content is widely used to determine the microphytobenthic biomass in sediments. This biomass in the intertidal mudflat estuary has been regulated by various environmental factors. Although we have no quantitative data on the abundance of microphytobenthos in the current study, we usually microscopically observed various species of pennate diatoms, *e.g. Navicula* spp. and *Nitzschia* spp. contained in surficial sediment samples.

In the present study, the average microphytobenthic biomass of September was 63% higher than that of November. The difference in microphytobenthic biomass between two observations might be explained by considering the available irradiance during exposure. Unfortunately, we have no irradiance data at surface sediment, whereas the exposure periods obtained from the tide table were used for discussion in the present study. Table 1 shows the entire aerial exposure periods and the aerial exposure periods in daytime (from 6 a.m.) at the tidal flat of the Maklong River estuary (Hydrographic Department, Royal Thai Navy, 2006). In August and September, the tidal flat was entirely exposed for 113 and 87 h, with a daily average of 3.65 and 2.90 h day^{-1}, respectively, and the aerial exposure periods in day-

Table 1. Entire aerial exposure periods (to air) and daytime aerial exposure periods (to sunlight from 6 a.m.) at the tidal flat of Maklong River estuary.

	Entire aerial exposure periods (to air)		Daytime aerial exposure periods (to sunlight)	
	Total (h)	Daily Average (h d^{-1})	Total (h)	Daily Average (h d^{-1})
August	113	3.6	93	3.0
September	87	2.9	54	1.8
October	48	1.5	14	0.5
November	29	1.0	0	0.0

* Data were obtained from Tide tables of Thai waters (Hydrographic Department, Royal Thai Navy, 2006).

time accounted for 82.3% and 62.1% of the entire exposure periods, respectively. Otherwise, the aerial exposure periods decreased continually to 1 h day^{-1}, and without aerial exposure in daytime in November. The longer daytime aerial exposure periods in September may well provide sufficient photosynthetically active radiation (PAR), which promotes the increase of the microphybenthos biomass in the tidal flat. On the other hand, the tidal flat was exposed a few hours during the night, and flooded throughout daytime in November; thus, the available PAR on the tidal flat would be less than that of September.

Irradiance is one of the most important factors that can regulate the variability of the microphytobenthos (MACINTYRE *et al.*, 1996; BARRANGUET *et al.*, 1998; YAMAGUCHI *et al.*, 2007; LOASSACHAN *et al.*, 2009). SUNDBÄCK and GRANÉLI (1988) found that microphytobenthic biomass (measured as Chl *a* content) decreased slightly and remained at a constant level for several weeks during exposure to no–light conditions, and increased markedly when exposed to light. KOH *et al.* (2007) also recently reported that the increase of surficial benthic Chl *a* (at 0–0.5 cm) reached 164%, accounting for 52 mg m^{-2} h^{-1} during daytime aerial exposure in the intertidal mudflat Ariake Sea, Japan. Furthermore, ADMIRAAL (1977) previously reported that the minimal daily quantum irradiance for light–saturated growth of estuarine benthic diatom investigated in a culture experiment ranged from 29 to 58 μmol photon m^{-2} s^{-1}. The growth of *Nitzschia* sp. isolated from surface sediment of Kaita Bay in Hiroshima, Japan showed a peak at 50 μmol photon m^{-2} s^{-1}, and its growth was inhibited under higher irradiance that (YAMAMOTO *et al.,* 2004). In contrast, COLIJIN and VAN BUURT (1975) reported the photosynthetic rate of microphytobenthos collected from the eastern part of the Dutch Waddensea was saturated by a light intensity of approximately 185 μmol photon m^{-2} s^{-1} (~10,000 lux), and no photo–inhibition was found at higher irradiance. In addition, MONTANI *et al.* (2003) also demonstrated that the photosynthetic rate of *Navicula* sp. isolated from an estuarine sand flat of the Seto Inland Sea was saturated at a light intensity of 165 μmol photon m^{-2} s^{-1} at 21℃, and no photo–inhibition was found at higher irradiance up to 400 μmol photon m^{-2} s^{-1}. Moreover, PINCKNEY and ZINGMARK (1993) also reported that the daily production of the microphytobenthos was highly variable, primarily due to the daily fluctuations in irradiance.

4.2 Relationship between microphytobenthos and sedimentary parameter

In the present study, however, there was no significant difference in the sedimentary LOI

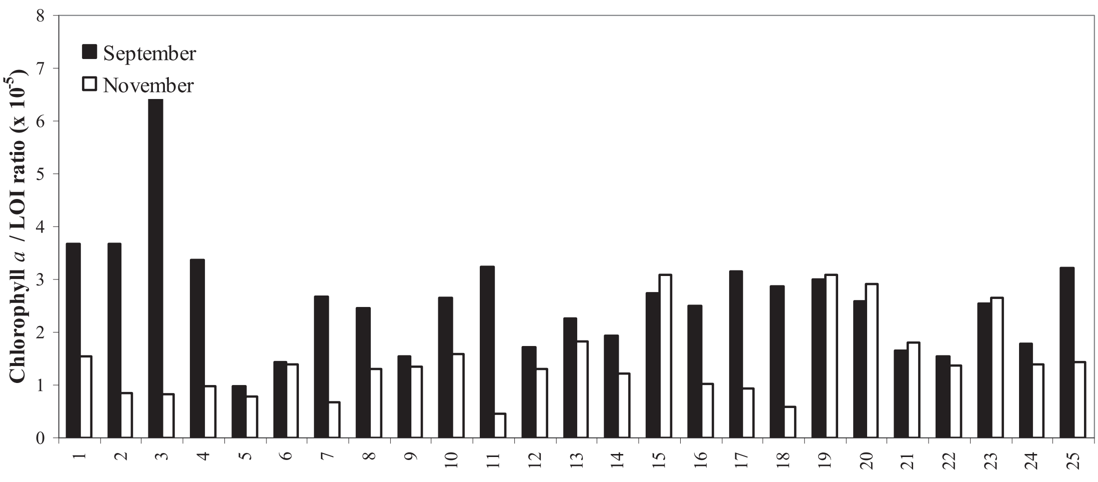

Fig. 4. Variability of benthic Chl *a* content to LOI ratio in surficial sediments.

in the surficial layer in the estuarine tidal flat between September and November. On the other hand, the Chl *a* to LOI ratio (Fig. 4) was statistically different between September and November ($P<0.0001$, $n=50$). The ratio of Chl *a* to LOI in September was significantly higher than that of November. Chl *a* to LOI ratio provides an index of sediment photo–autotrophy (LIGHT and BEARDALL, 1998), where high values correspond to high photo–autotrophic capacity relative to sedimentary organic matter. The result clearly suggested that the presence of higher microphytobenthic biomass observed in September contributed greatly to the sedimentary organic matter rather than that of November. This result corresponded well with the result of microphytobenthic biomass (discussed above). Chl *a* contents seem to be a small fraction of LOI in the sediments, because LOI contents did not change following the increasing Chl *a* contents in sediments. However, the increase in Chl *a* contents in September might result in the change of sedimentary organic matter in the tidal flat.

The inorganic nutrients at the sediment–water interface are one of the most important factors that control the variability of microphytobenthic production. On the other hand, microphytobenthos may also influence the nutrient concentrations at the sediment–water interface, acting as a filter (SUNDBÄCK *et al.*, 1991; WELKER *et al.*, 2002). Unfortunately, the correlations between benthic Chl *a* and NH_4^+–N, PO_4^{3-}–P and Si $(OH)_4$–Si contents in pore water, and also the difference of NH_4^+–N, PO_4^{3-}–P and Si $(OH)_4$–Si concentrations in pore water among two observations were not observed significantly in the present study. However, the significant correlation found between benthic Chl *a* and $NO_2^- + NO_3^-$–N concentration in pore water ($r=0.569$, $P<0.01$, $n=50$) coincided well with a previous study. TANTANASARIT and MEKSUMPUN (2007) reported a good relationship between Chl *a* concentration and $NO_2^- + NO_3^-$–N concentration in the water column at the Mae Klong River estuary. They concluded that $NO_2^- + NO_3^-$–N should be one of the most important factors regulating the growth of phytoplankton in the Mae Klong River estuary. Theses results suggested that $NO_2^- + NO_3^-$–N may also be the one of the important factors controlling photosynthetic growth of phytoplankton and microphytobenthos in the estuary.

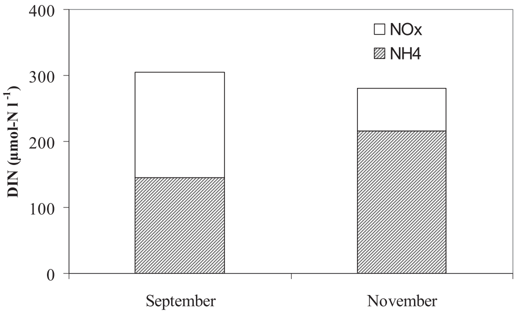

Fig. 5. Average concentrations of DIN ($NO_2^- + NO_3^-$–N + NH_4^+–N) in pore water.

In the present study, moreover, the higher $NO_2^- + NO_3^-$–N concentration was observed throughout September observations (Fig. 3b), and also statistically different from those observed in November ($P<0.001$, $n=50$). Otherwise, no significant difference in NH_4^+–N and DIN ($NO_2^- + NO_3^-$–N + NH_4^+–N) was observed between the two sampling months (Fig. 3b and Fig. 5). In addition, the average $NO_2^- + NO_3^-$–N concentrations of 160 μmol–N l^{-1} were found in September observation, contributing to the 52.5% to DIN concentration in pore water, and the contribution of $NO_2^- + NO_3^-$–N to DIN reduced to 22.8% (63.9 μmol–N l^{-1}) in November (Fig. 5). These results might be explained by considering that the oxygenation at the sediment–water interface was influenced by a longer aerial exposure period in September (discussed above), which might allow sediments at the sediment–air interface to reach aerobic conditions (THORNTON *et al.*, 1999). Also, the photosynthesis of microphytobenthos during daytime exposure might contribute partially to the oxygenation in the tidal flat, resulting in a higher $NO_2^- + NO_3^-$–N concentration in pore water via nitrification processes in the tidal flat of the Mae Klong River estuary.

Unfortunately, we planed firstly to investigate the spatial distribution of microphytobenthos in the tidal flat, whereas the all sedimentary parameter data between an each zone (3 zones) were not significantly different. Hence, we could not discuss clearly about spatial distribution of all parameters in the present study.

5. Conclusion

This study describes and quantifies the short–term variation of microphytobenthic biomass and associated controlling factors, as well as the influence of the microphytobenthic production on sediment quality in the tidal mudflat of the Mae Klong River estuary. Our results demonstrated that: (1) the difference of microphytobenthic biomass among two observations was due to irradiance available during aerial exposure in daytime, and (2) the higher microphytobenthic biomass might change the sedimentary composition in surficial sediments. Finally, (3) the oxygenation at sediment–water interface influenced by longer aerial exposure periods might allow sediments at the sediment–water interface to become aerobic conditions, resulting in increase of $NO_2^- + NO_3^-$–N concentration in pore water via nitrification processes in the tidal flat of the Mae Klong River estuary.

Acknowledgements

We gratefully acknowledge the generous assistance of Ms. Chayarat Tantanasarit and the students of the Laboratory of Marine Environment, Department of Marine Science, Kasetsart University during the field observations throughout the study period. We also acknowledge anonymous reviewers for their helpful comments and suggestions on the manuscript. A part of this research was funded by the Center for Advanced Studies in Tropical Natural Resources, NRU–KU, Kasetsart University.

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Received: April 13, 2011
Accepted: December 19, 2011

La mer 50 : 11-21, 2012
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Biomass of marine macrophyte debris on the ocean floor southeast of Hokkaido Island adjusted by experimental catch efficiency estimates

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Abstract: Most marine macrophytes detach from the bottom substrate after attaining highest biomass in their maturation season. Some marine macrophytes washes ashore or remain in the beds in coastal waters, the others are transported to offshore waters. There is little information on the fate of transported macrophytes. To estimate the biomass of marine macrophyte debris on the offshore deep–sea floor of the northwestern Pacific Ocean (off the southeastern coast of Hokkaido, Japan), we conducted bottom trawl surveys on the continental shelf and slope at depths from 330m to 920m during the summer season in 2008. The nets retrieved samples of macrophyte debris in 20 (83%) of 24 trawl tows. To quantify the *in situ* biomass, we calculated the catch efficiency of the bottom trawl net. We used two procedures to estimate a catch efficiency of 16.7% for *Sargassum horneri* fragments. Subsequently, we calculated that an average biomass density of macrophyte debris was 50.0 mg wet weight m^{-2} in our study area. Macrophyte debris included sargassaceous fucoid (70.0%), kelp (22.1%), seagrass (7.8%), and other brown and red algae (0.1%). We suggest that offshore transport of detached marine macrophytes, especially sargassaceous fucoid, constitutes an important pathway of organic carbon from coastal surface euphotic waters to the offshore deep ocean floor.

Keywords: *marine macrophyte debris, ocean floor, bottom trawl net, catch efficiency*

Introduction

Macrophyte beds of seaweed and seagrass in shallow coastal waters of the world's oceans are among the highest primary producer systems on the planet (SMITH, 1981; UNEP, 2009). Net primary production in macrophyte beds (i.e., mass of CO_2 fixed per unit area) is much higher than in phytoplankton blooms or in mangroves and closely similar to that in terrestrial rain forests (SMITH, 1981; SUZUKI, 1997). Most macrophytes are removed from the coastal seafloor by waves and currents, after attaining their highest biomass in their season of maturation (YOSHIDA, 1963; YATSUYA *et al.*, 2007; ITO *et al.*, 2009; KOMATSU *et al.*, 2009). Two surveys conducted in a bay on the Pacific coast of Japan (MIKAMI 2007) and in a bay facing the Sea of Japan (YATSUYA *et al.* 2007) reported that 80% of the annual primary production of sargassaceous fucoid fronds drifted from their beds with seaward outflow. After becoming detached from the substratum, macrophytes with positive buoyancy, including sargassaceous fucoid and seagrass, can float on the sea surface. These rafts of drifting macrophytes occur in ocean waters worldwide (THIEL and GUTOW, 2005; HERNÁNDEZ–

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CARMONA *et al.*, 2006; HINOJOSA *et al.*, 2010). In the waters surrounding Japan, drifting sargassaceous fucoid with positive buoyancy is the most common floating macrophyte (YOSHIDA, 1963; OHNO, 1984; HIRATA *et al.*, 2001; KOMATSU *et al.*, 2007).

After buoyant macrophytes lose positive buoyancy, they sink to the seafloor at velocities of 119–160m h^{-1} (in the case of sargassaceous fucoid) (SCHOENER and ROWE, 1970; JOHNSON and RICHARDSON, 1977; MIKAMI, 2007) and 98–120m h^{-1} in the seagrass species *Zostera caulescens* Miki (author's unpubl. data). Consequently, sinking macrophyte rafts may reach depths of about 2500m in one day.

Clumps of sargassaceous fucoid debris have been photographed in abyssal waters (SCHOENER and ROWE, 1970). Several photographic surveys using ROVs have found marine macrophyte debris aggregated in concave areas of the seafloor such as ocean basins and submarine canyons, where benthic material can easily accumulate (TORBEN, 1976; SMITH, 1978; LOWSON *et al.*, 1993; HARROLD *et al*, 1998; VETTER and DAYTON, 1999). Non–buoyant macrophytes such as *Eckloniopsis radicosa* (Kjellman) Okamura, *Undaria pinnatifida* (Harvey) Suringar, and *Undaria undarioides* (Yendo) Okamura have been found on the slopes of steep submarine valleys at depths of 200–400m off the coast of Suruga Bay, Japan (TAKAI *et al.*, 2010).

We suggest that buoyant macrophytes transported offshore by surface currents will eventually sink and become widely distributed on the ocean floor, while non–buoyant macrophytes heavier than seawater will be transported by bottom currents and gravity to offshore seafloors.

Hokkaido, the most northern major island of Japan, is in the subarctic North Pacific Ocean. Non–buoyant macrophyte species of kelp occur in this cold water region. Some cold water species of buoyant macrophyte, seagrass and sargassaceous fucoid, are also distributed around the island. IKEHARA (2004) observed sargassaceous fucoid of *Cystoseira hakodatensis* (Yendo) Fensholt floating in the waters offshore from southern Hokkaido (in the present study, *C. hakodatensis* was included in sargassaceous fucoid for simplicity, following HIRATA *et al.*, 2001).

Non–buoyant kelp species that grow inshore around Hokkaido may be transported to offshore seafloors when their blades erode. Buoyant macrophytes such as sargassaceous fucoid may eventually sink to offshore seafloors when their gas bladders deflate and lose their positive buoyancy. To determine the fates of non–buoyant and buoyant macrophytes, we conducted a field survey offshore from Hokkaido searching for fragments of macrophyte debris on the deep–sea floor.

Bottom trawling was used to survey the continental shelf and the continental slope between depths of 330 and 920m, at distances approximately 10–60km offshore from the southeastern coast of Hokkaido. Bottom trawl nets have a wide net mouth that enables collection of samples on the flat seafloors. Hence, this gear is commonly used for efficient sampling of deep benthic organisms (SPENGLER and COSTA, 2008). Substantial amounts of marine debris are frequently brought to the surface as bycatch in bottom trawl nets (PRENA *et al.*, 1999; PROBERT *et al.*, 1997).

An estimate of the catch efficiency of sampling gear is crucial in calculations of macrophyte biomass on the ocean floor. We used two different procedures to estimate the catch efficiency of the bottom trawl net and then proceeded with biomass calculations. We also determined the proportions of non–buoyant and buoyant species in the seafloor macrophyte debris accumulations.

Materials and Methods

Bottom trawling

We conducted systematic surveys southeast of Hokkaido from June to July 2008 using the R/V *Wakataka–maru* belonging to Tohoku National Fisheries Research Institute. We sampled the waters of the continental shelf and slope by trawls towed at depths of 330–920m at 24 stations (Fig. 1). The bottom trawl net had a wingspread of about 20m, a 27.4m head rope, and a 38m ground rope. The net was rigged with bridles and otter windows. A cylindrical rubber bobbin with a diameter of 150mm and steel sinkers were attached to the ground rope.

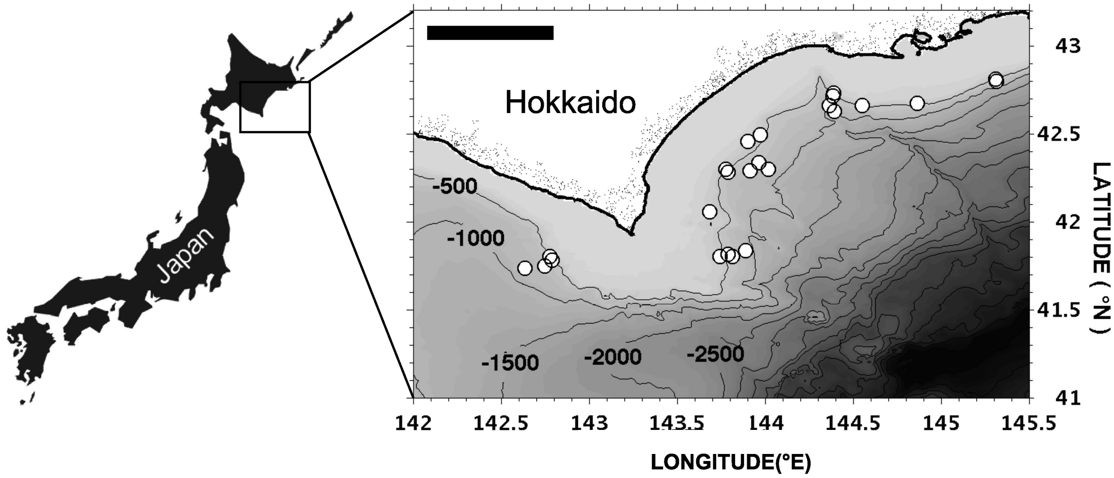

Fig. 1. Research area and macrophyte debris collection sites. Locations of bottom trawl casts in relation to bathymetric contours (m). Bathymetric depths are shown by a grayscale, with darker color indicating greater depth. Each trawl tow is represented by a circle plotted at the midpoint of deployment. Black scale bar＝50km.

The bottom trawl net was composed of a two-layered structure, each layer with a different mesh size: 50mm for the inner net, and 8mm for the outer net. The mean towing time from landing on the bottom to lifting the net from the bottom was 20 min at speeds of 2.5 to 3.5 knots. Every object captured in the bottom trawl was carefully investigated and analyzed immediately on board.

Sample treatment

Samples collected by bottom trawling may include floating macrophytes that are caught during the ascent or descent of the net. To distinguish between macrophyte debris from the seafloor and floating macrophytes, the relative densities of the samples in relation to seawater were examined onboard as follows. Macrophyte samples were immediately transported to a tank filled with surface seawater. Samples that were heavier than the water were classified as macrophyte debris obtained from the seafloor, while those that were lighter were classified as buoyant macrophytes and excluded from the analysis.

Macrophyte debris was weighed, identified to species, and preserved in a freezer at −40℃. All samples were photographed with a digital camera to record colors, and the images were used to verify species identifications.

Estimation of trawl catch efficiency

The catch efficiency of the bottom trawl net for macrophyte debris was examined by two procedures: a “frame-trawl experiment” and an “extra-net experiment.”

Frame-trawl experiment

An experimental frame-trawl net was deployed using the same ground rope as used on the actual bottom trawl net (Fig. 2). Two video cameras (Panasonic, DMC-FT1) were mounted on the center of the upper part of the frame trawl mouth and were oriented to view the entire length of the ground rope.

Sargassum horneri (Turner) C. Agardh was used for the experiment. It was freshly harvested from the sargassaceous fucoid bed in Funakoshi Bay, northeastern Japan, on 8 July 2009. We converted *S. horneri* to debris by removing all of the airbladders, thus eliminating positive buoyancy. Two hundred *S. horneri* debris fragments of 50 g each were prepared and randomly submerged on a sandy seafloor in a 20m square experimental area in Funakoshi Bay at a depth of 15 m (the center of the

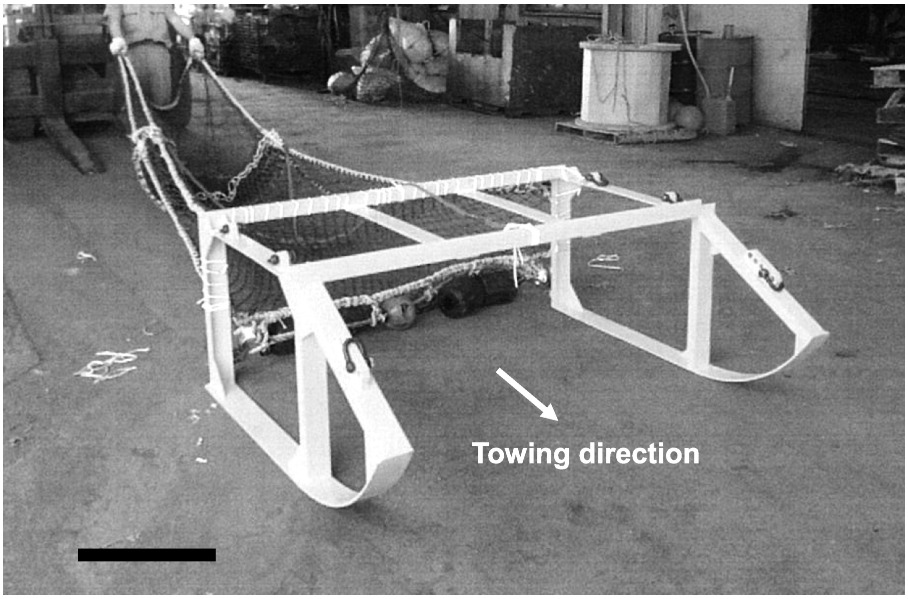

Fig. 2. Image showing the frame–trawl net used in the experimental catch efficiency test of the bottom trawl net. The ground–rope of this net was identical to that used in the actual bottom–trawl net assembly. Black scale bar＝50cm.

experimental area was at 39°23.0′N, 141°56.5′E). Fragments of *S. horneri* were collected with the experimental frame–trawl net and images of the ground rope were captured by video cameras. All trawls were towed at a speed of 2.0 knots.

Using the video images, we counted the number of *S. horneri* fragments that passed through the mouth of the frame–trawl in each tow. We calculated the efficiency of the bottom trawl net by comparing the numbers of *S. horneri* passing through the mouth and the numbers of fragments caught in the net. Sandy substratum dominated both the experimental site and the locations where we performed the bottom trawl surveys.

Extra–net experiment

The macrophyte debris catch efficiency of the bottom trawl net was also examined in 23 sampling tows in waters off the Pacific coast of northeastern Japan at bottom depths of 150–450m during April 2010. Trawls were deployed from the T/V *Tanshu–maru* belonging to Kasumi Senior High School, Hyogo Prefecture. The exterior of the net was covered by an extra net with an 8mm mesh and a chain ground rope (Fig. 3). Assuming that the catch efficiency (E) of the extra net was 100%, we estimated the efficiency of the bottom trawl net by comparing the masses of macrophyte debris caught by the regular and extra nets, expressed as the ratio of catch in the trawl net (TN) and catch in the extra net (EN) for each tow: $E=TN/(TN+EN)$. The mean towing duration was 10 min and towing speeds were those used in the normal bottom trawling survey (2.5 to 3.5 knots).

Estimation of biomass density

To estimate the density of macrophyte debris, the wet weight of each catch was divided by the area swept in each tow (following calculation procedures of KITAGAWA and HATTORI, 1998). The wingspread of the bottom trawl net was measured with an otter recorder (Furuno, CN–22A) 10 min before ascent of the net from the seafloor. Differential GPS was used to calculate towing distance. To measure the duration of each tow, the times when the net

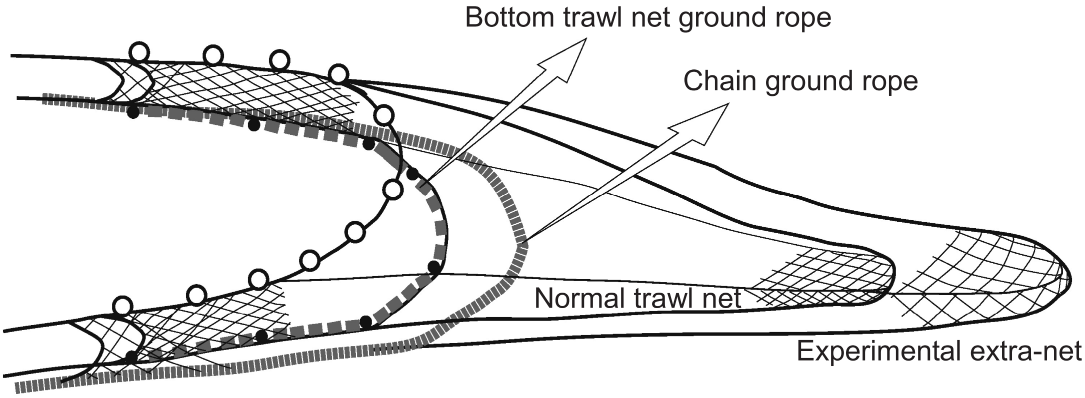

Fig. 3. Schematic of the extra–net used in the bottom–trawl net catch efficiency experiment. The experimental extra–net with a chain ground rope enveloped the bottom–trawl net.

Table 1. Marine macrophyte species netted in the survey trawls measured in terms of wet weight and frequencies of occurrence. The species are listed in decreasing order of weight. Catch efficiency of the bottom trawl net was not taken into consideration. Numbers in parentheses are frequencies of occurrence. Total number of hauls and areas sampled by the bottom trawl net were 24 and 0.60 km^2, respectively.

types		species name	wet weight (g) (number of occurrence)
seagrass		*Zostera marina* Linnaeus *Phyllospadix iwatensis* Makino	372 (17)
seaweed	sargassaceous fucoid	*Cystoseira hakodatensis* (Yendo) Fensholt	2292 (12)
		Sargassum horneri (Turner) C. Agardh	595 (3)
		Sargassum siliquastrum (Turner) C. Agardh	34 (1)
		Sargassum muticum (Yendo) Fensholt	23 (1)
		Sargassum sp.	18 (1)
	kelp	*Arthrothamnus bifidus* (Gmelin) Ruprecht	6500 (1)
		Costaria costata (C. Agardh) Saunders	250 (3)
	other algae	*Coilodesme japonica* Yamada	7 (2)
		Petalonia binghamiae (J. Agardh) Vinogradova	4 (1)
		Ptilota filicina J. Agardh	6 (1)

reached and left the bottom were determined acoustically using a net–mounted probe attached to the head rope. Based on the measured wingspread and towing distance, the swept area was calculated (mean±SD) as 0.025km^{-2} ±0.009km^2. The biomass density D (mg wet weight m^{-2}) of each towing location was estimated as follows:

$$D = \frac{W}{A \times E} \quad \cdots\cdots\cdots\cdots (1)$$

where A and W are the swept area and the wet weights of macrophyte debris samples collected from each towing location, respectively. To correct biomass density estimations, the calculated W/A was multiplied by the reciprocal of experimental catch efficiency E.

Results

Marine macrophyte debris

Marine macrophyte debris was collected from a wide area of the continental shelf and gentle slope in the study area. Eleven species of seagrasses and seaweeds (brown and

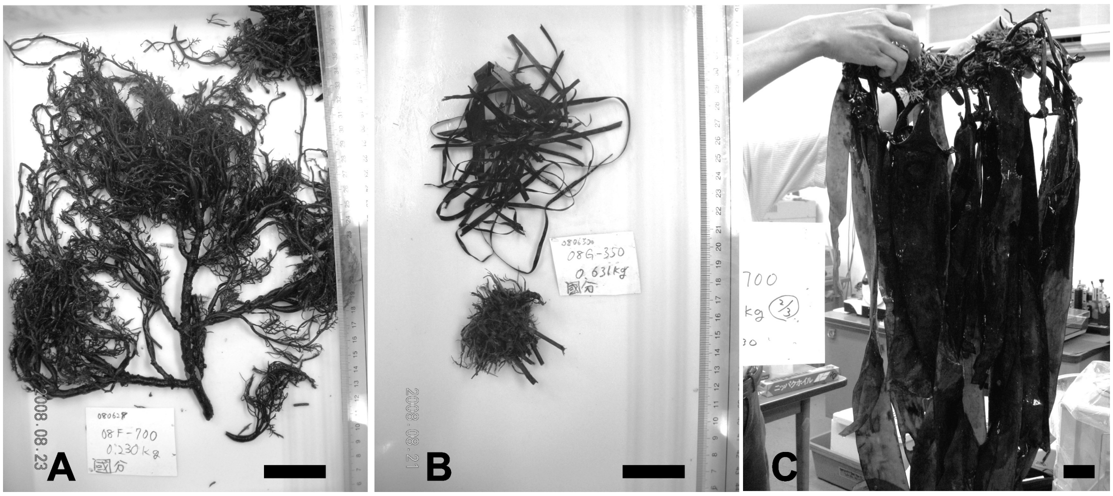

Fig. 4. Examples of frequently collected marine macrophyte debris. Fresh sample of *Cystoseira hakodatensi* (A) collected from a bottom depth of 880m at 41° 50.00′N,143° 53.26′E. (B) Seagrass (a mix of *Zostera marina and Phyllospadix iwatensis*) collected from a bottom depth of 330m at 42° 3.47′N, 143° 41.07′E. Most seagrass blades were discolored (dark green or black) and were presumed to be dead. (C) Kelp species (*Arthrothamnus bifidus*) collected from a bottom depth of 770m at 42° 17.38′N, 143° 54.88′E. Black scale bar = 5cm.

red algae) were collected (Table 1). The most abundant was sargassaceous fucoid. Among the species of sargassaceous fucoid, *C. hakodatensis* was dominant in the wet biomass (Fig. 4, A). *Cystoseira hakodatensis* occurs only in northern regions of Japan, mainly around Hokkaido (YOSHIDA, 1963; YOSHIDA, 1984). Two seagrass species, *Zostera marina* Linnaeus and *Phyllospadix iwatensis* Makino were also common (Fig. 4, B). Two kelp species, *Arthrothamnus bifidus* (Gmelin) Ruprecht and *Costaria costata* (C. Agardh) Saunders, were found. A large 6500 g fragment of *A. bifidus* debris was sampled at a bottom depth of 770 m (42° 17.38′ N, 143° 54.88′ E) (Fig. 4, C). Most of the sargassaceous fucoid samples appeared fresh, whereas most of the seagrasses were discolored (black) and appeared to be old.

Sargassaceous fucoid occurred in 14 of the 24 tows. The frequencies of kelp and seagrass occurrence were 4 and 17 of 24 tows, respectively. The quantity of seagrass collected was small, while their frequency of occurrence was high.

Catch efficiency of bottom trawling

Frame–trawl experiment

In video images, *S. horneri* fragments were seen to escape entrapment by the ground rope of experimental frame trawl (Fig. 5). Comparing the amount of *S. horneri* passing through the mouth with the amount caught in the net, we calculated a catch efficiency of 19% (N = 5, SD = 14.0).

Extra–net experiment

In 10 of 23 tows, fragments of *S. horneri* debris were caught in either the regular or extra nets. In 4 of 23 tows, *S. horneri* was caught in "both" nets at the same time and the catch efficiency was estimated as 14.5% (N = 4, SD = 7.3) (Table 2). Other types of macrophyte debris were not netted during the experiments.

Biomass estimations of marine macrophyte debris

The catch efficiencies estimated from the frame–trawl and extra–net experiments were similar at 19% and 14.5%, respectively. The similar estimates based on two quite different approaches convinced us that our calculations

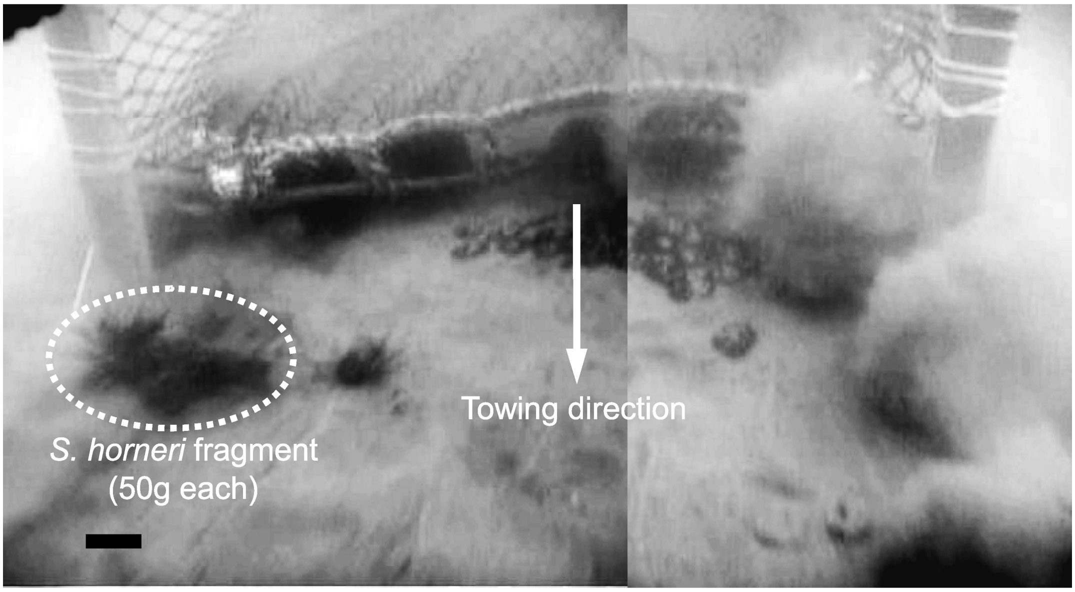

Fig. 5. Video image showing the frame–trawl net ground rope and *S. horneri* fragments in front of it during the frame–trawl experiment. Black scale bar = 10cm.

Table 2. Catch efficiency of marine macrophyte fragments (*Sargassum horneri*) captured with the bottom trawl net, estimated from experimental trawls with an extra net deployed outside of the main net. The total catch by the main net was divided by the catch of the extra net.

	Location		Depth operated (m)	Total catch by the botton trawl net (TN) (g)	Total catch by the extra net (EN) (g)	Catch efficiency (%) TN/ (TN+EN)
1	38° 25.8′N	141° 59.7′E	350	10	80	11.1
2	38° 55.6′N	142° 5.4′E	350	20	110	15.4
3	38° 24.9′N	142° 3.4′E	450	3	38	7.3
4	38° 24.9′N	142° 3.4′E	450	9	28	24.3
						14.5 ± 7.3*

* Average bottom trawl net catch efficiency ± SD
SD: Standard deviation

of catch efficiency were suitable for biomass estimation. We averaged the two estimates and obtained 16.7% for the catch efficiency of the bottom trawl.

This catch efficiency was applied to all other samples to adjust biomass densities, except for kelp which was always collected in large clumps. Because the large kelp clumps would not pass readily beneath the bottom trawl, we used a catch efficiency of 100% for kelp biomass estimation.

We calculated the average biomass density of

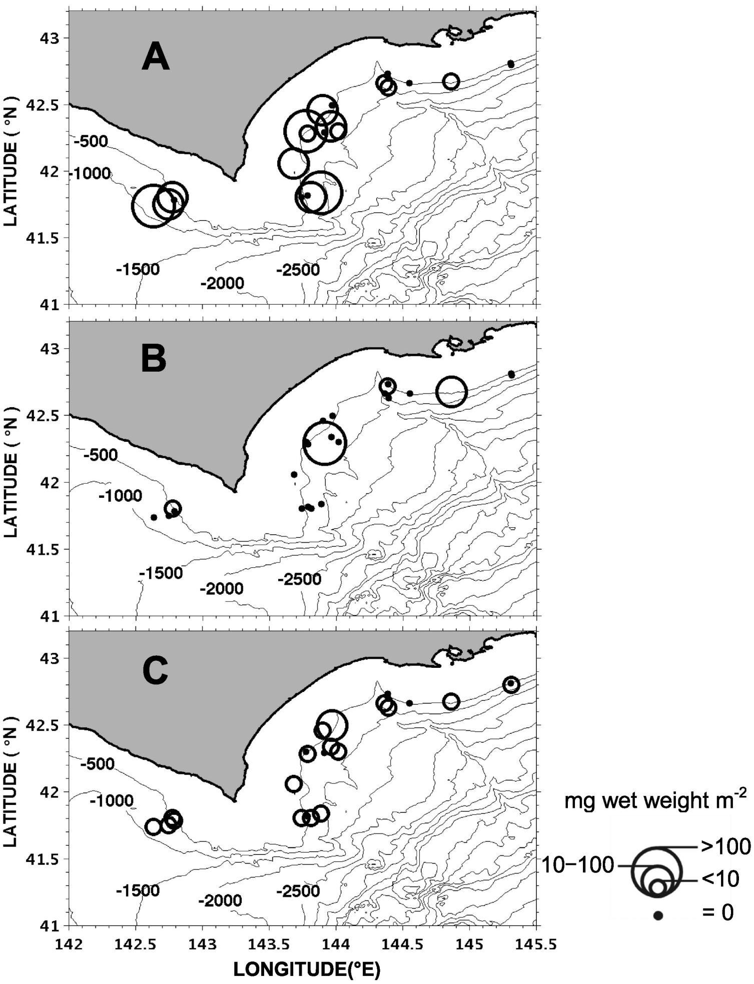

Fig. 6. Density distributions of macrophyte debris (mg wet weight m^{-2}). (A) Distribution of sargassaceous fucoid debris. (B) Distribution of kelp debris. (C) Distribution of seagrass debris. Biomass density at each station is indicated by the size of the circles.

total macrophyte debris as 50.0 mg wet weight m^{-2} (N=24, SD=67.0) across the entire study area. The total biomass in the survey area was composed mainly of species of sargassaceous fucoid, kelp, seagrass, and other brown and red algae in rank order. The average biomass density of sargassaceous fucoid was 35.0 mg wet weight m^{-2} (N=24, SD=52.9) (Table 3). Sargassaceous fucoid was made up with *C. hakodatensis, S. horneri*, and “other” sargassaceous species, constituting of 77%, 20%, and 3%, respectively. The average biomass density of kelp and seagrass were 11.0 mg wet weight m^{-2} (N=24, SD=51.0) and 3.9 mg wet weight m^{-2} (N=24, SD=7.6), respectively.

The distribution of macrophyte debris on the seafloor is shown in Figure 6. The frequently collected sargassaceous fucoid and seagrass were widely distributed and there were no discernible trends in their spatial distribution patterns within the survey area.

Carbon biomass of sargassaceous fucoid

The dry weight of sargassaceous fucoid is

Table 3. Biomass density (mg wet weight m^{-2}) of sargassaceous fucoid, kelp and seagrass calculated from the estimated catch efficiency and the bottom trawl operation. * Catch efficiency of 100% was applied to calculate the kelp biomass density.

sampling point				bottom depth	swept area (A)	2008 Spring								
latitude(N)		longitude(E)				sargassaceous fucoid			kelp			seagrass		
deg	min.	deg.	min.	(m)	(km^2)	catch efficiency (E)	wet weight (W) (g)	density W/(E×A) (mg wet weight m^{-2})	catch efficiency (E)*	wet weight (W) (g)	density W/(E×A) (mg wet weight m^{-2})	catch efficiency (E)	wet weight (W) (g)	density W/(E×A) (mg wet weight m^{-2})
42	48.70	145	18.65	480	0.025	0.167	0	0.00	1.00	0	0.00	0.167	0	0.00
42	47.91	145	18.85	600	0.016	0.167	0	0.00	1.00	0	0.00	0.167	3	1.03
42	40.42	144	51.78	390	0.016	0.167	7	2.73	1.00	224	14.33	0.167	1	0.40
42	39.57	144	33.15	500	0.025	0.167	0	0.00	1.00	0	0.00	0.167	0	0.00
42	43.92	144	23.33	450	0.038	0.167	0	0.00	1.00	0	0.00	0.167	0	0.00
42	42.92	144	23.18	540	0.027	0.167	0	0.00	1.00	10	0.38	0.167	0	0.00
42	39.68	144	21.99	780	0.021	0.167	13	3.73	1.00	0	0.00	0.167	14	4.02
42	37.57	144	23.61	880	0.021	0.167	24	6.94	1.00	0	0.00	0.167	11	3.06
42	27.31	143	54.12	340	0.024	0.167	277	67.94	1.00	0	0.00	0.167	8	1.99
42	29.69	143	58.39	440	0.028	0.167	0	0.00	1.00	0	0.00	0.167	170	36.48
42	20.10	143	57.94	720	0.016	0.167	154	57.47	1.00	0	0.00	0.167	6	2.29
42	17.96	144	1.23	880	0.014	0.167	12	5.08	1.00	0	0.00	0.167	6	2.63
42	3.47	143	41.07	330	0.035	0.167	573	98.73	1.00	0	0.00	0.167	52	8.93
42	17.97	143	46.67	500	0.026	0.167	637	148.47	1.00	0	0.00	0.167	0	0.00
42	16.75	143	47.49	570	0.034	0.167	15	2.69	1.00	0	0.00	0.167	8	1.40
42	17.38	143	54.88	770	0.026	0.167	0	0.00	1.00	6500	249.91	0.167	0	0.00
41	48.23	143	44.55	450	0.048	0.167	0	0.00	1.00	0	0.00	0.167	13	1.70
41	48.82	143	47.28	580	0.047	0.167	0	0.00	1.00	0	0.00	0.167	0	0.00
41	48.02	143	48.99	650	0.027	0.167	49	10.94	1.00	0	0.00	0.167	1	0.29
41	50.00	143	53.26	880	0.012	0.167	332	165.00	1.00	0	0.00	0.167	20	9.78
41	46.80	142	47.44	550	0.016	0.167	0	0.00	1.00	0	0.00	0.167	11	4.18
41	48.23	142	46.64	570	0.024	0.167	236	59.58	1.00	16	0.68	0.167	1	0.23
41	44.79	142	44.86	770	0.021	0.167	299	86.64	1.00	0	0.00	0.167	27	7.92
41	44.01	142	38.09	920	0.016	0.167	332	124.65	1.00	0	0.00	0.167	20	7.39
Average							123	35.02		281.26	11.05		15.50	3.90
Total							2961			6750			372	

generally approximately 20% of wet weight (TANIGUCHI, 1998; ITO *et al.*, 2009). The carbon content of sargassaceous fucoid is about 30% of its dry weight (YOSHIDA *et al.*, 2001). Using these ratios, we estimated the carbon biomass of sargassaceous fucoid from the wet masses of samples collected in our survey area. The average biomass density of sargassaceous fucoid (35.0 mg wet weight m^{-2}) is equivalent to a carbon biomass of 2.1 mg C m^{-2}. The average carbon biomass of sargassaceous fucoid in each of three bottom layer was calculated (Fig. 7). The average carbon biomass was high in the bottom layers deeper than 500 m.

Discussion

Bottom trawling is among the most efficient methods for sampling organisms on the ocean floor (SPENGLER and COSTA, 2008). We used this method and successfully obtained samples of macrophyte debris from the seafloor. However, the catch efficiency of a bottom trawl net is not 100%. Thus, the catch efficiency was estimated through two different procedures.

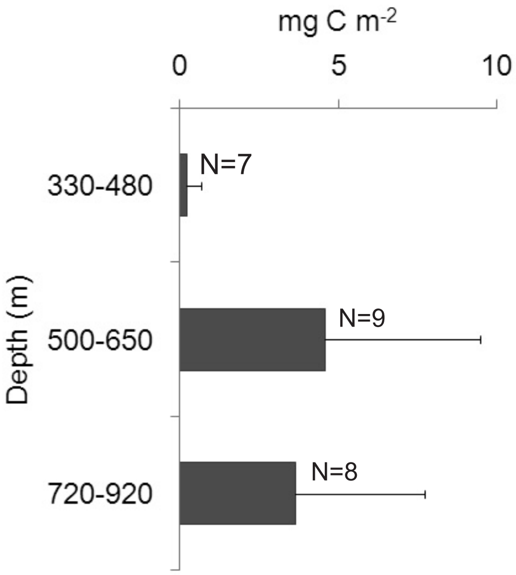

Fig. 7. Relationship between depth and carbon biomass of sargassaceous fucoid debris. Average carbon biomass (mg C m^{-2}) was calculated for depth layers of 330–480, 500–650, and 720–920 m. N values are the numbers of stations, while error bars indicate the standard deviation.

The catch efficiency of the bottom trawl net used in this study had been estimated previously for snow crab *Chionoecetes opilio* (FUJITA *et al.*, 2006). In the snow crab study, the ground–rope was observed with an underwater video camera attached at the trawl net mouth during the towing operation. The number of crabs caught in the net and the number of crabs approaching the ground–rope were compared, giving a catch efficiency estimate of 13.0%. Average carapace widths of the snow crabs measured during the experiment were 11.0cm for males and 6.8cm for females. In our "frame–trawl experiment," the observed diameters of *S. horneri* fragments in seawater were about 10–30cm, and the calculated catch efficiency was 16.7%. Thus, two kinds of benthic organism of similar size had similar catch efficiencies with the same net gear, which will allow some degree of generalization in future studies.

Drifting macrophytes with positive buoyancy are the most abundant floating objects on the world's oceans (THIEL and GUTOW, 2005), and the most common in Japanese waters are species of sargassaceous fucoid (YOSHIDA, 1963; OHNO, 1984; HIRATA *et al.*, 2001; KOMATSU *et al.,* 2007). In our study area, sargassaceous fucoid composed 70.0% of the total biomass of bottom samples. Sargassaceous fucoid of *C. hakodatensis* was the major macrophyte debris species off southeastern Hokkaido. Our results agree with those of IKEHARA (2004), who reported this *Cystoseira* floating in the offshore waters of southern Hokkaido. The specimens collected in our survey were still fresh, suggesting that they had sunk to the bottom shortly before collection. Hence, sargassaceous fucoid drifting from the coast of southern Hokkaido had lost its buoyancy and sunk to the offshore seafloor.

The primary organic carbon source for the ocean floor is generally thought to be sinking particles that originate mainly from phytoplankton in surface waters (JOSEFSON and CONLEY, 1997). However, TORBEN (1975) reported several photographic surveys conducted off the east coast of the USA and in the Caribbean Sea showing the utilization of seagrass debris by benthic isopods as a source of food and shelter on the deep–sea floor. Our study also indicates that macrophytes are supplied to the deep–sea floor off Hokkaido. Marine macrophytes transported from the coast of southern Hokkaido may play an important role in supplying organic carbon to the surrounding offshore deep ocean.

On the basis of published reports of carbon content ratio of sargassaceous fucoid, we estimated that 2.1 mg C m^{-2} of sargassaceous fucoid derived carbon accumulated on the seafloor throughout our study site. This value was similar to the biomass of giant kelp, *Macrocystis pyrifera* (Linnaeus) C. Agardh, on the bottom of the continental shelf off California USA (0.5–10 mg C m^{-2}) (HARROLD *et al.*, 1998). Therefore, the amount of seaweed–derived carbon on the continental shelf is similar off the east and west Pacific coasts. Hence, there is a global pathway of organic matter transport from coastal waters to the deep ocean driven by drifting macrophytes. The present study revealed an annual organic carbon pathway from temperate coastal waters to the ocean floor below the euphotic surface ocean, driven by newly recruited macrophytes grown up every year. This phenomenon probably also occurs in drifting seaweeds in boreal and tropical waters. To elucidate the fate of macrophyte–derived organic matter in the ocean, we plan further studies of macrophyte transport from the coast to the deep ocean.

Acknowledgments

We are deeply indebted to Dr. Y. ISHIDA of Tohoku National Fisheries Research Institute, Fisheries Research Agency for providing us with opportunities to take part in their research activities off the Pacific coast of northern Japan. Our thanks also go to two anonymous journal reviewers for corrections and comments that greatly improved the manuscript. We wish to thank the captain and crew of the R/V *Wakataka–maru* (Tohoku National Fisheries Research Institute, Miyagi Prefecture) for their skillful trawling operations and help in collecting the samples analyzed in this study. We are grateful to Mr. R. IKEDA of Nichimo Co., Ltd. for his support throughout the production process of the frame trawl net used in this study. Thanks are also due to Mr. K. MORITA, Mr. M. KUROSAWA and Mr. M. HIRANO of Otsuchi Marine Research Center, Ocean Research Institute, the University of Tokyo for their cooperation in the "frame–trawl" catch–efficiency experiment mentioned in this study. Finally, we want to express our gratitude to the captain and crew of the T/V *Tanshu–maru* (Kasumi Senior High School, Hyogo Prefecture) for their skillful trawling operations in the "extra–net" catch efficiency experiment described in this study.

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Received: July 26, 2011
Accepted: November 28, 2011

La mer 50 : 23-35, 2012
Société franco-japonaise d'océanographie, Tokyo

Use of mangroves for treatment of wastewater from shrimp aquaculture ponds: Nitrogen and phosphorus budgets under increased area ratio of shrimp ponds

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Abstract: To assess the capacity of uptake of nitrogen and phosphorus by mangrove *Rhizophora mucronata* enclosures from shrimp *Penaeus monodon* aquaculture ponds, we carried out culture experiments at Samut Songkhram, Thailand. The area ratio of the shrimp culture pond to the mangrove enclosure was 1:1 in the previous study. Shrimp farmers hope that the area of the mangrove region can be reduced in view of effective economic management. In this study, an experimental area ratio between the shrimp aquaculture ponds and mangrove enclosures of 2:1 was conducted and the effect was evaluated. However, it was shown that the deterioration of the pond sediments could not be prevented in the case that the area ratio between the shrimp aquaculture ponds to the mangrove enclosure was 2:1. For sustainable pond usage, the necessity for increasing the area ratio of mangroves to shrimp culture ponds was indicated based on these results.

Keywords: *mangrove, shrimp aquaculture, treatment, budgets*

1. Introduction

Japan is the second largest shrimp importing country in the world and is importing more than 60% of the shrimp produced in brackish waters from Southeast Asian countries (HAMANO *et al.*, 2010). Therefore, shrimp aquaculture is an important export industry in these countries and the shrimp farming areas have been developed in order to acquire foreign currency. In these countries, however, mangrove trees have been cut down in order to construct shrimp aquaculture ponds (BARBIER and SATHIRATHAI, 2004), and the total area of mangrove in Thailand has decreased by more than 50% since the 1960's (BHODTHIPUKS, 1988; CLOUGH, 1993). Mangrove forests have an important role in the coastal tropical environment for purification of effluents from aquaculture and other terrestrial sources (ROBERTSON and PHILLIPS, 1995; RIVERA–MONROY *et al.*, 1999).

Intensive shrimp culture needs a large amount of feed and only 24% of nitrogen and 13% of phosphorus in feed input has been shown to be incorporated into the shrimp body (BRIGGS and FUNGE–SMITH, 1994). The remainder of the feed flows out into the surrounding waters or is accumulated in the sediment. After shrimp ponds are used for several years, they are disused and left (STEVENSON, 1997; OKUBO *et al.*, 2004) even if the sediment is removed

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after harvest.

In order to develop sustainable shrimp aquaculture practices, several methods have been proposed to decrease the impact of shrimp effluent (BOYD *et al.*, 1994; SANDIFER and HOPKINS, 1996; DIERBERG and KIATTISIMKUL, 1996; LIN *et al.*, 2003; TSUTSUI *et al.*, 2010). Although integrated mangrove–aquaculture systems have been initiated in Southeast Asia (RIVERA–MONROY *et al.*, 1999; PRIMAVERA, 2000; PRIMAVERA *et al.*, 2007; ALDON *et al.*, 2008), they are still at the verification and early dissemination stage and the use of mangrove areas for treatment of nutrients from intensive shrimp farming has not been widespread in tropical aquaculture regions (HAMANO *et al.*, 2010).

When shrimp culture density is high, disease outbreaks occur (SHIMODA *et al.*, 2005a), and the feed conversion ratio (FCR) also deteriorates and production efficiency decreases even if the shrimp remain healthy. Between the pond where water was circulated with mangroves and the control pond where water was not circulated, the production, survival rate and FCR were improved in the circulated pond, and therefore the aquaculture production efficiency was improved by the circulation with mangroves where the nutrients were utilized for enhancing mangrove growth. RIVERA–MONROY *et al.* (1999) suggested that an area of mangrove forest from 0.04 to 0.12 hectares is required to completely remove the DIN load from effluents produced by a 1 hectare pond. On the other hand, ROBERTSON and PHILLIPS (1995) reported that between 2 and 22 hectares of forest are required to filter the nitrogen and phosphorus loads from effluent produced by a 1 hectare pond. PRIMAVERA *et al.* (2007) suggested that 1.8–5.4 hectares of mangroves are required to remove nitrate wastes from 1 hectares of shrimp pond in the Central Philippines. GAUTIER *et al.* (2001) reported that the efficiency for effluent treatment as a biofilter using mangrove wetlands is less predictable than expected. However, these calculations are largely based on hypothetical theory because model experiments have not been carried out quantitatively.

The area ratio of shrimp culture ponds and mangrove enclosures was carried out at a ratio of 1:1 in the previous study (SHIMODA *et al.*, 2005b; SHIMODA *et al.*, 2007). Needless to say, shrimp farmers hope that the area of the mangrove region can be reduced in view of economic management. In this study, to develop sustainable shrimp culture methods, an experiment using an area ratio between shrimp aquaculture ponds and mangrove enclosures of 2:1, was conducted and the effect was evaluated in comparison to ponds of a ratio of 1:1 and a control of shrimp aquaculture pond only (no circulation to a mangrove enclosure).

2. Materials and methods

Experiments that involved the circulation of water between shrimp aquaculture ponds stocked with *Penaeus monodon* and mangrove enclosures planted with *Rhizophora mucronata,* were carried out at the Samut Songkhram Coastal Aquatic Research Station, Faculty of Fisheries, Kasetsart University, Thailand. Six ponds of 40×20 m for the upper level, 35×15 m for the lower level and 1.5 m depth were used for this experiment (Fig. 1). Shrimp were cultured in four ponds, and mangrove trees were planted in two. In Ponds 1, 2, 3 and 6, 12,500 shrimp larvae *Penaeus monodon* at the PL (post larvae) 20 days stage, were stocked (about 24 shrimp per m^2) and shrimps were intensively cultured for about 5 months from Friday, September 19, 2003. Totals of 476 one–year–old mangrove saplings *Rhizophora mucronata* had been planted in each of Ponds 4 and 5 in June, 2002.

Ponds 5 and 6 were connected, and the area ratio of shrimp culture pond and mangrove enclosure was 1:1. Ponds 2 and 3 where shrimp were cultured and Pond 4 where mangroves were planted, and they were connected so that the area ratio was 2:1 (Fig. 1). First, brackish water was added to a depth of 110 cm in the shrimp aquaculture ponds on the first Friday and water was removed from the mangrove ponds. Pond 1 was the control pond and shrimp were cultured in a closed system. In Ponds 4 and 5, every Monday, Wednesday and Friday, about 30% of the water in shrimp pond was transferred by siphon from the mangrove pond to the shrimp pond and the water was pumped

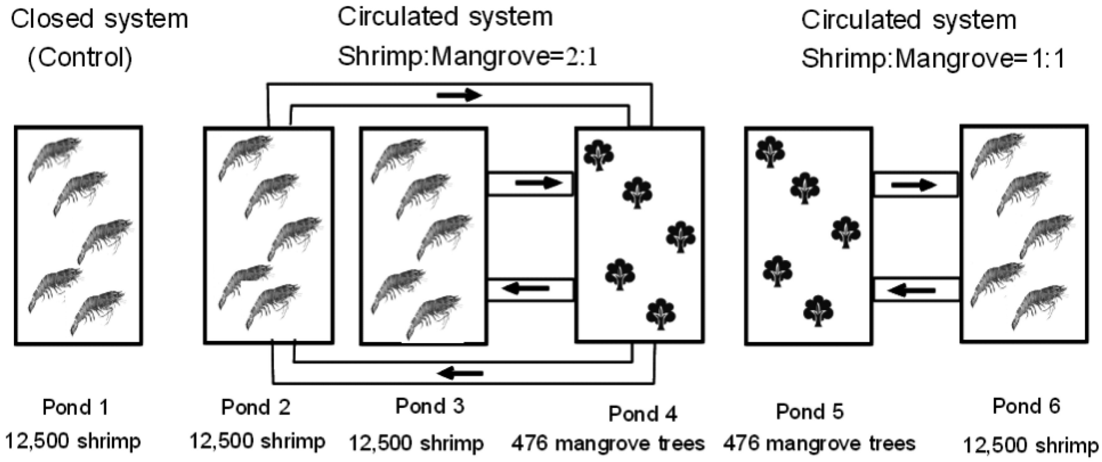


Fig. 1. Schematic outline of shrimp aquaculture ponds and mangrove enclosures used in the experiment.

back into the shrimp pond using a gasoline–powered water pump. In Ponds 2, 3 and 4, about 30% of the water in Pond 2 was transferred to Pond 4, every Monday. Water in Pond 4 was pumped back to Pond 2 every Wednesday. After that, about 30% of water in Pond 3 was transferred to Pond 4 on the same day. Water in Pond 4 was pumped back to Pond 3 every Friday. There was no standing water in Pond 4 from Fridays to Mondays.

Monitoring of the water quality and collection of water and soil samples were conducted weekly before circulation of the water by paddle wheels. The surface water temperature, salinity, dissolved oxygen, turbidity, and pH were measured with a TOA model WQC–20A water quality checker. Water samples were collected in two plastic bottles from the center of each pond. The samples were immediately filtered through Whatman GF/F filters for the collection of chlorophyll *a* + phaeopigment (Chl. *a* + Phaeo.), particulate nitrogen and phosphorus. For Chl. *a* + Phaeo. analysis, the filters were soaked in *N, N*–dimethylformamide (SUZUKI and ISHIMARU, 1990), and then Chl. *a* + Phaeo. was extracted in solvent and analyzed with a fluorometer (Turner Designs TD–700). Particulate nitrogen was analyzed with an elemental analyzer (Fisons EA–1108). Particulate phosphorus was analyzed using the method of SOLORZANO and SHARP (1980b). The ammonia concentration was measured immediately after filtration using a method developed by SASAKI and SAWADA (1980). Nitrate, nitrite and phosphate (DIP) were analyzed by the standard method (PARSONS *et al.*, 1984) using a spectrophotometer (Shimadzu UV–1201). After potassium peroxydisulfate ($K_2S_2O_8$) was added to the samples, and digestion was carried out by autoclaving, the nitrate and phosphate concentrations were measured according to the method of SOLORZANO and SHARP (1980a) for total dissolved nitrogen and that of MENZEL and CORWIN (1965) for total dissolved phosphorus. Dissolved inorganic nitrogen (DIN) concentration was calculated from ammonia, nitrate and nitrite. Dissolved organic nitrogen (DON) and phosphorus (DOP) concentrations were calculated from TDN–DIN and TDP–DIP, respectively. Core–mud samples of 3-cm depth were collected from the surface using a syringe with 23-mm in diameter. The collected mud was dried, weighed, and crushed with a mortar. The nitrogen content in the sediment was analyzed with an elemental analyzer (Fisons EA–1108). The phosphorus content in mud was analyzed with the method developed by ANDERSEN (1976). *N, N*–dimethylformamide was added directly to the surface 1-cm depth mud sample for Chl. *a* and Phaeo. extraction. After centrifugal separation, the supernatant was analyzed.

Table 1. Mean ± standard deviation of height, number of leaves and stalk diameter of mangrove trees *Rhizophora mucronata* at the beginning and end of the experiment in Ponds 4 and 5

	Height (cm)		Number of leaves (no.)		Diameter of stalk (mm)	
	Beginning	End	Beginning	End	Beginning	End
Pond 4	89.4±9.8	110.5±13.9	41.2±14.0	82.5±34.7	27.8±2.7	31.4±3.3
Pond 5	94.1±12.0	111.5±16.4	40.8±14.7	79.4±28.4	24.8±3.4	27.3±3.7

Table 2. Number of stocked larvae, shrimp total weight and individuals at harvest, survival rate, average shrimp size, the amount of feed during the experimental period and the food conversion ratio (FCR)

Pond	The area ratio	Stocked larvae		Harvest		Survival rate	Average size	Feed	FCR*
		(Individuals)	(/m²)	(kg)	(Individuals)	(%)	(g)	(kg)	
1	Control	12500	24	240.4	8273	66.2	29.1	352.8	1.47
2	Circulated with a ratio of 2:1	12500	24	194.6	7733	61.9	25.2	345.4	1.77
3	Circulated with a ratio of 2:1	12500	24	193.7	7652	61.2	25.3	320.6	1.66
6	Circulated with a ratio of 1 :1	12500	24	264.8	8971	71.8	29.5	400.1	1.51

*FCR= (We ight of fe ed) / (Weight of harvest−larvae)

The net nitrogen and phosphorus transport (NT and PT) from the shrimp ponds to the mangrove enclosures were calculated as follows:

NT or PT = (total quantity of nitrogen or phosphorus in water transported from a shrimp pond to a mangrove enclosure) − (total quantity of nitrogen or phosphorus returned from the mangrove enclosure to the shrimp pond).

The mean height, number of leaves, and diameter of the stalks of 10 mangrove trees were measured at the beginning and end of the experiment. At harvest, shrimp and other organisms in the ponds were sampled. The biomass, and their nitrogen and phosphorus contents were analyzed using the same method as that used for particulate nitrogen and phosphorus analysis.

3. Results

Table 1 shows mean± standard deviation of height, number of leaves and stalk diameter of mangrove trees *Rhizophora mucronata* at the beginning and end of the experiment in Ponds 4 and 5 for about 5 months from 19 September, 2003. All the values increased, showing that the mangroves grew. Table 2 shows the number of stocked larvae, shrimp total weight and individuals at harvest, survival rate, average shrimp size, the amount of feed and the food conversion ratio (FCR) during the experiment in Ponds 1, 2, 3 and 6. The shrimp total weight at harvest, survival rate and FCR were 193.7–194.6 kg/ pond, 61.2–61.9 % and 1.66–1.76 in Ponds 2 and 3 where the area ratio between shrimp aquaculture ponds and mangrove enclosure was 2:1, and they were 264.8 kg/ pond, 71.8% and 1.51 in Pond 6 where the area ratio was 1:1. In the control pond, they were 240.4 kg/ pond, 66.2% and 1.47. Therefore, aquaculture efficiency was better in Pond 6.

The water temperature decreased gradually from 30 to 24℃ (Fig. 2), and salinity increased from 13 to 31 in the aquaculture ponds. Though anoxic water did not occur in the shrimp aquaculture ponds, low level of dissolved oxygen were observed at the end of the experiment in Pond 4 that was a mangrove enclosure. The pH showed a tendency to decrease slightly and turbidity tended to increase.

DIN concentration spiked occasionally but

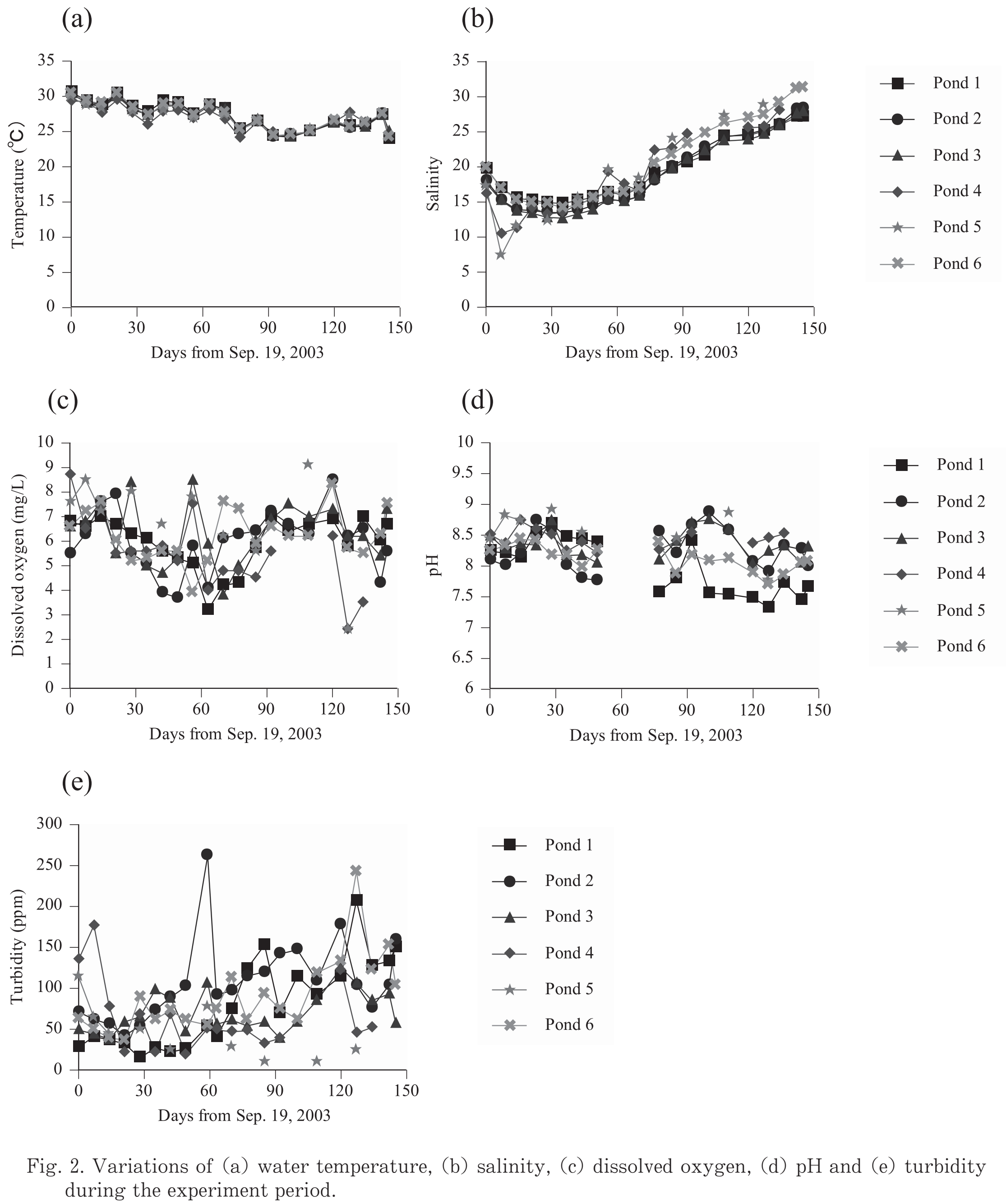


Fig. 2. Variations of (a) water temperature, (b) salinity, (c) dissolved oxygen, (d) pH and (e) turbidity during the experiment period.

the contribution to TN was small (Fig. 3). After an initial decrease in DON, it showed a tendency to increase. PN also increased in the culture ponds. As a result, the contribution of DON and PN was large to TN, and TN concentration increased from 2 mgN/L to 5 mgN/L on average in all aquaculture ponds. Though DIP concentration varied largely, both of DOP and PP concentrations gradually increased (Fig. 4). Contribution to TP was

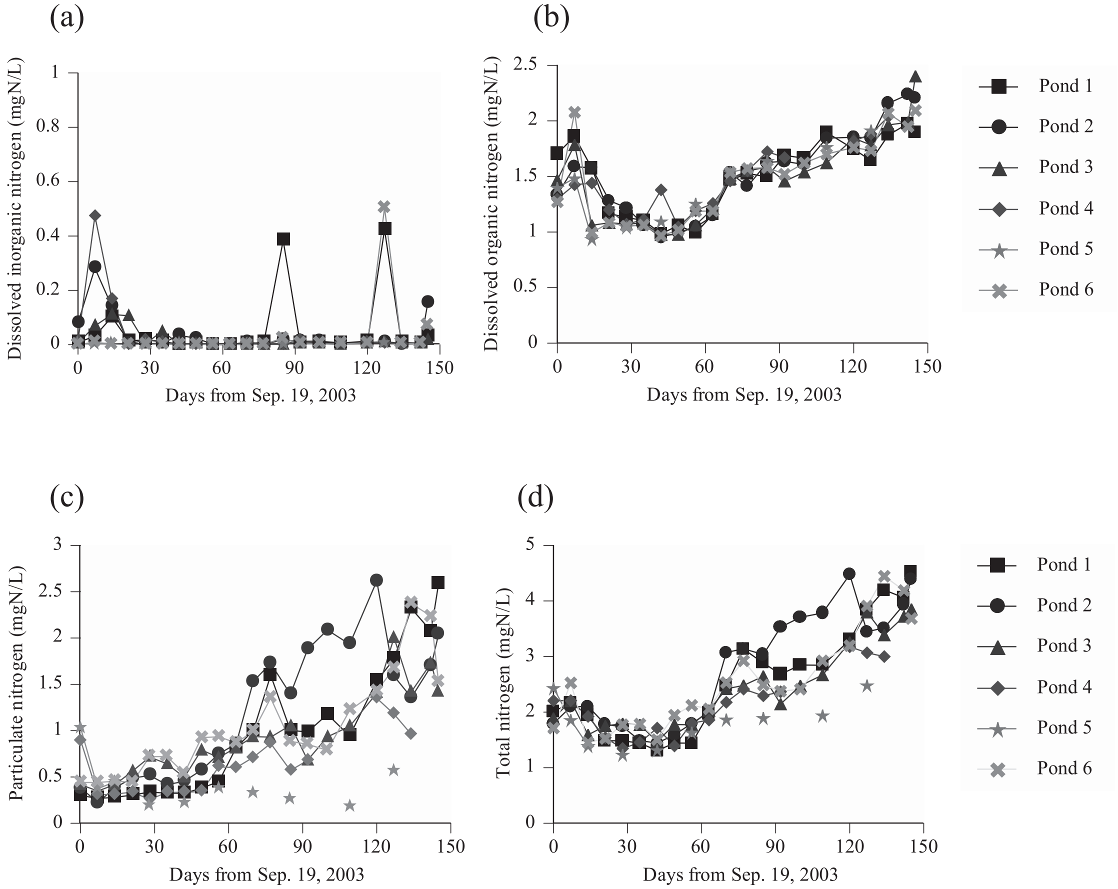


Fig. 3. Concentrations of (a) dissolved inorganic nitrogen, (b) dissolved organic nitrogen, (c) particulate nitrogen, and (d) total nitrogen.

largely in PP, and the TP concentration in the culture ponds increased from 0.16 mgP/L to 0.42 mgP/L on average. Chl. a + Phaeo. concentration in the water also increased (Fig. 5). Though nitrogen and phosphorus contents in mud (Fig. 6) fluctuated largely, they increased at the end of this experiment. The linear regression slopes between nitrogen content and Days were 1.194×10^{-3} μgN/cm^2/days, 5.300×10^{-3} μgN/cm^2/days, 3.862×10^{-3} μgN/cm^2/days, and 1.800×10^{-3} μgN/cm^2/days in Ponds 1, 2, 3 and 6, respectively. And the slopes between phosphorus content and Days were 1.387×10^{-3} μgP/cm^2/days, 8.996×10^{-4} μgP/cm^2/days, -1.307×10^{-4} μgP/cm^2/days and 2.510×10^{-3} μgP/cm^2/days, respectively. Though they were not significant statistically because of the large fluctuations, the slope for nitrogen was small and that for phosphorus was large in Ponds 1 and 6 where the aquaculture efficiency was better, and they showed the opposite trend in Ponds 2 and 3 where the aquaculture efficiency was worse.

The amount of transported nitrogen or phosphorus (Fig. 7) from Pond 6 that was a shrimp aquaculture pond to Pond 5 that was a mangrove enclosure, gradually increased during the experimental period. In Ponds 2, 3 and 4, the amount of transported phosphorus decreased temporally. The net nitrogen or phosphorus transports were large in Pond 6 where the area ratio between the aquaculture pond

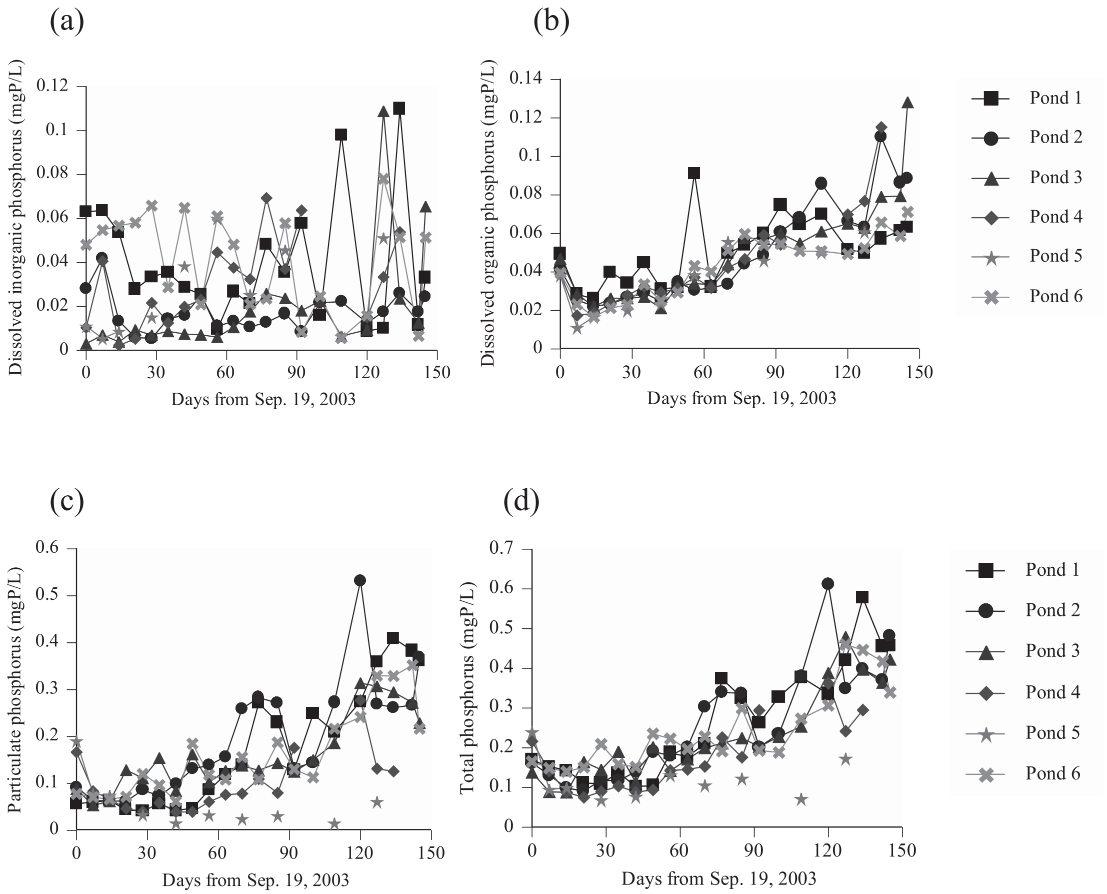


Fig. 4. Concentrations of (a) dissolved inorganic phosphorus, (b) dissolved organic phosphorus, (c) particulate phosphorus, and (d) total phosphorus.

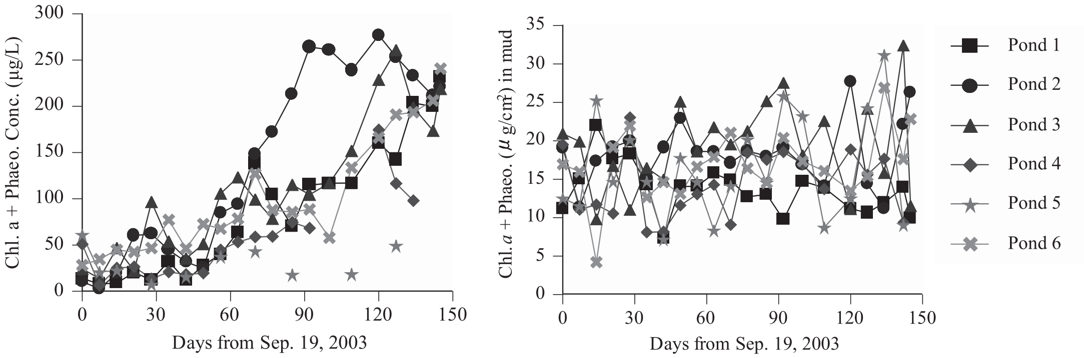
and the mangrove enclosure was 1:1.

4. Discussion

Relative growth rate (RGR_H) (HUNT, 1982) of *Rhizophora mucronata* was not so high in comparison with some mangrove species and rates of 0.720±0.036 and 0.743±0.035 (mm/cm/mo) are reported in Thailand (Thampanya *et al.*, 2002). In this study, RGR_H was calculated with 0.621±0.208 in Pond 4 and 0.512±0.184 (mm/cm/mo) in Pond 5. Though mangrove saplings grew during this experiment, the growth rate was at a comparative level but slightly lower in the mangrove enclosures compared to saplings under natural conditions. Circulation of water between the shrimp aquaculture ponds and the mangrove enclosure simulated the level of water experienced during a tidal change. However, the weekly circulation of water might be insufficient to fully enhance mangrove growth.

The dry season of Thailand is from November to February and it doesn't rain around November and the temperature falls. Therefore, the water temperature fell and salinity rose during the experimental period, though salinity fell slightly immediately after the beginning of the experiment (Fig. 2). *Penaeus monodon* is euryhaline (0–52) (MOTOH, 1981) and the most suitable salinity is about 15 to 20 and ideal water temperature is thought to be 25–30 degrees (YOSHIDA, 1987). Therefore, the

(a) (b)



(a) (b)

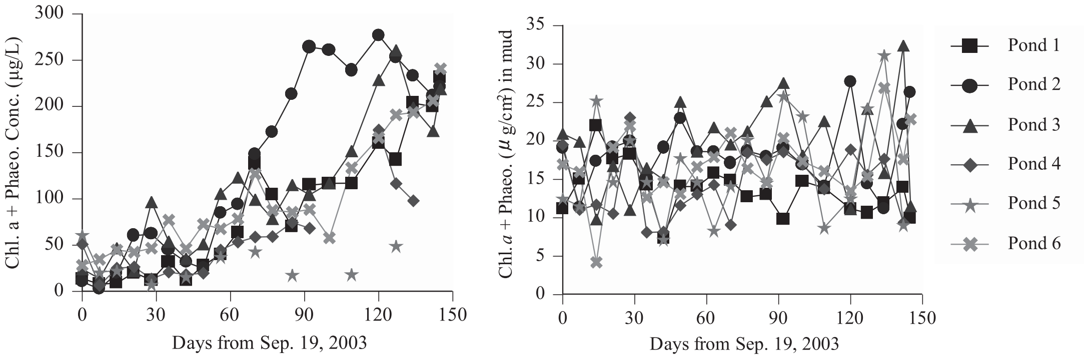


Fig. 5. Chl. a + Phaeo. concentration in (a) water and (b) mud.

water temperature and salinity were in a suitable range for *Penaeus monodon* during this experiment.

Though both DIN and DIP concentrations did not increase in all the ponds (Figs. 3 and 4), organic and particulate nitrogen or phosphorus increased in water. And Chl. *a* + Phaeo. concentration in water also increased in the shrimp aquaculture ponds (Fig. 5). Although their concentrations increased largely in the water, it was considered that water quality was kept within tolerable limits for shrimp growth during the experiment. Though Chl. *a* + Phaeo. concentration in the mud fluctuated largely, there was not an increasing trend. *Penaeus monodon* is omnivorous and can feed on benthic algae (YOSHIDA, 1987). It was considered they ate the benthic algae.

In Pond 6 where the area ratio between the shrimp aquaculture pond and mangrove enclosure was 1:1, the shrimp total weight, the number of individuals harvested and the survival rate were high, and FCR was low. However, in Ponds 2 and 3 where the area ratio was 2:1, the shrimp total weight, number of individuals harvested and the survival rate were low, and FCR was high. Though the aquaculture efficiency was higher in Pond 1 than Ponds 2 and 3, the previous use history as a shrimp aquaculture pond might have influenced the nutrient budgets. From the nitrogen and phosphorus budgets (Table 3), the difference (In–Out) of nitrogen was –0.36 kgN/ pond/ experimental period in Pond 6. This means that nitrogen was not accumulated into the mud in Pond 6, and it was thought that nitrogen was released by denitrification and ammonia evaporation (BRIGGS and FUNGE–SMITH, 1994). On the

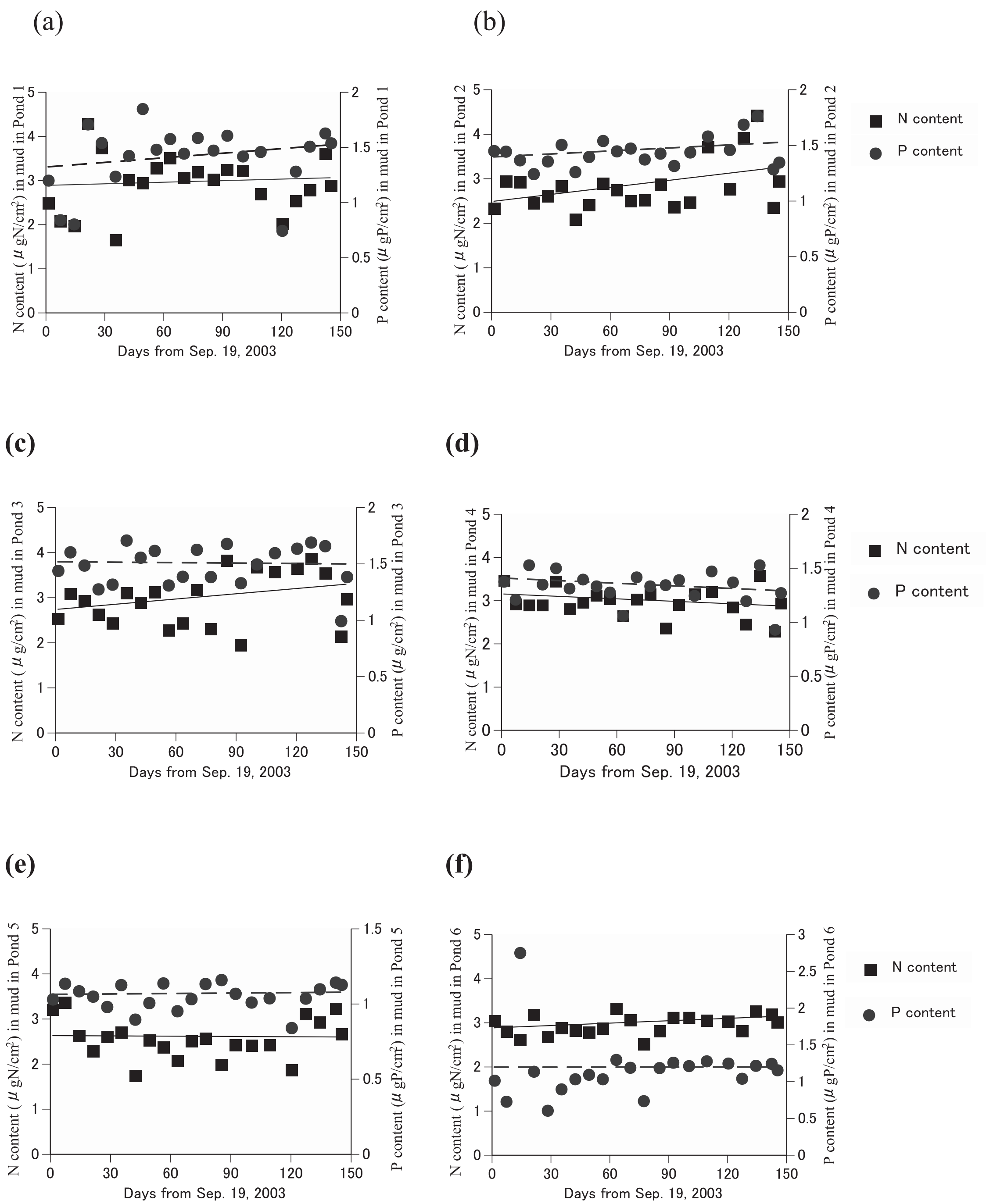


Fig. 6. Nitrogen and phosphorus contents in mud in Ponds 1 (a) –6 (f).
The solid and broken lines show the regression line of nitrogen and phosphorus contents in mud, respectively.

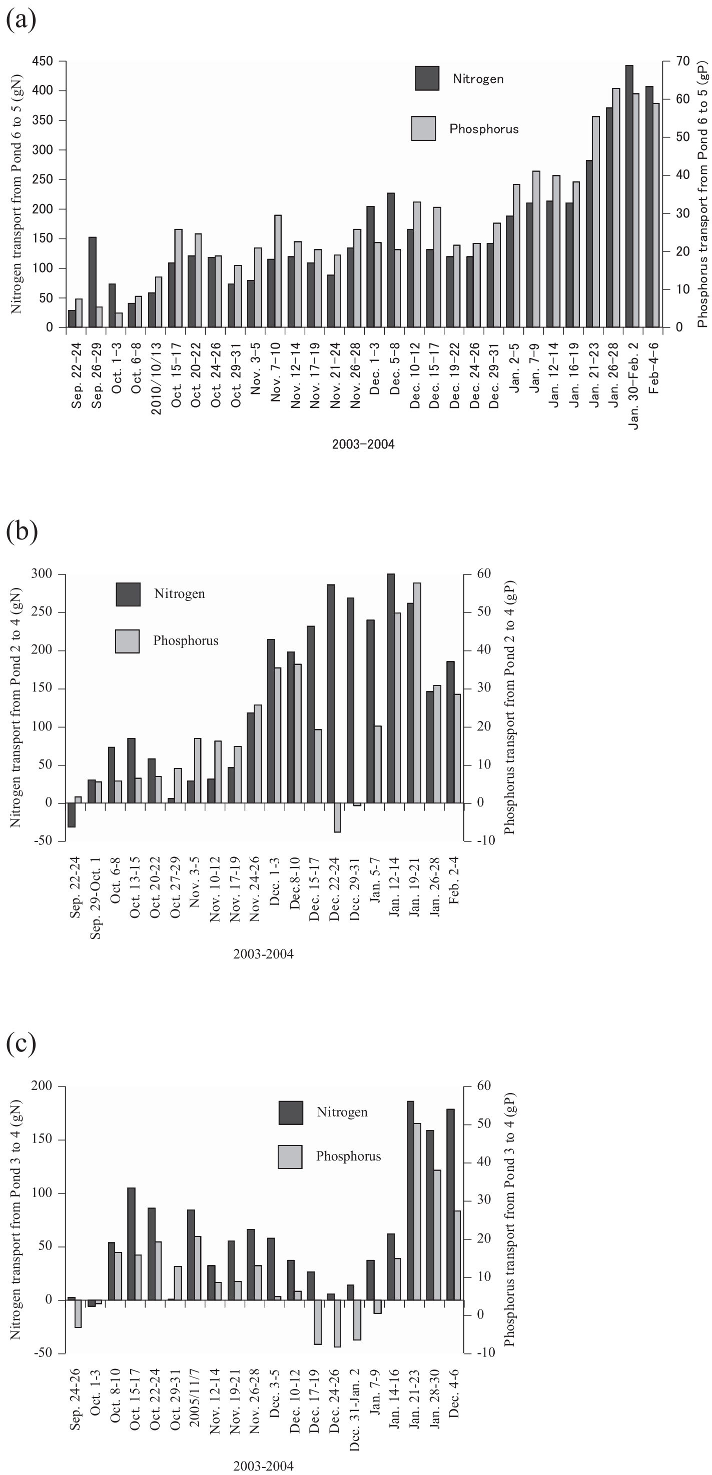


Fig. 7. Nitrogen and phosphorus transports (a) from Ponds 6 to 5, (b) from Ponds 2 to 4 and (c) from Ponds 3 to 4.

Table 3. Nitrogen and phosphorus budgets in the shrimp aquaculture ponds during the experimental period.

	Pond 1	Pond 2	Pond 3	Pond 6
In				
N supplied from feed	21.25	20.60	19.00	24.10
Initial N content in shrimp at stocking	0.01	0.01	0.01	0.01
Out				
N accumulated in shrimp at harvest	6.70	5.01	5.43	7.29
N accumulated in snail	1.91	3.41	2.89	0.19
N accumulated in barnacle	0.21	0.20	0.22	0.17
N accumulated in water	1.53	1.59	1.82	1.87
N accumulated in mud	6.40	9.48	6.77	−0.36
N transport to mangrove encclosure		2.78	1.24	4.83
N differences (In−Out)	4.51	−1.86	0.64	10.12

(kgN/pond/experimental period)

	Pond 1	Pond 2	Pond 3	Pond 6
In				
P supplied from feed	4.41	4.28	3.94	5.00
Initial P content in shrimp at stocking	<0.01	<0.01	<0.01	<0.01
Out				
P accumulated in shrimp at harvest	0.64	0.48	0.47	0.69
P accumulated in snail	0.12	0.21	0.16	0.19
P accumulated in barnacle	0.02	0.02	0.03	0.12
P accumulated in water	0.18	0.20	0.17	0.11
P accumulated in mud	5.35	−1.61	−0.90	2.25
P transport to mangrove encclosure		0.38	0.24	0.83
P difference (In−Out)	−1.89	4.60	3.78	0.81

(kgP/pond/experimental period)

other hand, the difference of nitrogen was −1.86 –0.64 kgN/ pond/ experimental period in Ponds 2 and 3. This shows that nitrogen accumulated in the bottom and it means that the sediment environment deteriorated. The difference of phosphorus was negative in Pond 1 that was the control, and the difference of phosphorus was low in Pond 6 where the area ratio was 1:1 compared to 2:1. Phosphorus content in mud decreased in Ponds 2 and 3 while it increased in Ponds 1 and 6. This means phosphorus desorbed from the bottom in Ponds 2 and 3 where phosphorus had accumulated in the past. The results showed that the deterioration of mud of the ponds could not be prevented in the case that the area ratio between the shrimp aquaculture ponds and the mangrove enclosure was 2:1. The necessity for increasing the area ratio of the mangrove region to the shrimp culture pond was indicated based on these results for sustainable ponds usage.

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Received: August 24, 2011
Accepted: March 07, 2012

La mer 50 : 37-50, 2012
Société franco-japonaise d'océanographie, Tokyo

鉛直微細構造の特性をトレーサーにする海況解析の試み —潮岬周辺微細海況への適用－

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Tracer analysis by using micro-structure found in vertical profiles of several quantities －Application for detailed analysis of oceanic structure in the vicinity of Cape Shionomisaki－

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Abstract : Detailed oceanic structure was investigated by setting dense observation network in the sea near Cape Shionomisaki. A cold water eddy was observed just off the cape in April, 2009. The Kuroshio was located very near the tip of the cape, and was flowing eastwards in October, 2009. MAEKAWA *et al.* (2011) discussed the horizontal distribution of sea level height by setting several reference levels. The sea level difference between Kushimoto and Uragami tide gauge stations is shown to be created essentially in the narrow zone just off Cape Shionomisaki. The sea level difference is related to the oceanic conditions in the surface layer above 300 m depth. They showed that the usual water mass analysis is not applicable because the correlation between temperature and salinity fields is not high enough. In this paper, we used micro-structures found in the vertical profiles of dissolved oxygen, turbidity and chlorophyll a together with temperature and salinity profiles, as passive tracers. We concluded: (1) maxima and/or minima found in profiles of dissolved oxygen in the layer shallow than 100m depth have small horizontal extent, and these maxima and minima are found only near the outer edge of the cold water belt. (2) water of high temperature, high salinity and high dissolved oxygen which was found in the depth range from 50 to 150m depth near station F7 in April, 2009. This water was shown to be the Kuroshio Water, which had been brought into Kumano-nada area a few days before the observation, (3) observed area in October, 2009 is classified into three sub-regions by vertical profiles of dissolved oxygen. The sub-region consisted of relatively lowest oxygen values are found extends from coast to offshore. The offshore margin of this sub-region is located is located more southward than the northern edge of the current zone of the Kuroshio. This indicates that the coastal water is entrained into the flow area of the Kuroshio in the area to the east of Cape Shionomisaki.

Keywords : *Detailed oceanic structure in vicinity of Cape Shionomisaki, microstructure in vertical profiles, dissolved oxygen*

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1. はじめに

串本・浦神間の水位差が，本州南方での黒潮が直進路を取るか蛇行路を取るかの指標を与えることはよく知られている。われわれは黒潮が直進路を取るときに，紀伊半島南西岸に生じる振り分け潮が，このことに大きな役割を果たすことを明らかにしてきた（TAKEUCHI *et al.*, 1998, NAGATA *et al.*, 1999，UCHIDA *et al.*, 2000）。すなわち，黒潮が直進路を取っているときに紀伊半島南西海岸に生じる振り分け潮に伴って，黒潮系水が沿岸域にもたらされ串本沖合の水位を高めるために，串本・浦神間の水位差が生まれることを明らかにしてきた。また，中村ら（2008）は潮岬すぐ沖に，黒潮とは逆方向に流れる強い西向流が現れる事例を紹介し，この流れが潮岬を挟む東西の水位差に起因することを示唆している。この強い西向流の発生は浦神検潮所の水位が串本検潮所の水位より顕著に高まる時に生じるが，両者の発生時期の間には若干の位相差が存在するらしい。このような現象を理解するためには，潮岬周辺の微細海況を調べ，串本・浦神間の水位差を生じさせる水位勾配が，両検潮所間で緩やかに起こっているのか，ある限られた海域で生じているのかを明確に示す必要がある。

われわれは，三重大学大学院生物資源学研究科附属練習船勢水丸（以下，勢水丸と略す）によって，2009 年 4 月と 10 月の 2 回にわたって，Fig. 1 に示すような非常に密な観測点を設けて，潮岬周辺の微細海況観測を行い，串本・浦神間の水位差は潮岬半島部の沖，東西幅数 km の狭い範囲で起こっていることを見出した（前川ら，2011)。また，この水位差は 500m（実質的には 300m）以浅の海洋構造によって作り出されていることを示した。

2009 年 4 月は黒潮北縁の小蛇行が潮岬沖を通過中の時にあたり，2009 年 10 月は黒潮は典型的な直進路を取っている時にあたる。これらの海況は，200m 深の水温や塩分場にも現れているが，その細部の構造，例えば 4 月では冷水渦の中心の位置，10 月では潮岬すぐ西方での振り分け潮につながる黒潮水の岸側への侵入域の構造は，水温場と塩分場でかなり異なっている。このような水温場と塩分場の非対応性は，深さが 200m よりも浅くなると，より顕著になる。田中ら（2008）は，潮岬西方の海況解析で，流れの指標とされる 200m 深の等温線が海岸にぶつかる形となることがあることを報告している。そうして，微細な海洋構造を論じる場合には，厳密な定常的な状態は成り立たず，過渡的現象が観測されるためではないかとしている。

また，ADCP の観測による流速場と水温・塩分場との間にも，良い相関関係が認められない。4 月の場合には，全体として，潮岬に接する形で低温・低塩分水域が見られるが，流速場は観測域全体が東向流域となっており，10 月の場合にも潮岬の西で高温・高塩分水の岸方向への水の侵入が見られるにも関わらず，これに対応するような岸向きの流れは観測されていない。もちろん，黒潮系水の流入は連続的に起こっているとは限らず，間欠的に起こっている可能性があるから，岸向きの流れが観測時に観測されなくても，黒潮系水の沿岸域への流入は否定されるわけではない。

さらに，黒潮直進時の串本・浦神間の水位差を起こす要因が潮岬西方での黒潮水の岸近くへの侵入であると考えられるが，海面水位分布を決めているのが 300m 以浅の表層の水温・塩分構造であるという前川ら（2011）の結論は注目される。そうであるならば，岸近くに侵入してくる黒潮水は，その源泉を黒潮域の表層，主温度躍層の上の表層混合層に求めなければならない。黒潮流域の表層混合層は明確な季節変化を持つから，振り分け潮に伴って沿岸域にもたらされる黒潮系水も季節変動を持つことになるはずである。この問題は現在検討中であるが，前川ら（2011）がその Fig. 3 に示している串本・浦神間の水位差に明確な季節変動が現れている事例の原因を説明するものであろう。

われわれは，紀伊半島南西海岸に向かっての比較的高温・高塩分の水の張り出しから，黒潮系水の沿岸域への侵入を類推して，これから串本・浦神間の水位差と黒潮流路パターンの関係を論じてきたが，上述のようにその細部の機構についてはほとんどわかっていないのが現状である。もし，海水の動きを示すようなトレーサーが利用できれば，より詳細な海水流動の様子を知ることができよう。しかし，上述のように，水温・塩分の分布に必ずしも相関が見出せない以上，通常の水塊分析の手法を直接的に適用することは難しい。

勢水丸の CTD には水温・塩分の他に溶存酸素・クロロフィル a・濁度のセンサーが付けられている。4 月の船上観測中に，溶存酸素の鉛直プロファイルに顕著な極大あるいは極小が現れる測点があることに気付いた。この溶存酸素の微細構造の形状を追うことによって海水の流動特性を調べることを試みようとした。しかし，Fig. 1 で示すような密度の高い観測点網を用いても，隣り合った測点間でも殆ど形状の連続性は見出すことができなかった。しかし，このような微細構造が現れるのはある限られた海域に限られる。形状に連続性が見られないことは，その構造の成因や，海水の流

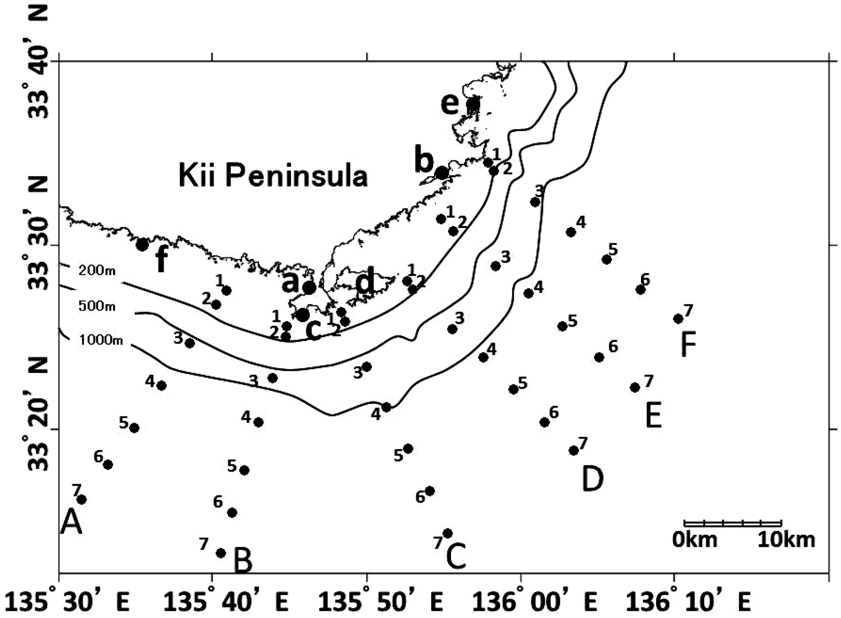

Fig. 1. Standard distribution of observation points. Some observation points were omitted due to limitation of available time. Real distributions of observation points in April 2009 and in October 2009 are shown in horizontal distribution maps of temperature, salinity and so on. Line names are indicated with capitals A, B, C, D, E and F from west to east. Station numbers are indicated with numbers 1 through 7 from coast to offshore. The small alphabets a through h indicate the position of tide gauge stations and positions of town; a: the Kushimoto tide gauge station, b: Uragami tide gauge station, c: Cape Shionomisaki, d: Ohshima Island, e: Katsuura, and f: Cape Esuzaki.

動の進行方向などを求めることが困難であることを意味する。しかし，海域が限られることは，何らかの微細海況特性のトレーサーとして用いられる可能性を示す。

2. 観測の概要と使用した観測器機

前川ら（2011）は，串本・浦神の検潮所間の水位差が，約 15km 離れた両地点間のどの場所で生起しているかを知るために潮岬周辺に Fig. 1 に示すような測点を設けて 2009 年 4 月 13 日～17 日と同年 10 月 19 日～20 日に，勢水丸によって微細海況観測を実施した。観測経緯及び水温・塩分構造と 300m 層を基準に計算された海面高度プロファイル等の観測結果については前川ら（2011）が報告している。この論文では，溶存酸素，クロロフィル a，濁度の鉛直プロファイルに見られた微細構造の空間分布に注目し，それを一種のトレーサーとして海況特性を論じる。水温・塩分等の水平分布等の海況は必要に応じて前論文（前川ら，2011）の結果を引用するが，観測時の海況の詳細については前論文を参照されたい。

使用した測器は主として勢水丸の所有する CTD と ADCP である。CTD は Sea-Bird 社製 SBE25 であるが，CTD オクトパス装置として溶存酸素センサー（Sea-Bird 社製 SBE-43），クロロフィル a を測る蛍光光度センサー（Seapoint 社製 Seapoint Fluorometer），濁度センサー（WET-Labs 社製 C-Star）が装備されている。ただし，時間の関係で各測点における採水観測は省略しているので，溶存酸素量については相対値を示すものである。ADCP は 128 層の観測が可能な RD 社製（75kHz）である。

水温・塩分・溶存酸素・クロロフィル a・濁度のプロファイルには，多くの極大や極小が現れ，それらの出現する測点には地域的なつながりがあるように見える。しかし，これらのプロファイルの構造は，後に述べるように，観測点密度が非常に高いにもかかわらず，最も近い測点間でも非常に異なっており，極大・極小の空間的なつながりを見出すことは難しい。また，水温・塩分のプロファイルを含めて，諸量に共通に現れることは少なく，一つの量のプロファイルのみに現れるのが

通例である。そのため，通常の水塊分析の手法をそのまま適用することは困難である。

しかし，諸量のプロファイルに現れる極大・極小形状の出現が，ある地域的な空間に限られて見出されることは，何らかの微細海況特性を示すはずである。上述のように，鉛直プロファイルの構造の形状の連続性を追うことが難しいことから，その成因や起源を議論することは諦め，微細構造

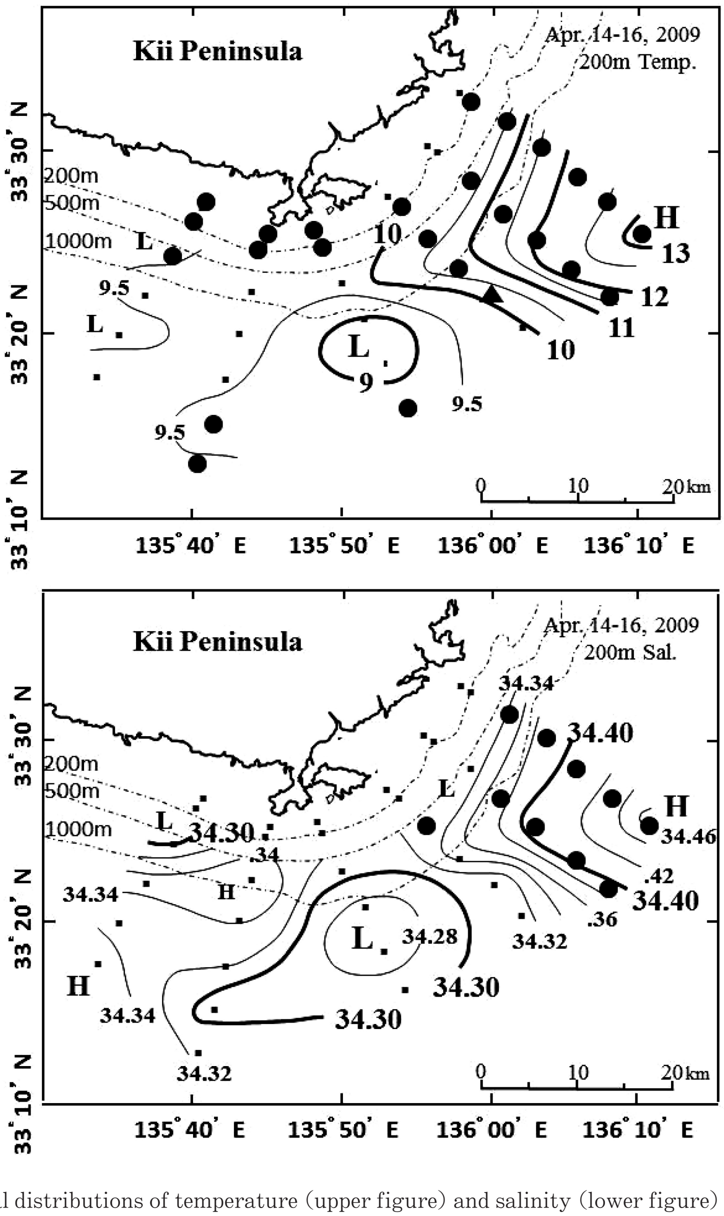

Fig. 2. Horizontal distributions of temperature (upper figure) and salinity (lower figure) at 200m depth on April 14–16, 2009. Isotherm is drawn at 0.5℃ interval, and isohaline at 0.02interval. The black circles in the upper figure indicate the observation points where micro–structure in vertical profile of dissolve oxygen was found in the layer shallower than 100m depth. The black triangle indicates the observation point where somewhat ambiguous micro–structure was found. The black circles in the lower figure indicate the observation points where thick high oxygen layer is found in the range from 60m and 150m.

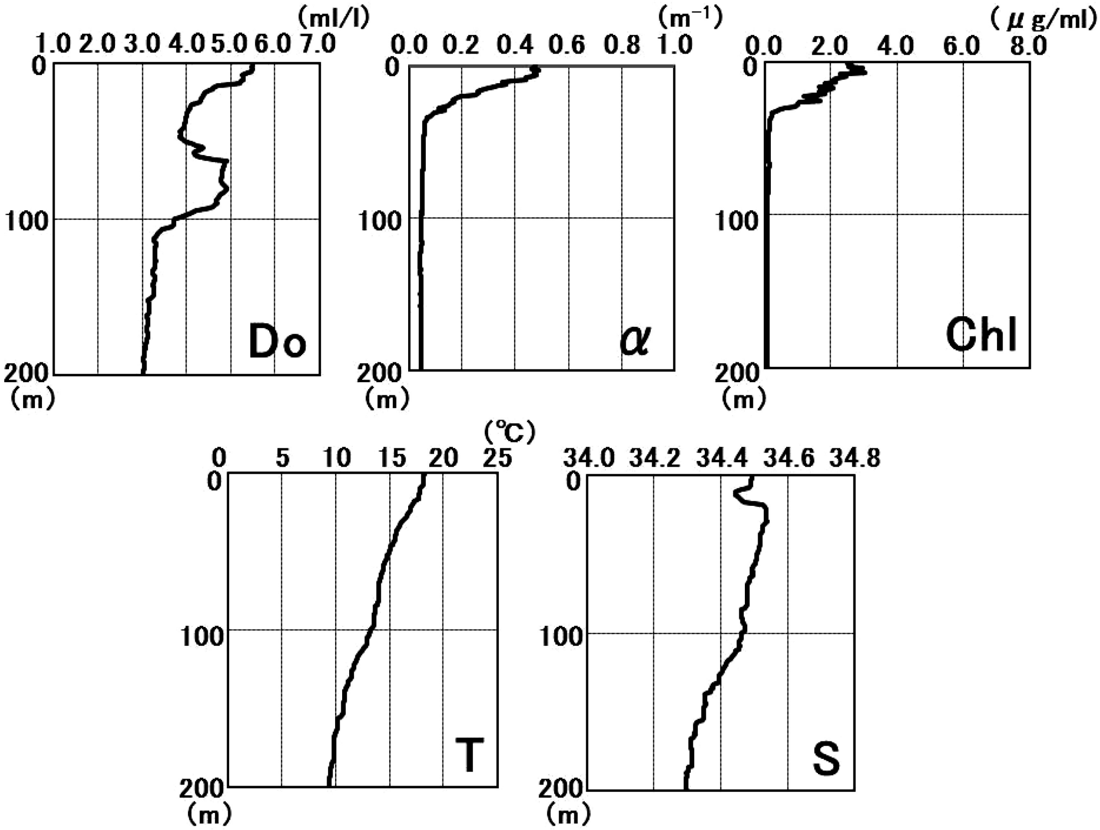

Fig. 3. Vertical profiles of dissolved oxygen (upper left: ml/l), turbidity (upper middle: shown by beam attenuation coefficient (660nm) in m^{-1}), chlorophyll *a* (upper right: μg/ml), temperature (lower left: ℃) and salinity (lower right) observed at station A3 on April 16, 2009.

の存在を一種のトレーサーとして利用し，海況微細構造の地域的な特性を調べることにする。

なお，以下の議論において，観測点の名称や，その位置を適宜引用するので，Fig. 1（前川ら，2011）に示した基本的な測点配置図を参照されたい。

3. 黒潮の北縁の小蛇行が潮岬沖を通過中の海況（2009 年 4 月）と溶存酸素の鉛直微細構造

3–1. 2009 年 4 月の観測時の海況

2009 年 4 月の観測時に得られた 200m 層の水温（上図）と塩分（下図）の水平分布を Fig. 2 に示す。潮岬沖に低温・低塩分の水塊が認められ，潮岬沖を黒潮北縁の小蛇行が通過中であることがわかる。観測域が狭く，この水塊の南縁は観測されていないが，衛星画像等から黒潮の北縁は観測域のすぐ南方に存在していたことが推測される。この図からは，低温・低塩分域の中心位置は水温場でも塩分場でもほぼ一致しているが，潮岬東方沖の水温・塩分構造にはかなりの違いが見られる。観測層をさらに浅く取ると，水温・塩分場の相関が明確でなくなり，分布構造も層毎に変化する。

3–2. 2009 年 4 月の観測で 100m 以浅に現れる高溶存酸素層

2009 年 4 月のこの航海において，16 日に測点 A3 で観測された溶存酸素，濁度（光束消散係数 α），クロロフィル *a*（蛍光光度センサーで測定）の鉛直プロファイルを Fig. 3 の上段に，水温・塩分の鉛直プロファイルを下段に示す。溶存酸素のプロファイルに注目すると，表層で溶存酸素が深さとともに減少する顕著な躍層が見られる。40m 水深付近に極小が現れ，その下に高い溶存酸素の層を示す極大が現れる。しかし，このよう

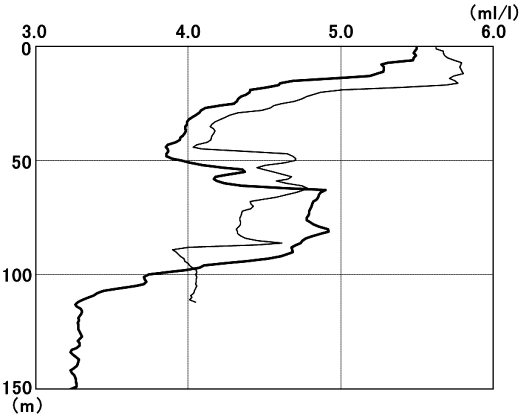

Fig. 4. Vertical profiles of dissolved oxygen at stations A3 (thick line) and B2 (thin line) on April 16, 2009.

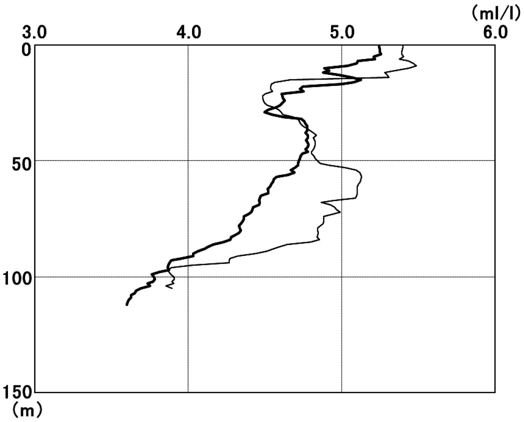

Fig. 5. Vertical profiles of dissolved oxygen at stations D2 (thick line) measured on April 15, 2009 and at F2 (thin line) on April 14, 2009

な構造は，水温・塩分，濁度 α やクロロフィル a 等の他のプロファイルには見られない。

また，近接する測点間のプロファイルを比べてみても，相互に関連していると思われる構造は殆ど見られない。わずかに測点 A3 と B2，D2 と F2 の間で似た形状が認められた。この二例を，Fig. 4 と Fig. 5 に示す。測点 A3 と B2 の間に 40m 深付近の極小，60m 深付近での極大の形状には類似性があり，測点 D2 と F2 の間には 30m 深付近の極小の間にある程度の類似性がある。しかし，隣り合う測点間で曲がりなりにも相似性を認められたのはこの二例のみであり，このような構造の水平スケールは非常に小さいと考えられる。

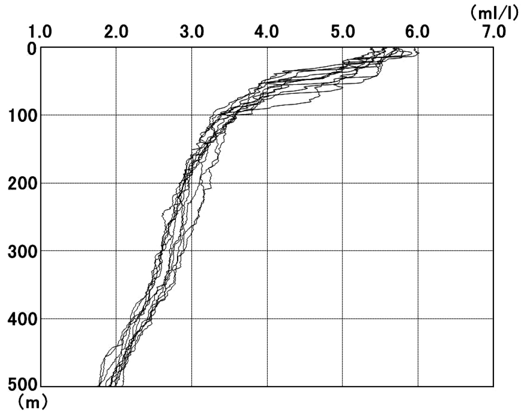

Fig. 6. Vertical profiles of dissolved oxygen (ml/l) in the central part of cold water eddy observed in April, 2009. Stations A4 through A6, B3 through B5, C3 through C5, and D5 and D6 are included in this central part.

このような構造が観測された測点を 200m 層の水温場（Fig. 2 上図）上に黒丸で示す（測点 D5 では 100m 深近くに小さな極小が見えるが，明確な構造が現れているとはいえないので黒三角にしてある）。微細構造は，低温・低塩分水塊の中心域に現れず，出現がその周辺部に限られることがわかる。低温・低塩分水域の周辺部に溶存酸素の水平勾配の大きな部分があり，そこで活発な海水の水平交換が行われていることを示しているのであろう。

鉛直プロファイルだけから，このような形状をもたらしたものが，低溶存酸素水の貫入によるものか，高溶存酸素水の貫入によるものかは判断できない。Fig. 2 において低温・低塩分水塊の中では，溶存酸素に特異な構造は現れず，プロファイルがスムーズである。このスムーズなプロファイルを全て一枚の図に描いたものが Fig. 6 である。これらのプロファイルや，全くこのような構造が見られなかった 2009 年 10 月の観測時の溶存酸素のプロファイル（Fig.13）を基準的なプロファイルと考えると，高溶存酸素水が侵入してきたと考える方が自然である。

もしも，高溶存酸素水の侵入が，その水の密度に応じて，それに見合う密度面に沿って水平に準静的に貫入してくるならば，プロファイルは空間的にある程度の広がりを持ち，その空間スケールを類推することが可能であるはずである。4 月の観測で 100m 以浅に現れたプロファイルの極小や極大構造が隣り合った測点間で類似性が認められ

なかったことは，その空間スケールが小さいことを示す。おそらく，小蛇行の通過に伴う渦動による撹拌，混合過程の中で高溶存酸素水の水平移流が起こったものであろう。

前川ら（2011）で示した 4 月の流速場には，低温・低塩分水塊域を取り巻くような流速場はみられず，冷水域は全般的に東流域となっている（前川ら，2011，Fig. 4 上）。台風の右半円の風速が相対的に強くなる現象を，渦巻く風速場と，台風の移動に伴う風速場の重ね合わせで説明されている。海洋の渦について，それを運ぶ流速場を議論された例を知らないが，現在対象としている潮岬沖を東に移動する低温・低塩分渦を取り巻く流れが小さければ，観測された流速場は渦の移動に伴う東向流が観測されたものと考えるべきであろう。そうであるならば，ここで論じているような渦を取り巻いて存在する溶存酸素の微細構造が，ある期間保存されることが考えられる。

3–3. 4 月の観測で水深 50〜150m 付近に見られる厚さ 100m 内外の高溶存酸素層

2009 年 4 月の観測で得られた溶存酸素の鉛直プロファイルには，100m 以浅に見られる上述の構造の他に，50〜150m の深度範囲に 100m 内外

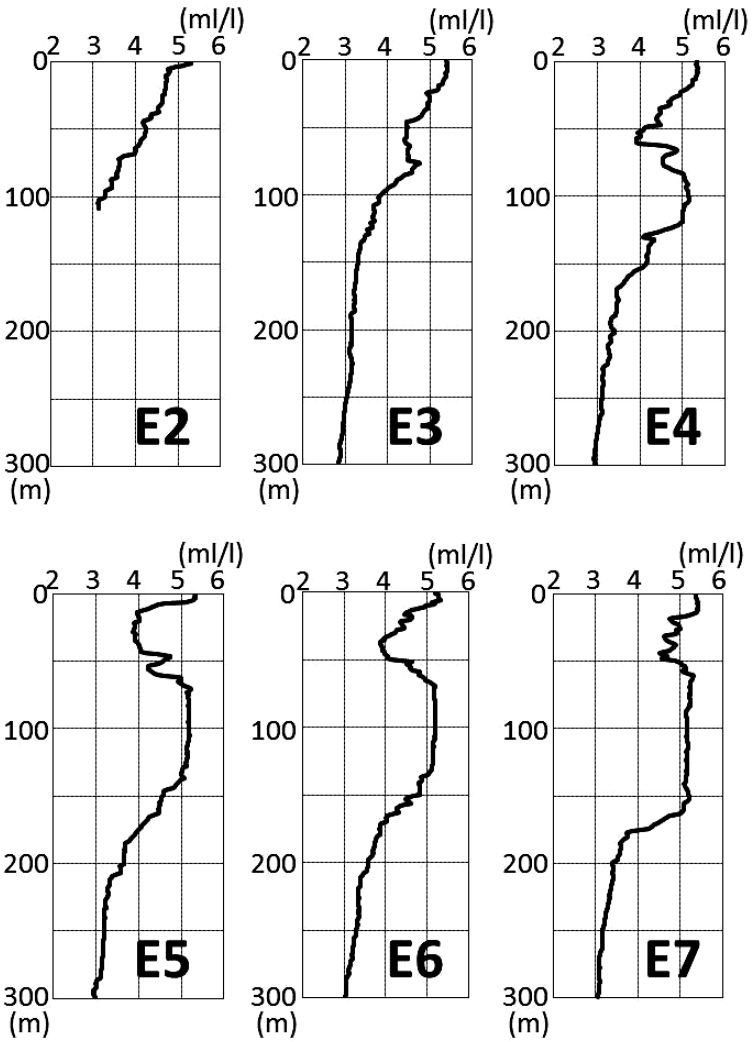

Fig. 7. Vertical profiles of dissolved oxygen (ml/l) at stations E2 though E7 observed on April 15, 2009.

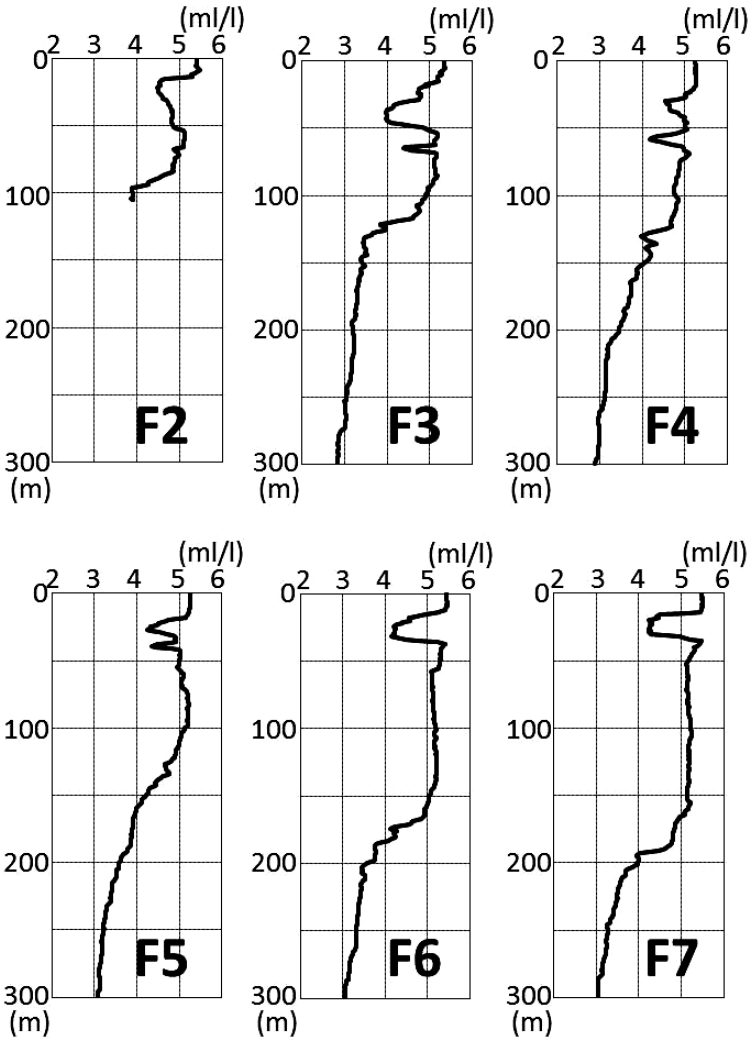

Fig. 8. Vertical profiles of dissolved oxygen (ml/l) at stations F2 through F7, observed on April 14, 2009.

の厚さを持つ高溶存酸素水が，測線Ｅあるいは測線Ｆ上で見出される。測線Ｅ上の各測点についてのプロファイルを Fig. 7 に，測線Ｆ上の各測点についてのプロファイルを Fig. 8 にそれぞれ示す。測点 E5〜E7，F5〜F7 のプロファイルに，厚さ 100m を超すような高溶存酸素水の層が存在している。厚さは少し減じるが，測点 E4，F3，F4 にも厚い高溶存酸素層が認められる。このような厚い高溶存酸素水層は，より西方の測線Ａ〜Ｄには，測点 D3 を除き全く見い出せない。この厚い高溶存酸素水層の現れた測点を 200m 層の塩分場（Fig. 2 下）上に黒丸で示す。存在域は観測海域の東側に限られており，測点 F7 を中心とする高水温・高塩分域と一致している。

4 月の観測の全測点の溶存酸素プロファイルを 1 枚の図にプロットしたのが，Fig. 9 である。この図で厚い高溶存酸素水の現れた測点 D3，E4〜E7，F3〜F7 のプロファイルを実線で，他の測点のプロファイルを点線でプロットしてある。水深 80m 付近から水深 200m 付近の間で，他の測点に比べて著しく高酸素の水が存在していることが明瞭に示されている。

ADCP による流速分布図（前川ら，2011 の Fig. 3 上）では，この測点での流れが弱く，この

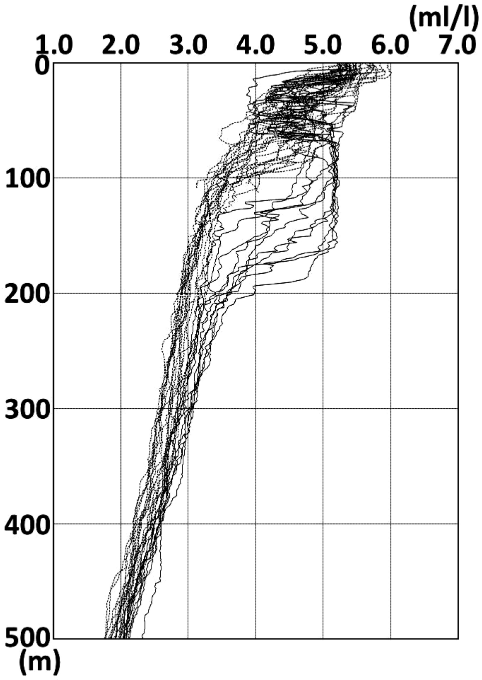

Fig. 9. All of vertical profiles of dissolved oxygen (ml/l) obtained during the observation in April, 2009. Solid curves indicate the profiles taken at stations D3, E4 through E7 and F3 through F7, and dotted lines indicate the profiles taken at other stations.

測点は黒潮流域から岸側に離れていると思われる。しかし，水温値・塩分値からみると，この地点に存在する海水は，黒潮系の水の特性を持っている。2009 年 4 月 7〜8 日に三重県水産研究所がこの海域で ADCP 観測を行っている。その結果を Fig. 10 に示す。この図では，われわれの観測の直前に熊野灘三木埼沖に黒潮水が侵入していたことが分かる。2009 年 4 月 7 日の NOAA による日合成画像を Fig. 11 に示すが，この画像でも熊野灘沖への黒潮水の侵入が認められる。観測された厚い高酸素水はこの侵入した黒潮水が，われわれの観測時に測点 F7 周辺にとどまっていたと考えるのが自然である。

Fig. 9 の実線で示したプロファイルが，80m 以浅で，他のプロファイルに比べ，むしろ低酸素にある。観測開始の 1 日前の 4 月 13 日の衛星画像では，観測域表層は全体に黒潮水よりも低温の水で覆われている。観測時には表層には，低酸素，低温の沿岸水系の水が沖側に張り出していたと類推される。そのため，表層中の溶存酸素プロファイルに極大・極小をともなう微細構造が生じており，これ等の測点にも 3–1 で論じたような構造が現れている。しかし，その成因は，沿岸水が表層で沖側に張り出したもので，低温・低塩分水塊の回りに生じたものとは性質が異なっていると思われる。

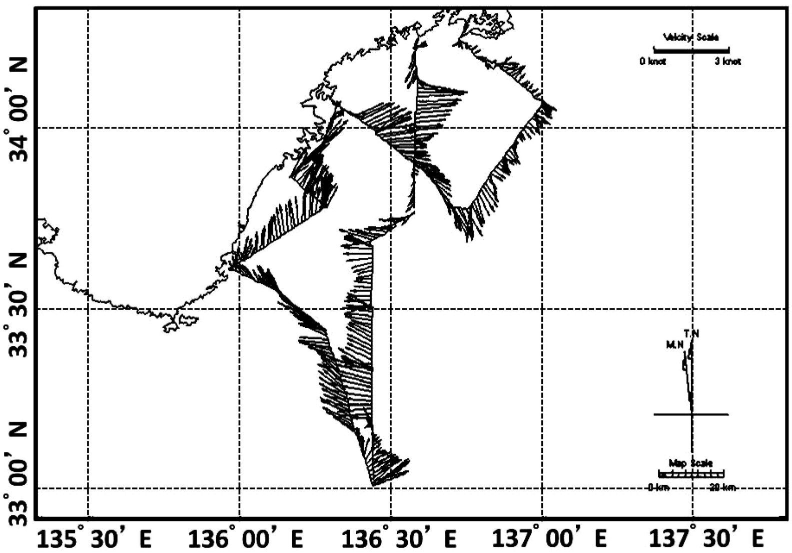

Fig. 10. Current velocity vectors measured with ADCP by the Mie Prefecture Fisheries Research Institute on April 7–8, 2009. A northward intrusion of the Kuroshio water was found off Kumano-nada.

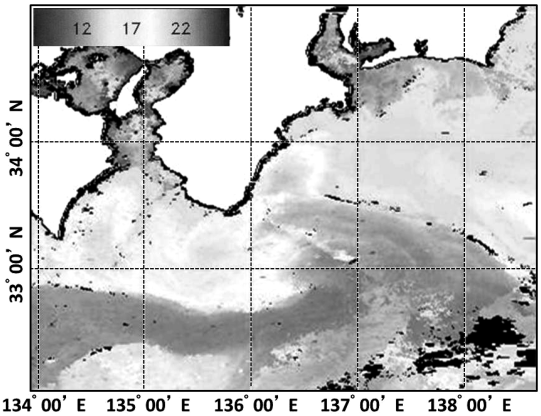

Fig. 11. Infrared image observed by NOAA satellite on April 7, 2009. One day composite picture is shown.

4. 黒潮の流路が典型的な直進路を取っていた時の潮岬周辺の微細海況（2009 年 10 月）と溶存酸素の鉛直微細構造

4–1. 2009 年 10 月の海況

2009 年 10 月に観測された 200m 層の水温（上図）と塩分（下図）の水平構造を Fig. 12 に示す。この図で分かるように，黒潮はその北縁を潮岬先端に接する形で流れており，潮岬沖を通過後，北縁はやや沖側に離れるが，その後真東に流れる形を取っており，典型的な直進路を示している。前川ら（2011）は，この時の串本・浦神の水位差は潮岬半島の沖の数 km の狭い海域で生じていたと結論しているが，このことはこの図からも推定できよう。また，潮岬の西方で等温線・等塩分線が北にくびれており，この部分で黒潮系の水が岸近くに侵入していることを示唆される。しかし，ADCP の測定結果では，この部分でも北流成分は全く観測されておらず，また水温・塩分の分布パターンも特に 200m 以浅では良い相関を示していない。

4–2. 2009 年 10 月の観測で得られた溶存酸素の鉛直プロファイルの特性

10 月の全ての観測点で得られた溶存酸素の鉛直プロファイルを重ねてプロットしたのが Fig. 13 である。この図で，80m 付近から 350m 付近までの部分で溶存酸素の値の存在範囲が広がっている。100m から 250m 深の間を注目すると，溶存酸素量の相対的な値からプロファイルを三つのグループに分けることができる。図では相対的に酸素量が相対的に小さいグループを点線で，酸

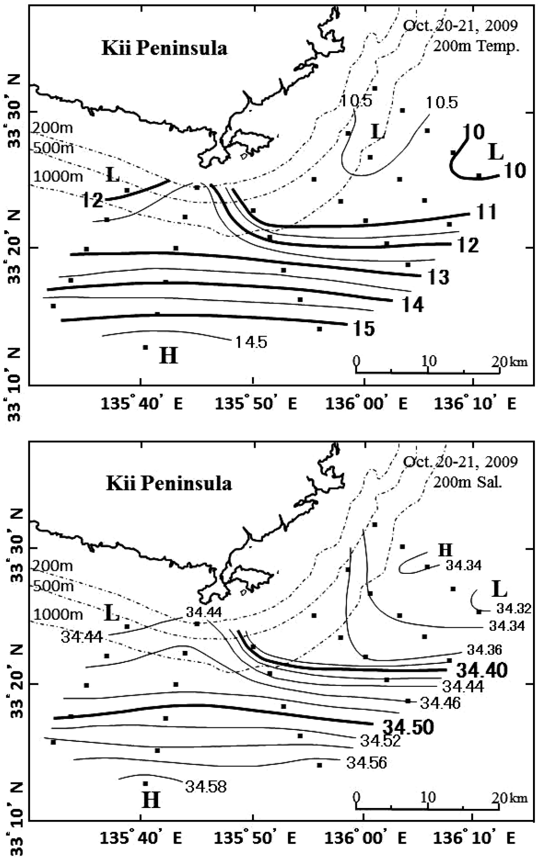

Fig. 12. Same as in Fig. 2 except for on October 20–21, 2009. Isotherm is drawn at 0.5℃ interval, and isohaline at 0.02 interval.

素量が相対的に大きな値を持つグループを破線で，中間の値を持つグループを実線で示してある。点線のグループと実線のグループの間，実線と破線のグループの間には，プロファイルがほとんど存在しない空白部が存在している。それぞれのグループが観測された測点の分布を，Fig. 14 に示した。図では，最も高溶存酸素側のグループ（Fig. 12 で破線のグループ）を●で，中間のグループ（Fig. 12 で実線のグループ）を◎で，低溶存酸素側のグループ（Fig. 13 の点線のグループ）を○で示してある。注目すべきことは，これらのグループの地域的な現れ方は非常に規則的で，●が最も沖側に，◎がそれより岸側に，○がさらに岸側で海岸までの海域に現れている。これを見ると，少なくとも 80m 付近から 350m 付近までの深度範囲では，溶存酸素量は全体的に沖に行くほど高く

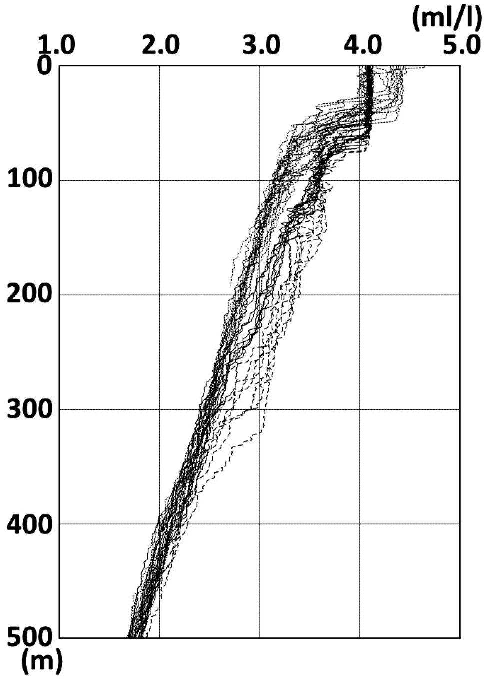

Fig. 13. All of vertical profiles of dissolved oxygen (ml/l) obtained during the observation in October, 2009. Dotted curves indicate the profile taken at stations B2, C2 through C4, D2 through D5, E2 through E7, and F2 through F7, solid curves indicate taken at stations A2 through A5, B3 and B4, C5, and D6 and D7, and broken curves indicate taken A6 and A7, B5 through B7, and C6 and C7.

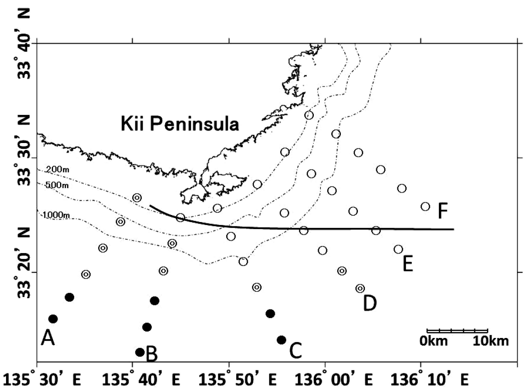

Fig. 14. Three sub−regions classified by characteristics of vertical profiles of dissolved oxygen shown in Fig. 13. The stations where broken curves are found are shown with black circles, those solid curves found are with double circles, and those dotted curves found are shown with single circles. The northern boundary of strong current zone of the Kuroshio deduced from temperature field at 200m depth surface is shown with a thick curve in figure.

なることが示されている。これは，前節の厚い高溶存酸素層の起源を黒潮系水に求めたことと矛盾しない。

Fig. 14 には，経験的に黒潮の流線を代表するとされる 200m 層の水温の水平分布から推定した黒潮北縁の位置を実線で示してある。（通常黒潮流軸は，この黒潮北縁から 24km 沖にあるとされている。また，黒潮北縁の位置は ADCP による表面流速の分布から求めても同じ結果が得られる。）ここで，最も低溶存酸素のグループ（○）の存在範囲が，この黒潮北縁の位置よりも沖側にまで及んでいることが注目される。潮岬より西方では○で示した低酸素水が認められないのに対して，潮岬東方では，低酸素の沿岸系の水が，黒潮北縁よりも黒潮流域側に広がっていることになる。プリュームやジェットの流れは，その中に周辺の水を吸い込んでいくエントレインメントという現象を起こすが，黒潮流域の中は，沿岸水域に比べてより強い乱流状態にあると考えられるから，沿岸系水が黒潮流の中にエントレインメントによって供給されることは十分考えられる。したがって，潮岬東方で沿岸水が黒潮に取り込まれて，その範囲が黒潮北縁に沿って，その沖側に帯状に延びている可能性がある。Fig.14 の結果はこの推論を支持するものと考えられる。潮岬東方の浦神沖の沿岸水が，黒潮の直進時に黒潮流に取り込まれるならば，浦神沖沿岸水が絶えず更新されることになり，潮岬東方の沿岸水を一様化する一因になるであろう。このことは，串本・浦神間の水位差が良い黒潮流路の指標となることに寄与しているのではなかろうか。

もしも，このような推論が正しければ，他の諸量，水温や塩分の分布にも同じようなエントレインメントの効果が出るはずである。そこで，溶存酸素量の鉛直プロファイルに適用した海域分類を，そのまま，水温・塩分のプロファイルに適用した結果が，Fig. 15 と Fig. 16 である。溶存酸素の地域区分に従って，点線・実線・破線に分けて示してある。これらのプロファイルでは，各区分の移り変わりがやや連続的であるが，水温・塩分においても 100m 以深で対応した地域分けができることは興味深い。

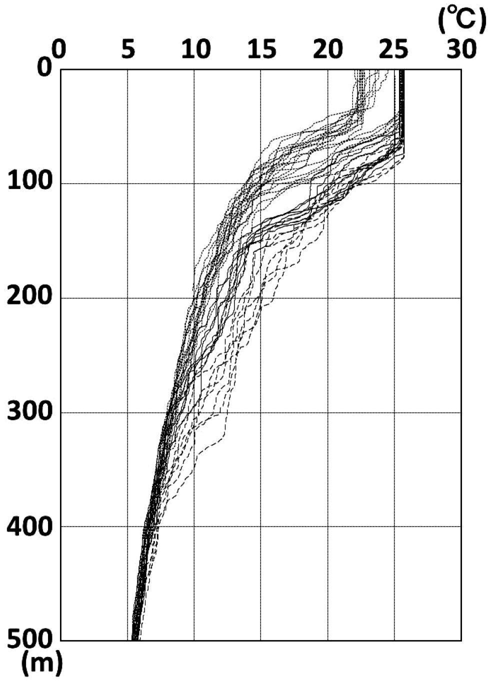

Fig. 15. Same as in Fig. 13, except for temperature in ℃.

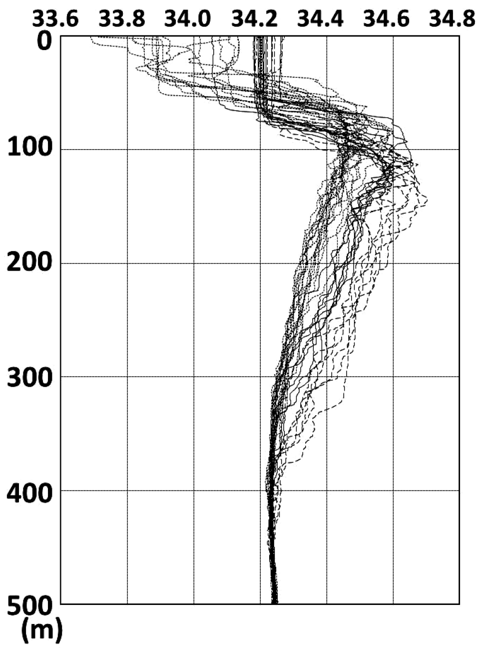

Fig. 16. Same as in Fig. 13, except for salinity.

5. 2009年4月および10月の観測で見出された濁度α，クロロフィルaのプロファイルの構造

濁度（α）やクロロフィルaは，少なくとも紀伊半島周辺部では，沿岸水域で高い値が観測される。また，一般に表層近くで大きな値を示す。したがって，その分布から，沿岸水の動向を探ることが可能であると考えられる。

溶存酸素と同様に濁度（α）やクロロフィルaについても，特異な水の侵入現象を示すような特異な極大・極小構造が見られることがある。濁度の例をFig. 17に，クロロフィルaの例をFig.18に示す。Fig. 17は2009年10月19日に測点A3で季節躍層のすぐ下で観測された，顕著な特異構造であるが，近くの観測点ではこのような構造は全く観測されなかった。また，この構造に対応するような構造はこの点での他の諸量のプロファイルには全く認められなかった。Fig.18のクロロフィルaの例は，2009年4月16日に測点C3で観測されたものである。この場合には，濁度や溶存酸素のプロファイルにも，海面のすぐ下にピークが現れており，50m以浅の表層水の流動を示していると思われる。しかし，細部のプロファイル構造は相互に大きく異なっている。これらの例は，観測中で最も顕著な例であるが，いずれも，空間的な連続性を認めることができなかった。

溶存酸素のそれとは異なり，以上の結果に見られるように，濁度やクロロフィルaのプロファイルに顕著な構造が見出されるのは，極浅い表層に限られている。また，測点密度の高いわれわれの観測でも，構造の測点間の連続性は全く見出すことはできなかった。これらの量の解析から，有意な結論を得るには，さらに測点間隔を小さく取った観測が必要とされよう。

6. おわりに

串本の験潮所から浦神の験潮所までの直線距離は約15kmであるが，Fig. 1に示すように，この両地点沖を含めた海域において，水深50m沿いで約30kmの部分から，沖方向に扇状に広がる6本の観測線を設けるという，従来に見られないような細かい測点分布を持つ観測を実施した。2009年4月の観測時には，潮岬のすぐ南方に黒潮の小蛇行に伴う冷水渦が存在し，2009年10月の観測時には黒潮が潮岬にほとんど接する形で東進している典型的な直進路を取っていた。得られた海面水位の分布等の力学的な構造については前

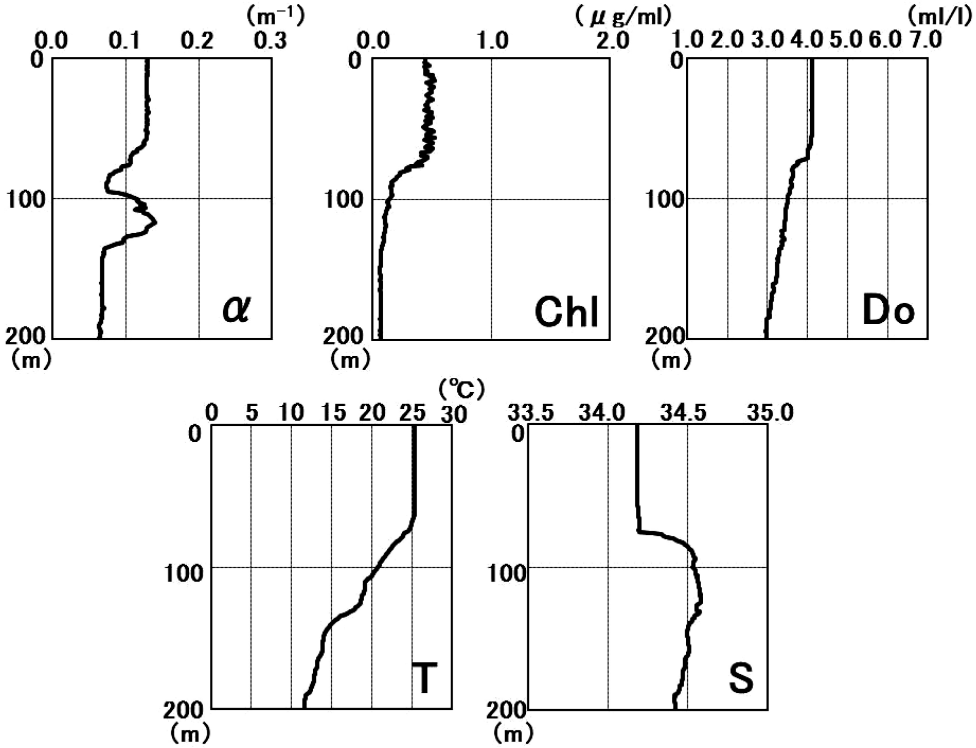

Fig. 17. Vertical profiles of turbidity (upper left: shown by beam attenuation coefficient (660nm) in m^{-1}), chlorophyll a (upper middle: μg/ml), dissolved oxygen (upper right: ml/l), temperature (lower left: ℃) and salinity (lower right) observed at station A3 on October 20, 2009.

川ら（2011）が報告している。この論文では，これを補足する形で，溶存酸素のプロファイルの形状に注目して，次のような結論を得た。

（1）2009 年 4 月の観測で 100m 以浅に現れる溶存酸素のプロファイルの極大（高溶存酸素層）の構造の空間スケールは小さく，実施された測点分布では水平構造を検討できなかった。しかし，そのような構造の見られるのは，潮岬沖の冷水渦の周辺部にのみ限られていた。このような構造は渦の周辺部での激しい海水の拡散・混合の現れとして解釈できること

（2）2009 年 4 月の観測で，観測域の南東端測点 F7 を中心として水深 50～150m 付近に見出だされた高水温，高塩分，高酸素水は，この観測の直前に熊野灘に流入した黒潮水から構成されていること，

（3）2009 年 10 月の観測時において，溶存酸素の鉛直プロファイルのグルーピングから，観測海域を三つの副領域に分けることができた。この最も岸寄りの領域の南縁は，水温場や流速場から見た黒潮強流部の北縁よりも沖側（南方）にある。これは，沿岸水が黒潮域に取り込まれるエントレインメント現象として説明できる。

狭い海域の観測からでは，測点密度を高く取っても，諸量の鉛直プロファイルに現れる極小値や極大値を形作る海水の起源や移動経路を論ずることは非常に難しい。この論文では，諸量の値そのものや，プロファイルの空間的つながりを議論することもできなかった。ここでは，諸量の鉛直プロファイル上の微細な構造の存在域の空間的なつながりを，いわば一種の受動的なトレーサーとして活用する試みである。このような試みは，過去に殆ど例が無く，上記の結論の信頼性も，今後の観測研究を待つ必要があろう。しかし，ここに得られた結果は種々の示唆に富んでおり，今後の研究に役立つものと考える。

謝辞

この研究に当たり，種々ご指導を頂いた勢水丸の内田誠船長をはじめとして，困難な観測に献身

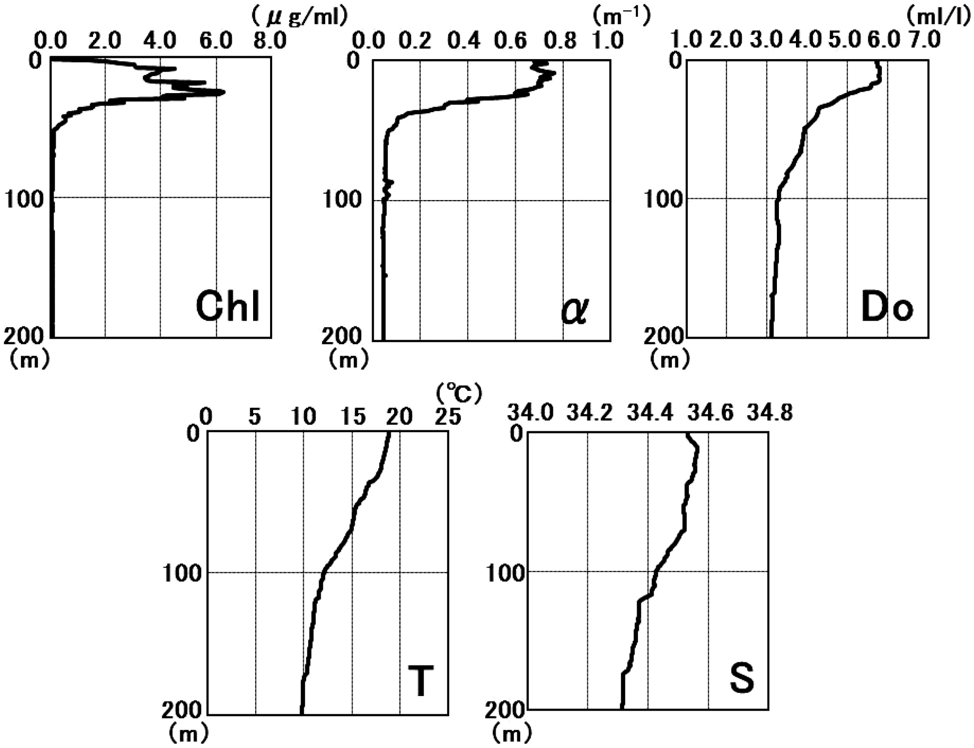

Fig. 18. Vertical profiles of chlorophyll a (upper left: μg/ml), turbidity (upper middle: shown by beam attenuation coefficient (660nm) in m^{-1}), dissolved oxygen (upper right: ml/l), temperature (lower left: ℃) and salinity (lower right) observed at station C3 on April 16, 2009.

的に従事していただいた勢水丸の乗組員に心からの感謝の意を表します。

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受付：平成 23 年 12 月 3 日
受理：平成 24 年 3 月 9 日

La mer 50 : 51, 2012
Société franco-japonaise d'océanographie, Tokyo

資　料

第50巻第1–2号掲載欧文論文の和文要旨

Nattapong Loassachan[1)]・Shettapong Meksumpun[2)]・多田邦尚[3)]：**タイ王国 Mae Klong River 河口干潟における底生微細藻類現存量の変動：堆積物–直上海水境界面における環境要因との関係**

タイ王国の Mae Klong River 河口域の泥干潟において，底生微細藻類の現存量の変動と，相互に連関する環境要因について研究した。2006 年の 9 月（雨季）と 11 月（乾季）の干潟干出時に，干潟全域におよぶ 25 定点で表層泥（0–0.5 cm）を採取し，底生微細藻類の現存量（表層泥中の Chl *a* 含量），強熱減量および，間隙水中の栄養塩濃度を測定した。9 月の底生微細藻類の平均現存量（8.49±2.86 mg m^{-2}）は，11 月（5.21±2.58 mg m^{-2}）よりも 63%高く，この差は統計的にも有意であった（$P<0.0001$）。この要因として干潟の干出時間に直接影響を受ける有効日射量の違いが大きく影響していると考えられた。底生微細藻類による現存量が 9 月に高い事は，表層堆積物を構成する有機物の起源にも影響を及ぼしていた。また，干出時間が長いことは，表層泥中の酸化を促進し，その結果として硝化が進行し，間隙水中の NO_{2-}＋NO_{3-} 濃度が増加していると考えられた。無機三態窒素（DIN）に対する NO_2^-＋NO_3^- の寄与は 52.5%であった。これらの結果は，底生微細藻類の現存量の変動は主に，干出時の有効日射量に制御されており，その変動が Mae Klong River 河口干潟の表層泥の化学組成にも大きく影響していることを示している。

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國分優孝[1)]・小松輝久[1)]・伊藤正木[2)]・服部努[2)]・成松庸二[2)]：**トロール網の採集効率推定値で調整した北海道南東部沖における堆積海産大型植物の生物量**

藻場を構成する海産大型植物は，毎年の成熟期に繁茂し，その後，沿岸の海底から脱落する．そして，海岸へ打ち上げられたり現場で枯死する個体もあるが，ほとんどは海流により沖合へ流出する．北海道南東部沖の深海底における海産大型植物の堆積量を明らかにするため，2008 年の夏季に同海域の底深 330－920m において海底トロール調査を実施した．その結果，24 点中 20 点（83%）の曳網地点でトロール網の採集物の中から海産大型植物が確認された．また，調査海域における海産大型植物の堆積量を推定するため，トロール網の採集効率を調べた．海産大型植物のホンダワラ類に属するアカモクについて実験を行った結果，トロール網の採集効率は 16.7%と推定された.この採集効率から堆積密度を試算したところ，平均 50.0mg wet weight m-2 が堆積していることがわかった．海産大型植物の堆積密度のうちホンダワラ類が占めた割合は 70.0%であり，以下コンブ類は 22.1%，海草は 7.8%，その他の海藻類は 0.1%であった．量的に優占したホンダワラ類は，他の海産大型植物に比べて多量の有機炭素を深海底に供給しており，これは，同種が沿岸の有光層から沖合の深海底への重要な炭素輸送の担い手であることを示唆している．

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下田　徹[1)*]・藤岡義三[2)]・チュンポンスリトン[3)]・チティマアユタカ[3)]：**エビ養殖池からの排水処理のためのマングローブの利用：養殖池の面積を増加させたときの窒素リン収支**

エビ養殖池から運ばれた水のマングローブエンクロジャーによる窒素リン吸収能を評価するために，タイで養殖実験を行った。経済的な観点からエビ養殖者はマングローブ域の面積が小さくなることを望む。そこでエビ養殖池とマングローブエンクロージャーとの間の面積比が 2:1 となる実験が行われ，その効果が評価された。しかしながら面積比が 2:1 である場合，池底質の劣化を食い止めることはできなかった。エビ養殖池に対するマングローブ域面積比を増加させる必要性が示された。

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La mer 50 : 52-54, 2012
Société franco-japonaise d'océanographie, Tokyo

学　会　記　事

津波で被災した三陸の養殖漁業復興のための活動

1）活動の趣旨

日仏海洋学会は，日本とフランスの海洋学および水産学の研究交流を促進することを目的として，1960年に創設された。発足当初は海洋学分野が主流でバチスカーフなどを用いた深海資源開発研究の交流を進めてきたが，1960年代後半からは水産学分野で養殖技術研究の交流が活発に行われてきた。

フランスにおける養殖分野の主要種であるヨーロッパヒラガキおよびポルトガルガキの生産量は1950年代には10万トンに達したが，その後，沿岸開発などの環境変化と都市化による排水などが原因で疾病による死亡率が高くなり，生産量が著しく減少し続けた。そのため，日仏海洋学会の働きかけで，1970年～1973年にかけて日本の三陸沿岸，特に宮城県から，環境変化に強い日本産のマガキ稚貝約1万トンがフランスに移植され，フランスのカキ生産の復興に大きく貢献した。日本産マガキの新しい環境への優れた適応能力のおかげで，フランスのカキ養殖の生産量は再び急速に回復し，1990年代には15万トンに達した。このためフランスでは太平洋産マガキを，「日本のカキ：Les huîtres japonaises」と呼ぶようになった。日仏海洋学会は，研究者交流や研究成果の交換等を通じて，フランスのカキ養殖の危機救済に非常に大きな貢献を果たすことができた。

今回，東日本大地震に伴う津波によって三陸のカキ養殖業が甚大な被害を被ったことに対し，フランスの水産養殖振興協会マリオジュウルス会長および仏日海洋学会のセッカルデイ会長から，40年前の救援に対するお礼の意味を込め

宮城県漁業協同組合で早速利用される顕微鏡

て，義援金を募りたいとの申し出があった。

このフランス側の好意に応えるため，学会では「津波で被災した三陸カキ養殖業復興のための日仏海洋学会義援金募集実行委員会」（略称：三陸津波被災復興実行委員会，委員長：小松輝久副会長（当時））を立ち上げ，募金活動を開始した。

2）支援方法の決定

義援金の利用（支援）方法として現金ではなく，被災地の研究機関と漁業組合で不足する物品等を寄贈する支援策を決め，フランス側関係者もこれに同意した。そこで宮城県の水産技術総合センターおよび県漁協に問い合わせたところ，希望物品は津波で流失した顕微鏡とプランクネットと判明した。

3）寄贈物品の納入

実行委員会ではオリンパスメデイカルサイエンス社に顕微鏡，離合社にはプランクトンネットをそれぞれ発注した。両社からは被災地支援を対象とした値引きと早期調達にご協力をいただいた。生産地では津波被害にもかかわらず例年通り7月にカキの産卵が認められたため，続く採苗時期に合わせ，7月29日に宮城県水産技術総合センターと宮城県漁業協同組合に顕微鏡2台（実体顕と生物顕）とプランクトンネット2個を納入した。寄贈はフランス水産養殖振興協会と日仏両海洋学会の3団体の連名で行い，各団体のロゴマークを物品へ貼付けた。

その後，フランス側との協議により，同様に津波の被害を受けた岩手県水産技術センターと県水産振興センターに，11月11日に同様の顕微鏡2台を寄贈した。

4）義援金総額

義援金総額（フランス水産養殖振興協会と日仏両海洋学会の3団体）：754,749円（資料；収支決算表参照）。

5）追　記

＊宮城・岩手両県の知事と両センター長から3団体に対し寄付受領通知および礼状が寄せられた。

＊河北新報社・岩手日々新聞・岩手放送などが寄贈式の状況を報道した。

＊マリオジュウルス水産養殖振興協会会長が2011年12月，セッカルデイ仏日海洋学会会長と同会員マルセイユ海洋研究所ストーラ博士が2012年2月にそれぞれ被災地視察と見舞いの訪問を行った。

＊募金協力者各位および物品価格に特別措置を執っていただいたオリンパスメデイカルサイエンス販売株式会社と離合社に謝意を表す。

＊被災地への出張およびフランス関係者の視察訪問に際し，多大なご協力をいただいた宮城県漁協の佐々木 良顧問にお礼申し上げる。

（三陸津波被災復興実行委員会　小池康之）

報告事項

1. 2012–2013年度評議員選挙が行われた。
選出された者は以下の通り。
荒川久幸，石坂丞二，石丸隆，磯田　豊，
市川　香，今脇資郎，内田　裕，神田穣太，
北出裕二郎，小池勲夫，小池　隆，河野　博，
小松輝久，斉藤誠一，千手智治，田中祐志，
中田英昭，長島秀樹，森永　勤，門谷　茂，
柳　哲雄，山口征矢，山崎秀勝，吉田次郎

2. 2012–2013年度会長選挙が行われ，小松輝久会員（東大大気海洋研）が選出された。

3. 学会賞選考委員会半数改選が行われ，2012–2013年度委員として，荒川久幸，石坂丞二，河野　博，小松輝久が選出された。2012年度非改選委員は吉田次郎，瀬川　進，千手智治，北出裕二郎，有元貴文の5名。

4. 新入会員

氏名	所属	紹介者
吉永　潔	芙蓉海洋開発株式会社九州センター	
横内一樹	長崎大学環東シナ海環境資源研究センター	小松輝久
高見秀輝	独立行政法人　水産総合研究センター東北区水産研究所	荒川久幸

5. 退会（逝去者含む）
小島　博，木谷浩三，峰　雄二，高木和徳，
寺崎　誠，中嶋秀夫，鷲見浩一，小牧加奈絵，
渡部　武，兵庫県水産技術センター

6. 所属および住所変更
土井　航　〒424-8610　静岡県静岡市清水区折戸3-20-1　東海大学海洋学部水産学科生物生産学専攻　電話　054-334-0411
柴田玲奈　〒314-0408　茨城県神栖市波崎

7620-7 独立行政法人水産総合研究センター水産工学研究所 電話 0479-44-5929

7. 寄贈図書

農工研ニュース（農村工学研究所） No. 75-78
神奈川県立博物館研究報告（神奈川県立生命の星地球博物館） No. 41
FRAN NEWS（水産総合研究センター） No. 28-30
水産総合研究センター研究報告（水産総合研究センター） No. 35-36
広島観光コンベンション（広島観光コンベンションビューロー） Vol. 84-85
Ship & Ocean Newsletter（海洋政策研究財団） No. 265-280
なつしま（JAMSTEC） Vol. 89-95
水産技術（水産総合研究センター） Vol. 4 No. 1
J-STAGE NEWS（独立行政法人科学技術振興機構） No. 29
「海ー自然と文化」（東海大学海洋学部） Vol. 9 No.2
Techno-ocean News（テクノオーシャンネットワーク） No. 42-44
養殖研究レター（水産総合研究センター） 第2号
年報（水産総合研究センター） 平成22年度
Niogata Convention Topics 2010（新潟県産業労働観光部環境局交流企画課コンベンション推進グループ） Vol. 1
東海大学海洋研究所研究報告 第33号
Ocean Breeze（東京大学大気海洋研究所） No. 5-7
ATOMOSPHERE AND OCEAN RESEARCH INSTITUTE THE UNIVERSITY OF TOKYO（東京大学大気海洋研究所） 2011年度
日仏生物学会誌 第51巻
ABSCJF No. 42
気候システムニュース No. 2
中国海洋大学 第41巻1-8，11-12
PROGRESS IN FISHERY SCIENCES Vol. 32 No. 4-6, Vol. 33 No. 1
Meereswissenchaftliche Berichte Marine Science Repoorts No. 84-85
Annual report of Korea ocean research & institute No.2011
Chinese Journal of Ceanology and Limnology Vol. 29 No. 1-5

賛　助　会　員

ＪＦＥアレック株式会社	神戸市西区井吹台東町７－２－３
株式会社　イーエムエス	神戸市中央区東川崎町１－３－３
	神戸ハーバーランドセンタービル　13F
有限会社　英和出版印刷社	北区中里２－14－８シャンボール駒込101
財団法人　海洋生物環境研究所	千代田区神田神保町３－29　帝国書院ビル５Ｆ
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日仏海洋学会入会申込書

（正会員・学生会員）

	年度より入会	年　　月　　日申込
氏　　名 ローマ字		 年　　月　　日　生

勤務先	住　所　〒 機関名 電　話　　　　　　E-mail:
自　宅	住　所　〒 電　話　　　　　　E-mail:
紹介会員氏名	

送付金額	円	送金方法	
会誌の送り先（希望する方に○をつける）		勤務先	自　宅

（以下は学会事務局用）

受付	名簿 原簿	会費 原簿	あて名 カード	学会 記事

入会申込書送付先：〒150-0013 東京都渋谷区恵比寿 3-9-25

（財）日仏会館内

日　仏　海　洋　学　会

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