Journal of Coastal Development
Volume 14, Number 3, June 2011 : 242-254

ISSN : 1410-5217
Accredited : 83/Kep/Dikti/2009

Original Paper

CORRELATION OF ENVIRONMENTAL FACTORS AND DIATOM ASSEMBLAGES IN AKKESHI-KO ESTUARY SYSTEM

Ma'ruf Kasim

Faculty of Fishery and Marine Science, Haluoleo University, Indonesia
Kampus Baru Unhalu, Jln. Mokodompit, Andounhalu, Kendari, Indonesia

Received : May, 15, 2010 ; Accepted : June, 27, 2011

ABSTRACT

The correlation between diatoms and environmental factor were studied in Akkeshi-ko estuary, easthern part of Hokkaido, Japan. This studied were aimed to clarify whether the dynamic and distribution pattern can be made by correlating for environmental variation and diatoms assemblages in an estuarine system. During this research, there are positive correlations between pelagic diatom abundance in water column (PDWC), depth and salinity (r = 0.623 and r = 0.652; respectively). There are positive relationship between nitrite + nitrate and the abundance of diatom on the surface sediment. Seasonal variation of the relationship between abundance of diatoms assemblages and ammonia, nitrite+nitrate and phosphate showed occurs in most stations, the high abundance of benthic and pelagic diatoms in summer followed by the increasing of ammonia, nitrite and nitrate and phosphate.

Keyword : Diatoms; surface sedimen; water column; environmental factor.

Correspondence : Phone : +62-04013193782 ; email : marufkasim@hotmail.com

INTRODUCTION

Diatoms are unicellular microscopic algae, which play most important role in carbon cycling of estuarine food web (Pinckney and Zingmacrk, 1993). They are sensitive to wide range of environmental variables, and the species composition may quickly response to changing physical, chemical and biological conditions in the environment (Harrison and Turpin, 1982; Lapointe, 2000; Mitbavkar and Anil, 2002). The structure of benthic diatom assemblages is related to the sediment characters, light, temperature, salinity and depth (Colijn and Dijkema, 1981; Jonsson, 1987; Miller and Florin, 1989; Zalat, 1995; Nozaki *et al.,* 2002), aside the grazing pressure by benthic suspension feeder (Kasim and Mukai, 2009; Mukai, 1992; Yusoff *et al.,* 2002). The concentration of nutrient affects phytoplankton growth (Smith, 1982; Hillebrand *et al.*, 2000; Kormas *et al.*, 2001). Nutrients (ammonia, nitrate, nitrite, silicate and phosphate) are strongly addressed to the diatom abundance and species composition (Egge, 1998; Lim *et al.*, 2001, Chiba and Saino, 2002). Nitrogen and phosphate are usually limiting factors of growth and abundance of diatoms (Hashimoto and Nakano, 2003). Availability of nutrients in estuary is strongly affected by terrestrial inputs, including human sewage and river inputs (Tappin, 2002). In the most estuaries, the fluctuation of diatom assemblages is characterized by an abundance of diatoms during spring, which corresponds with the increasing of nutrient concentration in water column and perhaps nutrient-inputs from the rivers (Andren, 1999; Gianesella *et al.*, 2000; Nozais *et al.*, 2001; Townsend and Thomas, 2002).

Biological factors such as epiphytic diatoms on seagrass leaves affect the biomass of diatoms in both surface sediment and water column surrounding the habitats. They are playing an important role and most

ISSN : 1410-5217
Accredited : 83/Kep/Dikti/2009

contributors to a primary production of seagrass ecosystems (Klumpp *et al.*, 1992) and they have a possibility of a food source of some benthic suspension feeders. In fact, the epiphytes including epiphytic diatoms have been bigger contributors for herbivores than seagrass leaves (Kitting *et al.*, 1984). Epiphytic diatoms were indirectly utilized by benthic suspension feeder (Jernakoff *et al.*, 1996). Current and/or any other physical factors are able to tear off epiphytic microalgae from seagrass leaves into water column (Sawai, 2001) and suspended epiphytes have been available for benthic suspension feeders (Cognie *et al.*, 2001).

The purpose of this research is to identify and evaluate the environmental variables related to diatom assemblages' in estuary system and to examine whether the dynamic and distribution pattern can be made by correlating for environmental variation and diatoms assemblages.

MATERIALS AND METHODS

Study sites

The field study was conducted at the Akkeshi-ko estuary, eastern Hokkaido (43^o 00' N 144^o 51' E), northern Japan which is almost enclosed but connected to Akkeshi Bay with a narrow channel (**Fig. 1**). Most of the estuary is relatively shallow (4 m in depth) and is covered with extensive eelgrass beds of *Zostera marina* L. and *Z. japonica* Aschers. (Kasim and Mukai, 2006).

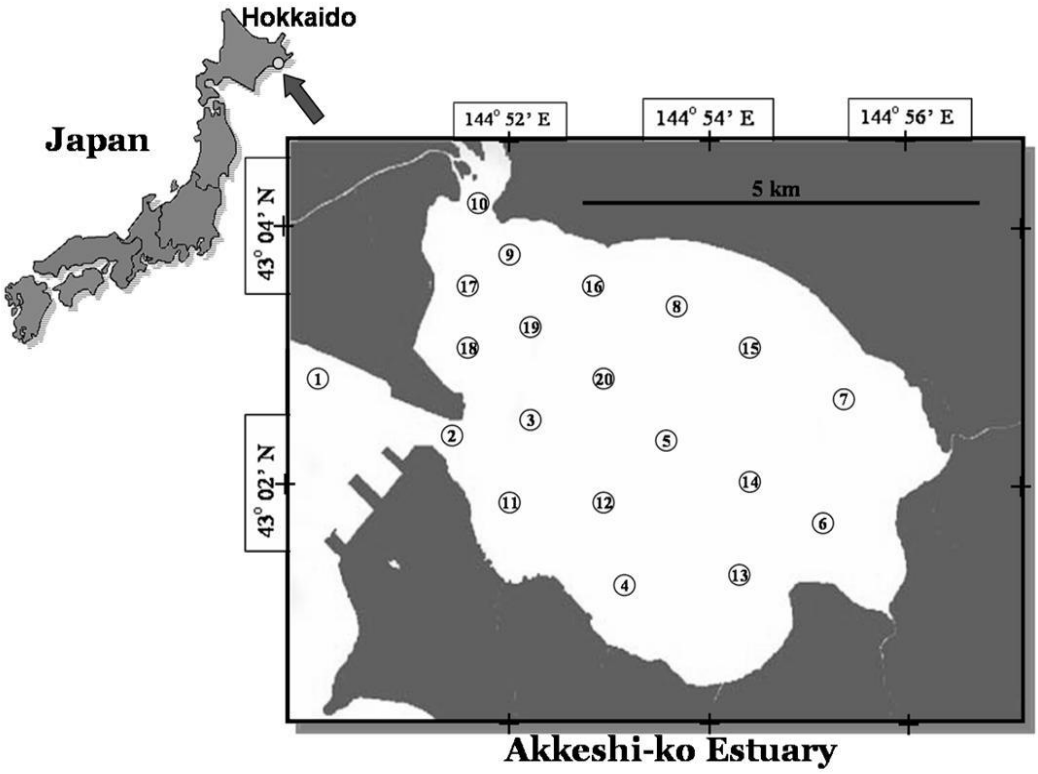

Fig. 1. Sampling stations (Sts. 1 – 20) in the Akkeshi-ko estuary, Hokkaido, Japan.

Field methods

Diatom samples were collected from the water column in the field; 1 L water samples were carried out monthly at 20 stations for 10 month (March – December) in tidal shallow Akkeshi-ko estuary. Three seasons were considered (spring: March – June; summer: July - September and autumn: October - December). In winter season, all surface water was covered by ice, so impossible to do water sampling.

ISSN : 1410-5217
Accredited : 83/Kep/Dikti/2009

Sediment samples were also collected by an Ekman–Birdge grab at 20 stations in the Akkeshi-ko estuary. Benthic diatoms were sub sampled from the sediment by a mini core (diameter: 3 cm). About 1 cm surface layer of sediment was picked up by cellophane plastic. I restricted 1 cm of the surface sediments for observation, because vertical change of diatom assemblages has been known (Rathburn *et al.*, 2001, Kasim, and Mukai, 2009).

Sample analysis

Immediately after sampling, 100 ml water samples were preserved with formaldehyde solution of 0.2 % final concentration. Diatoms in the water samples were collected by the concentration method from 100 ml to 10 ml using hand centrifuge. The samples were pipetted 2 ml and examined under a microscope. All the living diatom samples were enumerated under light microscopic examination using phase contrast optics under 40x and 100x objective. The diatoms from water samples and sediments were identified and counted to the lowest taxonomic level as well as possible. The taxonomic identification of diatoms was carried out using the text of Yamaji (1977), Kato *et al.*, (1977), Kawamura and Hirano (1989), Mizuno and Saito (1990), Sawai and Nagumo (2003), and online publication by; http://www.marbot.gu.se/sss/diatoms, http://www.bio.mtu.edu/~jkoyadom/algae_webpage/HOME.htm, http://www.protist.i.hosei.ac.jp/PDB/Galleries/indexE.html

Physical and chemical parameters

Physical parameters such as water temperature, salinity, and depth were measured *in situ* by electronic apparatus 'Chlorotec', (Alec electronic Co), and current was measured by a current-meter, 'Compact EM' (Alec electronic Co).

Ammonia (NH_4^+), nitrite + nitrate (NO_2^- + NO_3^-) and phosphate (PO_4^-) concentrations in the surface sea water were measured. Ammonia (NH_4^+) concentration was obtained by using a phenol hypochlorite method, as soon as possible within 4 hours after collection (Strickland and Parsons 1968). Nitrite and nitrate (NO_2^- + NO_3^-) concentrations were measured with an autoanalyzer (BRAN+LUEBE, TRAACS800, Cd-Cu methods). Phosphate was determined colorimetrically by the method of Murphy and Riley (1962).

Data analysis

The MINITAB 10 software package for statistical analyses were performed in this research. Standard correlation analysis was addressed to statistically evaluate on these data. Correlation coefficients $\geq$ 0.3 or $\leq$ - 0.3 are established significant.

Results And Discussion

RESULTS

Distribution of physical factors

Yearly means of physical parameters and diatoms density in water column and sediments derived from March to December in the Akkeshi-ko estuary are presented in **Table 1.**

The depths of the estuary were generally within the range 0.3 – 3.0 m, except the Sts. 2 and 3 (4.7-5.0 m). Salinity was lowest in St. 10 (14.5 psu), which was located in the river-mouth, and a maximum in Sts. 2 and 3 (30.5 psu) which were located in or face to the narrow channel between Akkeshi Bay and the estuary (**Fig. 2**).

ISSN : 1410-5217
Accredited : 83/Kep/Dikti/2009

Table 1. Summary characteristics of the 20 station in the Akkeshi-ko estuary.

No Station	average of				Diatoms in Water column	Diatoms in Sediment
	depth (m)	Salinity (psu)	Temperature (°C)	Current velocity (cm.s^{-1})	(cell.L^{-1})	(cell.mg^{-1})
1	1.17	29.8	9.9	17.9	94670	94250
2	5.03	30.5	10.0	46.6	80490	No data
3	4.73	30.5	9.0	32.9	83380	No data
4	0.62	26.3	13.0	16.5	91180	106250
5	3.82	27.8	10.7	14.6	114030	119850
6	0.56	24.4	10.2	24.9	55050	51050
7	1.04	23.4	9.2	14.4	50150	34450
8	1.51	24.8	9.1	10.4	57050	140200
9	1.73	24.3	11.6	10.5	104050	181000
10	0.29	14.5	11.3	12.0	70400	162100
11	2.61	29.2	10.3	17.6	89950	49750
12	3.21	28.8	10.0	24.0	93550	108000
13	0.50	24.3	13.1	11.0	90270	136250
14	0.92	25.9	11.4	21.2	75550	91700
15	0.76	24.3	11.3	18.1	46750	67200
16	0.89	25.4	9.6	15.3	62420	164050
17	0.88	27.5	10.1	21.9	64750	104550
18	0.92	28.7	9.1	21.9	83100	100750
19	0.54	28.9	10.2	14.7	84450	158850
20	0.78	28.2	7.6	11.5	70200	122950

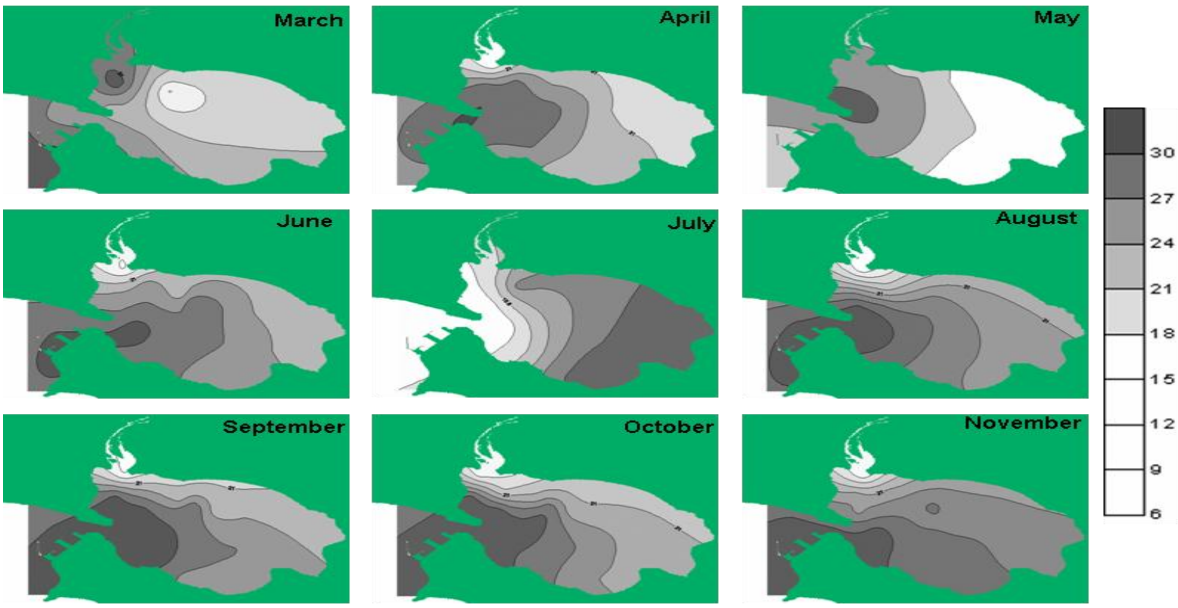

Fig. 2. Distributions of salinity (psu) of surface seawater in the Akkeshi-ko estuary from March to November.

ISSN : 1410-5217
Accredited : 83/Kep/Dikti/2009

Temperature varied depending on the season. Water temperature increased during summer season. Generally, the water temperature was between 7.6 and 13.1 ^oC in summer and autumn season (**Fig. 3**).

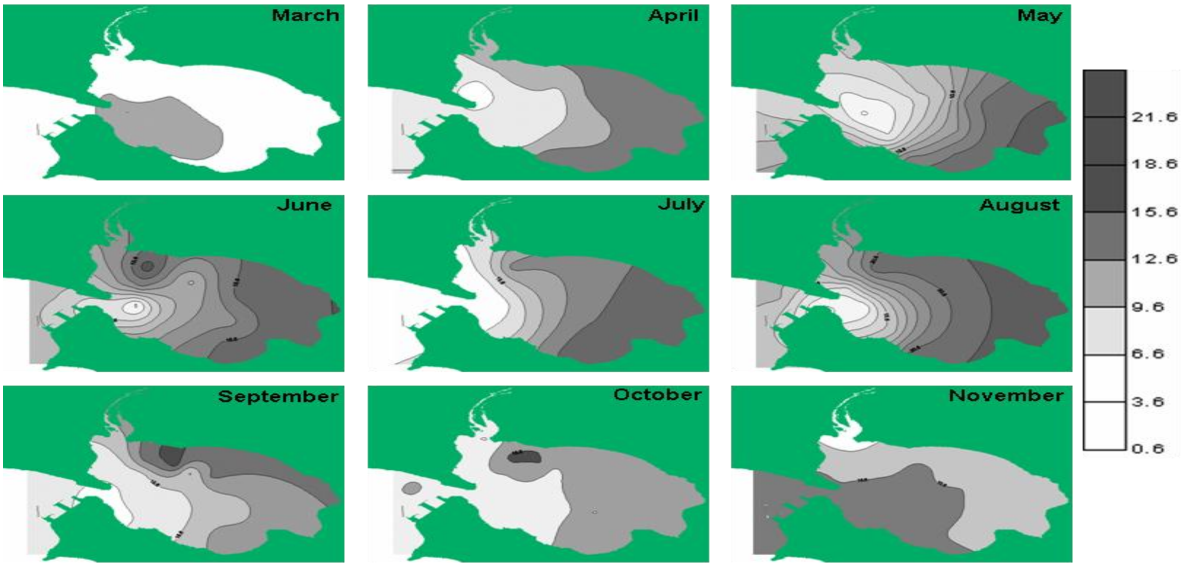

Fig. 3. Distributions of temperature (^oC) of surface seawater in the Akkeshi-ko estuary from March to November.

Correlation analysis between physical environmental factors and abundance of benthic and pelagic diatom assemblages in both, surface sediment and water column, was performed on these data. From these analyses, positive correlations between pelagic diatom abundance in water column (PDWC) and depth and salinity (r = 0.623 and r = 0.652; respectively) were found. Correlation between benthic diatom abundance in sediment (BDSed) and in water column (BDWC) and correlation between benthic diatom abundance and depth or salinity were not significant (**Table 2**).

Table 2. Correlation coefficients (R) between physical environmental factors and the abundance of benthic and pelagic diatom assemblages in both, surface sediment and water column (BDWC = benthic diatoms in water column, PDWC = pelagic diatoms in water column, BDSed = benthic diatoms on the sediment, and PDSed = pelagic diatoms on the sediment).

	depth (m)	*Salinity (‰)*	*Temperature (^oC)*	*Current vel. (ms^{-1})*
BDWC	0.244	0.179	0.431	-0.171
PDWC	0.623	0.652	-0.148	0.41
BDSed	-0.502	-0.409	0.248	-0.731
PDSed	-0.469	-0.195	-0.016	-0.622

ISSN : 1410-5217
Accredited : 83/Kep/Dikti/2009

Distribution of Chemical Factors

Ammonia and Nitrate and nitrite ranged from 0.6 - 2.4 µM and 0.3 - 5.5 µM, in the Akkeshi-ko estuary, respectively. Ammonia concentration was highest in Sts. 10, 17, 18 and 19 (near the river mouth) than other stations in almost all seasons (**Fig. 4**). Nitrate and Nitrite showed highest concentration in Sts. 9, 10 and 19 (**Fig. 5**). This suggests that the Sts. 9, 10, 17, 18 and 19 in the front of the river-mouth were influenced by terrestrial input of ammonia and nitrate and nitrite from the Bekanbeusi River.

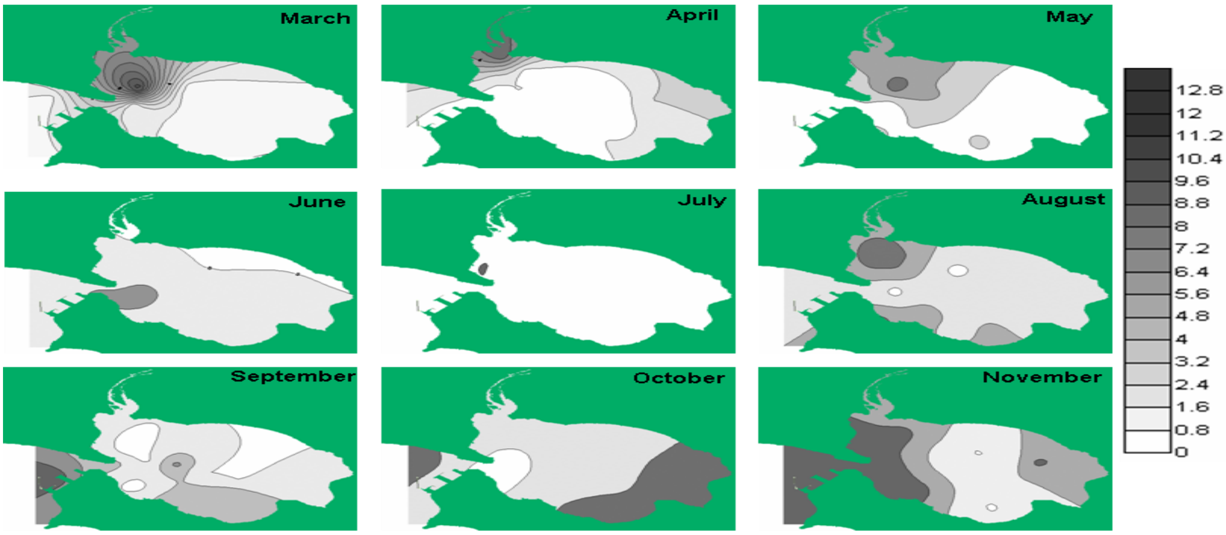

Fig. 4. Distributions of ammonia (µM) of surface seawater in the Akkeshi-ko estuary from March to November.

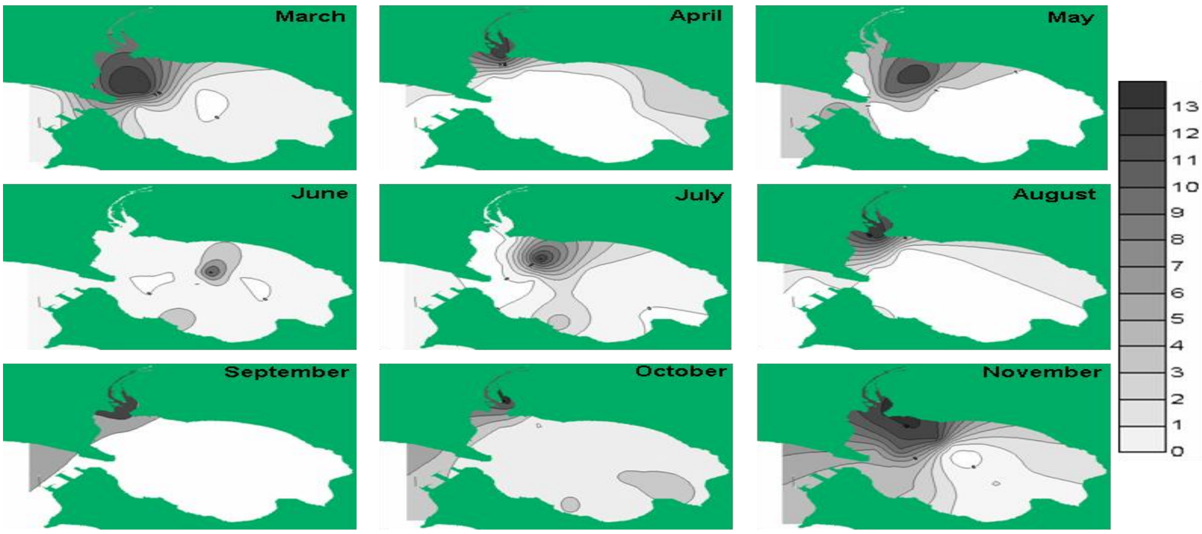

Fig. 5. Distributions of nitrite+nitrate (µM) of surface seawater in the Akkeshi-ko estuary from March to November.

For chemical factors, correlation coefficients between annual mean abundance of diatom assemblages and annual mean concentration of ammonia (NH_4), nitrite and nitrate (NO_2- + NO_3-) and phosphate (PO^4) were calculated. Nitrite and nitrate had positive relationship with the abundance of diatom on the surface sediment (**Table 3**).

ISSN : 1410-5217
Accredited : 83/Kep/Dikti/2009

Table 3. Correlation coefficients (R) between chemical factors and the abundance of benthic and pelagic diatom assemblages in both, surface sediment and water column (BDWC = benthic diatoms in water column, PDWC = pelagic diatoms in water column, BDSed = benthic diatoms on the sediment, and PDSed = pelagic diatoms on the sediment).

	Ammonia (µM)	**Nitrate + Nitrite (µM)**	**Phosphate (µM)**
BDWC	0.283	0.238	-0.145
BDSed	0.289	0.475	0.308
PDWC	-0.086	-0.307	-0.264
PDSed	0.279	0.408	-0.032

Cell number of diatoms was high in Sts 9, 10, 16 and 19 when ammonia and nitrite and nitrate had high concentration. Phosphate concentration showed opposite trends in relation to the abundance of benthic diatoms (**Fig. 6**).

On the other hand, seasonal variation of the relationship between abundance of diatoms assemblages and ammonia, nitrite and nitrate and phosphate showed that generally in most stations, the high abundance of benthic and pelagic diatoms in summer followed by the increasing of ammonia, nitrite & nitrate and phosphate (**Figs. 7, 8, and 9**).

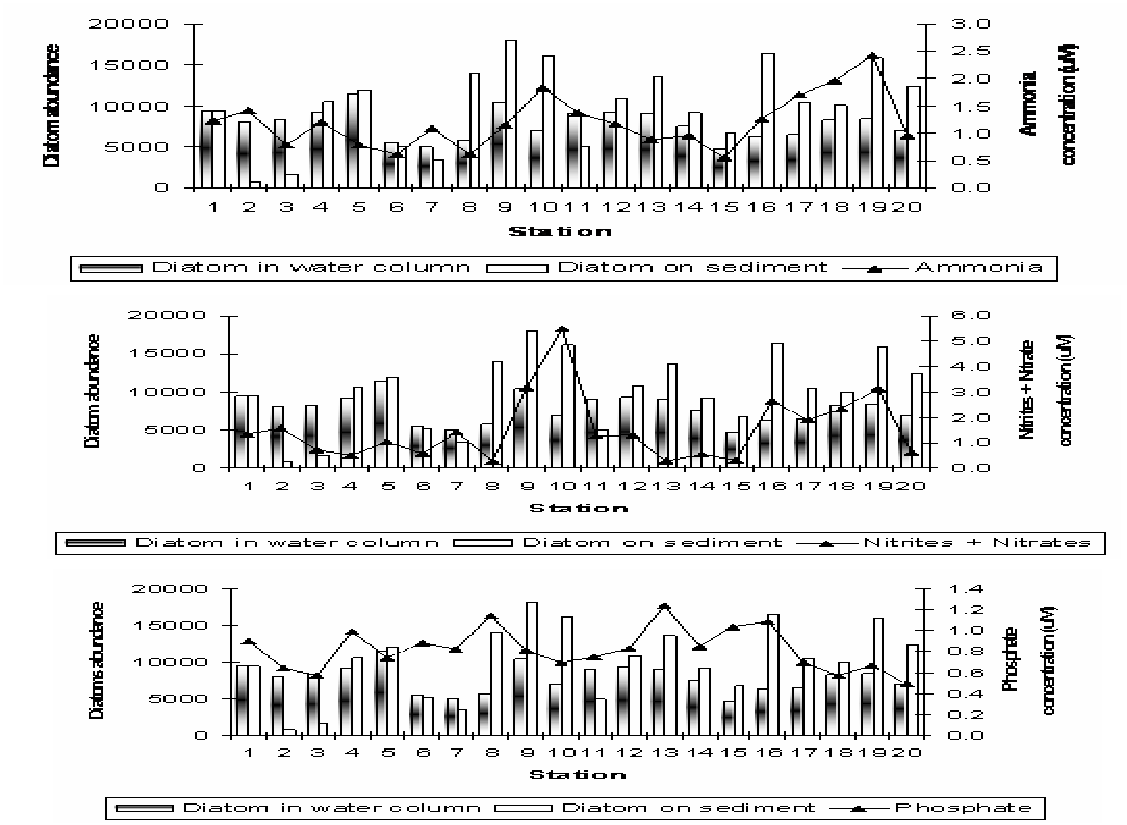

Fig 6. The relationship between annual mean of diatoms abundance in water column (cell/L) and surface sediment (cell/mg) and annual mean concentrations of chemical factors; ammonia

ISSN : 1410-5217
Accredited : 83/Kep/Dikti/2009

(NH_4^+), Nitrite (NO_3^-) and Nitrate (NO_2^-), and Phosphate (PO_4^-).

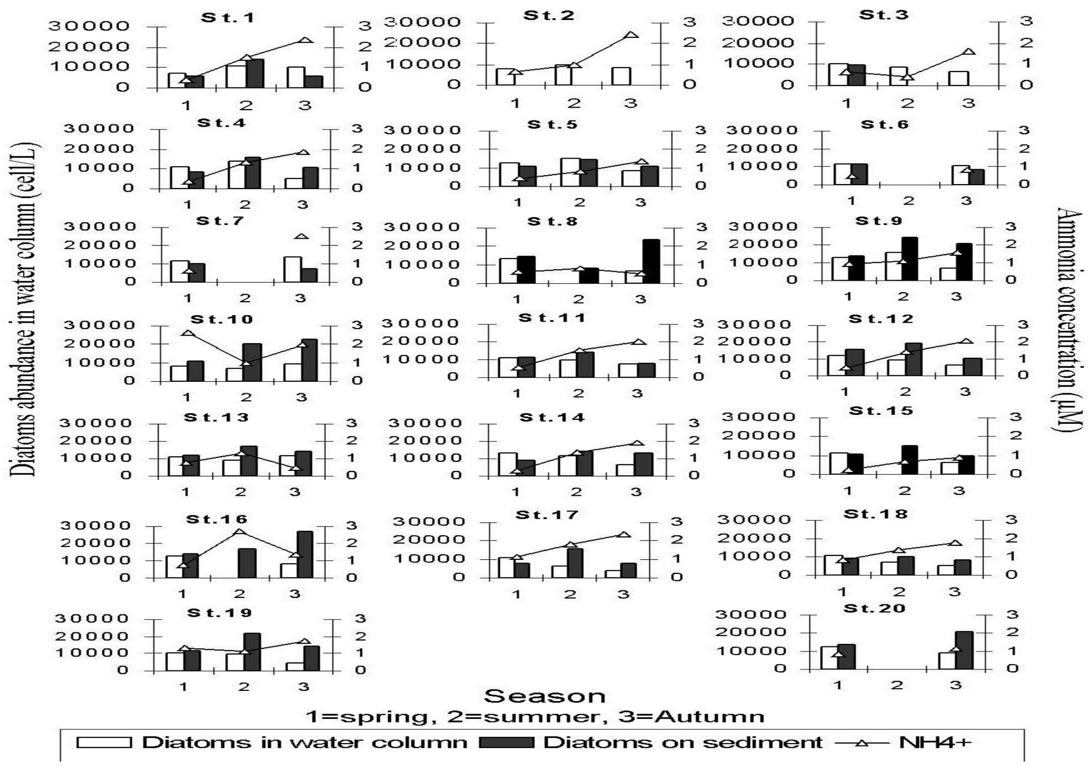

Fig.7. Seasonal variation of diatoms abundance and correlation with ammonia ($NH4^+$) in each stations in the Akkeshi-ko estuary

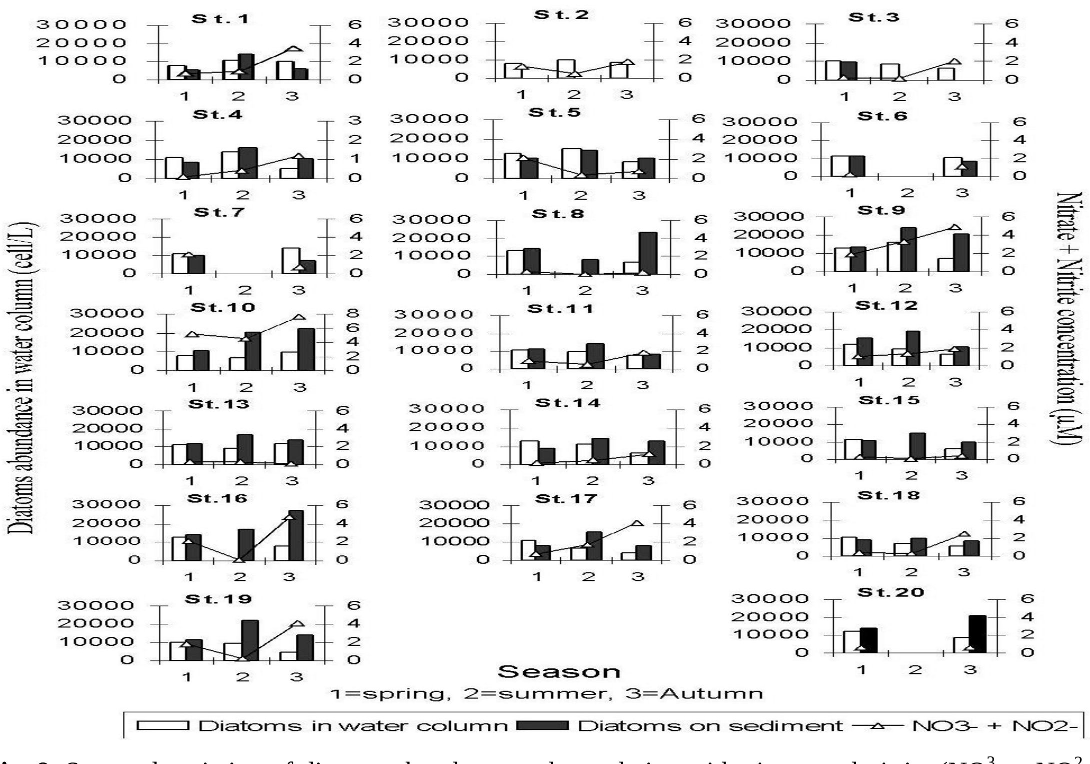

Fig. 8. Seasonal variation of diatoms abundance and correlation with nitrate and nitrite (NO^{3}- + NO^{2}-) in each stations in the Akkeshi-ko estuary

ISSN : 1410-5217
Accredited : 83/Kep/Dikti/2009

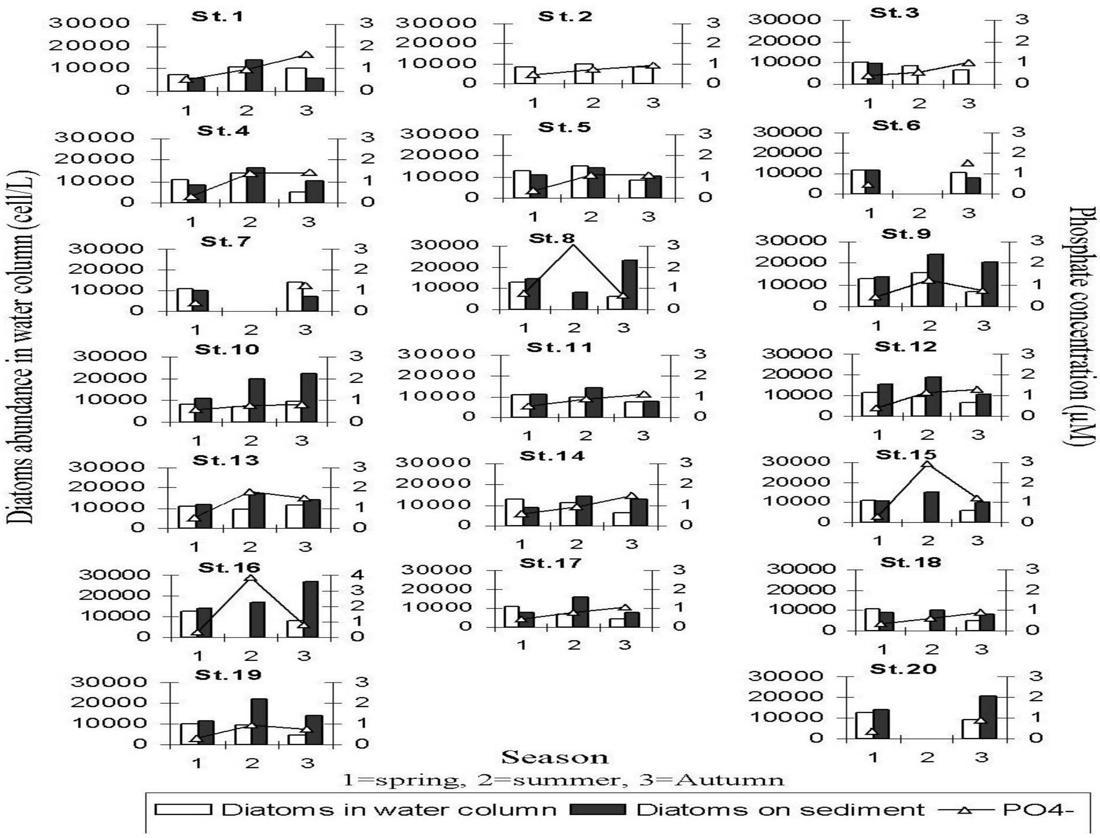

Fig 9. Seasonal variation of diatoms abundance and correlation with Phosphate (PO^{4}-) in each stations in the Akkeshi-ko estuary.

DISCUSSION

The abundance of diatoms in water column fluctuates by many abiotic and biotic factors. It is influenced by light and nutrient availability. Dissolved inorganic nitrogen, as ammonia, nitrate, nitrite, phosphate, silicate and so on, are basically important factors on diatom production (Hillebrand *et al.*, 2000; Lim *et al.*, 2001). These nutrients are supplied from rivers fundamentally. The nutrient concentration and availability for diatoms would be changed with seasons and precipitation in the Akkeshi-ko estuary (Mukai, unpublished). Dominant species of benthic diatom assemblages in the Akkeshi-ko estuary were occurred also adjacent to Bekanbeusi River mouth in Sts. 9, 10, 16 and 19. These observations suggest that dynamic of diatom assemblages was always associated with the availability of nutrient particularly from a river. It is interesting to find out that, several stations near the river, had high diatom abundance.

The spatial and temporal fluctuation of benthic and pelagic diatoms generally addressed to light and nutrient availability (Kormas *et al.*, 2001, Welker *et al.*, 2002), tidal current (Perrisinotto *et al.*, 2002) and grazing pressure by suspension feeders (Blackford, 2002). Basically, benthic and pelagic diatoms would be controlled by nutrient concentration as bottom-up effect and or by top down effects such as feeding process by suspension feeder (Bennett *et al.*, 2000; Kasim and Mukai, 2009). In mid summer, the biomass of benthic diatoms was higher than pelagic diatoms in several stations in Adriatic Sea, with the nutrient and light availability as key factors for limiting fluctuation of diatoms abundance (Blackford, 2002). The inorganic nutrient concentration at the water column near the sediment surface was importance factor influenced the spatial fluctuation of diatoms. In the Gulf of Trieste (northern Adriatic Sea), there were

ISSN : 1410-5217
Accredited : 83/Kep/Dikti/2009

significant correlations between diatom abundance and ammonium, silicate and phosphate concentrations. And also the fluctuation of diatoms in water column near the surface bottom layer is influenced by not only the total annual regeneration of ammonium, silicate and phosphate, but also the characteristic sediment and bioturbation that may displace diatoms to water column from the surface layer caused by benthic faunal activity (Welker *et al.,* 2002).

In the Akkeshi-ko estuary, occupation ratio of diatom species in water column diatom assemblage was about 20% in winter and it increased in May to July with increasing biomass of seagrasses (Kasim and Mukai, 2006). On the other hand, some pelagic diatom species were included in the diatom assemblages on surface sediments. Furthermore, diatoms have to compete the nutrients with marine macrophytes, in particular eelgrasses, *Zostera marina* and *Z. japonica*, in Akkeshi-ko. *Z. marina* is a strong competitor for 'phytoplankton' during spring-summer, because the biomass and production rate of *Z. marina* is very high in these seasons in the Akkeshi-ko estuary (Mukai *et al*., unpublished). Riaux-Gobin and Bourgoin (2002) reported that the increase of several benthic diatom species such as *Cocconeis* sp. and *Grammathopora* sp. during summer in Kerguelen Archipelago (Indian Ocean) were strongly related to the dense macroalgal canopy as important source of these diatoms. Facca *et al.,* (2002) found out low diatom concentration in several sites of Venice lagoon, Italy, when macroalgae disappeared in season. It suggests that epiphytic diatoms are important for sustaining 'phytoplankton' assemblages in the water column.

ACKNOWLEDGMENTS

The study was funded by a Monbukagakusho Scholarship to M. Kasim. I wish thank to Prof. Hiroshi Mukai for all time, idea, consultation, correction and suggestion. I wish thank to Natsuki Hasegawa for helping with chemical analyses, and Yoshiyuki Tanaka and Andrei Krasnenko for helping with sample collection. We also thank Sho-ichi Hamano and Hidenori Katsuragawa for logistic support during the field collection.

REFFERENCES

Andren, E. 1999. Change in composition of the diatom flora during the last century indicate increased eutrophication of the Oder Estuary, South-western Baltic Sea. *Estuarine, Coastal and Shelf Science*. 48: 665-676.

Bennett, A., T.S. Bianchi, J. Means. 2000. The effect of PAH contamination and grazing on the abundance and composition of microphytobenthos in salt marsh sediment Pass Fourchon, LA, USA.: II : The use of plate pigment as biomarkers. *Estuarine, Coastal and Shelf Science*. 50 : 425-439.

Blackford, J.C. 2002. The influence of microphytobenthos on the Northern Adriatic ecosystem : A modelling study. *Estuarine, Coastal and Shelf Science*. 55: 109-123.

Chiba, S. and T. Saino. 2002. Interdecadal change in the upper water column environment and spring diatom community structure in the Japan Sea: an early summer hypothesis. *Marine Ecology Progress Series*. 231:23-35.

Cognie, B., L. Barille, Y. Rince. 2001. Selective feeding of the *Crassostrea gigas* feed on a natural microphytobenthos assemblages. Estuaries. 24: 126-131.

Colijn, F. and K.S. Dijkema. 1981. Species composition of benthic diatoms and distribution of chlorophyll *a* on an intertidal flat in Dutch Wadden Sea. *Marine Ecology Progress Series*. 4 : 9–21.

Egge, J.K. 1998. Are diatoms poor competitor at low phosphate

ISSN : 1410-5217
Accredited : 83/Kep/Dikti/2009

concentrations?. *Journal of Marine Systems*. 16:191-198.

Facca, C., A. Sfriso, and G. Socal. 2002. Changes in abundance and composition of phytoplankton and microphytobenthos due to increased sediment fluxes in the Vecine Lagoon, Italy. *Estuarine, Coastal and Shelf Science*. 54: 773-792.

Gianesella, S.M.F., F.M.P. Saldanha-Correa and C. Teixeira. 2000. Tidal effect on nutrient and phytoplankton distribution in Bertioga Channel, Sao Paulo, Brazil. *Aquatic Ecosystem Health and Management* 3:533-544.

Harrison, P.J., and D.H. Turpin. 1982. The manipulations of physical, chemical and biological factors to select species from natural phytoplankton community. In: Marine Mesocosm ed. By G.D. Grice and M.R. Reeve. pp 275-289. Springer-Verlag, New York.

Hashimoto, T. and S. Nakano. 2003. Effect of nutrient limitation on abundance and growth of phytoplankton in a Japanese pearl farm. *Marine Ecology Progress Series*. 258:43-50.

Hillebrand, H., B. Worm, and H.K. Lotze. 2000. Marine microbenthic community structure regulated by nitrogen loading and grazing pressure. *Marine Ecology Progress Series*. 204 : 27 – 83.

Jernakoff, P., A. Brearley and J. Nielsen. 1996. Factors affecting grazer-epiphyte interactions in temperate seagrass meadows, Oceanography *Marine Biology Annual Review*. 34:109–162.

Jonsson, G.S. 1987. The depth distribution and biomass of epilithic periphyton in lake Thingvallavatn. *Archiv für Hydrobiologie*. 108 : 531-547.

Kato, K., H. Kobayashi and T. Minamigumo. 1977. The diatoms in artificial pond, Hachiro Marsh. The report of biota survey in artificial pond of Hachiro marsh. Akita Prefecture. Japan.

Kasim M, and H. Mukai. 2006. Contribution of benthic and epiphytic diatoms to clams and oyster production in the Akkeshi-ko estuary. *J. Oceanography*, 62: 267–281.

Kasim, M and H. Mukai. 2009. Food sources of the oyster *Crassostrea gigas*. and the clam *Ruditapes philippinarum*. in the Akkeshi-ko estuary, Plankton Benthos Research 43.: 104–114.

Kawamura, T. and R. Hirano. 1989. Notes on attached diatoms in Aburatsubo Bay, Kanagawa Prefecture, Japan. Bulletin of Tohoku Regional Fisheries Research Laboratory. 51 : 41 – 73. in Japanese with English Abstract.

Kitting, C.L., B. Fry and M.D. Morgan. 1984. Detection of inconspicuous epiphytic algae supporting food webs in seagrass meadows. *Oceologia*. 62:145–149.

Klumpp, D.W., J. Salita-Espinosa, M.D. Fortes, 1992. The Role of epiphytic periphyton and macroinvertebrate grazers in the trophic flux of tropical seagrass community. Aquat. Bot., 43:327-349.

Kormas, K.A., A. Nicolaidou and S. Reizopoulou. 2001. Temporal variation of nutrients, chlorophyll *a* and particulate matter in three coastal lagoon of Amvrakikos gulf Ionian sea, Greece. *Marine Ecology*. 22: 201-213.

Lapointe, M. 2000. Modern Diatom assemblages in surface sediments from the marine estuary and the gulf of St. Lawrence, Quebec. Canada. *Marine Micropelaeontology*. 40:43-65.

Lim, D.S.S., M.S.V. Douglas and J.P. Mol. 2001. Diatoms and their relationship to environmental variables from lakes and

ISSN : 1410-5217
Accredited : 83/Kep/Dikti/2009

ponds on Bathurst Island, Nunavut, Canadian High Arctic. *Hydrobiologia*. 450:215-230.

Miller, U. and M.B. Florin. 1989. Diatom analysis, introduction to methods and applications. Paleoecological Analysis of Circumpolar Treeline. 24: 133-157.

Mitbavkar, S. and A.C.Anil. 2002. Diatoms of the microphytobenthic community: population structure in a tropical intertidal sand flat. *Marine Biology*. 140 : 41-57

Mizuno, M. and S. Saito. 1990. Planktonic diatoms from lake Oike of lake Tsugaru-Juniko Group, Aomori Prefecture. Diatom. 5 : 9-89 in Japanese with English abstract.

Mukai, H. 1992. The importance of primary inhabitant in soft-bottom community organization. *Benthos Research*. 42:13-27.

Murphy, J. and J.P. Riley. 1962. A modified single solution for the determination of phosphorus in natural waters. *Analytica Chimica Acta*. 27:21–36.

Nozais, C., R. Perissinotto, and S. Mundree. 2001. Annual cycle of microalgal biomass in a South African temporarily-open estuary: nutrient versus light limitation. *Marine Ecology Progress Series*. 223:39-48.

Nozaki, K., H. Morino, H. Munehara, V.G. Sideleva, K. Nakai, M.Yamauchi, O.M. Kozhova and M. Nakanishi. 2002. Composition, biomass, and photosynthetic activity of the benthic algal communities in a littoral zone of lake Baikal in summer. Limnology. 3: 175-180.

Perissinotto, R., C. Nozais, and I. Kibirige, 2002. Spatio-temporal dynamic of phytoplankton and microphytobenthos in a South Africa temporarily-open estuary. *Estuarine*, *Coastal and Shelf Science*. 55: 47-58.

Pinckney, J. and R.G. Zingmark. 1993. Modeling the annual production of intertidal benthic microalga in estuarine ecosystems. *Journal Phycology* 29: 396–407.

Rathburn, A.E., M.E. Perez and C.B.Lange. 2001. Benthic-pelagic coupling in the southern California Bight: Relationship between sinking organic materials, diatoms and benthic foraminifera. *Marine Micropaleontology*. 43: 261-271.

Riaux-Gobin, C.and P. Bourgoin. 2002. Microphytobenthos biomass at Kerguelen's land Subantarctic Indian Ocean.: repartition and variability during austral summer. *J. Marine Systems.* 32: 295-306.

Sawai, Y. 2001. Distribution of living and dead diatoms in the tidal wetland of northern Japan : relation to taphonomy. Palaeogeography, *Palaeoclimatology, Palaeoecology*. 173 : 125–141.

Sawai, Y. and T. Nagumo. 2003. Diatoms Bacillariophyceae. flora of salt marshes along the pacific coast of eastern Hokkaido, northern Japan. Bulletin on the Nippon Dental University. 32: 93-108.

Smith, V. M. 1982. The nitrogen and phosphorus dependence of algal biomass in lakes. An empirical and theoretical analysis. *Lymnology and Oceanograph* 19: 889-901

Tappin, A.D. 2002. An examination of the fluxes of nitrogen and phosphorus in temperate and tropical estuaries: current estimates and uncertainties. *Estuarine, Coastal and Shelf Science.* 55:885-901.

Townsend, D.W. and M. Thomas. 2002. Springtime nutrient and phytoplankton dynamics on Georges Bank. *Marine Ecology Progress Series*. 228: 57-74.

ISSN : 1410-5217
Accredited : 83/Kep/Dikti/2009

Welker, C., E. Sdrigotti, S. Covelli and J. Faganeli. 2002. Microphytobenthos in the Gulf of Trieste Northern Adriatic Sea. : Relationship with labile sedimentary organic matter and nutrients. *Estuarine, Coastal and Shelf Science.* 55: 259-273.

Yamaji, I. 1977. Illustration of the Marine Plankton of Japan. Hoikusha Publishing Co. Ltd. Japan. 369 pp.

Yusoff, F.M., M.S. Zubaidah, H.B. Matias and T.S. Kwan. 2002. Phytoplankton succession in intensive marine shrimp culture pond treated with a commercial bancterial product. *Aquaculture Research*. 33: 269-278.

Zalat, A.A. 1995. Diatoms from the quaternary sediments of the Nile Delta, Egypt, and their palaeoecological significance. *Journal of African Earth Sciences*. 20: 133-150.

.

ISSN : 1410-5217
Accredited : 83/Kep/Dikti/2009

Table 1. Summary characteristics of the 20 station in the Akkeshi-ko estuary.

No	average of				Diatoms in	Diatoms in
Station	depth (m)	Salinity (psu)	Temperature (°C)	Current velocity ($cm.s^{-1}$)	Water column ($cell.L^{-1}$)	Sediment ($cell.mg^{-1}$)
1	1.17	29.8	9.9	17.9	94670	94250
2	5.03	30.5	10.0	46.6	80490	No data
3	4.73	30.5	9.0	32.9	83380	No data
4	0.62	26.3	13.0	16.5	91180	106250
5	3.82	27.8	10.7	14.6	114030	119850
6	0.56	24.4	10.2	24.9	55050	51050
7	1.04	23.4	9.2	14.4	50150	34450
8	1.51	24.8	9.1	10.4	57050	140200
9	1.73	24.3	11.6	10.5	104050	181000
10	0.29	14.5	11.3	12.0	70400	162100
11	2.61	29.2	10.3	17.6	89950	49750
12	3.21	28.8	10.0	24.0	93550	108000
13	0.50	24.3	13.1	11.0	90270	136250
14	0.92	25.9	11.4	21.2	75550	91700
15	0.76	24.3	11.3	18.1	46750	67200
16	0.89	25.4	9.6	15.3	62420	164050
17	0.88	27.5	10.1	21.9	64750	104550
18	0.92	28.7	9.1	21.9	83100	100750
19	0.54	28.9	10.2	14.7	84450	158850
20	0.78	28.2	7.6	11.5	70200	122950

Table 2. Correlation coefficients (R) between physical environmental factors and the abundance of benthic and pelagic diatom assemblages in both, surface sediment and water column (BDWC = benthic diatoms in water column,

ISSN : 1410-5217
Accredited : 83/Kep/Dikti/2009

PDWC = pelagic diatoms in water column, BDSed = benthic diatoms on the sediment, and PDSed = pelagic diatoms on the sediment).

	depth (m)	***Salinity (‰)***	***Temperature (°C)***	***Current vel. (MS-1)***
BDWC	**0.244**	**0.179**	**0.431**	**-0.171**
PDWC	**0.623**	**0.652**	**-0.148**	**0.41**
BDSed	**-0.502**	**-0.409**	**0.248**	**-0.731**
PDSed	**-0.469**	**-0.195**	**-0.016**	**-0.622**

Table 3. Correlation coefficients (R) between chemical factors and the abundance of benthic and pelagic diatom assemblages in both, surface sediment and water column (BDWC = benthic diatoms in water column, PDWC = pelagic diatoms in water column, BDSed = benthic diatoms on the sediment, and PDSed = pelagic diatoms on the sediment).

	Ammonia (µM)	**Nitrate + Nitrite (µM)**	**Phosphate (µM)**
BDWC	0.283	0.238	-0.145
BDSed	0.289	0.475	0.308

ISSN : 1410-5217
Accredited : 83/Kep/Dikti/2009

PDWC	-0.086	-0.307	-0.264
PDSed	0.279	0.408	-0.032

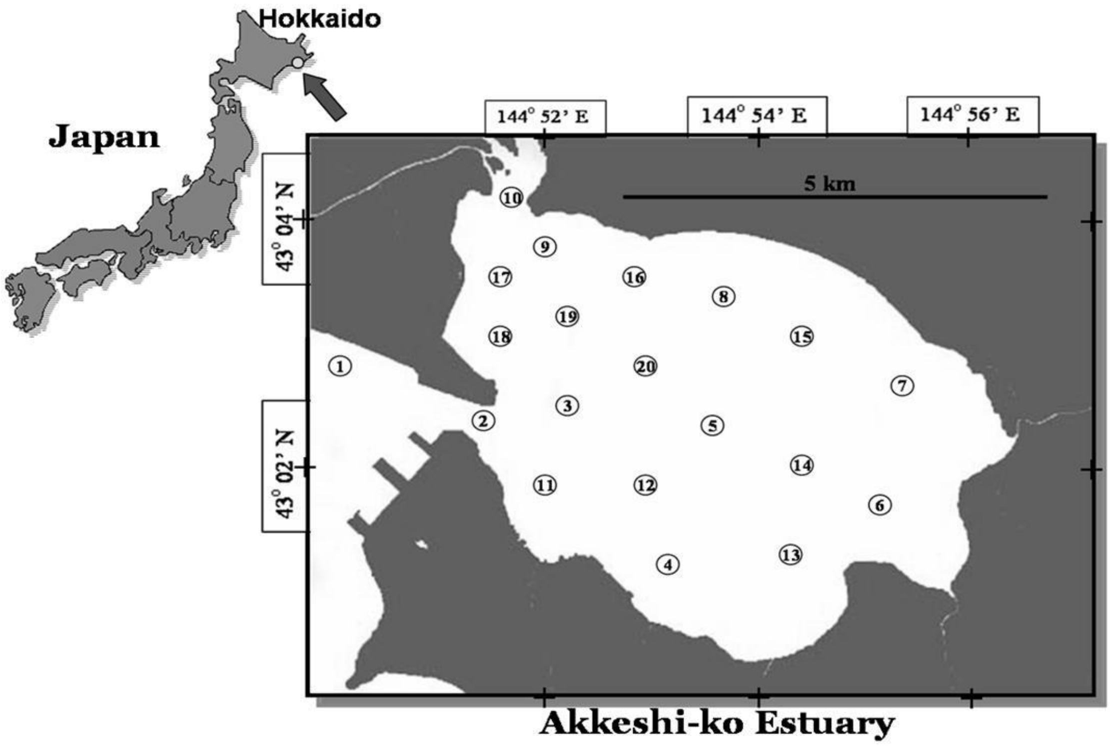

Figure 1. Sampling stations (Sts. 1 – 20) in the Akkeshi-ko estuary, Hokkaido, Japan.

ISSN : 1410-5217
Accredited : 83/Kep/Dikti/2009

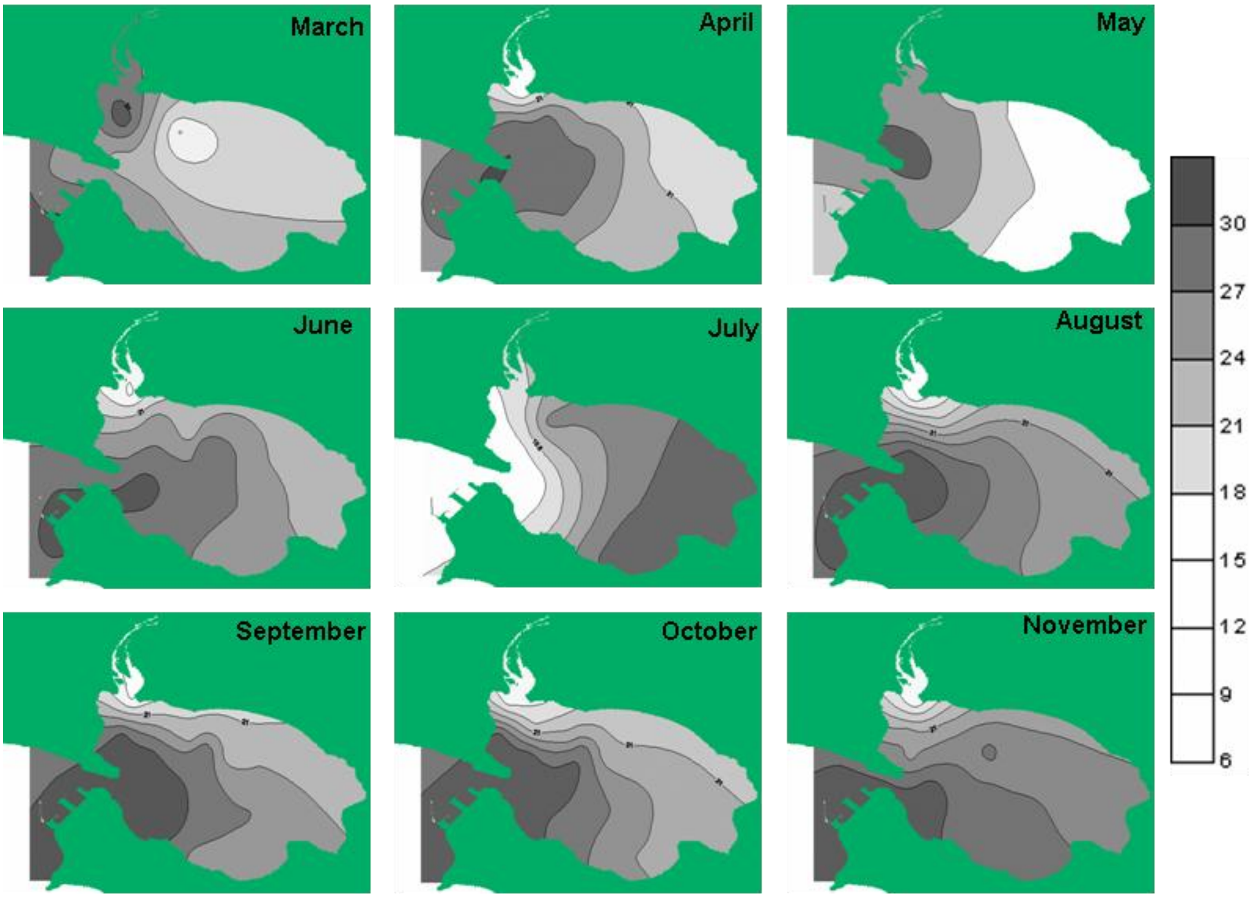

Figure 2. Distributions of salinity (psu) of surface seawater in the Akkeshi-ko estuary from March to November.

ISSN : 1410-5217
Accredited : 83/Kep/Dikti/2009

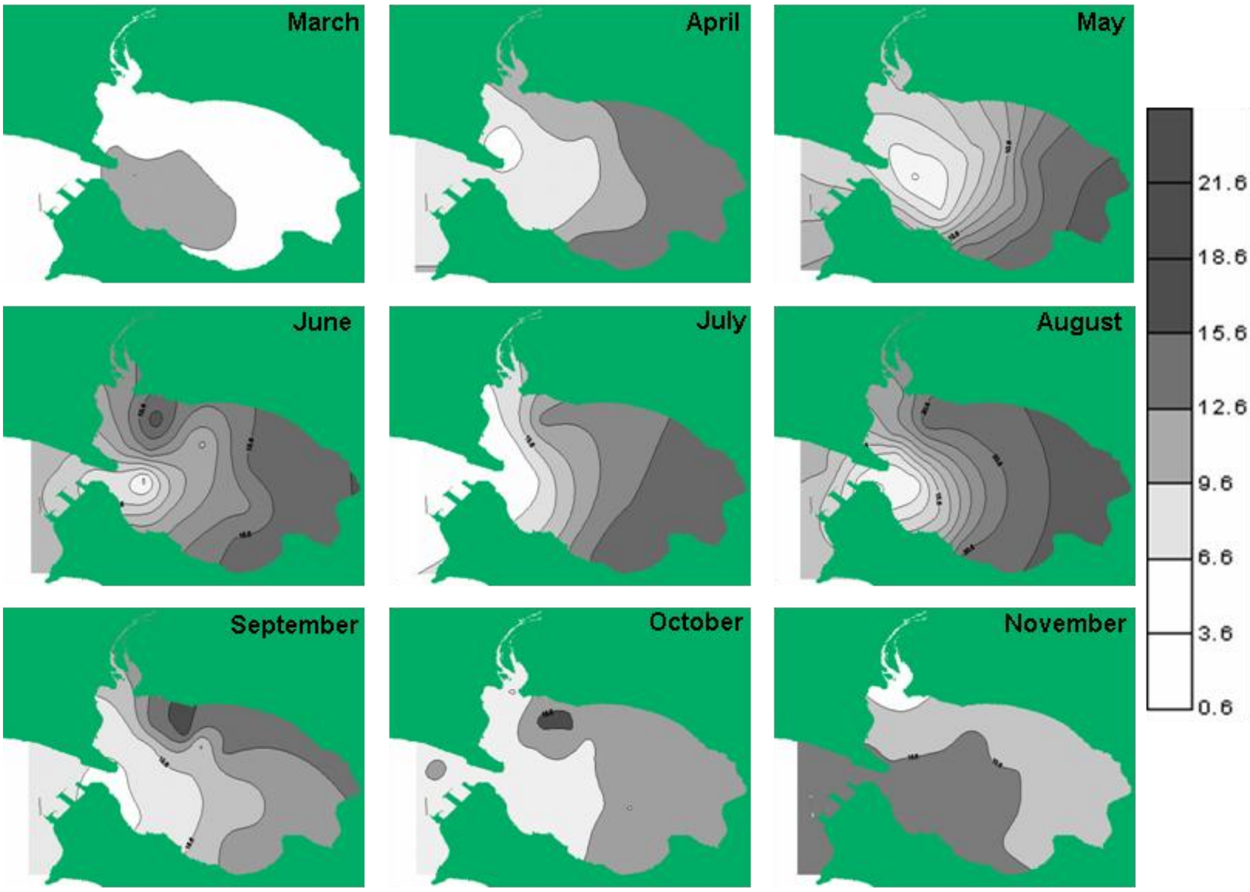

Figure 3. Distributions of temperature (^{o}C) of surface seawater in the Akkeshi-ko estuary from March to November.

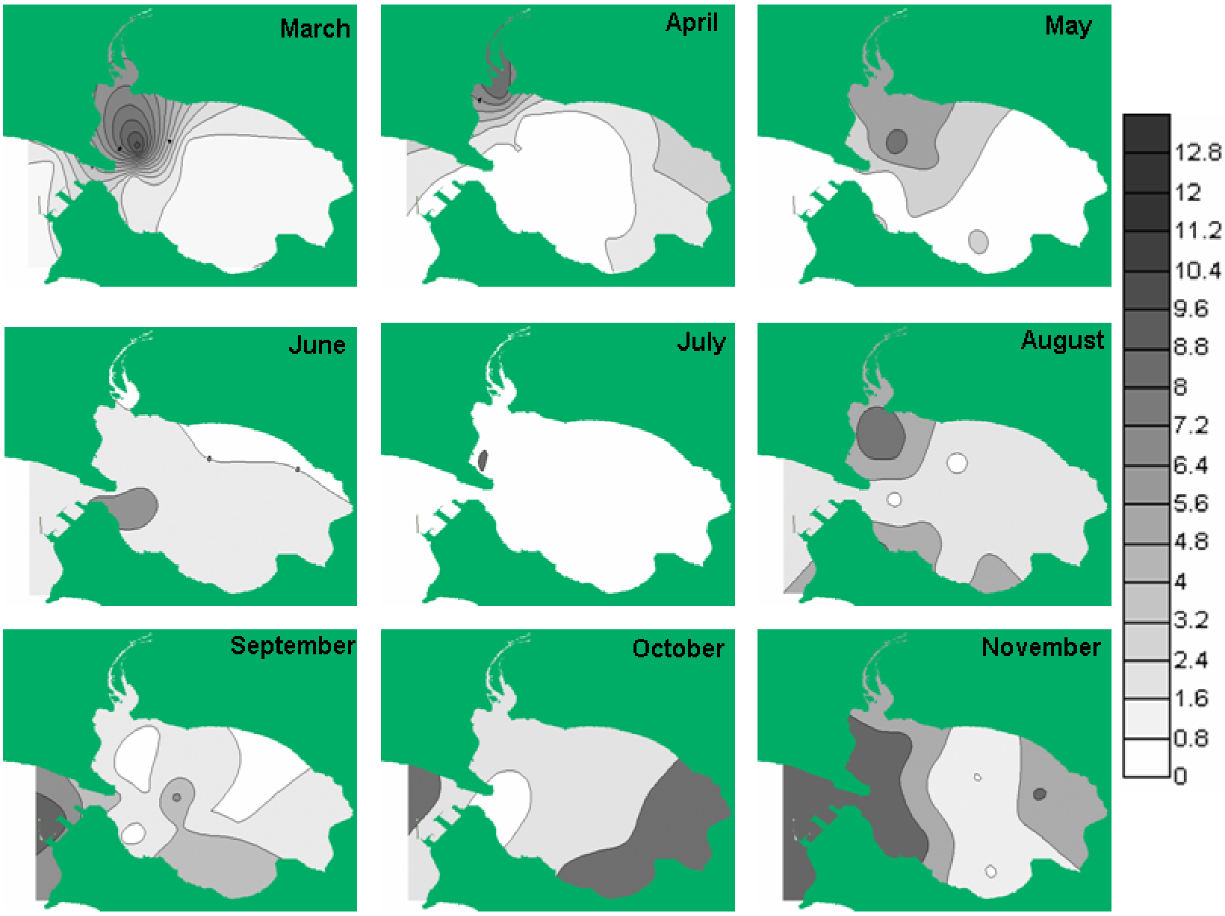

Figure 4. Distributions of ammonia (µM) of surface seawater in the Akkeshi-ko estuary from March to November.

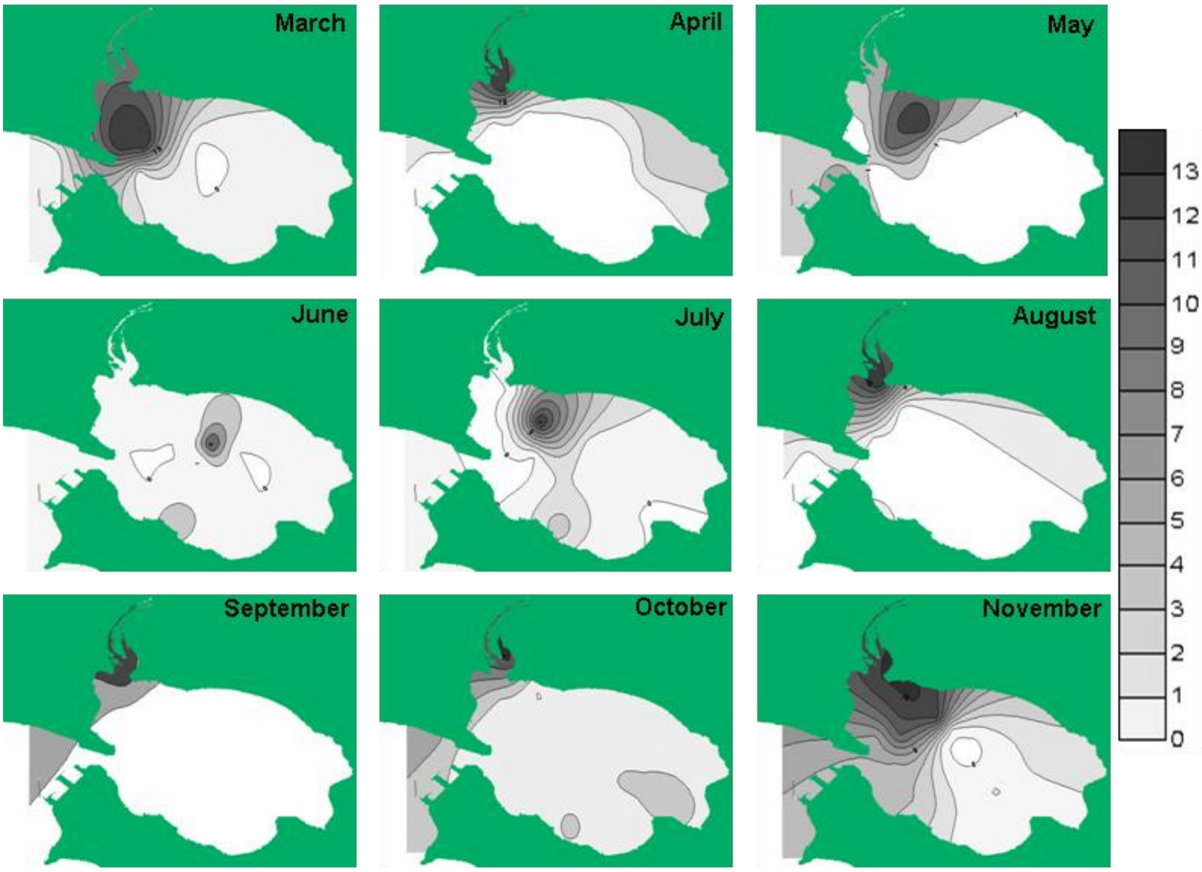

Figure 5. Distributions of nitrite+nitrate (µM) of surface seawater in the Akkeshi-ko estuary from March to November.

ISSN : 1410-5217
Accredited : 83/Kep/Dikti/2009

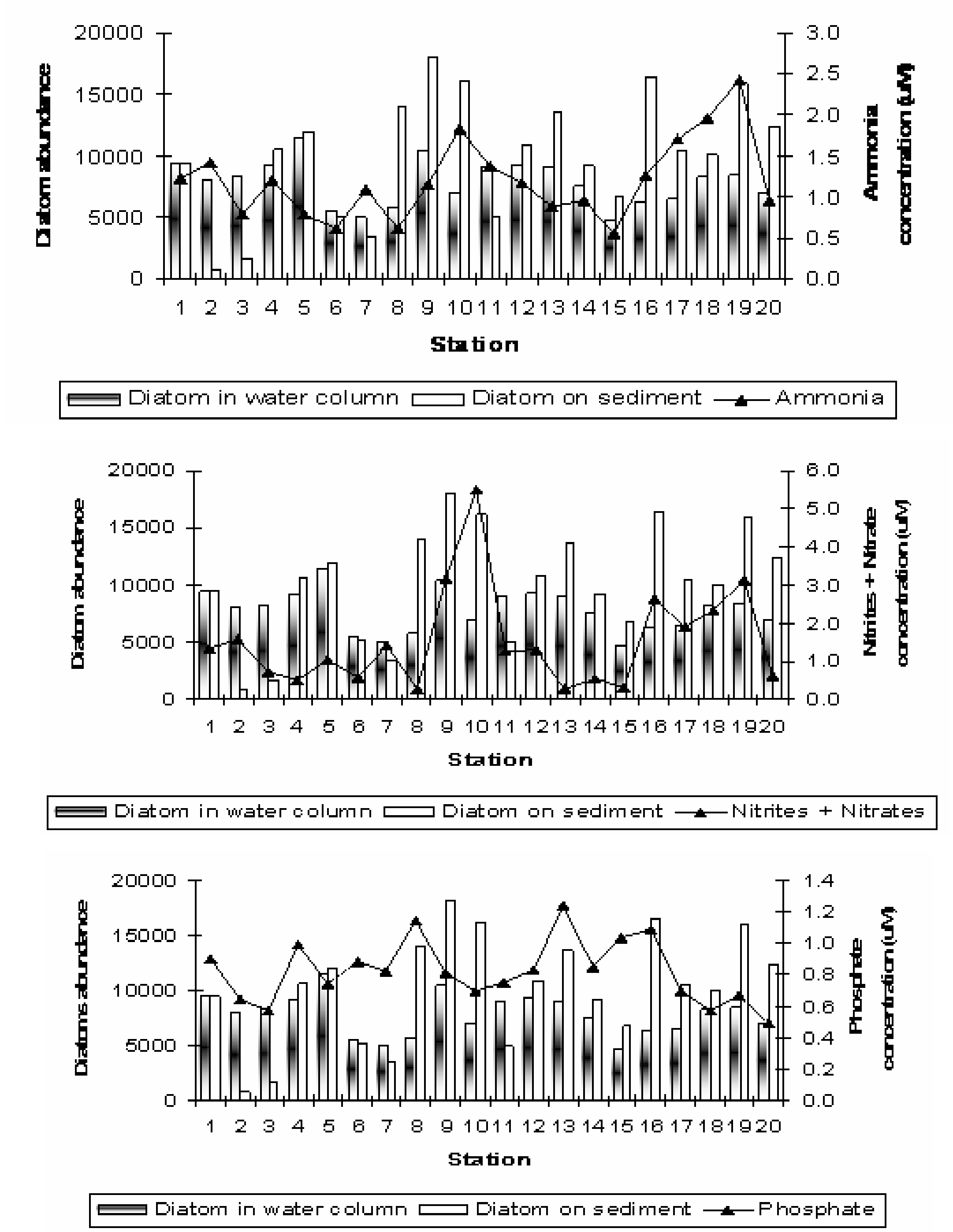

Figure 6. The relationship between annual mean of diatoms abundance in water column (cell/L) and surface sediment (cell/mg) and annual mean concentrations of chemical factors; ammonia (NH_4^+), Nitrite (NO_3^-) and Nitrate (NO_2^-), and Phosphate (PO_4^-).

Journal of Coastal Development
Volume 14, Number 3, June 2011 : 242-254

ISSN : 1410-5217
Accredited : 83/Kep/Dikti/2009

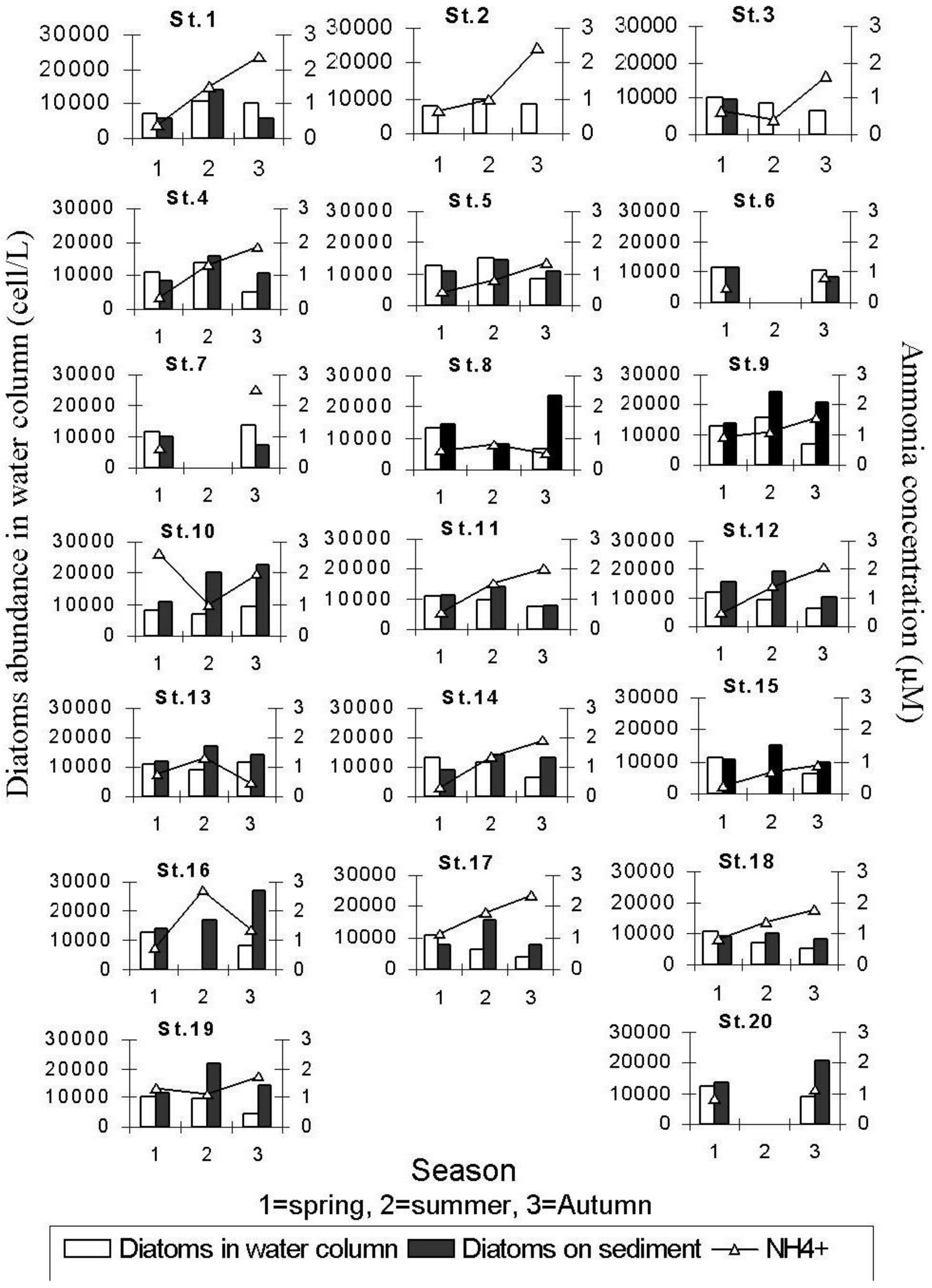

Figure 7. Seasonal variation of diatoms abundance and correlation with ammonia ($NH4^+$) in each stations in the Akkeshi-ko estuary

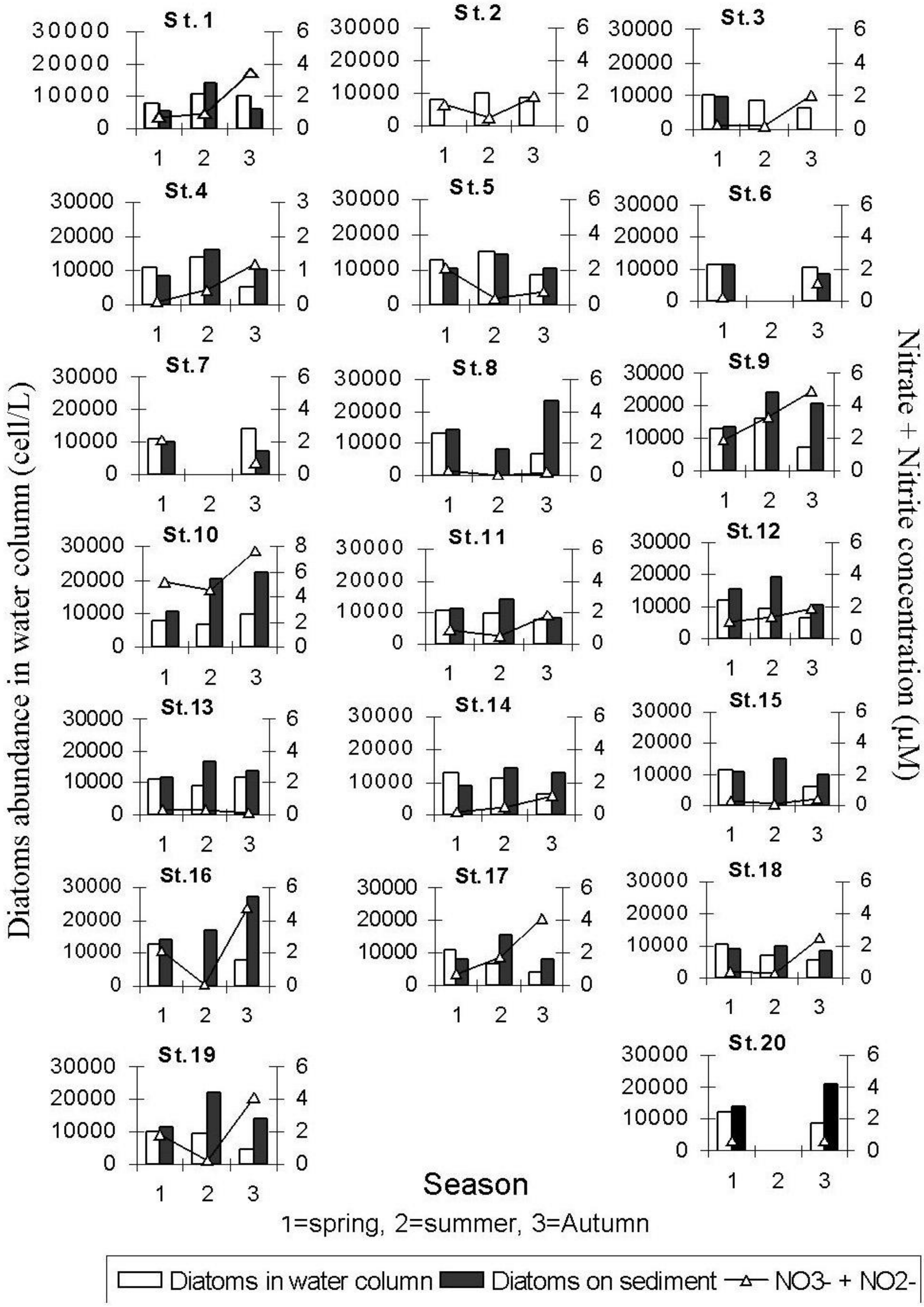

Figure 8. Seasonal variation of diatoms abundance and correlation with nitrate + nitrite (NO^3- + NO^2-) in each stations in the Akkeshi-ko estuary

ISSN : 1410-5217
Accredited : 83/Kep/Dikti/2009

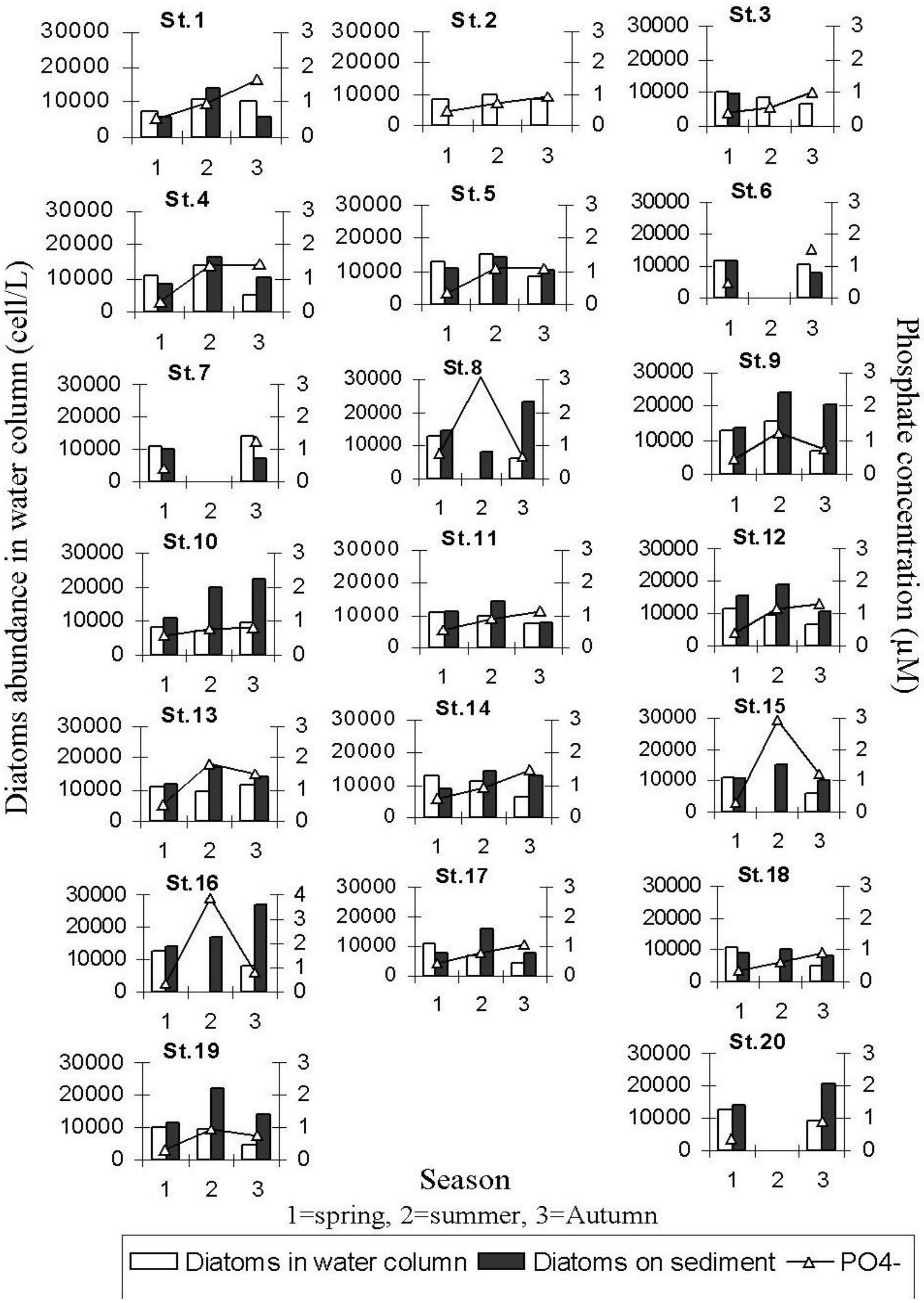

Figure 9. Seasonal variation of diatoms abundance and correlation with Phosphate (PO^{4}-) in each stations in the Akkeshi-ko estuary.

ISSN : 1410-5217
Accredited : 83/Kep/Dikti/2009