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Distribution and variability of nutrients, chlorophyll a, particulate organic matters, and their carbon and nitrogen contents, in Akkeshi-Ko, an estuary in northern Japan

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Salinity, temperature, nutrient concentrations (nitrate, nitrite, silicate, and phosphate), chlorophyll a and phaeopigment concentrations, particulate organic mater, zooplankton, and their carbon and nitrogen contents were measured monthly from June 1993 to July 1994 at a semi-closed estuary, Akkeshi-Ko, in northern Japan. Horizontal distribution patterns of nutrients, chlorophyll a and salinity indicate that the estuary is divided into three areas; riverine, estuarine and marine areas. These areas are characterized by high nitrate and silicate concentrations (riverine), high phosphate concentration (estuarine) and low and stable nutrients and chlorophyll a concentrations (marine). Zooplankton biomass in the estuary is high, but, phytoplankton biomass is comparable to the coastal water outside the estuary. Epiphytes and other primary producers may be important in maintaining high zooplankton production.

Introduction

Estuaries are the interface between terrestrial and marine environments, characterized as highly productive ecosystems (Whittacker and Linkens, 1975). Various matters, organic and inorganic, living and non-living, dissolved and particulate, are loaded into an estuary both from the land and from the ocean, and subject to biological and physicochemical processes, which take place at a wide range of environments in the estuary. Thus, the estuary functions as a "filter" which not only traps matter but transforms input signals into output signals (Schubel and Kennedy, 1984). As a result of those processes, standing stocks of biological and chemical components are determined. As gradients of environmental factors such as salinity, water velocity and temperature, are large, an estuary is not a single functional filter. It will be divided into various parts according to the distribution of various components.

The primary objective of this paper is to characterize spatial and temporal distributions of standing stocks of nutrients, phytoplankton, zooplankton, and particulate matter in Akkeshi-Ko, an estuary on the Pacific coast of northern Japan (Inoue et al. 1987). Biological and chemical processes which may govern the distributions will be discussed.

Secondary, a data set of observations will be presented for general use in future biological and geochemical studies.

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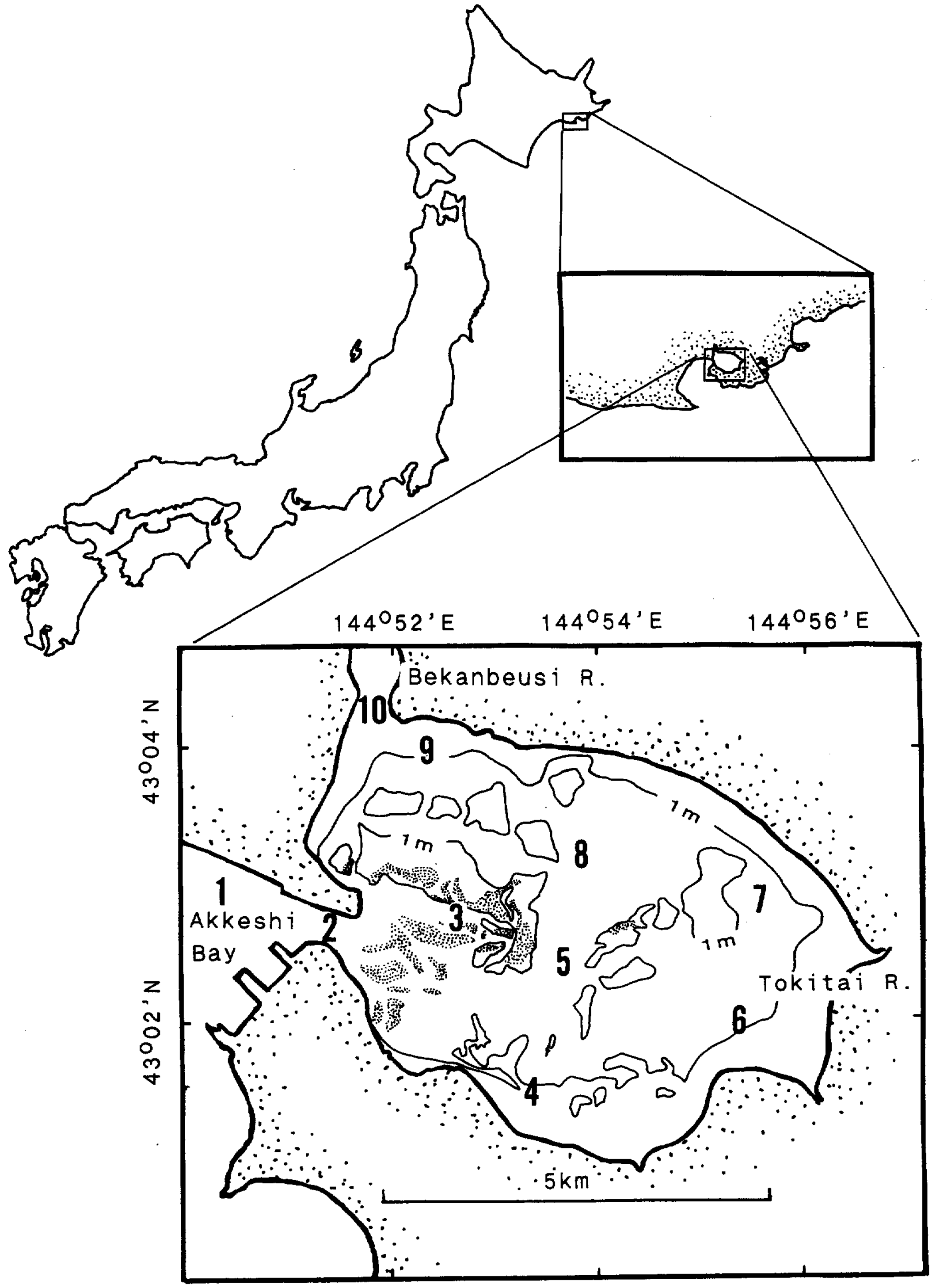


Fig. 1. Map of study sites. Contour of 1m depth is shown. Dotted areas are grounds for clam culture.

The study sites

Akkeshi-Ko is located at 43°2′N 144°52′E in northern Japan (Fig. 1). It is connected to Akkeshi Bay with a narrow channel (ca. 500m wide). South of Akkeshi Bay it is open to the Pacific Ocean. Two rivers flow into the estuary; Bekanbeusi River and Tokitai River (Fig. 1). The surface area of the estuary is ca. 32km^2, and the water depth is mostly less than 2m. Most of the estuary is covered with eelgrass (*Zostera marina* L.) vegetation, except near the mouth of the estuary where coarse sand was introduced to make shallow (mean water level ca. 0m) beds for clam (*Ruditapes philippinarum* Adams and Reeve) culture (Fig. 1). Sampling was conducted at ten sites (Fig. 1, Appendix A).

Materials and methods

Field sampling was conducted every month from June 1993 to July 1994. During December to March, the estuary was partly covered by ice. Therefore, sampling at all stations was not possible during this period. Water temperature and salinity were measured with a T-S meter (Model 33 S-T-C meter, YSI; or ACT2-D portable TS meter, Alec Elec. Co.).

Water samples were taken with a hand-operating water sampler (Kitahara-type sampler, volume : 1liter, Rigosha Co.). Temperature and salinity measurement and water sampling were conducted at two layers at each station, the surface and ca. 30cm above the bottom. Water samples put in dark bottles were transported to the laboratory in ice-cooled conditions. At the laboratory, a portion of each water sample was transferred into a test tube and frozen for later nutrient analysis. The rest was kept in a refrigerator overnight and processed for chlorophyll a and particulate organic matter analysis. Chlorophyll a and total phaeopigment concentrations were determined fluorometrically with a Turner Designs model-10 by using an acetone extraction method (Holm-Hansen et al. 1965). Particulate organic matter was filtered through a Whatman GF/F filter, and dried at 60°C until constant weight. Total carbon and nitrogen on the filter were determined with a CHN analyzer (MT-5, Yanaco Co.). Nutrient concentrations (nitrate, nitrite, phosphate, and silicate) were determined with a TRAACS 800 autoanalyzer (Bran and Luebbe, 1989). Nutrient analysis of winter samples failed, and data were not obtained.

Large particles were collected with a NORPAC plankton net (mesh size, 315μm; diameter, 45 cm). After large plant fragments (mainly terrestrial plant or eelgrass) were removed, a portion of the sample was filtered through a Whatman GF/A filter. Particles consisted mostly of zooplankton. Dried at 60°C, the sample was ground together with the filter with a pestle. Carbon and nitrogen contents were determined with the CHN analyzer. Inorganic carbon content was determined after the ground sample was combusted at 500°C for 4hrs. Organic carbon was calculated as the difference between the total and the inorganic carbon contents.

Results and Discussion

Salinity in the estuary was nearly as high as at Stn 1, which was outside the estuary, both at the surface and the bottom, except at Stns 8, 9 and 10 (Fig. 2a), which were near the river mouth of the Bekanbeusi River. Sampling at all stations took about 6 hours during which tidal heights at

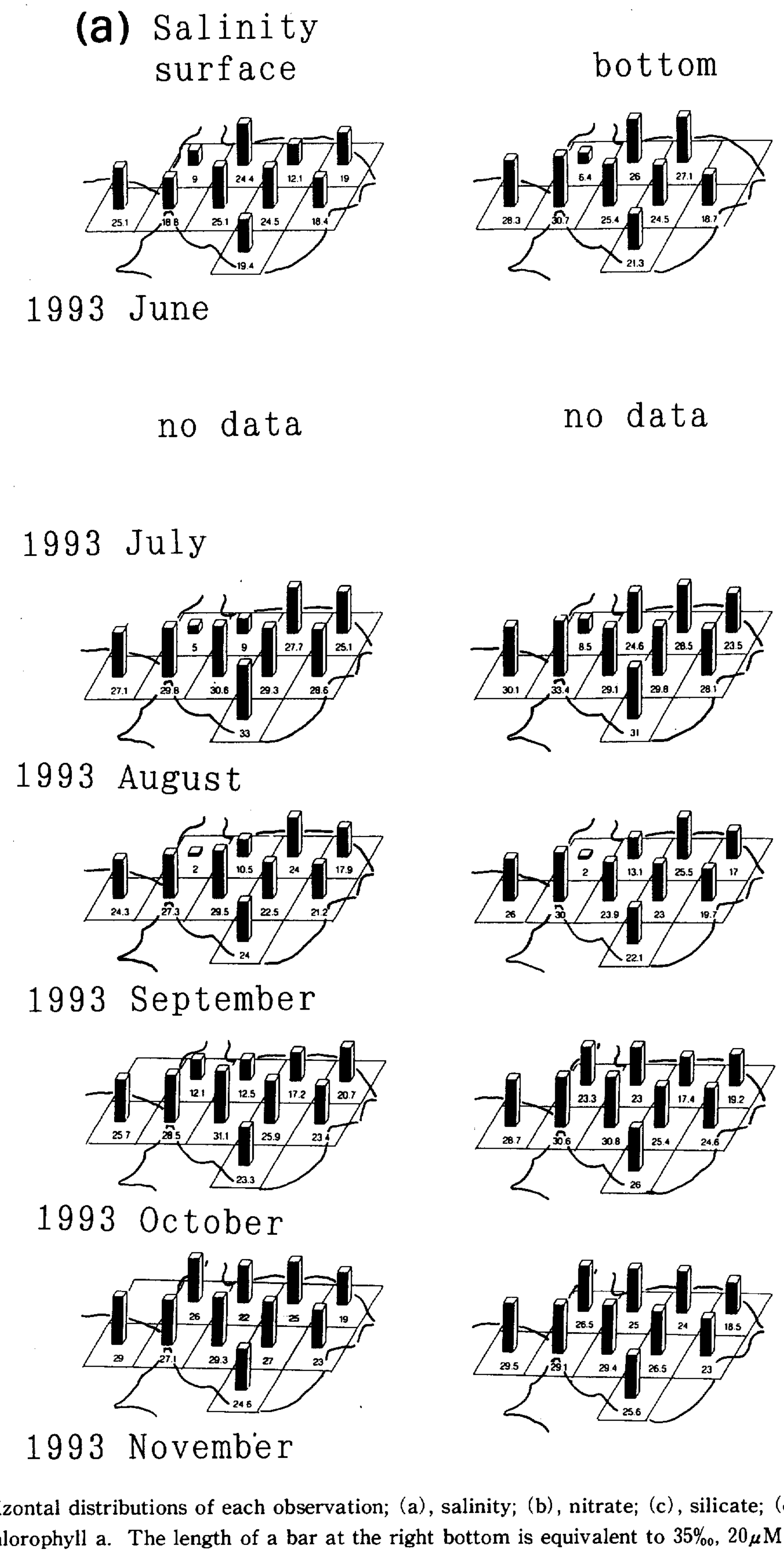
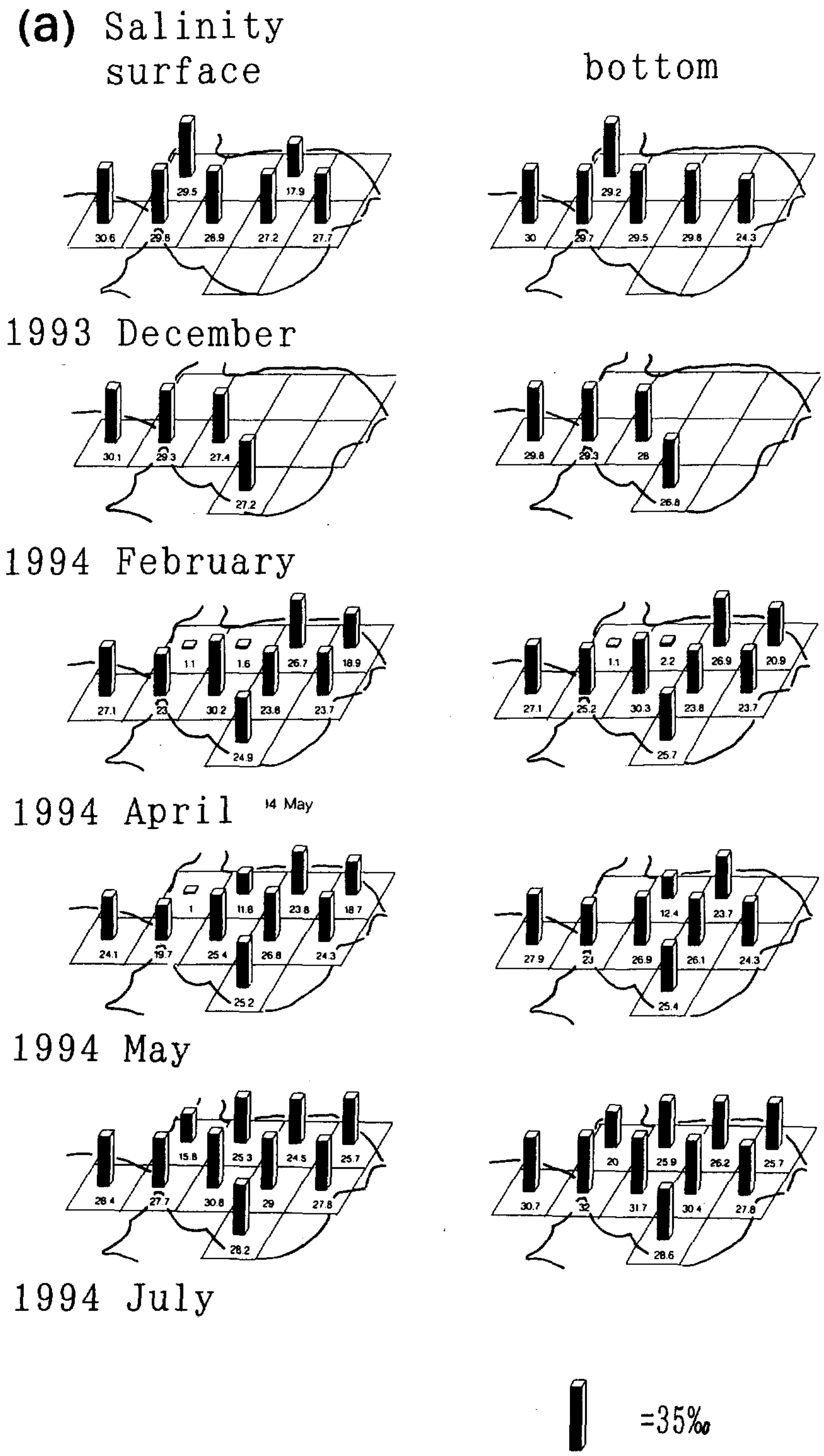
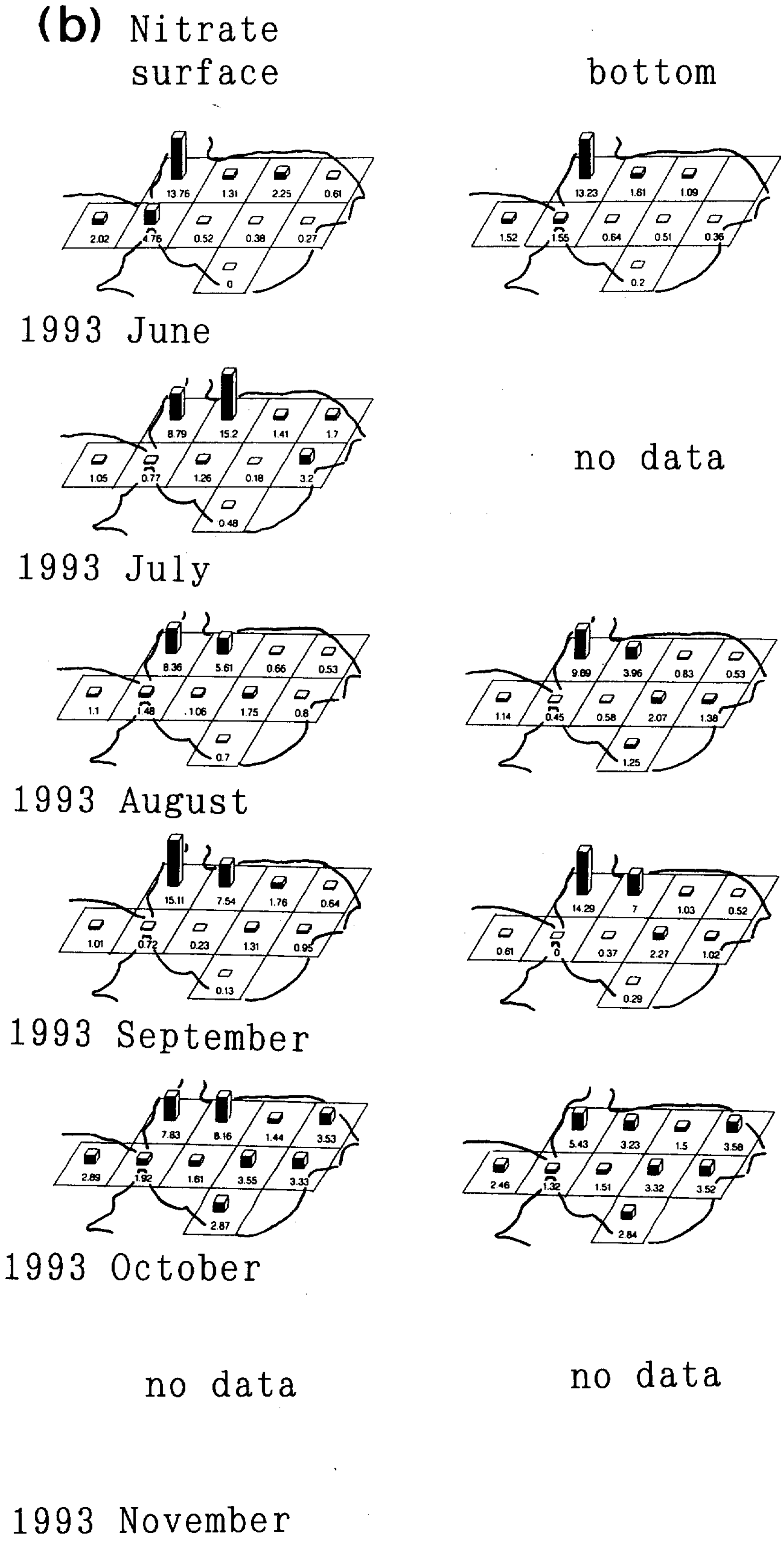


Fig. 2. Horizontal distributions of each observation; (a), salinity; (b), nitrate; (c), silicate; (d), phosphate; and (e), chlorophyll a. The length of a bar at the right bottom is equivalent to 35‰, 20μM, 500μM, 5μM and 35μg l^{-1}, for salinity, nitrate concentration, silicate concentration, phosphate concentration and chlorophyll a concentration, respectively.


(a) Salinity
surface
bottom
1993 December
1994 February
1994 April
14 May
1994 May
1994 July
=35‰


(b) Nitrate
surface
bottom
1993 June
no data
1993 July
1993 August
1993 September
1993 October
no data
no data
1993 November

(b) Nitrate

surface | bottom

no data | no data

1993 December

no data | no data

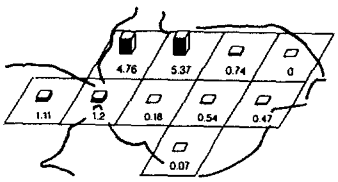
1994 February

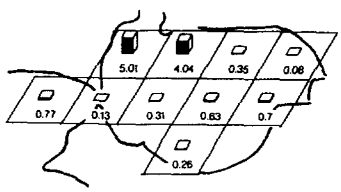
no data | no data

1994 April

no data | no data

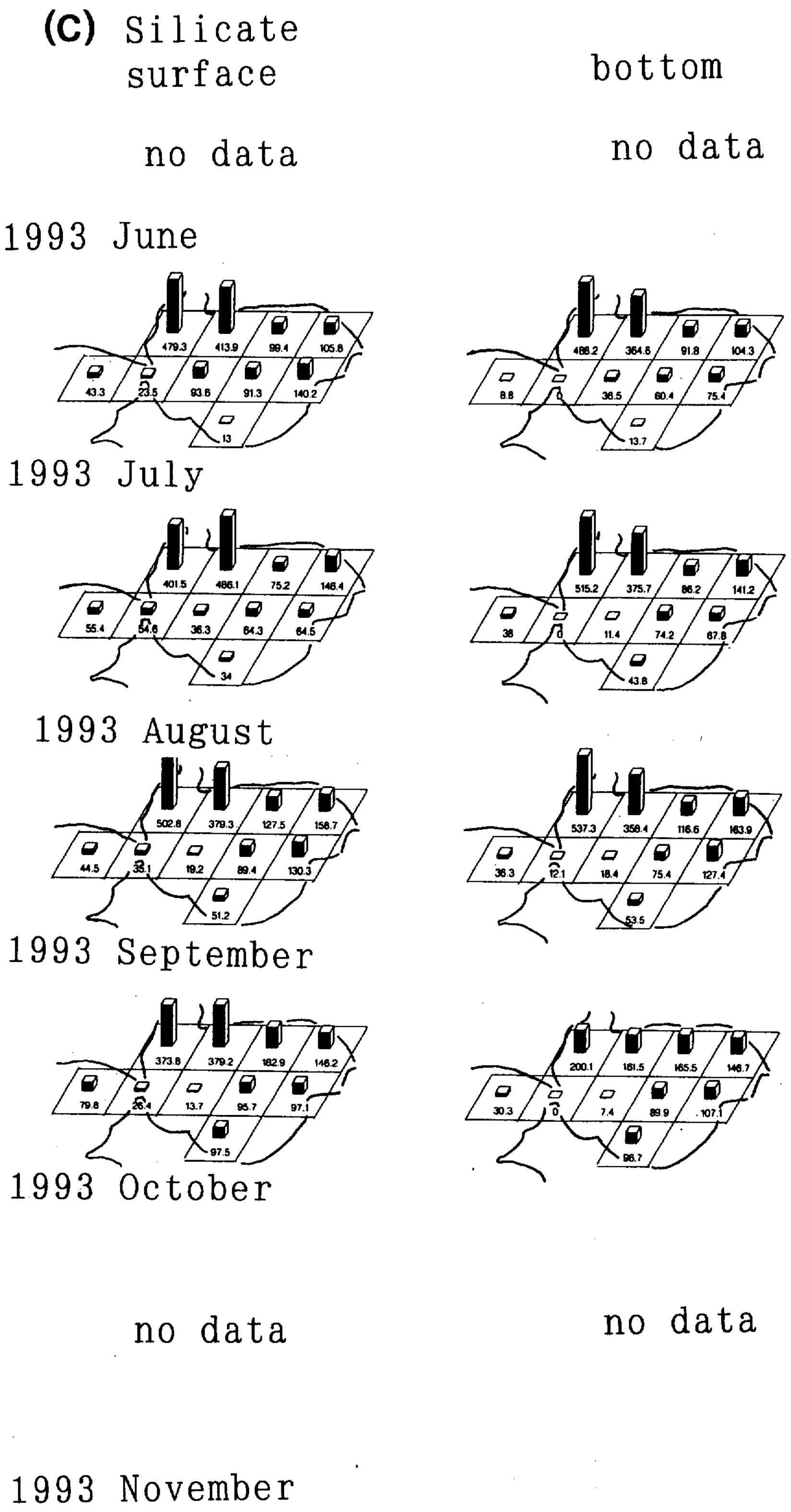
1994 May





1994 July

 =20 μM


(C) Silicate
surface
bottom
no data
no data
1993 June
479.3
413.9
99.4
105.8
43.3
23.5
93.6
91.3
140.2
13
488.2
364.6
91.8
104.3
8.8
0
36.5
60.4
75.4
13.7
1993 July
401.5
486.1
75.2
148.4
55.4
54.6
36.3
64.3
64.5
34
515.2
375.7
86.2
141.2
38
0
11.4
74.2
67.8
43.8
1993 August
502.8
379.3
127.5
158.7
44.5
38.1
19.2
89.4
130.3
51.2
537.3
358.4
116.6
163.9
36.3
12.1
18.4
75.4
127.4
53.5
1993 September
373.8
379.2
162.9
146.2
79.8
26.4
13.7
95.7
97.1
97.5
200.1
181.5
165.5
146.7
30.3
0
7.4
89.9
107.1
96.7
1993 October
no data
no data
1993 November

(C) Silicate

surface | bottom

no data | no data

1993 December

no data | no data

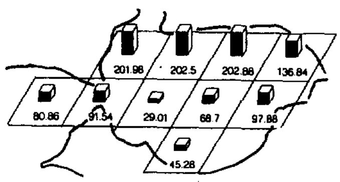
1994 February

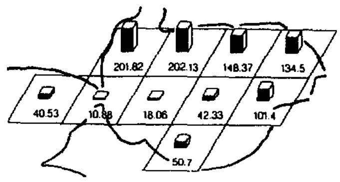
no data | no data

1994 April

no data | no data

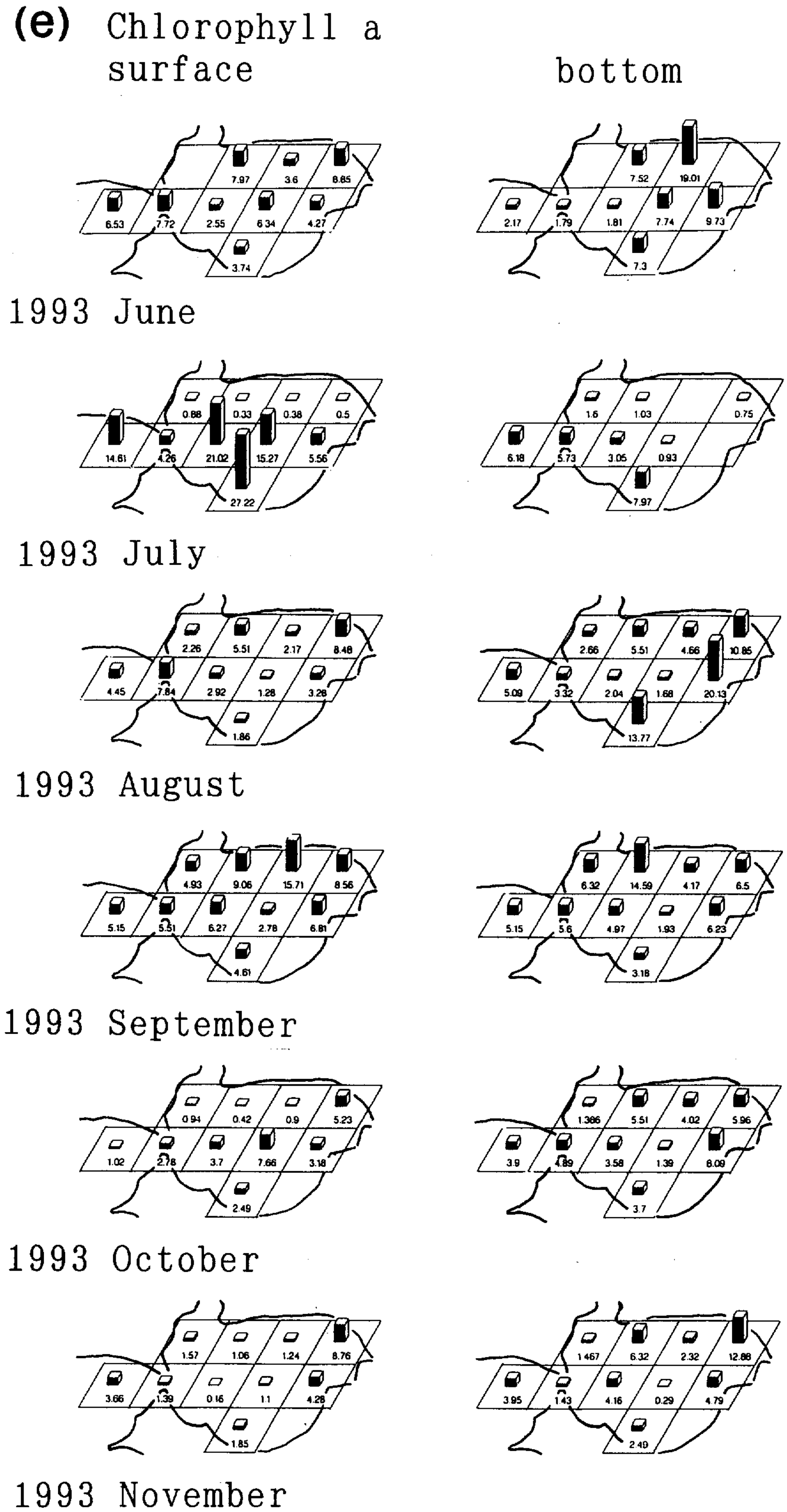
1994 May

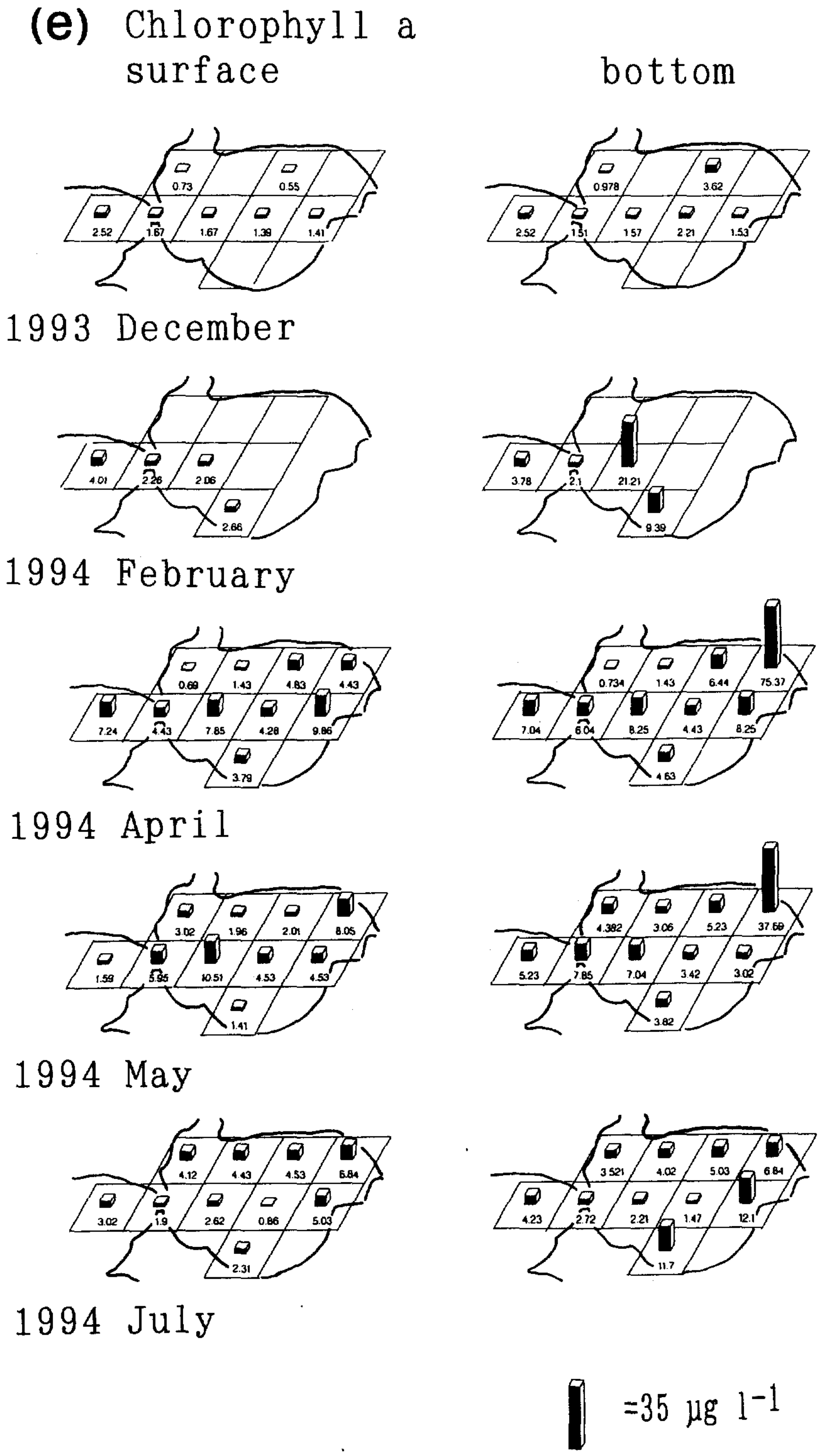




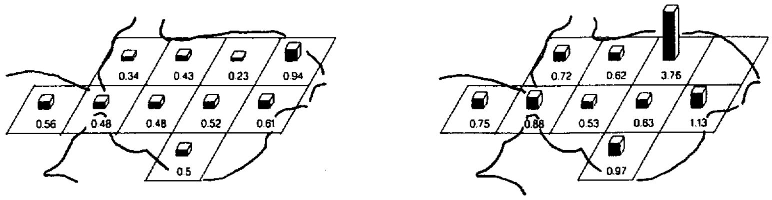
1994 July

 =550μM

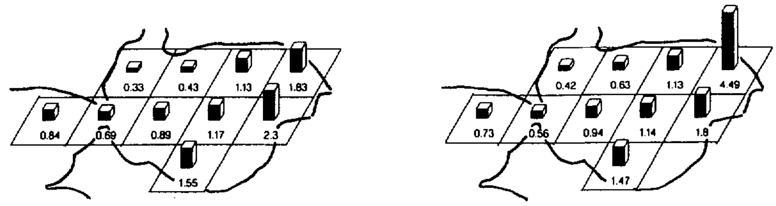

(e) Chlorophyll a
surface
bottom
1993 June
1993 July
1993 August
1993 September
1993 October
1993 November


(e) Chlorophyll a
surface
bottom
1993 December
1994 February
1994 April
1994 May
1994 July
=35 μg l-1

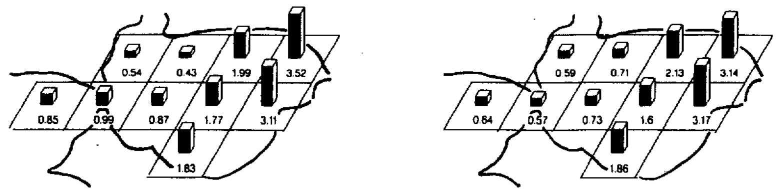
(d) Phosphate
surface bottom



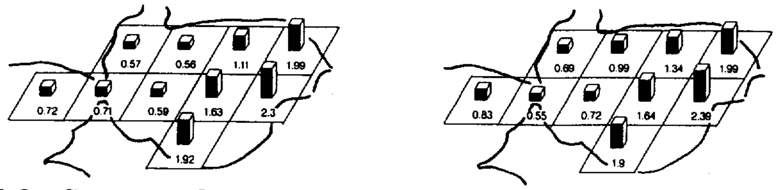
1993 June



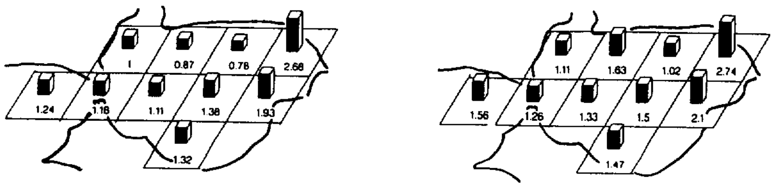
1993 July



1993 August



1993 September



1993 October

no data no data

1993 November

(d) Phosphate

surface | bottom

no data | no data

1993 December

no data | no data

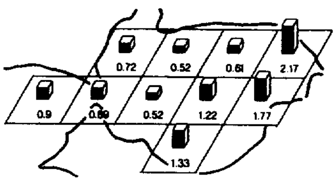
1994 February

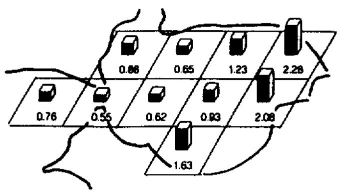
no data | no data

1994 April

no data | no data

1994 May





1994 July

 =5μM

the mouth of the estuary changed at most by 100cm, which was calculated by using a tide table (Hydrographic Department Maritime Safety Agency, 1993). However, due to shallow areas near the mouth of the estuary, the actual times of low tides and high tides within the estuary were delayed sometimes by one hour, and tidal heights were smaller at the eastern end of the estuary (Mizohata, personal communication). However, irrespective of varying tidal heights during our observation, the salinity distribution showed an apparent effect of riverine water at the northern part of the estuary and that of coastal water at other parts. Temperature and salinity measurement within a relatively short period (2 to 3 hours) also showed that the water of the estuary is divided into two types; riverine and estuarine (Hokkaido, 1981).

Throughout the year, concentrations of nitrate and silicate were higher at stations near the mouth of the Bekanbeusi River, namely Stns 8, 9, and 10, than at other stations (Figs. 2b and 2c), indicating that those nutrients were supplied mainly from the river. When compared with the catchment area of the Bekanbeusi River ($680km^2$), that of the Tokitai River and small creeks at the southern estuary is small ($46km^2$). Thus, the effects of riverine water of the Tokitai River on nitrate and silicate concentrations at the eastern and southern stations would be small. Salinity, which indicates an extent of the mixture of marine water and riverine water, was inversely correlative with nitrate and silicate (Figs. 3a and 3b). Correlation coefficients(r) were -0.898 ($p<0.0002$) and -0.778 ($p<0.0002$) for silicate and salinity, and nitrate and salinity, respectively. Linear relationships between nitrate and salinity and between silicate and salinity (Figs. 3a and 3b) indicated that those nutrients in the estuary were conservative, that is, their concentrations were primarily determined by the physical mixture of riverine water and marine water. Biological effects on nitrate and silicate, such as uptake by primary producers, regeneration, and denitrification (this could only affect nitrate concentration), would not be so strong as the physical process. Linear regression analysis showed that riverine water (salinity$=0‰$) contained $10.8\mu M$ of nitrate and $529\mu M$ of silicate.

On the contrary to nitrate and silicate, phosphate showed a different pattern. Phosphate concentrations were higher at the eastern side (Stns. 6 and 7) in the estuary (Fig. 2d). There was no apparent correlation between phosphate and salinity when all data were plotted (Fig. 3c). However, when the data of each month were plotted separately, phosphate concentration tended to be higher at the middle than at the lower or higher range of salinity (Fig. 4). This observation suggested that phosphate was not supplied from the river or from the ocean, but may be regenerated in the estuary.

Increase in phosphate concentration in the water column may be due to dissolution of adsorbed phosphate onto calcite when calcite is transported from the sea to the estuary where the ph becomes low (Jonge and Villerius, 1989). However, as the ph in the Akkeshi-Ko does not fluctuate annually; average$=7.77$, S.D.$=0.14$ (Hokkaido, 1993), this would not be the case at the estuary. Another possible reason would be a release of phosphate from metallic phosphate in the sediment. In anaerobic conditions, metallic phosphate which is precipitated in oxic conditions, releases dissolved phosphate (Fenchel and Blackburn, 1979). As the estuary is mostly covered by eelgrass, there may be eelgrass-originating organic matter accumulating in the sediment. Ignition loss of sediment was higher at the central and southern parts where seagrass biomass was higher than in other areas (Inoue et al. 1987), suggesting a high organic content in the sediment. When the water temperature is high and bacterial sulfate reduction is active in the sediment, precipitated metallic phosphate

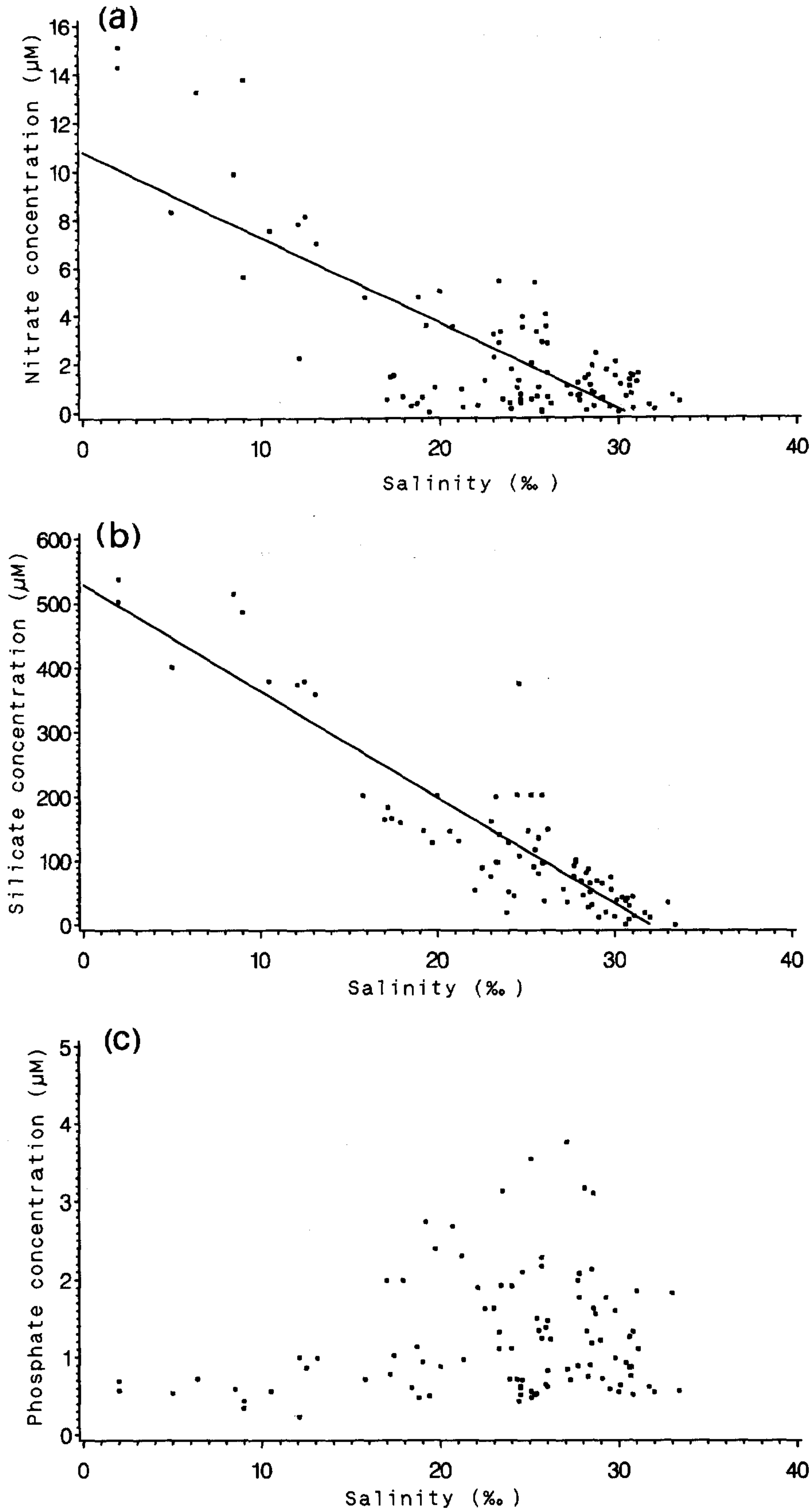


Fig. 3. Correlation between (a), nitrate concentration and salinity; (b), silicate concentration and salinity; and (c), phosphate concentration and salinity. In Figs. 3a and 3b, regression lines are shown.

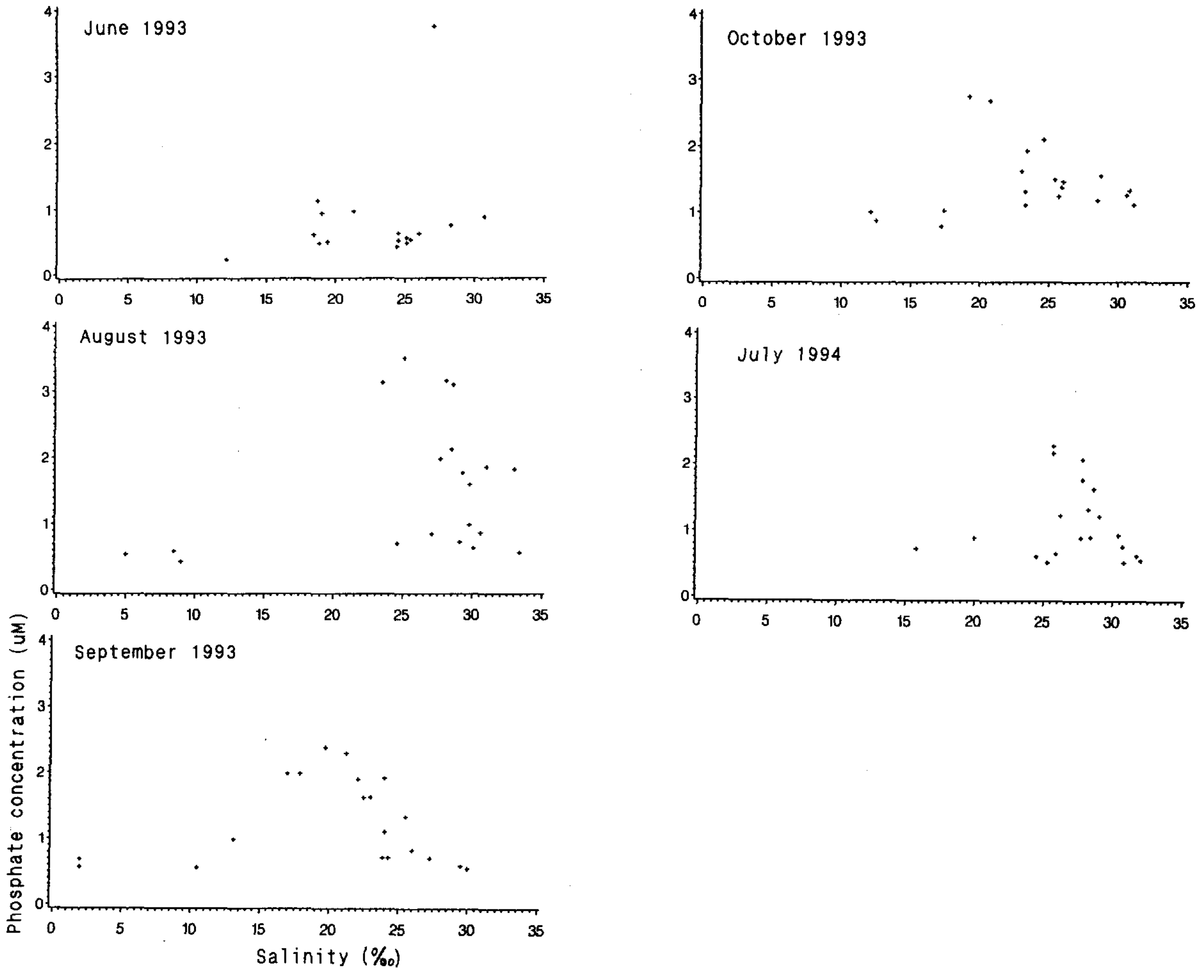
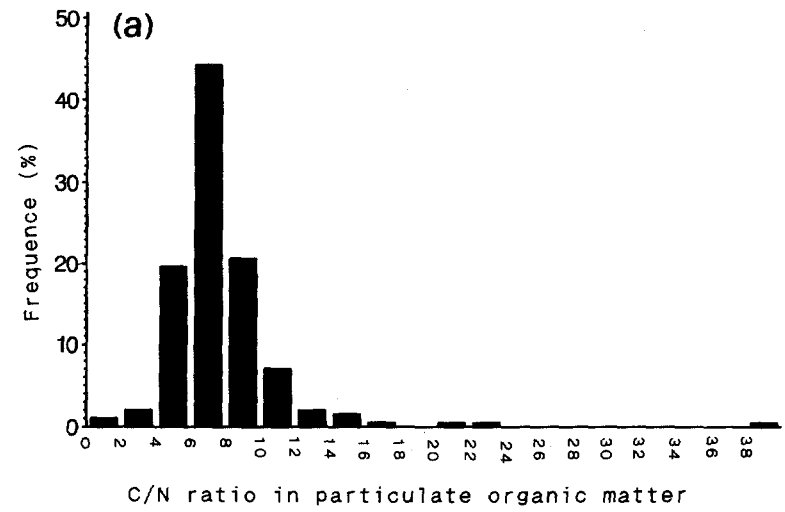


Fig. 4. Relationship between phosphate concentration and salinity in each month.

releases dissolved phosphate into the water column. When the water body above the phosphate-releasing sediment is stagnant, the increase in phosphate concentration in the water column becomes apparent. Although the residence time of water at the eastern and southern parts of the estuary is not known, the topographical features of the estuary suggest that the water body would be less affected by tidal exchanges than that at the mouth of the estuary. The increase of phosphate concentration could be an indicator of an estuarine water which is strongly affected by sediment-water exchange.

Chlorophyll a distribution showed no apparent pattern (Fig. 2e). The highest concentration was observed often at the eastern side, and both at the outside and near the river mouth chlorophyll a concentrations were comparably low. However, the lowest concentration was also observed at the eastern side. There was no correlation between chlorophyll a and nutrient concentrations, or salinity (data not shown).

In Akkeshi Bay, outside of the estuary, phytoplankton blooms were observed in spring (March-April) and autumn (October-November) (Taguchi and Iseki, 1977; Taguchi et al., 1977). On the contrary, there was no apparent increase in chlorophyll a concentration during those periods in the estuary. As eelgrass in the estuary accumulates epiphytes on their leaves, epiphytic microalgae detach and drift in the water column. The amount of drifting epiphytes would be greatly affected



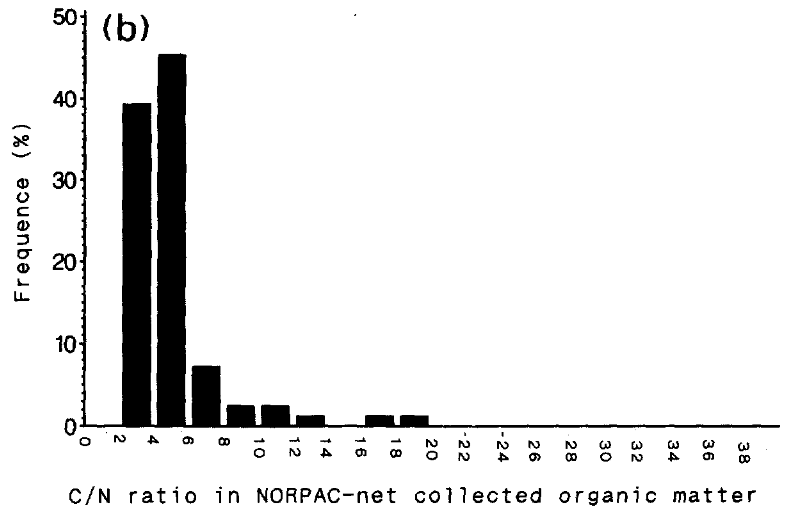


Fig. 5. Frequency of C/N ratio (w/w) in whole observation of, (a) particulate organic matter collected with a water sampler, and (b) large particles collected with a NORPAC net.

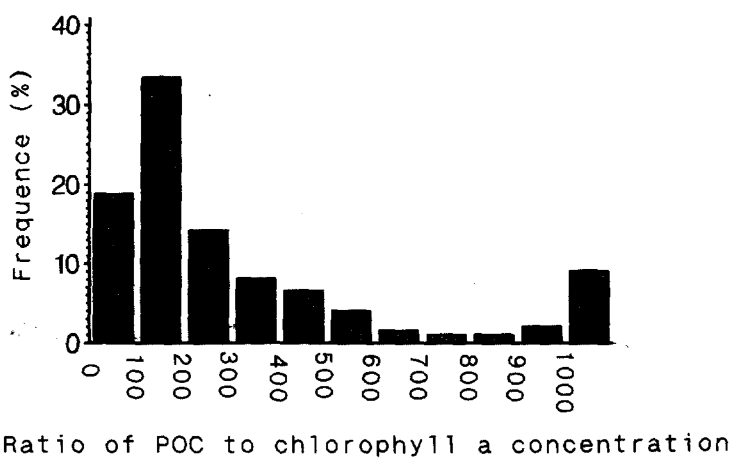


Fig. 6. Frequency of a ratio of particulate organic carbon to chlorophyll a concentration, in whole observation.

by incidental turbulences, such as wind or sampling procedures. This turbulence may reflect on the fluctuation in chlorophyll a concentration. If this is the case, drifting epiphytes should cause only the increase in chlorophyll a concentration. Compared with chlorophyll concentrations in the bay (Taguchi and Iseki, 1977), those in the estuary were in the same range, suggesting that the drifting epiphytes may not be the cause of the absence of apparent blooms. There are two possible reasons for the absence of plankton bloom in the estuary. One is that we might not have encountered any blooms. At an inlet of northern Japan, a spring phytoplankton bloom lasts only for several days to a week (Furuya et al. 1993). As our sampling was only once a month and no sampling was conducted in March, we might not have any sample during the blooming period. However, weekly observation of chlorophyll a concentration in coastal water at Kushiro, ca. 40km west of Akkeshi-Ko, started to increase from February, peaked in March and lasted until early May in 1989 (Taguchi, 1992). Though fluctuation of chlorophyll a concentration was large, its level was high during the spring bloom period. Another possible reason for the absence of phytoplankton bloom is high grazing pressure. Zooplankton biomass in the estuary (Appendix B) wan 1 to 1020mg m^{-3} (average=80mg m^{-3}), far exceeded that observed in the bay, 17.5mg m^{-3}, during summer when the standing stock was maximum (Nishizawa et al. 1977). Abundant zooplankton could cause a strong grazing pressure on phytoplankton. To elucidate the role of phytoplankton at Akkeshi-Ko, detailed field observation would be needed.

Carbon to nitrogen ratios (C/N ratio, w/w) of particulate organic matter and of NORPAC-net collected organic particles showed a different tendency (Figs. 5a and 5b). The C/N ratio of particulate matter (average=7.4, S.D.=2.15) was significantly higher ($p<0.0002$, t-test on paired variables) than that of NORPAC-net sampled organic matter (average=4.27, S.D.=0.848). Samples at Stns. 9 and 10 were omitted in the above calculation, because the water near the river mouth contained a lot of terrestrial plant debris which could not be removed thoroughly. Organic particles of the former samples were mainly phytoplankton, detached epiphytes and small detritus, which were drifting in the water column. The latter samples, on the contrary, consisted of large particles (>315μm), mainly zooplankton, which might be richer in protein and other nitrogen-rich compounds than smaller particles, such as microalgae or detritus. The carbon to chlorophyll a ratio was also high (Fig. 6), showing high carbon contents in organic particles smaller than 315μm.

Our study illustrates that Akkeshi-Ko is a semi-closed estuary having three areas; riverine (Stns 8, 9 and 10), estuarine (Stns 4, 5, 6 and 7) and marine areas (Stns 1, 2 and 3). The riverine area is distinguished from the others by low salinity, high silicate and high nitrate concentrations. The estuarine area is characterized by high phosphate concentration. And the marine area is the area left near the mouth of the estuary. This compartmentation would be governed mainly by a topographical feature of the estuary.

Acknowledgements

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北日本の汽水水域，厚岸湖における栄養塩濃度，クロロフィルａ濃度，粒状有機物濃度及びその炭素・窒素含有量の分布及び変動

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摘　要

半閉鎖的汽水域である厚岸湖において，1993年６月から1994年７月まで毎月，塩分濃度・水温・栄養塩濃度（硝酸塩，亜硝酸塩，ケイ酸塩，リン酸塩）・クロロフィルａ及びフェオ色素濃度・粒状有機物及び動物プランクトンの現存量と炭素・窒素含有量を観測した．栄養塩，クロロフィルａ，塩分濃度の水平分布から湖内が河川水域・汽水水域・海洋水域の３つの区分に分かれることが示唆された．河川水域は硝酸塩・ケイ酸塩濃度が高く，汽水水域ではリン酸塩濃度が高く，海洋水域は栄養塩濃度・クロロフィルａ濃度が低いことが特徴であった．湖内では動物プランクトン現存量が高かったが，植物プランクトンは湖外とほぼ同レベルであった．付着藻類や他の基礎生産者が動物プランクトンの高い現存量の維持に重要な役割を果たしていると推定された．

Appendix A. Location of study sites

Station	latitude	longitude	depth* (m)
Stn 1	43°3.1′	144°50.2′	1.7
Stn 2	43°2.7′	144°51.4′	8.1
Stn 3	43°2.8′	144°52.4′	5.4
Stn 4	43°1.6′	144°53.4′	1.1
Stn 5	43°2.3′	144°53.7′	1.5
Stn 6	43°2.1′	144°55.3′	1.2
Stn 7	43°3.0′	144°55.5′	0.7
Stn 8	43°3.3′	144°53.9′	1.2
Stn 9	43°3.9′	144°52.3′	0.9
Stn 10	43°4.4′	144°51.8′	0.8

* : average water depth when observations were made.

Appendix B. Observation data.

Temperature (°C)

		Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Feb.	Apr.	May.	Jul.
Stn 1	surface	9.5	12.2	19.5	23.0	10.5	5.0	1.5	nd	3.9	8.7	16.5
	bottom	nd	9.9	18.0	22.8	11.9	5.0	1.8	nd	3.9	7.8	15.5
Stn 2	surface	12.1	nd	20.0	17.4	11.5	4.0	0.9	nd	4.8	10.3	16.9
	bottom	nd	nd	16.0	16.5	12.2	4.9	1.0	nd	4.6	9.6	12.8
Stn 3	surface	12.2	13.0	15.5	17.0	11.7	5.1	-0.2	nd	3.7	8.7	15.9
	bottom	nd	10.9	17.0	23.0	12.0	5.2	1.0	nd	3.7	8.0	14.0
Stn 4	surface	15.0	15.8	21.0	21.2	9.9	2.3	nd	nd	6.3	11.3	21.3
	bottom	nd	15.8	19.0	21.5	11.0	4.0	nd	nd	6.3	10.9	20.1
Stn 5	surface	12.1	14.8	22.5	21.6	10.1	4.0	-1.1	nd	7.2	8.1	17.8
	bottom	nd	14.0	22.5	21.8	10.9	5.0	-0.1	nd	7.2	8.1	15.7
Stn 6	surface	15.2	16.3	22.7	21.0	9.1	2.0	-1.0	nd	8.4	12.4	21.2
	bottom	nd	16.1	23.0	21.0	9.7	2.0	-0.1	nd	8.4	12.4	21.1
Stn 7	surface	16.3	15.6	24.1	20.9	9.1	-0.5	nd	nd	10.4	11.8	22.4
	bottom	nd	nd	25.0	20.9	9.4	0.0	nd	nd	10.5	nd	22.4
Stn 8	surface	13.8	nd	23.5	18.0	10.5	3.5	-1.2	nd	7.0	9.3	19.4
	bottom	nd	nd	21.2	19.0	10.6	4.0	nd	nd	7.1	9.3	19.2
Stn 9	surface	11.1	nd	21.8	22.4	10.5	3.5	nd	nd	5.7	10.3	19.7
	bottom	nd	nd	21.0	22.2	11.0	4.5	nd	nd	7.6	10.1	19.1
Stn 10	surface	11.4	nd	20.0	23.1	10.5	5.0	0.5	nd	6.8	10.8	21.1
	bottom	nd	nd	20.5	23.4	11.5	4.5	0.8	nd	5.9	nd	20.6

nd: no data

Salinity (‰)

		Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Feb.	Apr.	May.	Jul.
Stn 1	surface	25.1	nd	27.1	24.3	25.7	29.0	30.6	nd	27.1	24.1	28.4
	bottom	28.3	nd	30.1	26.0	28.7	29.5	30.0	nd	27.1	27.9	30.7
Stn 2	surface	18.8	nd	29.8	27.3	28.5	27.1	29.8	nd	23.0	19.7	27.7
	bottom	30.7	nd	33.4	30.0	30.6	29.1	29.7	nd	25.2	23.0	32.0
Stn 3	surface	25.1	nd	30.6	29.5	31.1	29.3	28.9	nd	30.2	25.4	30.8
	bottom	25.4	nd	29.1	23.9	30.8	29.4	29.5	nd	30.3	26.9	31.7
Stn 4	surface	19.4	nd	33.0	24.0	23.3	24.6	nd	nd	24.9	25.2	28.2
	bottom	21.3	nd	31.0	22.1	26.0	25.6	nd	nd	25.7	25.4	28.6
Stn 5	surface	24.5	nd	29.3	22.5	25.9	27.0	27.2	nd	23.8	26.8	29.0
	bottom	24.5	nd	29.8	23.0	25.4	26.5	29.8	nd	23.8	26.1	30.4
Stn 6	surface	18.4	nd	28.6	21.2	23.4	23.0	27.7	nd	23.7	24.3	27.8
	bottom	18.7	nd	28.1	19.7	24.6	23.0	24.3	nd	23.7	24.3	27.8
Stn 7	surface	19.0	nd	25.1	17.9	20.7	19.0	nd	nd	18.9	18.7	25.7
	bottom	nd	nd	23.5	17.0	19.2	18.5	nd	nd	20.9	nd	25.7
Stn 8	surface	12.1	nd	27.7	24.0	17.2	25.0	17.9	nd	26.7	23.8	24.5
	bottom	27.1	nd	28.5	25.5	17.4	24.0	nd	nd	26.9	23.7	26.2
Stn 9	surface	24.4	nd	9.0	10.5	12.5	22.0	nd	nd	1.6	11.8	25.3
	bottom	26.0	nd	24.6	13.1	23.0	25.0	nd	nd	2.2	12.4	25.9
Stn 10	surface	9.0	nd	5.0	2.0	12.1	26.0	29.5	nd	1.1	1.0	15.8
	bottom	6.4	nd	8.5	2.0	23.3	26.5	29.2	nd	1.1	nd	20.0

nd: no data

Nitrate concentration (μM)

		Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Feb.	Apr.	May.	Jul.
Stn 1	surface	2.02	1.05	1.10	1.01	2.89	nd	nd	nd	nd	nd	1.11
	bottom	1.52	1.20	1.14	0.61	2.46	nd	nd	nd	nd	nd	0.77
Stn 2	surface	4.76	0.77	1.48	0.72	1.92	nd	nd	nd	nd	nd	1.20
	bottom	1.55	0.28	0.45	0.00	1.32	nd	nd	nd	nd	nd	0.13
Stn 3	surface	0.52	1.26	1.06	0.23	1.61	nd	nd	nd	nd	nd	0.18
	bottom	0.64	0.91	0.58	0.37	1.51	nd	nd	nd	nd	nd	0.31
Stn 4	surface	0.00	0.48	0.70	0.13	2.87	nd	nd	nd	nd	nd	0.07
	bottom	0.20	0.36	1.25	0.29	2.84	nd	nd	nd	nd	nd	0.26
Stn 5	surface	0.38	0.18	1.75	1.31	3.55	nd	nd	nd	nd	nd	0.54
	bottom	0.51	0.40	2.07	2.27	3.32	nd	nd	nd	nd	nd	0.63
Stn 6	surface	0.27	3.20	0.80	0.95	3.33	nd	nd	nd	nd	nd	0.47
	bottom	0.36	1.58	1.38	1.02	3.52	nd	nd	nd	nd	nd	0.70
Stn 7	surface	0.61	1.70	0.53	0.64	3.53	nd	nd	nd	nd	nd	0.00
	bottom	nd	nd	0.53	0.52	3.58	nd	nd	nd	nd	nd	0.08
Stn 8	surface	2.25	1.41	0.66	1.76	1.44	nd	nd	nd	nd	nd	0.74
	bottom	1.09	3.97	0.83	1.03	1.50	nd	nd	nd	nd	nd	0.35
Stn 9	surface	1.31	15.2	5.61	7.54	8.16	nd	nd	nd	nd	nd	5.37
	bottom	1.61	7.69	3.96	7.00	3.23	nd	nd	nd	nd	nd	4.04
Stn 10	surface	13.8	8.79	8.36	15.1	7.83	nd	nd	nd	nd	nd	4.76
	bottom	13.2	9.25	9.89	14.3	5.43	nd	nd	nd	nd	nd	5.01

nd: no data

Nitrite concentration (μM)

		Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Feb.	Apr.	May.	Jul.
Stn 1	surface	0.12	0.11	0.17	0.16	0.32	nd	nd	nd	nd	nd	0.11
	bottom	0.23	0.17	0.15	0.25	0.45	nd	nd	nd	nd	nd	0.14
Stn 2	surface	0.14	0.11	0.20	0.21	0.32	nd	nd	nd	nd	nd	0.07
	bottom	0.20	0.05	0.07	0.11	0.35	nd	nd	nd	nd	nd	0.07
Stn 3	surface	0.08	0.10	0.13	0.14	0.29	nd	nd	nd	nd	nd	0.06
	bottom	0.11	0.11	0.11	0.21	0.34	nd	nd	nd	nd	nd	0.10
Stn 4	surface	0.04	0.02	0.12	0.11	0.35	nd	nd	nd	nd	nd	0.10
	bottom	0.22	0.08	0.15	0.27	0.38	nd	nd	nd	nd	nd	0.14
Stn 5	surface	0.11	0.05	0.24	0.29	0.41	nd	nd	nd	nd	nd	0.09
	bottom	0.14	0.04	0.25	0.12	0.44	nd	nd	nd	nd	nd	0.11
Stn 6	surface	0.10	0.22	0.14	0.34	0.65	nd	nd	nd	nd	nd	0.11
	bottom	0.26	0.04	0.15	0.37	0.67	nd	nd	nd	nd	nd	0.21
Stn 7	surface	0.21	0.10	0.16	0.39	0.95	nd	nd	nd	nd	nd	0.07
	bottom	nd	0.17	0.15	0.52	1.03	nd	nd	nd	nd	nd	0.13
Stn 8	surface	0.09	0.07	0.13	0.35	0.30	nd	nd	nd	nd	nd	0.06
	bottom	0.87	0.09	0.21	0.32	0.35	nd	nd	nd	nd	nd	0.15
Stn 9	surface	0.11	0.21	0.24	0.30	0.28	nd	nd	nd	nd	nd	0.10
	bottom	0.37	0.14	0.21	0.34	0.44	nd	nd	nd	nd	nd	0.13
Stn 10	surface	0.18	0.16	0.28	0.49	0.34	nd	nd	nd	nd	nd	0.14
	bottom	0.72	0.15	0.39	0.50	0.37	nd	nd	nd	nd	nd	0.20

nd: no data

Silicate concentration (μM)

		Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Feb.	Apr.	May.	Jul.
Stn 1	surface	nd	43.3	55.4	44.5	79.8	nd	nd	nd	nd	nd	80.9
	bottom	nd	8.8	38.0	36.3	30.3	nd	nd	nd	nd	nd	40.5
Stn 2	surface	nd	23.5	54.6	35.1	26.4	nd	nd	nd	nd	nd	91.5
	bottom	nd	0.0	0.0	12.1	0.0	nd	nd	nd	nd	nd	10.9
Stn 3	surface	nd	93.6	36.3	19.2	13.7	nd	nd	nd	nd	nd	29.0
	bottom	nd	36.5	11.4	18.4	7.4	nd	nd	nd	nd	nd	18.1
Stn 4	surface	nd	13.0	34.0	51.2	97.5	nd	nd	nd	nd	nd	45.3
	bottom	nd	13.7	43.8	53.5	96.7	nd	nd	nd	nd	nd	50.7
Stn 5	surface	nd	91.3	64.3	89.4	95.7	nd	nd	nd	nd	nd	68.7
	bottom	nd	60.4	74.2	75.4	89.9	nd	nd	nd	nd	nd	42.3
Stn 6	surface	nd	140.	64.5	130.	97.1	nd	nd	nd	nd	nd	97.9
	bottom	nd	75.4	67.8	127.	107.	nd	nd	nd	nd	nd	101.
Stn 7	surface	nd	106.	146.	159.	146.	nd	nd	nd	nd	nd	137.
	bottom	nd	104.	141.	164.	147.	nd	nd	nd	nd	nd	135.
Stn 8	surface	nd	99.4	75.2	128.	183.	nd	nd	nd	nd	nd	203.
	bottom	nd	91.8	86.2	117.	166.	nd	nd	nd	nd	nd	148.
Stn 9	surface	nd	414.	486.	379.	379.	nd	nd	nd	nd	nd	203.
	bottom	nd	365.	376.	358.	162.	nd	nd	nd	nd	nd	202.
Stn 10	surface	nd	479.	402.	503.	374.	nd	nd	nd	nd	nd	202.
	bottom	nd	488.	515.	537.	200.	nd	nd	nd	nd	nd	202.

nd: no data

Phosphate concentration (μM)

		Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Feb.	Apr.	May.	Jul.
Stn 1	surface	0.56	0.84	0.85	0.72	1.24	nd	nd	nd	nd	nd	0.90
	bottom	0.75	0.73	0.64	0.83	1.56	nd	nd	nd	nd	nd	0.76
Stn 2	surface	0.48	0.69	0.99	0.71	1.18	nd	nd	nd	nd	nd	0.89
	bottom	0.88	0.56	0.57	0.55	1.26	nd	nd	nd	nd	nd	0.55
Stn 3	surface	0.48	0.89	0.87	0.59	1.11	nd	nd	nd	nd	nd	0.52
	bottom	0.53	0.94	0.73	0.72	1.33	nd	nd	nd	nd	nd	0.62
Stn 4	surface	0.50	1.55	1.83	1.92	1.32	nd	nd	nd	nd	nd	1.33
	bottom	0.97	1.47	1.86	1.90	1.47	nd	nd	nd	nd	nd	1.63
Stn 5	surface	0.52	1.17	1.77	1.63	1.38	nd	nd	nd	nd	nd	1.22
	bottom	0.63	1.14	1.60	1.64	1.50	nd	nd	nd	nd	nd	0.93
Stn 6	surface	0.61	2.30	3.11	2.30	1.93	nd	nd	nd	nd	nd	1.77
	bottom	1.13	1.80	3.17	2.39	2.10	nd	nd	nd	nd	nd	2.08
Stn 7	surface	0.94	1.83	3.52	1.99	2.68	nd	nd	nd	nd	nd	2.17
	bottom	nd	4.49	3.14	1.99	2.74	nd	nd	nd	nd	nd	2.28
Stn 8	surface	0.23	1.13	1.99	1.11	0.78	nd	nd	nd	nd	nd	0.61
	bottom	3.76	1.13	2.13	1.34	1.02	nd	nd	nd	nd	nd	1.23
Stn 9	surface	0.43	0.43	0.43	0.56	0.87	nd	nd	nd	nd	nd	0.52
	bottom	0.62	0.63	0.71	0.99	1.63	nd	nd	nd	nd	nd	0.65
Stn 10	surface	0.34	0.33	0.54	0.57	1.00	nd	nd	nd	nd	nd	0.72
	bottom	0.72	0.42	0.59	0.69	1.11	nd	nd	nd	nd	nd	0.88

nd: no data

Chlorophyll a concentration ($\mu g\ l^{-1}$)

		Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Feb.	Apr.	May.	Jul.
Stn 1	surface	6.53	14.6	4.45	5.15	1.02	3.66	2.52	4.01	7.24	1.59	3.02
	bottom	2.17	6.18	5.09	5.15	3.90	3.95	2.52	3.78	7.04	5.23	4.23
Stn 2	surface	7.72	4.26	7.84	5.51	2.78	1.39	1.67	2.26	4.43	5.95	1.90
	bottom	1.79	5.73	3.32	5.60	4.89	1.43	1.51	2.10	6.04	7.85	2.72
Stn 3	surface	2.55	21.0	2.92	6.27	3.70	0.16	1.67	2.06	7.85	10.5	2.62
	bottom	1.81	3.05	2.04	4.97	3.58	4.16	1.57	21.2	8.25	7.04	2.21
Stn 4	surface	3.74	27.2	1.86	4.61	2.49	1.85	nd	2.66	3.79	1.41	2.31
	bottom	7.30	7.97	13.8	3.18	3.70	2.49	nd	9.39	4.63	3.82	11.7
Stn 5	surface	6.34	15.3	1.28	2.78	7.66	1.10	1.39	nd	4.28	4.53	0.86
	bottom	7.74	0.93	1.68	1.93	1.39	0.29	2.21	nd	4.43	3.42	1.47
Stn 6	surface	4.27	5.56	3.28	6.81	3.18	4.28	1.41	nd	9.86	4.53	5.03
	bottom	9.73	208.	20.1	6.23	8.09	4.79	1.53	nd	8.25	3.02	12.1
Stn 7	surface	8.85	0.50	8.48	8.56	5.23	8.76	nd	nd	4.43	8.05	6.84
	bottom	nd	0.75	10.9	6.50	5.96	12.9	nd	nd	75.4	37.7	6.84
Stn 8	surface	3.60	0.38	2.17	15.7	0.90	1.24	0.55	nd	4.83	2.01	4.53
	bottom	19.0	491.	4.66	4.17	4.02	2.32	3.62	nd	6.44	5.23	5.03
Stn 9	surface	7.97	0.33	5.51	9.06	0.42	1.06	nd	nd	1.43	1.96	4.43
	bottom	7.52	1.03	5.51	14.6	5.51	6.32	nd	nd	1.43	3.06	4.02
Stn 10	surface	7.94	0.88	2.26	4.93	0.94	1.57	0.73	nd	0.69	3.02	4.12
	bottom	14.8	1.60	2.66	6.32	1.39	1.47	0.98	nd	0.73	4.38	3.52

nd: no data

Phaeopigment concentration ($\mu g\ l^{-1}$)

		Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Feb.	Apr.	May.	Jul.
Stn 1	surface	9.76	10.7	1.14	1.44	1.10	1.92	1.01	0.63	0.95	2.08	0.40
	bottom	1.61	3.59	4.24	2.86	2.95	1.86	1.13	0.65	1.61	4.79	1.47
Stn 2	surface	8.95	1.36	1.25	1.57	1.71	28.9	0.64	0.30	1.49	5.72	1.03
	bottom	1.63	1.20	1.55	1.24	2.06	4.16	1.26	0.44	1.48	5.13	1.04
Stn 3	surface	1.01	16.6	0.58	1.54	1.58	5.37	0.64	0.30	1.03	5.20	0.46
	bottom	1.31	3.30	1.57	2.75	2.79	2.30	0.99	11.8	1.54	5.02	1.20
Stn 4	surface	1.38	17.4	1.06	1.83	1.30	1.34	nd	0.84	1.01	2.69	2.01
	bottom	5.48	3.85	27.0	3.37	1.40	1.67	nd	2.18	1.06	4.60	3.34
Stn 5	surface	0.73	13.0	0.71	2.40	0.00	1.14	0.64	nd	1.62	3.78	0.78
	bottom	1.42	1.45	1.39	8.92	3.27	6.08	1.20	nd	1.27	5.46	0.95
Stn 6	surface	0.97	2.75	2.13	2.67	2.26	7.71	0.85	nd	2.66	3.78	0.89
	bottom	3.77	347.	44.0	4.13	2.70	8.01	1.31	nd	2.91	4.95	2.49
Stn 7	surface	8.85	0.21	1.78	5.37	3.88	16.6	nd	nd	6.50	14.2	0.90
	bottom	nd	0.58	6.44	8.65	4.29	25.4	nd	nd	149.	43.1	1.58
Stn 8	surface	0.66	0.23	1.44	17.8	1.46	1.99	0.79	nd	1.55	2.43	0.48
	bottom	35.0	209.	8.86	6.68	2.90	4.23	6.85	nd	1.76	4.10	1.57
Stn 9	surface	10.4	0.21	0.55	6.61	1.28	1.32	nd	nd	2.40	3.58	0.36
	bottom	15.6	1.03	2.18	15.5	11.1	4.98	nd	nd	2.73	7.86	1.21
Stn 10	surface	10.0	0.41	0.86	8.02	1.83	2.08	0.97	nd	1.61	4.50	0.43
	bottom	23.3	1.56	1.73	9.81	1.80	2.50	1.10	nd	1.57	10.3	0.69

nd: no data

Particulate organic carbon in water column ($\mu g\ l^{-1}$)

		Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Feb.	Apr.	May.	Jul.
Stn 1	surface	179	519	575	490	334	516	407	240	443	300	251
	bottom	406	1160	1760	1110	890	582	632	348	583	596	457
Stn 2	surface	258	619	705	685	406	400	336	165	550	629	257
	bottom	416	894	896	592	472	536	578	352	605	990	587
Stn 3	surface	206	470	497	671	597	488	338	273	604	840	258
	bottom	426	1030	860	492	743	809	918	2720	777	962	808
Stn 4	surface	519	523	308	716	390	377	nd	302	491	458	346
	bottom	1420	1610	11600	790	513	1210	nd	864	787	913	1120
Stn 5	surface	301	401	392	362	332	313	248	nd	644	596	184
	bottom	577	3660	854	13700	923	1130	1050	nd	725	1170	409
Stn 6	surface	622	579	983	543	607	1670	426	nd	1650	1220	414
	bottom	1330	9280	22100	1180	763	2290	727	nd	2160	1930	1220
Stn 7	surface	273	800	1190	1190	1070	6950	nd	nd	4300	5090	396
	bottom	nd	1800	5170	1600	1310	3120	nd	nd	101000	15900	749
Stn 8	surface	295	449	361	323	436	466	310	nd	814	878	342
	bottom	2550	4730	3790	128	717	442	1780	nd	1050	1180	625
Stn 9	surface	181	994	955	1590	664	355	nd	nd	1470	1120	643
	bottom	331	2800	2370	1440	3160	885	nd	nd	1940	3040	1090
Stn 10	surface	833	991	853	2630	930	759	403	nd	1240	2930	501
	bottom	1410	4700	1250	1260	736	497	322	nd	1250	3390	929

nd: no data

Particulate organic nitrogen in water culumn ($\mu g\ l^{-1}$)

		Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Feb.	Apr.	May.	Jul.
Stn 1	surface	27	60	115	21	59	70	58	32	65	56	41
	bottom	52	161	441	127	121	98	77	50	74	113	104
Stn 2	surface	21	86	124	18	82	59	39	32	68	137	36
	bottom	19	151	255	75	39	71	86	37	88	190	115
Stn 3	surface	18	66	81	0	78	66	53	35	82	181	30
	bottom	69	161	143	38	192	78	128	385	115	176	151
Stn 4	surface	57	54	44	63	62	55	nd	34	94	89	59
	bottom	187	218	1900	108	51	132	nd	107	120	143	186
Stn 5	surface	32	47	73	36	43	46	39	nd	109	116	25
	bottom	80	470	105	1750	115	127	110	nd	80	200	85
Stn 6	surface	45	63	161	97	94	227	35	nd	348	211	57
	bottom	169	1210	3450	554	106	301	89	nd	358	346	203
Stn 7	surface	33	152	220	160	162	856	nd	nd	655	794	74
	bottom	nd	277	689	211	176	391	nd	nd	13400	2720	130
Stn 8	surface	26	75	32	457	56	68	21	nd	150	159	70
	bottom	291	655	491	171	97	38	212	nd	167	164	93
Stn 9	surface	17	161	64	161	64	50	nd	nd	216	136	148
	bottom	36	317	269	187	339	91	nd	nd	256	415	156
Stn 10	surface	51	134	73	239	97	103	49	nd	137	297	99
	bottom	95	494	153	124	91	44	43	nd	165	389	140

nd: no data

C/N ratio (w/w) of particulate organic matter

		Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Feb.	Apr.	May.	Jul.
Stn 1	surface	6.6	8.7	5.0	23.3	5.7	7.4	7.0	7.5	6.8	5.4	6.1
	bottom	7.8	7.2	4.0	8.8	7.4	5.9	8.2	7.0	7.9	5.3	4.4
Stn 2	surface	12.3	7.2	5.7	38.1	5.0	6.8	8.5	5.2	8.1	4.6	7.1
	bottom	21.9	5.9	3.5	7.9	12.1	7.6	6.7	9.5	6.9	5.2	5.1
Stn 3	surface	11.4	7.1	6.1	0.0	7.7	7.4	6.3	7.8	7.4	4.6	8.6
	bottom	6.2	6.4	6.0	12.9	3.9	10.3	7.1	7.1	6.8	5.5	5.4
Stn 4	surface	9.1	9.7	7.0	11.4	6.3	6.9	nd	8.9	5.2	5.1	5.9
	bottom	7.6	7.4	6.1	7.3	10.1	9.1	nd	8.1	6.6	6.4	6.0
Stn 5	surface	9.4	8.5	5.4	10.1	7.7	6.8	6.4	nd	5.9	5.1	7.4
	bottom	7.2	7.8	8.1	7.8	8.0	8.9	9.6	nd	9.1	5.8	4.8
Stn 6	surface	13.8	9.2	6.1	5.6	6.5	7.4	12.3	nd	4.7	5.8	7.3
	bottom	7.9	7.7	6.4	2.1	7.2	7.6	8.2	nd	6.0	5.6	6.0
Stn 7	surface	8.3	5.3	5.4	7.4	6.6	8.1	nd	nd	6.6	6.4	5.4
	bottom	nd	6.5	7.5	7.6	7.5	8.0	nd	nd	7.5	5.8	5.8
Stn 8	surface	11.3	6.0	11.3	0.7	7.8	6.8	14.8	nd	5.4	5.5	4.9
	bottom	8.8	7.2	7.7	0.7	7.4	11.5	8.4	nd	6.3	7.2	6.7
Stn 9	surface	10.6	6.2	14.9	9.9	10.4	7.1	nd	nd	6.8	8.3	4.3
	bottom	9.2	8.8	8.8	7.7	9.3	9.7	nd	nd	7.6	7.3	7.0
Stn 10	surface	16.3	7.4	11.7	11.0	9.6	7.4	8.2	nd	9.1	9.9	5.1
	bottom	14.9	9.5	8.2	10.1	8.1	11.2	7.5	nd	7.6	8.7	6.6

nd: no data

NORPAC-net sampled organic particle (mg m^{-3})

	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Feb.	Apr.	May.	Jul.
Stn 1	nd	36.	3.6	15.4	35.4	13.2	20.4	21.0	16.8	16.2	12.2
Stn 2	nd	106.	8.7	15.2	16.4	21.6	155.	19.5	29.2	6.2	1.9
Stn 3	nd	15.	7.8	53.5	17.4	31.6	nd	5.8	32.0	24.7	48.8
Stn 4	nd	171.	91.2	158.	16.4	36.0	nd	nd	1020.	588.	58.5
Stn 5	nd	6.	12.8	11.6	18.2	81.3	13.0	nd	32.3	27.2	3.2
Stn 6	nd	260.	25.8	291.	5.5	104.	nd	nd	178.	137.	1.4
Stn 7	nd	270.	4.3	49.7	33.4	481.	nd	nd	91.6	59.3	6.2
Stn 8	nd	82.	75.8	3.6	6.9	31.7	nd	nd	84.1	331.	11.9
Stn 9	nd	20.	18.2	61.2	46.0	56.1	nd	nd	108.	31.3	4.4
Stn 10	nd	33.	6.3	101.	4.0	63.5	197.	nd	82.4	432.	6.5

nd: no data

Carbon content in NORPAC-net sample (%)

	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Feb.	Apr.	May.	Jul.
Stn 1	nd	nd	18.6	33.1	34.2	32.4	34.2	38.5	38.1	37.2	17.5
Stn 2	nd	42.1	33.4	35.0	62.7	35.3	62.7	41.0	41.6	25.6	31.4
Stn 3	nd	26.4	29.9	36.3	15.7	34.3	15.7	39.0	37.3	42.6	36.9
Stn 4	nd	7.2	26.7	18.1	71.4	39.6	71.4	nd	8.1	36.9	15.7
Stn 5	nd	14.6	11.1	9.6	3.3	38.5	3.3	nd	24.9	40.8	48.0
Stn 6	nd	8.0	16.9	19.8	22.0	40.5	22.0	nd	17.5	41.0	16.6
Stn 7	nd	7.1	19.5	26.1	6.2	39.1	6.2	nd	22.3	39.6	24.4
Stn 8	nd	12.4	27.6	20.0	nd	38.9	nd	nd	20.0	30.5	24.9
Stn 9	nd	12.2	31.5	29.2	1.9	32.8	1.9	nd	26.6	37.2	11.9
Stn 10	nd	20.8	5.9	24.2	nd	38.0	nd	nd	35.6	32.2	8.2

nd: no data

Nitrogen content in NORPAC-net sample (%)

	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Feb.	Apr.	May.	Jul.
Stn 1	nd	nd	2.8	8.0	9.3	8.8	9.3	10.2	9.8	8.9	4.6
Stn 2	nd	7.5	8.2	8.1	15.3	9.3	15.3	10.3	9.5	6.3	8.8
Stn 3	nd	7.5	7.0	9.2	3.6	9.4	3.6	10.0	9.7	9.0	10.0
Stn 4	nd	1.3	6.0	3.2	17.2	11.4	17.2	nd	1.4	10.1	3.3
Stn 5	nd	2.2	2.1	1.9	0.6	11.2	0.6	nd	5.7	9.2	12.1
Stn 6	nd	1.2	4.1	4.3	4.6	10.7	4.6	nd	5.7	10.3	2.6
Stn 7	nd	1.4	3.9	7.6	1.2	10.9	1.2	nd	5.9	8.1	6.0
Stn 8	nd	2.7	6.2	3.6	nd	10.7	nd	nd	8.2	9.9	6.0
Stn 9	nd	2.2	8.3	2.5	0.3	9.9	0.3	nd	2.2	3.2	1.7
Stn 10	nd	2.2	0.9	2.9	nd	6.8	nd	nd	1.8	1.9	1.6

nd: no data

C/N ratio (w/w) of NORPAC-net sample

	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Feb.	Apr.	May.	Jul.
Stn 1	nd	nd	6.55	4.16	3.66	3.70	3.68	3.79	3.88	4.17	3.80
Stn 2	dn	5.61	4.06	4.31	4.11	3.78	3.66	3.97	4.37	4.05	3.58
Stn 3	nd	3.51	4.29	3.93	4.32	3.65	nd	3.88	3.83	4.74	3.70
Stn 4	nd	5.53	4.42	5.63	4.15	3.48	nd	nd	5.63	3.65	4.71
Stn 5	nd	6.55	5.17	5.18	5.15	3.43	3.77	nd	4.38	4.45	3.97
Stn 6	nd	6.63	4.16	4.64	4.82	3.78	nd	nd	3.08	3.97	6.32
Stn 7	nd	4.56	4.95	3.43	4.38	3.59	nd	nd	3.76	4.87	4.06
Stn 8	nd	4.60	4.43	5.57	3.93	3.65	nd	nd	2.44	3.08	4.13
Stn 9	nd	5.69	3.81	11.8	5.87	3.32	nd	nd	12.1	11.5	6.99
Stn 10	nd	9.35	6.44	8.48	nd	5.60	3.35	nd	19.6	16.8	5.18

nd: no data