T H E S I S

TEMPORAL VARIATION IN NUTRIENT AND WATER STRUCTURE AND ITS RELATIONSHIP IN THE SURUGA BAY

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December 2004

THESIS

TEMPORAL VARIATION IN NUTRIENT AND WATER STRUCTURE AND ITS RELATIONSHIP IN THE SURUGA BAY

駿河湾における栄養塩と海洋構造の時間変動と相互関係

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2004 年 12 月

Abstract

Temporal variation in nutrients [NO_3, PO_4 and $Si(OH)_4$] and water structure was observed in the Suruga Bay from April 2000 to July 2002. Salinity at the subsurface salinity maximum layer varied from 34.48 to 34.73. In the subsurface salinity maximum layer, when salinity was high, potential temperature was also high in each season. Nutrients concentration also showed large temporal variation in the surface and the subsurface layers. Seasonal variation in nutrients concentration was larger at the surface layer (0 - 50 m) compared to that in below 100 m. On the other hand, the difference between the sampling dates in each season was larger in the subsurface layer (100 - 300 m) than those in the surface and the deep layers. At the subsurface salinity maximum layer, there was a significant negative correlation between nutrients concentration and salinity. In the Offshore Water, which was characterized by the salinity maximum and was defined as salinity > 34.4, the difference of nutrients between in each sampling periods was negatively correlated with that of salinity. This suggests an increasing intrusion of warm and saline water bring about lower nutrients concentration in the Offshore Water. Vertical section of salinity in east-west cross-section in September 2000, when salinity maximum was high in fall, showed that the saline water was intruded from east to west, implying the

counterclockwise circulation in the bay related with approaching of the Kuroshio axis. When the salinity maximum was high in each season, the path of the Kuroshio Current was nearly to the Suruga Bay. These suggest that the warm and saline water intruded to the Offshore Water would be originated from Kuroshio Water. In May 2002, salinity maximum was 34.71 and decreased to 34.62 after two weeks, whereas salinity maximum in July 2002 was 34.71. This suggests that the intrusion of warm and saline water is changes 20 - 40-days period. In this period, nutrients budget in 0 - 200 m increased ca. 1.6 - 2.0 times after two weeks. This implies that the effect of the increasing intrusion of saline water on nutrient budget decreases about 50 % of budget when salinity maximum is low. To determine influence of saline water intruded to the Offshore Water, the relationship among the salinity maximum, integrated nutrients and chlorophyll *a* in the upper 200 m. This relationship was examined by the difference of the salinity maximum (ΔS_{max}), integrated nutrients (Δ[nutrients-int]: Δ[NO_3-int], Δ[PO_4-int], Δ[$Si(OH)_4$-int]) and chlorophyll *a* (Δ[chl.*a*-int]) between each sampling periods. ΔS_{max} was significantly negatively correlated with Δ[nutrients-int] and Δ[chl.*a*-int], implying that lower nutrient concentration in the Offshore Water due to an increasing intrusion of saline water effected on phytoplankton productivity at the surface layer. Δ[chl.*a*-int] was a significantly correlated with Δ[NO_3-int], whereas was not significantly correlated with Δ[PO_4-int] or Δ[$Si(OH)_4$-int]. These results suggest that a primary productivity was limited by NO_3 rather than PO_4 and $Si(OH)_4$. It is supported that NO_3 concentration in the surface water (0 - 20 m) was mostly depleted from April to October, whereas PO_4 and $Si(OH)_4$ was not always depleted, implying limitation of primary production by NO_3 from spring to fall. On the other hand, total organic nitrogen (TON) and phosphorus (TOP) was also observed in the Suruga Bay. Average concentration of TON was ranged from 5.6 to 7.4 μmol l^{-1} in the surface layer and that of TON was ranged from 0.09 to 0.28 μmol l^{-1}. Below the surface layer, TON and TOP varied relatively little and average concentration of TON and TOP from 100 to 200 m was 4.3 and 0.13 μmol l^{-1}, respectively. To estimate the characteristics of TON and TOP in the surface layer, semi-labile TON and TOP (S-TON, S-TOP, respectively) was calculated from 0 to 50 m. S-TON and S-TOP was calculated by subtracting average concentration of TON and TOP from 100 to 200 m from TON and TOP concentration in the surface layer (0 – 50 m). Since TON and TOP was mostly constant in 100 - 200 m during the sampling periods, refractory TON and TOP defined as the average concentration of TON and TOP in 100 - 200 m. S-TON, which was integrated from 0 to 50 m, was varied among 42 - 177 mmol m^{-2} and it occupied 16 - 45% of TON. This result is consistent with S-TON proportions reported in recent reports on degradation experiment. On the other hand, S-TOP was ranged from 1.0 - 8.6 mmol m^{-2} and the proportion of S-TOP with regard to TOP was 13 - 58%. Integrated chlorophyll *a* from 0 to 50 m was a significant correlated with integrated S-TON. This seems that S-TON varies due to the increasing intrusion of warm and saline water. On the other hand, it was not significantly correlation between integrated S-TOP and chlorophyll *a*. These show that the behavior of S-TON is different from that of S-TOP. This is first study for the processes between the nutrients dynamics in the Suruga Bay and the Kuroshio Current intrusion. These results would be important to estimated biogeochemical cycle in the Suruga Bay.

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Chapter I: General introduction

Nutrients distribution in the ocean is observed generally, and nutrient is one of the basic biological items in oceanographic research. Nutrients are consumed by phytoplankton (photosynthesis process) in euphotic layer. Nutrient is used until it become limiting and further growth is inhibited. In generally, phytoplankton productivity in the ocean has been limited by nutrients, especially nitrogen (*e.g.,* Millero, 1996; Tyrell, 1999). But it was also reported to be controlled by phosphorus in the Mediterranean Sea and the North Atlantic Ocean (Krom *et al.*, 1991; Diaz *et al.*, 2001). Moreover, Church *et al.* (2002) suggests that limiting factor of productivity of phytoplankton changes to phosphorus from nitrogen in during 20 years before in North Pacific subtropical gyre. These studies indicate the importance of nutrient shift for controlling primary production, but it is not clear that which of nitrogen and phosphorus is more important for limiting factor of primary productivity. In order to solve this issue, it is important to explain the stoichiometry of N (nitrogen) and P (phosphorus) in the ocean. For example, recent studies suggested that change of N: P ratio influenced on phytoplankton size and species with incubation experiment (*e.g.,* Granéli *et al.*, 1999; Carlsson and Granéli, 1999; Havskum *et al.*, 2003). It was also suggested that N: Si (silicate) ratio was also related with phytoplankton productivity (*e.g.*, Wilkerson and Dugdale, 1996; Kristensen 2001). The stoichiometry approach of N, P and Si should be also necessary to explain the production and biogeochemical cycle in the ocean, in addition to nutrient dynamics.

One of the most important concepts to emerge in the nutrient field has been the distinction between new and regenerated production (Dugdale and Goering, 1967; MaCarthy and Goldman, 1979). This concept is related to the way in which nutrients are supplied to the euphotic layer, and nutrient regenerated also influenced on primary production. This indicates that the characteristics and dynamics of organic nitrogen and phosphorus controled the magnitude of primary productivity in euphotic layer. The characteristics on degradation of organic nitrogen and phosphorus are somewhat of reports (Kolowith *et al.*, 2001; Hopkinson *et al.*, 2002), and it is not enough clear.

On the other hand, nutrient dynamics is related with water structure. Many studies reported that nutrients were supplied from river water to coastal area (*e.g.*, Cabeçadas *et al.*, 1999; Evans *et al.*, 2003; Hydes *et al.*, 2004). Furthermore, recent studies reported that the nutrients concentration and nutrients ratio was difference from water masses (Gil *et al.*, 2000; Kress and Herut, 2001). The variation in water structure influenced on nutrient concentration and ratio supplied to the surface water due to the water mixing (Corwith and Wheeler 2002; Wilkerson *et al.*, 2002). Since nutrient concentration and ratio strongly effected on the phytoplankton productity, the characteristics of water structure would also control the phytoplankton productivity.

In this thesis, water structure, nutrients and organic matter was observed in the Suruga Bay from April 2000 to July 2002. The relationship between the characteristics of water structure and nutrient distribution were described for time series observation in chapter II, and for north-south cross-section in chapter III. In chapter IV, the relationship between increasing intrusion saline water, which was shown in chapter II and III, and path of the Kuroshio Current was discussed. The variation in total organic nitrogen and phosphorus was described and discussed for the characteristic of these in chapter V. This is first study to indicate long-term temporal variation in nutrients, organic nitrogen and organic phosphorus, and the relationship between water structure and nutrients induced the biological resource in the Suruga Bay.

Chapter II: Relationship between salinity and nutrients in the subsurface layer in the Suruga Bay.

Introduction

The Suruga Bay is located on the southern coast of Honshu, Japan. It opens to the Pacific Ocean by its south-end named the Suruga Trough, which the maximum water depth is about 2500 m. Kuroshio water intrudes into the bay along Suruga Trough, which extends from the bay head to the eastern part of the bay mouth. Intrusion of the Kuroshio water and its circulation within the bay is strongly influenced by the position of the Kuroshio axis (Inaba, 1984).

Nakamura (1982) defined the water structure in the Suruga Bay with five discrete water masses (Table 2-1): (A) Coastal Water located near the western coast and the bay head and influenced by river, (B) Surface Water consisting of the Coastal Water and the Offshore Water, (C) Offshore Water characterized by the salinity maximum and showing the characters of the Kuroshio, (D) Intermediate Water characterized by the salinity minimum, (E) Pacific Deep Water. Nakamura (1982) reported that temperature and salinity varied seasonally in the Coastal Water, the Surface Water and the Offshore Water, and could be not distinguished between the Surface Water and the Offshore Water in winter due to the convective mixing (Table 2-1).

Previous studies in the Suruga Bay mainly focused on its physical aspect (Inaba, 1981; Nakamura, 1982; Inaba, 1984; Takeuchi and Hibiya, 1997) and there are few biogeochemical studies. Aoki (1993) found a negative correlation between chlorophyll *a* and salinity in the surface layer in the Suruga Bay and suggested that the relationship was derived from the supply of nutrients from the river water. Shiomoto and Hashimoto (1999) reported the possible limitation of primary production by inorganic nitrogen in the offshore surface water of the Suruga Bay from spring to fall especially as for diatoms. These studies suggest that phytoplankton biomass is partially limited by the low level of nutrients. However, it is not clear what mechanism works on the limitation of nutrients in the Suruga Bay. Detailed information about the seasonal variation in nutrients and the relationships between nutrients and the water structure are necessary.

In this chapter, the spatio-temporal distributions of hydrographycal structure, nutrients and chlorophyll *a* were reported along the zonal vertical cross-sections located in the middle part of the Suruga Bay from April 2000 to July 2002. Large temporal variations in the salinity were found at the subsurface salinity maximum layer in spring, summer and fall, and negative correlations between salinity and nutrients at the depth of the subsurface salinity maximum.

Materials and Methods

Observations were conducted aboard R/V *Suruga-Maru* at St. 2, St. 3, St. E and St. F in the Suruga Bay from April 2000 to July 2002 (Fig. 2-1). Locations of sampling stations are shown in Table 2-2. St. 2 and St. 3 are the time-series station of the Shizuoka Prefectural Fisheries Experiment Station since 1997, and St. E and St. F were established later between St. 2 and St. 3. Temperature and salinity were measured by CTD (SBE 9 plus; Sea-Bird Electronics, USA) every 1 dbar between the surface and the depth above 20 m from the sea bottom [henceforth, B-20 (m)], and potential temperature (θ) and potential density (σ_θ) were calculated. Water samples were taken from April 2000 to July 2002 and the details of the sampling depths in each station are shown in Table 2-2. Samples were collected with 10-l Niskin bottles mounted on a CTD/Carousel water sampler system. Surface water samples were collected using a plastic bucket (Sts. 2, E and F) or Niskin bottle (St. 3; 2m).

Nutrient samples were collected into 100 ml polypropylene bottles from the Niskin bottles and kept in freezer (-30 ºC) until the analysis. Nutrients were measured for nitrate (NO_3), phosphate (PO_4) and silicate [$Si(OH)_4$] with TRAACS 2000 analyzer (BRAN + LUEBBE GmbH., Germany) (Hansen and Koroleff, 1999). $Si(OH)_4$ was measured only for the samples taken between November 2000 and July 2002. Precision of nutrients analysis was ±0.2%, ±0.8% and ±0.5 % as for NO_3, PO_4 and $Si(OH)_4$, respectively, estimated from the coefficient of variation of the replicated (n = 5) analyses of the seawater sample which contained 13.90 μmol l^{-1} of NO_3, 0.92 μmol l^{-1} of PO_4 and 18.83 μmol l^{-1} of $Si(OH)_4$. Detection limits which was estimated by 3 the standard deviation (SD) of the replicated (n = 5) analyses for 3.5% NaCl solution, were 0.05 μmol l^{-1}, 0.02μmol l^{-1} and 0.03 μmol l^{-1} as for NO_3, PO_4 and $Si(OH)_4$, respectively.

Chlorophyll *a* was measured for the samples taken at the depths of 0, 10, 20, 30, 50, 100, 150 and 200 m at Sts. 3, E and F, and 0, 10, 20, 50, 100, 150 and 200 m at St. 2. Samples were collected into dark polyethylene bottles from the Niskin bottles, and 300 ml of the samples were immediately filtered through GF-75 glass fiber filter (TOYO ROSHI Corp., Tokyo) with suction (~ 200 hPa). Although nominal pore size of GF-75 is mentioned as 0.3 μm by the manufacture, Pike and Moran (1997) reported that the retention efficiency of particulate organic matter was similar between GF-75 and Whatman GF/F filter when seawater was filtered. The filter samples were soaked in 10 ml *N, N*-dimethylformamide and kept in freezer (-30 °C) until the analysis (Suzuki and Ishimaru, 1990). Chlorophyll *a* concentration was measured with a spectrofluorometer (RF-5300PC; Shimadzu Co., Kyoto). The spectrofluorometer was calibrated with a chlorophyll *a* standard derived from *Spirulina* (Wako Pure Chemical Industries, Ltd., Osaka). On the analysis of the standard containing 50 μg l^{-1} of chlorophyll *a*, SD of fluorescence read was ± 0.4 μg l^{-1} (n = 4), which is equivalent to ± 0.01 μg l^{-1} after divided by a concentration factor [filtration volume (300 ml) / extraction volume (10 ml)] of the samples. Precision of analysis was ± 0.7% estimated by the coefficient of variation of the replicated (n = 4) analyses of the same standard solution and detection limit was 0.04 μg l^{-1} estimated by 3 SD.

Results

Characteristics of the water structure in the Suruga Bay

Figure 2-2 shows vertical profiles of salinity, potential temperature (θ), and potential density (σ_θ) at Sts. 3, F, E and 2 in the Suruga Bay between April 2000 and July 2002. To determine seasonal variation in water structure in the surface layer, we calculated the mixed layer depth (MLD). MLD was determined as a depth where σ_θ was larger 0.125 than the one at the surface (5 m) value (Levitus, 1982; Sprintall and Tomczak, 1992). Table 2-3 shows MLD at each station. MLD showed clear seasonal changes at all stations with which MLD was deeper in winter, while MLD was smaller in summer. MLD was 6 - 55 m in spring (April, 2000, April, 2001, May 14, 2001), 5 - 14 m in summer (July, 2000, 2001 and 2002), 6 - 65 m in fall (September and November, 2000 and October, 2001), and 61 - 160 m in winter (February and December, 2001 and February, 2002) at Sts. 2, 3, E and F (Table 2-3).

Salinity maximum layer was mostly observed in the upper 200 m in all stations, and maximum values varied among the sampling dates (Fig. 2-2). The salinity in the subsurface salinity maximum layer is shown in Table 2-4a, b, c and d with the ranges of its related depth, θ and σ_θ. Depth, θ and σ_θ show the range of the isohaline layer of the salinity maximum. In spring, the salinity at the subsurface salinity maximum layer was observed in 18 - 95 m, except for at St. 2 in April 2001 (4 - 8 m) and at St. E in May 2002 (0 - 39 m), when the subsurface salinity maximum layer was not clear and salinity maximum was extend to the surface. The salinity was higher in May 2002 (34.65 - 34.71) than in April 2000 (34.59 - 34.60) and in April 2001 (34.55 - 34.60). In summer, the salinity in the subsurface salinity maximum layer was observed at 38 - 104 m. The salinity was highest in July 2002 (34.71 - 34.73), followed by July 2000 (34.59 - 34.62) and in July 2001 (34.55 - 34.58). In September 2000, the depth of the subsurface salinity maximum was found at 66 - 93 m at Sts. F, E and 2, and it was shallower than at St. 3 (134-145 m). The salinity in September 2000 was higher in Sts. F, E and 2 (34.66 - 34.71) than at St. 3 (34.55). In November 2000 and October 2001, the depth of the subsurface salinity maximum layer was found in 81 - 126 m and the salinity was 34.53 - 34.57, and it was lower than at Sts. F, E and 2 in September 2000. In winter, the subsurface salinity maximum was not clear but the maximum value of salinity was found in the upper 163 m (Fig. 2-2). The maximum salinity was highest in February 2001 (34.60 - 34.61), followed by in December 2001 (34.48 - 34.50) and in February 2002 (34.50 - 34.54).

When the salinity maximum marked the highest value in each season, θ in the subsurface salinity maximum layer was also observed to be the highest value (Table 2-4). The highest salinity and θ in each season were observed in May 2002 for spring, in July 2002 for summer, in September 2000 for fall and in February 2001 for winter, respectively (Table 2-4). On the other hand, low σ_θ was observed at the depth of the subsurface salinity maximum layer when the salinity was high: lowest σ_θ was observed in May 2002, July 2002, September 2000 and February 2001 as for spring, summer, fall and winter, respectively (Table 2-4). Salinity, θ or σ_θ differed less with the sampling dates, respectively, below the subsurface salinity maximum layer (Fig. 2-2).

Figure 2-3 shows the vertical section of salinity in the Suruga Bay in fall. To emphasize the distribution of the subsurface salinity maximum, contours of the salinity less than 34.0 in the surface were omitted. The salinity maximum ranged from 34.55 to 34.71 among 4 stations in September 2000 (Table 2-4a, b, c and d). The subsurface salinity maximum was characterized as the water with the salinity higher than 34.6 in September 2000, and was observed between 60 m and 130 m at St. 2 (Fig. 2-3). The subsurface salinity maximum layer became thinner to the west, i.e. it was found at 60 - 100 m at St. E, 65 - 75 m at St. F and it was not observed St. 3. On the other hand, the water with the salinity higher than 34.6 was not observed at any stations in November 2000 or October 2001 (Fig. 2-3). In the other seasons, this tendency like in September 2000 was also not observed in spite of the variation in salinity at the subsurface salinity maximum.

Spatio-temporal distributions of nutrients

Figure 2-4a, b, c and d show the vertical profiles of nutrients at Sts. 3, F, E and 2, respectively. Note that $Si(OH)_4$ was not measured in April, July and September 2000. Several characteristics of the temporal changes of the vertical distribution of nutrient were observed. Nutrients concentration in the upper 20 m was low from April to October, and markedly high in February (Fig. 2-4). In the upper 20 m, NO_3 was mostly below the detection limit (0.05 μmol l^{-1}) from April to October except for April 2000 (0.31 - 2.59 μmol l^{-1}). PO_4, which was below the detection limit (0.02 μmol l^{-1}), was few (4 cases in 96 cases). $Si(OH)_4$, which was below the detection limit (0.03 μmol l^{-1}), was also few (1 cases in 48 cases) except for in July 2001 (10 cases in 12 cases). PO_4 and $Si(OH)_4$ were 0.08 ± 0.06 μmol l^{-1} (average ± standard deviation, n = 96) and 2.48 ± 1.84 μmol l^{-1} (n = 60) in the upper 20 m, respectively. These results suggest that primary productivity would have been limited mostly by the deficiency of NO_3 in spring (April and May), and summer (July) and fall (September and October). In November, NO_3 concentration increased to 1.89 ± 0.73 μmol l^{-1} (n = 12) in the upper 20 m, and PO_4 and $Si(OH)_4$ were 0.20 ± 0.02 μmol l^{-1} (n = 12) and 5.46 ± 2.70 μmol l^{-1} (n = 12), respectively (Fig. 2-4). NO_3 in November was at higher level compared to the ones from April to October. In winter, nutrient distributed at higher level compared to those in the other seasons. NO_3 was 3.42 ± 0.48 μmol l^{-1} (n = 12) in December 2001, and 8.24 ± 2.26 μmol l^{-1} (n = 24) in February 2001 and 2002 (Fig. 2-4). PO_4 and $Si(OH)_4$ were averaged at 0.38 ± 0.12 μmol l^{-1} (n = 12) and 7.96 ± 2.06 μmol l^{-1} (n = 12), respectively in December 2001, and 0.57 ± 0.20 μmol l^{-1} (n = 24) and 14.56 ± 5.86 μmol l^{-1} (n = 24), respectively in February 2001 and 2002 (Fig. 2-4). In winter, NO_3, PO_4 and $Si(OH)_4$ were almost uniform in the upper 100 m, although the concentrations varied among the sampling dates. In the upper 100 m, nutrients concentration was lowest in December 2001 and highest in February 2002 (Fig. 2-4). For example, Average concentration of NO_3 in the upper 100 m was 4.09 μmol l^{-1} in December 2001, 6.75 μmol l^{-1} in February 2001 and 10.36 μmol l^{-1} in February 2002. On the other hand, winter MLD was shallowest in December 2001 (64 - 88 m) and deepest in February 2002 (130 - 160 m) (Table 2-3). The average nutrients concentrations in the upper 100 m were significantly correlated with MLD at all the stations in winter (r^2 = 0.60 - 0.70, n = 12, $P < 0.05$) (Fig. 2-5), implying the regulation of the nutrients concentration in the upper 100 m by thickness of the MLD in winter.

Seasonal variation in nutrient concentrations was largest in the surface layer (0 - 50 m) (Fig. 2-6). Seasonal variation in nutrients was defined as a difference between the maximum and the minimum of the averages at each sampling depth in each season. For example, at St. 2, the seasonal variation in NO_3 was 5.93 - 6.62 μmol l^{-1} in 0 - 50 m, whereas it ranged from 1.99 μmol l^{-1} to 4.41μmol l^{-1} below 100 m. The seasonal variation in PO_4 exhibited similar characteristics: it was 0.37 - 0.46 μmol l^{-1} in 0 - 50 m, and 0.12 - 0.22 μmol l^{-1} below 100 m (Fig. 2-6). The seasonal variation in

$Si(OH)_4$ was relatively large (8.98 - 11.46 μmol l^{-1}) in 0 - 30 m compared to the one below 100 m (3.71 - 7.06 μmol l^{-1}), excluding at 800 m (10.22 μmol l^{-1}) (Fig. 2-6). Seasonal variation in nutrients was larger in 0 - 30 m at St. 3, and in the surface layer [0 - 50 m for NO_3 and PO_4; 0 - 30 m for $Si(OH)_4$] at St. F and E corresponded to those in the below layer (Fig. 2-6).

The large difference between the maximum and the minimum concentration of nutrients at each station in each season was observed at the depths between 100 m and 300 m than in the surface layer (0 - 50 m) and deeper layer (> 400 m) in spring, summer and fall (Fig. 2-7). For example, at St. 2, the range of NO_3 in spring was 7.83 - 11.40 μmol l^{-1} in 100 - 300 m, whereas it was 1.13 - 5.02 μmol l^{-1} in 0 - 50 m and 1.37 - 3.66 μmol l^{-1} in 400 - 1000 m. PO_4 and $Si(OH)_4$ exhibited similar characteristics: the range of PO_4 in spring was 0.53 - 0.82 μmol l^{-1} in 100 - 300 m, and it was 0.09 - 0.24 μmol l^{-1} in 0 - 50 m and 0.11 - 0.26 μmol l^{-1} in 400 - 1000 m. The range of $Si(OH)_4$ was also largest in 100 - 300 m in spring (11.49 - 17.00 μmol l^{-1}), whereas it was largest at 150 - 300 m in summer (13.37 - 16.80 μmol l^{-1}). However, the range of $Si(OH)_4$ in fall was larger in 400 - 1000 m (13.30 - 15.60 μmol l^{-1}) than that in 100 - 300 m (3.01 - 10.80 μmol l^{-1}). In winter, the range of nutrients was relatively large in 0-50 m compared to the one below 100 m: the range was 5.37 - 7.47 μmol l^{-1}, 0.32 - 0.47 μmol l^{-1}, and 11.37 - 13.01 μmol l^{-1} in 0 - 50 m for NO_3, PO_4 and $Si(OH)_4$, respectively, whereas the corresponding was 1.35 - 6.39 μmol l^{-1}, 0.07 - 0.40 μmol l^{-1}, and 3.25 - 11.29 μmol l^{-1}, respectively below 100 m (Fig.

2-7). Exceptions were found at 800 m [NO_3, PO_4 and $Si(OH)_4$] and 1000 m [$Si(OH)_4$], where the range was relatively large compared to that in 100 - 600 m (Fig. 2-7). At Sts. 3, F and E, the range of nutrients was also larger in the subsurface layer (100 - 300 m) than in the surface and deep layer in spring, summer and fall, except for the range of $Si(OH)_4$ in fall, which was largest in 400 - 1000 m among all the sampling layer (Fig. 2-7).

The nutrients concentration in the middle depth layer with the subsurface salinity maximum layer was estimated by applying linear interpolation using the concentrations at the above and below the middle depth. The nutrients concentration in the subsurface salinity maximum layer is shown in Table 2-5. The values of NO_3, PO_4 and $Si(OH)_4$ ranged from < 0.05 μmol l^{-1} to 16.38 μmol l^{-1} (average, 7.51 μmol l^{-1}), 0.04 - 1.12 μmol l^{-1} (0.54 μmol l^{-1}) and 2.18 - 26.52 μmol l^{-1} (13.08 μmol l^{-1}), respectively. To examine the relationships between salinity and nutrients at the salinity maximum layer, and the plot of salinity versus nutrient was shown in Fig. 2-8. The nutrient concentrations in the subsurface salinity maximum layer were significantly correlated with the salinity (r^2 = 0.49 - 0.58, n = 36 or 48, $P < 0.05$) (Table 2-6). The relationship between salinity and nutrients in this layer was also significant in each station (r^2 = 0.42 - 0.62, n = 9 or 12, $P < 0.05$) (Table 2-6). To standardize the slope by nutrients concentration, each slope was divided by the respective averages of nutrients concentration at the subsurface salinity maximum layer. These ratio were similar among the nutrients: -6.57, -5.85 and -6.09 as for NO_3, PO_4 and $Si(OH)_4$, respectively at all the station. The range of ratio in each station ranged from -5.47 to -7.76 for NO_3, from -4.65 to -6.91 for PO_4 and from -5.30 to -6.95 for $Si(OH)_4$. These results suggest that the apparent decrease rate of the nutrients concentration with the increase in the salinity in the subsurface salinity maximum layer differed less among NO_3, PO_4 and $Si(OH)_4$.

Spatio-temporal distribution of chlorophyll a

Figure 2-9 shows the vertical profiles of chlorophyll *a* at Sts. 3, F, E and 2. In most cases, chlorophyll *a* marked a maximum between 0 and 20 m and chlorophyll *a* was below the detection limit (0.04 μg l^{-1}) at the depths below 100 m. Chlorophyll *a* concentration was high at four stations in April 2000 (2.9 - 5.9 μg l^{-1}, the range of the maximum value from surface to 20 m), in April 2001 (1.6 - 2.8 μg l^{-1}) and in October 2001 (1.6 - 3.2 μg l^{-1}). In several periods, chlorophyll *a* concentration was high at St. 3, whereas at Sts. F, E and 2, chlorophyll *a* was not so high. For example, in February 2001, maximum concentration of chlorophyll *a* was 9.1 μg l^{-1} at St. 3, and 0.6 - 0.7 μg l^{-1} at St. 2, F and E (Fig. 2-9). This tendency was also observed in September 2000, November 2000 and July 2002. In the other sampling periods, chlorophyll *a* concentration varied from 0.5 to 1.5 μg l^{-1} between 0 to 20 m (Fig. 2-9).

Salinity, nutrients and chlorophyll *a* at 10 m in the Suruga Bay was summarized in Table 2-7. Note that 10 m was the shallowest depth where was obtained both chlorophyll *a* and salinity data. Surface (10 m) chlorophyll *a* was mostly (8 cases in all 12 cases) highest at St. 3 (0.3 - 5.8 $\mu g\ l^{-1}$), which is closest to the mouth of Oi and Abe Rivers (Fig. 2-1). Salinity in the surface water was also mostly (9 cases in all 12 cases) lowest at St. 3 (32.94 - 34.65; Table 2-7), implying that the riverine water supply of nutrients effect on phytoplankton biomass in the surface of the western part of the Suruga Bay throughout the year. On the other hand, nutrients in the surface water were not always high at St. 3 in all stations. The surface PO_4 was mostly highest (7 cases in all 12 cases) at St. 2, followed by St. 3 (n = 4) and St. F (n = 1) (Table 2-7). These results imply that riverine water did not directly influence caused to the high nutrient concentrations in the surface water. In summer, chlorophyll *a* was lowest at all the stations in the NO_3 depletion layer, implying the limitation of primary production by NO_3 in summer (Table 2-7).

Discussion

Seasonal variation in nutrients was largest in the surface layer (upper 50 m) (Fig. 2-6). In this layer, NO_3 was depleted between April and October, whereas PO_4 and $Si(OH)_4$ was mostly detected (Fig. 2-4). This result is consistent with the one by Shiomoto and Hashimoto (1999) in which they suggested that primary production was limited by inorganic nitrogen in the offshore surface water of the Suruga Bay from spring to fall.

Chlorophyll *a* concentration at 10 m was higher at St. 3 among the other stations (Table 2-7). St. 3 is closest to river mouth (Fig. 2-1) and the surface salinity was lowest at St. 3 in all stations (Table 2-7). This result implies the effect of riverine water on chlorophyll *a* distribution. These results suggest that the phytoplankton production is stimulated by supply of nutrients from riverine water (Lohrenz *et al.*, 1999; Chen *et al.*, 2000). This is supported by the survey of Aoki (1993), which suggested that this process occurs in the Suruga Bay, based on the spatial distribution of chlorophyll *a* and salinity and their negative relationship in the surface layer. On the other hand, in the present study, the surface nutrient concentrations differed little between St. 2 and St. 3 (Table 2-7). Toyota (1985) reported that NO_3 concentration near the Abe river estuary was 2.1 - 9.9 μmol l^{-1} at the surface water (0 and 5 m) in October, and these NO_3 concentrations were higher compared to NO_3 concentration in fall at the surface water in this study (Table 2-7). If nutrient was supplied by riverine water into the surface water, lower nutrient concentrations at the surface water, which was compared to previous report (Toyota, 1985), may be caused by consumption of phytoplankton. As another possibility, chlorophyll *a* distribution was mainly effected by the input of phytoplankton through the riverine water, because of little difference of nutrient concentration at the surface water between St. 2 and St. 3 had been related with the relatively lower supply of nutrient through the riverine water.

Salinity at the subsurface salinity maximum layer showed large temporal variations (Table 2-4). The salinity in the subsurface salinity maximum layer ranged from 34.48 to 34.73 during observations (Table 2-4). This value was consistent with the salinity value at the subsurface salinity maximum layer in the previous studies (Nakamura and Muranaka, 1979; Nakamura, 1982; Toyota *et al.*, 1993). Nakamura (1982) reported the depth of subsurface salinity maximum in the Suruga Bay as ca. 50 m in spring, 100 m in summer and 125 m in fall, and there was no clear subsurface maximum in winter. These values were consistent with the present study, i.e. relatively shallow salinity maximum in spring and deeper in summer and fall. The subsurface salinity maximum water was defined as the Offshore Water (Nakamura, 1982), which is characterized by 34.4 - 34.7 of salinity and 11 - 19 ºC of θ (Table 2-1). The Offshore Water was observed in whole area of the bay during all seasons. The Offshore Water was observed in ca. 0 - 320 m in spring, ca. 30 - 340 m in summer, 60 - 220 m in fall, and 100 - 230 m in December 2001 and 0 - 200 m in February 2001 and 2002 (Fig. 2-2).

The nutrient concentrations at the depth of the subsurface salinity maximum layer were significantly correlated with the salinity maximum (Fig. 2-8). To extend the finding in this study to the Offshore Water, which is characterized by the salinity maximum, the relationship between salinity and nutrients was examined in the water with salinity greater than 34.4. Difference in salinity (Δsalinity) and nutrients

[Δnutrients: ΔNO_3, ΔPO_4 and $\Delta Si(OH)_4$] was calculated between the sampling dates at the same depth and station in each season. These calculation values were conducted by subtracting the values at the later sampling date from those at the prior sampling date. This approach was applied, instead of subtraction between a given value and a fixed value (for example, the value of the sample taken in the first in each season), in order to obtain enough number of the data sets especially for $Si(OH)_4$ and use the results of all possible combination. Figure 2-10 shows the relationship between Δsalinity and Δnutrients in the Offshore Water from April 2000 to July 2002 and Table 2-8 shows the summary of the linear regression. There were negative correlations between Δsalinity and Δnutrients [ΔNO_3, ΔPO_4 and $\Delta Si(OH)_4$] (Table 2-8). These result indicate that when the higher salinity was observed in the Offshore Water in each season, the lower nutrient concentrations were observed, suggesting that an increasing intrusion of saline water brought down the nutrients level in the Offshore Water. One possible source of the saline water is the Kuroshio water, because the highest salinity was related to the highest θ in each season (Table 2-4). Recent studies reported that the salinity at the subsurface salinity maximum layer was greater than 34.8 near the Kuroshio axis (Komatsu and Kawasaki, 2002), and ca. 34.6 in Enshu-nada where locates outside of the Suruga Bay (Kasai *et al.*, 2002). When higher salinity maximum is observed, the salinity in the Offshore Water is higher than the value in Enshu-nada and close to the salinity in the Kuroshio Water (Table 2-4). This supports the possibility that the saline water is originated from the Kuroshio Water. Inaba (1984) observed the counterclockwise circulation of the surface water within the Suruga Bay when the Kuroshio axis approaching to the coast of Honshu. The salinity vertical section in September 2000 (Fig. 2-3) suggests that the water with the salinity greater than 34.6 intruded from east to west into the Suruga Bay, implying its counterclockwise circulation during its intrusion into the Suruga Bay. Therefore, the approach of the Kuroshio axis to the Suruga Bay might cause to lead the Offshore Water to the characteristics of higher salinity, higher θ, and lower nutrient concentrations.

Δsalinity and Δnutrients were also negatively correlated in each season, except for the relationship between Δsalinity and $\Delta Si(OH)_4$ in spring (r^2 = 0.0001, n = 31, $P >$ 0.05) (Table 2-8). In spring, Δnutrients were relatively constant at 0 μmol l^{-1} when Δsalinity varied from -0.2 to -0.1 (Fig. 2-10). This might result from the water structure in spring, in which the Offshore Water contained euphotic layer where nutrient was consumed by phytoplankton. The slope of the linear regression between Δsalinity and ΔNO_3 in summer (the slope of the linear regression: -48.77) was significantly different from that in spring (-30.73) and fall (-32.77) (Table 2-8). The slope between Δsalinity and ΔPO_4 was also significantly different between summer (-3.42) and the other seasons (-1.74 - -2.23). Excluding the data of July 2000, the slope between Δsalinity and ΔNO_3 in summer was -31.22 and it was not significantly different from the slope in the other seasons. This result implies that the steep slope between

Δsalinity and ΔNO_3 in summer resulted from the variation of NO_3 concentration in July 2000. In spring, chlorophyll *a* concentration in the upper 50 m was higher in April 2000 (1.7 - 5.8 μg l^{-1}) than in April 2001 (0.2 - 2.8 μg l^{-1}) and in May 2002 (0.2 - 1.2 μg l^{-1}) (Fig. 2-9), implying higher primary production in April 2000 than in April 2001 and in May 2002. On the other hand, MLD in summer was observed at 5 - 14 m (Table 2-3), and existed above the depth of the top of the Offshore Water, which was observed at ca. 30 m. It is hypothesized that organic matter produced in the upper mixed layer transports to the Offshore Water by sinking particles. Chester (2000) reported that sinking flux of particulate matter reflects the magnitude of primary production in the surface layer. It is suggested that more amount of organic matter was exported to the Offshore Water in July 2000 than in July 2001 and 2002, and that nutrient regeneration in the Offshore Water might be larger in July 2000 than in July 2001 and in July 2002. Therefore, the nutrient concentrations in July 2000 would be higher than their expected concentrations from salinity and it might bring the steep slope between Δsalinity and Δnutrients in summer.

To determine the relationship between the nutrients level in the Offshore Water and phytoplankton biomass, the concentrations of nutrients and chlorophyll *a* was integrated in the upper 200 m, where most of the Offshore Water was contained (see above). In spring, integrations of chlorophyll *a* and nutrients were lowest in May 2002 (Table 2-9), whereas salinity in the subsurface salinity maximum layer was higher in May 2002 than in April 2000 and 2001 (Table 2-4). Integrations of chlorophyll *a* and nutrients were lowest in July 2002 in summer (Table 2-9) when the salinity maximum was highest in summer (Table 2-4), except for at St. 3 (Table 2-4a).

Difference in integrated nutrients {Δ[nutrients-int]: Δ[NO_3-int], Δ[PO_4-int] and Δ[$Si(OH)_4$-int]} and integrated chlorophyll *a* {Δ[chl.*a*-int]} between the sampling dates was calculated at the same station in each season. Then, the relationship among Δ[nutrients-int], Δ[chl.*a*-int] and ΔS_{max} was examined by applying Spearman's rank correlation (Table 2-10). Note that ΔS_{max} was obtained as a difference in the salinity maximum between the sampling dates at the same station in each season. There were significant negative correlations between ΔS_{max} and Δ[NO_3-int], Δ[PO_4-int] and Δ[$Si(OH)_4$-int] (Table 2-10), which was contrast with relationship between Δsalinity and Δnutrients (Fig. 2-10). Δ[chl.*a*-int] was significantly negatively correlated with ΔS_{max}, and positively correlated with Δ[NO_3-int] (Table 2-10). These results indicate that an increasing intrusion of the saline water into the Offshore Water would bring them down the levels of nutrients and chlorophyll *a* in the upper 200 m. The depth of the upper mixed layer in spring and winter was 6 - 55 m and 61 - 160 m, respectively (Table 2-3), and reached the depth of the Offshore water. This result implies that decrease in the nutrient concentration in the Offshore Water would have extended into the euphotic layer in spring and winter. Lower nutrient concentration may cause lower productivity of phytoplankton in euphotic layer when the salinity maximum was higher than other season. Accordingly, biomass and productivity of phytoplankton in the upper 200 m of the Suruga Bay would have been depend on the degree of the influence of the saline water intruded into the Offshore Water on the Suruga Bay, whereas the surface (10 m) biomass and production would have been related with inflow of the riverine water (Table 2-7). On the other hand, Δ[chl.*a*-int] was not significantly correlated with Δ[PO_4-int] or Δ[$Si(OH)_4$-int] ($P > 0.05$) (Table 2-10). The result suggests that the regulation of phytoplankton biomass by NO_3 rather than by PO_4 or $Si(OH)_4$ in the upper 200 m. It is consistent with the finding in this study in summer when chlorophyll *a* was a low and NO_3 was depleted in the surface water (10 m) (Table 2-7), implying the regulation of surface phytoplankton biomass by NO_3, which is consistent with Shiomoto and Hashimoto (1999). Moreover, the positive correlation between Δ[NO_3-int] and Δ[chl.*a*-int] and the negative correlation between Δ[NO_3-int] and ΔS_{max} suggest a new mechanism to change the phytoplankton biomass and total primary production in the upper 200 m by the intrusion of NO_3 depleted, warm and saline Kuroshio water composing the Offshore Water.

In summary, large temporal variations in salinity, θ and nutrients concentrations were observed at the depth of the subsurface salinity maximum layer in the Suruga Bay from April 2000 to July 2002. Seasonal variation in nutrients was mostly largest in the surface layer (0 - 50 m). On the other hand, the variation in nutrients between the sampling dates in each season was largest in the subsurface layer (100 - 300 m) for spring, summer and fall. Large temporal variation in nutrient concentrations in the subsurface layer in each season was related with the low nutrient concentrations in the Offshore Water when its salinity and θ were high. The result indicates the frequent changes in the contribution of the warm and saline water (*e.g.*, Kuroshio Water) into the subsurface layer and then in the influence on the Offshore Water. The difference in salinity maximum between the sampling dates in each season was negatively correlated with that in integrated chlorophyll *a* {Δ[chl.*a*-int]} and that in integrated nutrients {Δ[nutrients-int]}. Δ[chl.*a*-int] was positively correlated to Δ[NO_3-int], but there were no significant correlations between Δ[chl.*a*-int] and Δ[PO_4-int] or Δ[$Si(OH)_4$-int]. These findings imply that an increasing intrusion of saline water in the Offshore Water would have resulted in the lower concentrations of chlorophyll *a* and nutrients in the upper 200 m and suggest that NO_3 regulates the total primary production in the upper 200 m. Because the Offshore Water accounts for the significant portion of the total water volume of the Suruga Bay [15.1 - 25.0%; Nakamura (1982)], and because a part of the euphotic zone [21 - 60 m; Shiomoto and Hashimoto (1999)] is usually occupied by the Offshore Water, changes in the contribution of Kuroshio Water to the Offshore Water may have considerable effects on the nutrient dynamics and primary production in the Suruga Bay.

Table 2-1. Water characteristics in the Suruga Bay. (Nakamura, 1982)

	season	A	B	C	D	E
θ (°C)	spring	16-19	16-19	11-18	3-11	<3
	summer	>25	19-25	11-19	3-11	<3
	fall	20-22	18-20	11-18	3-11	<3
	winter	13-15	11-16		3-11	<3
salinity	spring	<34.2	34.2-34.5	34.5-34.7	34.2-34.4	>34.4
	summer	<33.7	33.7-34.4	34.4-34.7	34.2-34.4	>34.4
	fall	<34.0	34.0-34.4	34.4-34.7	34.2-34.4	>34.4
	winter	<34.3	34.3-34.7		34.2-34.4	>34.4
depth (m)		0-20	0-100	100-200	200-1200	1200-

A : Coastal Water
B : Surface Water
C : Offshore Water
D : Intermediate Water
E : Pacific Deep Water

Table 2-2. Location of sampling stations and details of the sampling depth in each station.

station	latitude (N)	longitude (E)	sampling depth
St. 3	34° 51.0′	138° 23.0′	2, 10, 20, 30, 50, 70, 100, 125, 150, 200, 300, B-20 [d]
St. F	34° 51.0′	138° 28.0′	0 [c], 10, 20, 50, 70, 100, 125, 150, 200, 300, 400, 600, B-20 [e]
St. E	34° 51.0′	138° 33.0′	0 [c], 10, 20, 30, 50, 70, 100, 125, 150, 200, 300, 400, B-20 [f]
St. 2 [a,b]	34° 51.0′	138° 38.0′	0 [c], 10, 20, 50, 100, 150, 200, 300, 400, 600, 800, 1000, B-20 [g]

a : additional sampling depth in May 2002 were 30, 40, 60, 125 and 175 m.
b : additional sampling depth in July 2002 were 30, 40, 60, 125 and 1288 m.
c : water samples was collected using plastic bucket.
d : B-20 ranged from 490 m to 615 m.
e : B-20 ranged from 735 m to 839 m.
f : B-20 ranged from 625 m to 690 m.
g : B-20 ranged from 1160 m to 1620 m.

Table 2-3. Mixed layer depth (m) in the Suruga Bay between April 2000 and July 2002.

season	date	St. 3	St. F	St. E	St. 2
spring	April 24, 2000	8	33	55	41
	April 25, 2001	25	35	18	26
	May 14, 2002	6	37	40	22
summer	July 10, 2000	7	6	5	6
	July 11, 2001	7	6	7	14
	July 23, 2002	6	11	7	7
fall	September 20, 2000	16	15	13	13
	November 27, 2000	6	63	65	54
	October 25, 2001	7	48	45	30
winter	February 19, 2001	133	119	122	113
	December 12, 2001	64	61	66	88
	February 20, 2002	130	154	150	160

Table 2-4a. The maximum salinity in the upper 200 m and its related depth, θ and σ_θ at St. 3. Depth, θ and σ_θ are shown as the range in the isohaline of the maximum salinity.

season	date	salinity	depth (m)	θ (°C)	σ_θ
spring	April 24, 2000	34.60	85 - 95	14.58 - 14.50	25.77 - 25.75
	April 25, 2001	34.59	31 - 39	15.88 - 15.35	25.57 - 25.45
	May 14, 2002	34.68	42 - 46	19.48 - 19.29	24.70 - 24.66
summer	July 10, 2000	34.59	60 - 67	17.47 - 16.80	25.24 - 25.08
	July 11, 2001	34.57	38 - 72	17.02 - 15.07	25.62 - 25.17
	July 23, 2002	34.73	90 - 94	18.59 - 18.41	24.96 - 24.91
fall	September 20, 2000	34.55	134 - 145	15.61 - 15.11	25.60 - 25.49
	November 27, 2000	34.54	87 - 98	18.04 - 16.94	25.17 - 24.91
	October 25, 2001	34.54	96 - 114	16.33 - 15.21	25.56 - 25.31
winter	February 19, 2001	34.50	142 - 151	14.51 - 13.97	25.81 - 25.69
	December 12, 2001	34.61	61 - 86	15.10 - 15.05	25.65 - 25.64
	February 20, 2002	34.50	0 - 64	13.27 - 12.97	26.00 - 25.95

Table 2-4b. The maximum salinity in the upper 200 m and its related depth, θ and σ_θ at St. F. Depth, θ and σ_θ are shown as the range in the isohaline of the maximum salinity.

season	date	salinity	depth (m)			θ (℃)			σ_θ		
spring	April 24, 2000	34.59	51	-	77	14.74	-	14.19	25.83	-	25.71
	April 25, 2001	34.55	52	-	57	15.13	-	14.84	25.65	-	25.59
	May 14, 2002	34.65	65	-	82	19.58	-	18.64	24.84	-	24.61
summer	July 10, 2000	34.62	54	-	60	18.52	-	18.02	24.97	-	24.85
	July 11, 2001	34.56	43	-	63	16.46	-	15.02	25.63	-	25.30
	July 23, 2002	34.72	42	-	51	20.90	-	20.60	24.39	-	24.31
fall	September 20, 2000	34.66	66	-	68	20.70	-	20.52	24.36	-	24.32
	November 27, 2000	34.53	81	-	86	18.13	-	17.39	25.06	-	24.88
	October 25, 2001	34.57	109	-	119	15.60	-	15.05	25.62	-	25.50
winter	February 19, 2001	34.50	148	-	160	14.09	-	13.42	25.91	-	25.77
	December 12, 2001	34.61	4	-	87	15.14	-	15.05	25.66	-	25.64
	February 20, 2002	34.53	72	-	120	13.07	-	12.98	26.03	-	26.01

Table 2-4c. The maximum salinity in the upper 200 m and its related depth, θ and σ_θ at St. E. Depth, θ and σ_θ are shown as the range in the isohaline of the maximum salinity.

season	date	salinity	depth (m)	θ (℃)	σ_θ
spring	April 24, 2000	34.60	68 - 71	14.36 - 14.28	25.82 - 25.80
	April 25, 2001	34.58	18 - 22	16.03 - 15.89	25.45 - 25.42
	May 14, 2002	34.69	0 - 39	20.67 - 20.18	24.47 - 24.34
summer	July 10, 2000	34.60	46 - 51	18.91 - 18.20	24.91 - 24.73
	July 11, 2001	34.55	52 - 60	15.80 - 15.55	25.50 - 25.45
	July 23, 2002	34.71	60 - 67	19.37 - 19.12	24.76 - 24.70
fall	September 20, 2000	34.69	87 - 93	19.61 - 19.28	24.71 - 24.63
	November 27, 2000	34.53	110 - 126	15.69 - 14.41	25.73 - 25.45
	October 25, 2001	34.57	98 - 105	16.63 - 16.01	25.42 - 25.27
winter	February 19, 2001	34.48	153 - 163	14.06 - 13.58	25.87 - 25.77
	December 12, 2001	34.60	5 - 106	15.19 - 15.03	25.66 - 25.63
	February 20, 2002	34.54	110 - 124	13.15 - 13.09	26.02 - 26.01

Table 2-4d. The maximum salinity in the upper 200 m and its related depth, θ and σ_θ at St. 2. Depth, θ and σ_θ are shown as the range in the isohaline of the maximum salinity.

season	date	salinity	depth (m)	θ (°C)	σ_θ
spring	April 24, 2000	34.59	33 - 42	14.76 - 15.26	25.60 - 25.71
	April 25, 2001	34.60	4 - 8	16.33 - 16.34	25.36 - 25.37
	May 14, 2002	34.71	52 - 57	19.94 - 19.99	24.54 - 24.56
summer	July 10, 2000	34.61	90 - 98	15.45 - 15.73	25.51 - 25.57
	July 11, 2001	34.58	61 - 66	14.99 - 15.28	25.59 - 25.65
	July 23, 2002	34.71	74 - 104	18.07 - 18.66	24.88 - 25.03
fall	September 20, 2000	34.71	70 - 74	19.78 - 20.28	24.47 - 24.60
	November 27, 2000	34.57	105 - 111	15.44 - 16.05	25.40 - 25.54
	October 25, 2001	34.56	94 - 104	15.90 - 16.18	25.37 - 25.43
winter	February 19, 2001	34.60	5 - 90	15.05 - 15.14	25.64 - 25.65
	December 12, 2001	34.49	156 - 161	13.79 - 13.91	25.81 - 25.84
	February 20, 2002	34.54	106 - 123	13.03 - 13.07	26.02 - 26.03

Table 2-5. Nutrient concentrations [NO_3, PO_4, $Si(OH)_4$] at the subsurface salinity maximum layer. Nutrients concentrations were calculated at the middle depth of the subsurface salinity maximum layer.

season	date	NO_3 (μmol l^{-1})				PO_4 (μmol l^{-1})				$Si(OH)_4$ (μmol l^{-1})			
		St. 3	St. F	St. E	St. 2	St. 3	St. F	St. E	St. 2	St. 3	St. F	St. E	St. 2
spring	April 24, 2000	6.42	4.84	8.04	2.40	0.54	0.37	0.22	0.20	-	-	-	-
	April 25, 2001	2.17	6.05	0.00	0.00	0.27	0.54	0.06	0.11	5.77	10.95	2.71	2.85
	May 14, 2002	0.28	1.01	0.00	0.00	0.11	0.15	0.04	0.10	3.46	4.92	2.18	2.63
summer	July 10, 2000	6.58	3.43	4.17	4.41	0.42	0.28	0.32	0.36	-	-	-	-
	July 11, 2001	9.36	9.90	10.72	9.64	0.68	0.73	0.79	0.70	10.15	11.99	13.39	12.56
	July 23, 2002	6.81	3.51	5.77	6.81	0.48	0.28	0.43	0.51	8.90	4.99	7.48	11.00
fall	September 20, 2000	12.68	4.48	7.17	3.71	0.81	0.33	0.47	0.31	-	-	-	-
	November 27, 2000	10.62	7.74	13.73	11.78	0.70	0.53	0.89	0.76	15.08	11.24	20.21	16.78
	October 15, 2001	12.86	13.10	11.89	11.94	0.85	0.89	0.80	0.81	19.53	20.52	17.30	17.72
winter	February 19, 2001	12.49	16.38	14.64	7.07	0.80	1.12	1.00	0.59	19.07	26.52	23.52	11.28
	December 12, 2001	5.03	3.78	4.22	15.15	0.41	0.33	0.36	1.10	9.34	6.97	7.88	25.11
	February 20, 2002	11.03	11.02	14.80	10.13	0.82	0.80	1.04	0.66	22.20	20.45	26.16	18.04

-: Not determined.

Table 2-6. Summary of the linear regressions between salinity and nutrients [NO_3, PO_4 and $Si(OH)_4$]. The model used is nutrients = $a \times$salinity + b. Salinity and nutrients are the values at the subsurface salinity maximum layer.

station	y	slope (a)	intercept (b)	r^2	n	P*
all station	NO_3	-49.24	1710.73	0.49	48	< 0.05
	PO_4	-3.16	109.68	0.50	48	< 0.05
	$Si(OH)_4$	-79.65	2767.75	0.58	36	< 0.05
St.3	NO_3	-43.90	1526.06	0.50	12	< 0.05
	PO_4	-2.66	92.55	0.56	12	< 0.05
	$Si(OH)_4$	-66.83	2323.89	0.62	9	< 0.05
St.F	NO_3	-55.15	1914.70	0.59	12	< 0.05
	PO_4	-3.65	126.93	0.62	12	< 0.05
	$Si(OH)_4$	-84.28	2927.64	0.60	9	< 0.05
St.E	NO_3	-50.52	1755.63	0.45	12	< 0.05
	PO_4	-3.37	116.96	0.44	12	< 0.05
	$Si(OH)_4$	-93.32	3240.77	0.59	9	< 0.05
St.2	NO_3	-48.74	1693.71	0.47	12	< 0.05
	PO_4	-3.06	106.52	0.47	12	< 0.05
	$Si(OH)_4$	-78.81	2739.66	0.60	9	< 0.05

*Test of the null hypothesis: a = 0.

Table 2-7. Salinity and concentrations of NO_3, PO_4, $Si(OH)_4$ and chlorophyll *a* at 10 m in the Suruga Bay.

season	date	salinity				NO_3 (μmol l^{-1})				PO_4 (μmol l^{-1})				$Si(OH)_4$ (μmol l^{-1})				chlorophyll *a* (μg l^{-1})			
		St. 3	St. F	St. E	St. 2	St. 3	St. F	St. E	St. 2	St. 3	St. F	St. E	St. 2	St. 3	St. F	St. E	St. 2	St. 3	St. F	St. E	St. 2
spring	April 24, 2000	34.37	34.44	34.49	34.55	1.50	0.31	1.06	1.51	0.19	0.02	0.02	0.13	-	-	-	-	5.8	4.2	2.7	2.8
	April 25, 2001	34.46	34.51	34.50	34.60	0.00	0.00	0.00	0.00	0.14	0.12	0.08	0.00	3.08	3.64	3.74	0.77	2.8	1.9	1.6	1.1
	May 14, 2002	34.65	34.65	34.68	34.68	0.00	0.00	0.00	0.00	0.02	0.03	0.03	0.06	2.88	2.12	1.66	2.81	0.3	0.2	0.3	0.3
summer	July 10, 2000	33.80	33.82	33.75	33.75	0.00	0.00	0.00	0.07	0.05	0.08	0.03	0.11	-	-	-	-	0.4	0.5	0.5	1.2
	July 11, 2001	33.84	33.92	34.01	34.00	0.00	0.00	0.00	0.00	0.07	0.11	0.10	0.03	0.00	0.00	0.00	1.19	0.4	0.5	0.3	0.2
	July 23, 2002	33.87	33.93	33.86	33.92	0.00	0.00	0.00	0.00	0.06	0.05	0.06	0.07	2.67	1.43	0.91	3.09	0.7	0.6	0.4	0.3
fall	September 20, 2000	32.94	33.30	33.41	33.39	0.00	0.00	0.00	0.00	0.03	0.02	0.01	0.06	-	-	-	-	0.8	0.5	0.3	0.4
	November 27, 2000	33.51	34.10	34.19	33.88	2.68	1.35	1.20	2.30	0.20	0.16	0.19	0.23	8.69	3.86	3.17	5.64	1.9	1.0	0.9	0.6
	October 15, 2001	33.78	33.94	33.91	33.89	0.00	0.07	0.00	0.00	0.07	0.08	0.07	0.10	3.63	3.88	3.46	3.70	3.2	1.6	1.0	1.6
winter	February 19, 2001	34.53	34.61	34.60	34.60	3.82	3.71	3.13	2.90	0.33	0.30	0.28	0.26	7.26	6.35	5.92	4.89	4.5	0.7	0.7	0.6
	December 12, 2001	34.14	34.19	34.29	34.23	5.33	6.54	6.80	6.86	0.25	0.54	0.55	0.58	9.78	10.42	11.15	11.18	1.0	1.2	0.9	0.9
	February 20, 2002	34.49	34.51	34.49	34.49	10.99	10.24	10.43	8.27	0.82	0.74	0.74	0.53	20.54	21.29	19.97	16.27	0.6	0.9	0.8	0.8

-: Not determined.

Table 2-8. Summary of the linear regressions between Δsalinity and Δnutrients [ΔNO_3, ΔPO_4 and $\Delta Si(OH)_4$]. The model used is Δnutrients = $a \times \Delta$salinity + b .

period	Δnutrients	slope (a)	intercept (b)	r^2	n	P^*
all season	ΔNO_3	-37.76	-0.58	0.61	240	< 0.05
	ΔPO_4	-2.57	-0.06	0.58	238	< 0.05
	$\Delta Si(OH)_4$	-71.53	-1.09	0.73	109	< 0.05
spring	ΔNO_3	-30.73	-0.03	0.31	90	< 0.05
	ΔPO_4	-2.23	-0.04	0.33	88	< 0.05
	$\Delta Si(OH)_4$	2.38	7.27	0.00	31	> 0.05
summer	ΔNO_3	-48.77	-1.73	0.79	64	< 0.05
	ΔPO_4	-3.42	-0.13	0.75	64	< 0.05
	$\Delta Si(OH)_4$	-66.82	-0.07	0.58	21	< 0.05
fall	ΔNO_3	-32.77	-0.96	0.60	43	< 0.05
	ΔPO_4	-2.06	-0.09	0.48	43	< 0.05
	$\Delta Si(OH)_4$	-101.58	-0.80	0.56	14	< 0.05
winter	ΔNO_3	-35.49	0.16	0.40	43	< 0.05
	ΔPO_4	-1.74	-0.03	0.20	43	< 0.05
	$\Delta Si(OH)_4$	-71.92	-1.50	0.47	43	< 0.05

*Test of the null hypothesis: a = 0.

Table 2-9. Integrations of chlorophyll *a* and nutrients [NO_3, PO_4, $Si(OH)_4$] with depth in the upper 200 m.

season	date	chlorophyll *a* (mg m^{-2})				NO_3 (mmol m^{-2})				PO_4 (mmol m^{-2})				$Si(OH)_4$ (mmol m^{-2})			
		St. 3	St. F	St. E	St. 2	St. 3	St. F	St. E	St. 2	St. 3	St. F	St. E	St. 2	St. 3	St. F	St. E	St. 2
spring	April 24, 2000	340	180	283	181	1634	1648	2061	1591	127	109	135	103	-	-	-	-
	April 25, 2001	139	98	85	74	1873	2254	2357	2316	138	165	165	169	2984	3893	3788	3970
	May 14, 2002	52	62	38	61	939	1066	1116	971	73	80	83	79	1777	2050	2048	1847
summer	July 10, 2000	32	46	39	45	1797	1593	1894	1221	123	114	135	90	-	-	-	-
	July 11, 2001	77	60	67	42	2597	2812	2741	2430	185	204	199	173	3762	4315	4235	3514
	July 23, 2002	58	45	33	32	1363	1430	1431	1347	98	103	106	102	2064	2093	2000	2168
fall	September 20, 2000	39	32	39	49	1759	1526	1562	1482	114	98	105	103	-	-	-	-
	November 27, 2000	82	69	70	30	2183	2073	2045	2076	148	143	142	140	3591	3378	3275	3339
	October 15, 2001	120	64	63	79	1962	2051	2028	1941	133	141	142	136	3301	3404	3402	3150
winter	February 19, 2001	278	95	71	45	1950	2187	2153	2416	127	158	157	173	3139	3542	3482	3886
	December 12, 2001	75	101	74	78	1754	1864	1739	1621	130	138	132	121	3032	3219	3070	2789
	February 20, 2002	75	85	83	92	2750	2580	2603	2349	194	185	184	158	5085	4798	4871	4260

-: Not determined.

Table 2-10. Summary of Spearman's rank correlation coefficients between each two variables of ΔS_{max}, Δ[nutrients-int] and Δ[chl.*a* -int]. Nutrients and chlorophyll *a* were integrated from 0 to 200 m.

x	y	r_s	n	P^*
ΔS_{max}	$\Delta[NO_3\text{-int}]$	-0.68	48	< 0.05
	$\Delta[PO_4\text{-int}]$	-0.66	48	< 0.05
	$\Delta[Si(OH)_4\text{-int}]$	-0.64	24	< 0.05
	Δ[chl. *a* -int]	-0.45	48	< 0.05
Δ[chl. *a* -int]	$\Delta[NO_3\text{-int}]$	0.31	48	< 0.05
	$\Delta[PO_4\text{-int}]$	0.26	48	> 0.05
	$\Delta[Si(OH)_4\text{-int}]$	0.31	24	> 0.05

*Test of the null hypothesis: $a = 0$.

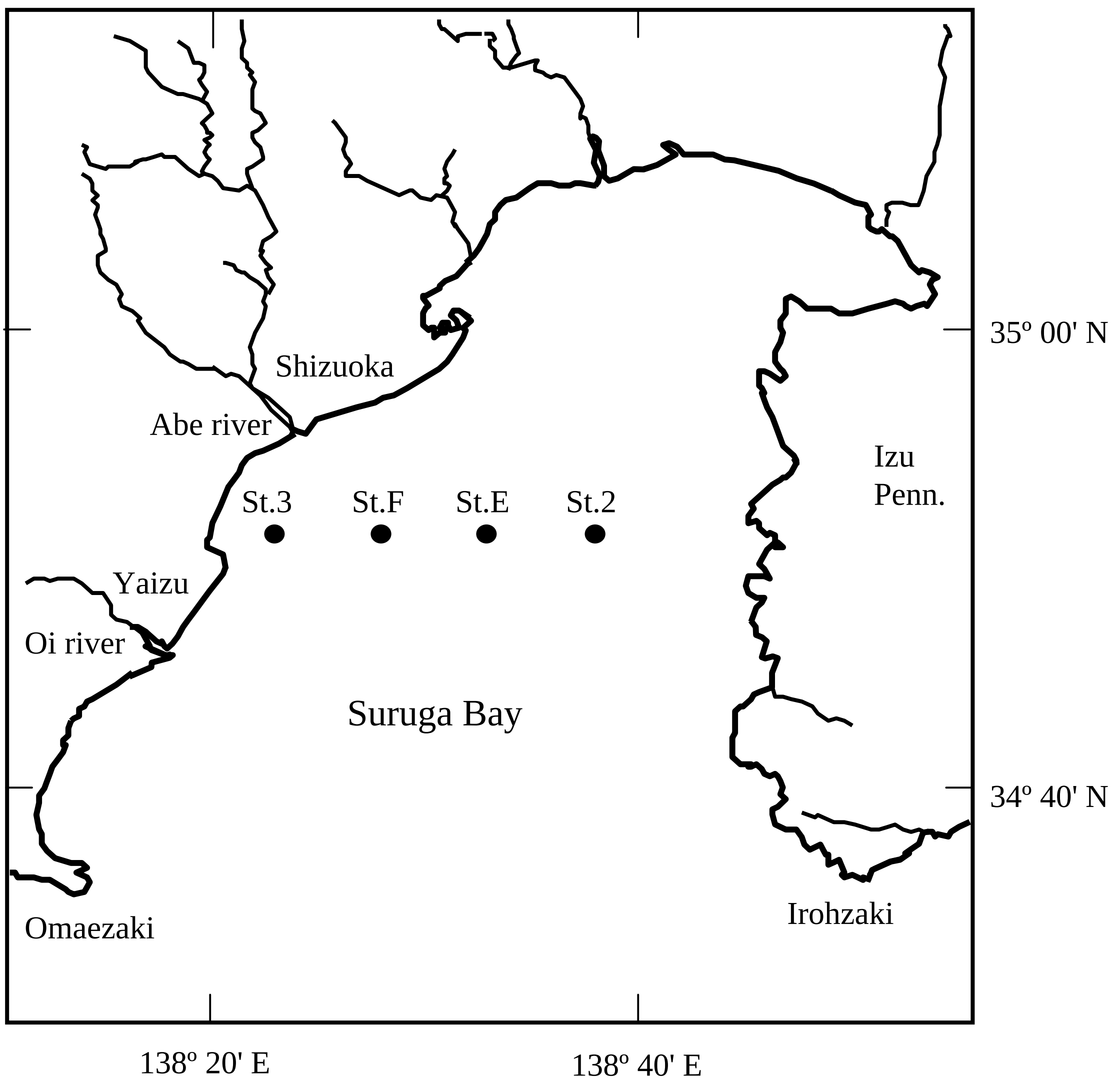

Fig. 2-1. Sampling stations in the Suruga Bay. Water depths were ca. 500 m at St. 3, 800 m at St. F, 700 m at St. E and 1600 m at St. 2.

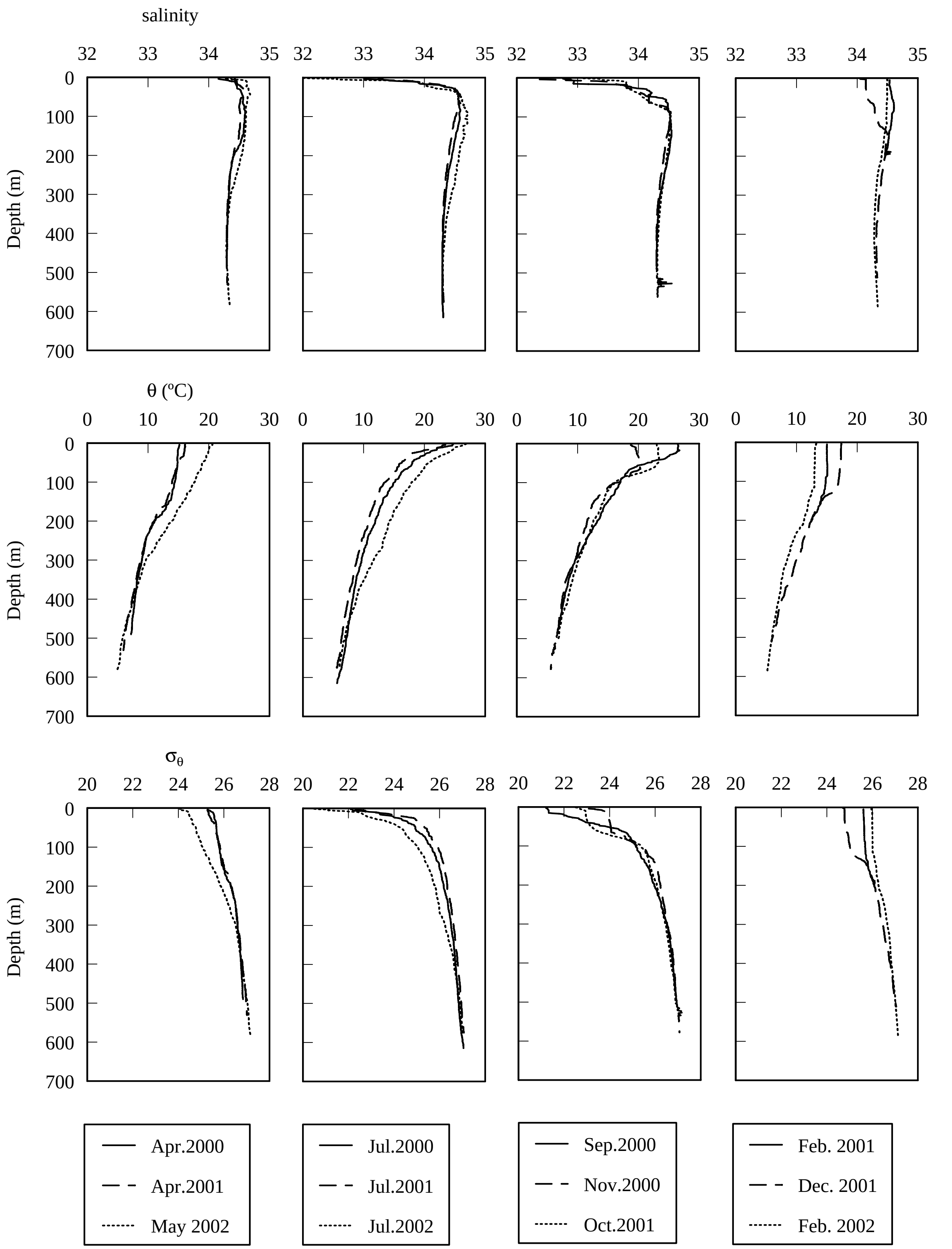

Fig. 2-2a. Vertical profiles of salinity, potential temperature (θ) and potential density (σ_θ) at St. 3 in the Suruga Bay between April 2000 and July 2002. The profiles in February 2001 are only shown for the upper 200 m due to the error on CTD below 200 m.

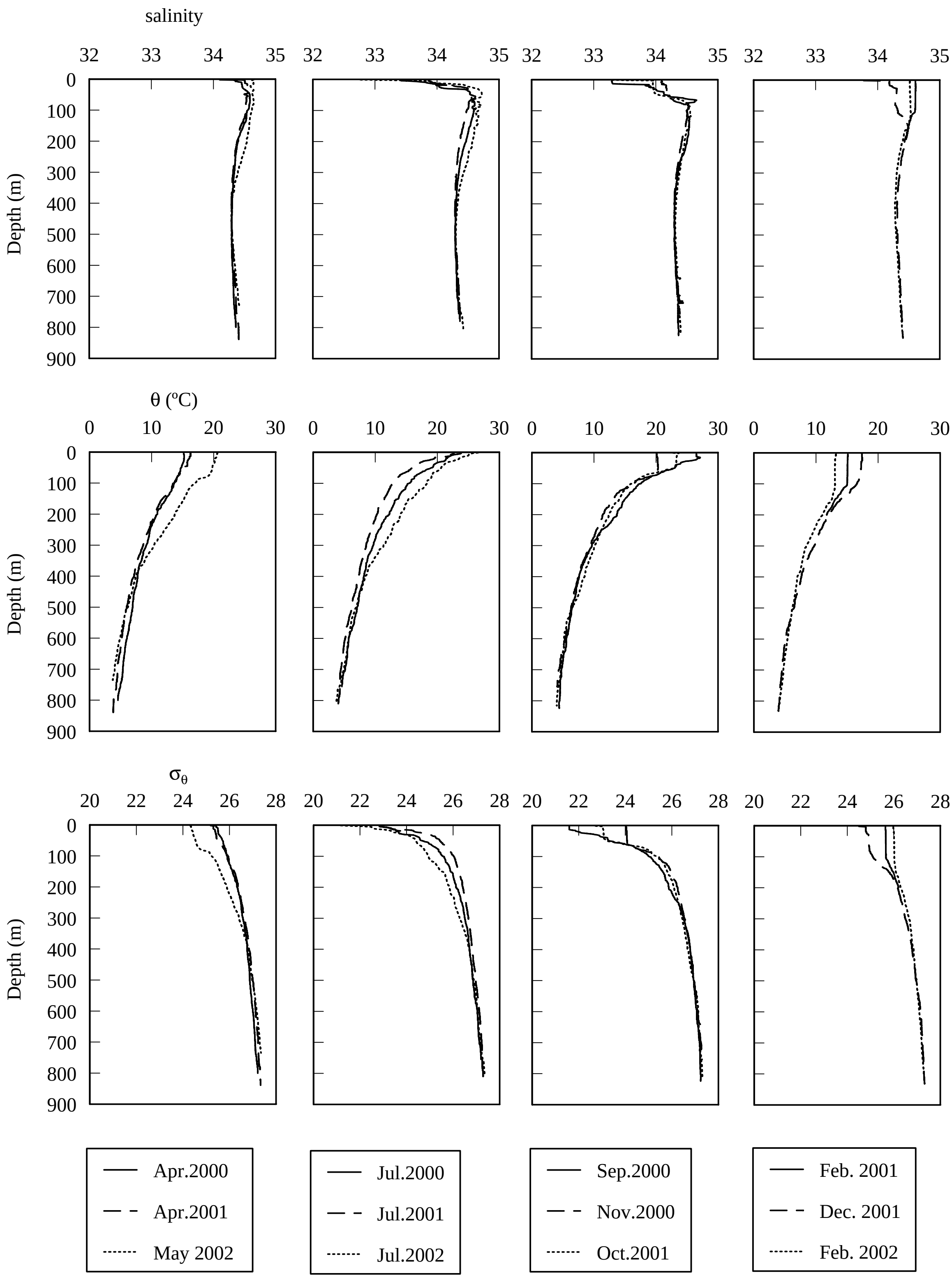

Fig. 2-2b. Vertical profiles of salinity, potential temperature (θ) and potential density (σ_θ) at St. F in the Suruga Bay between April 2000 and July 2002. The profiles in February 2001 are only shown for the upper 200 m due to the error on CTD below 200 m.

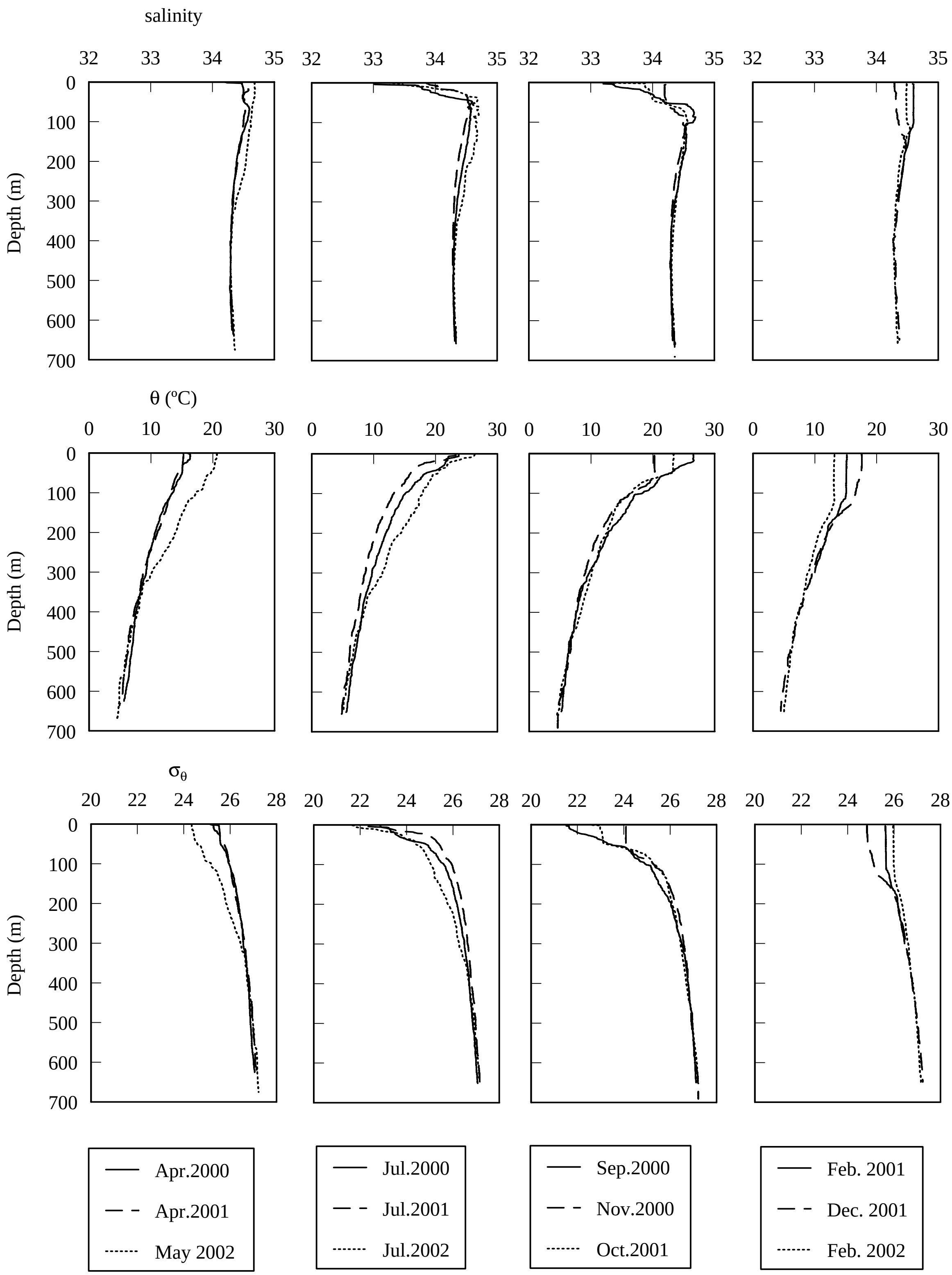

Fig. 2-2c. Vertical profiles of salinity, potential temperature (θ) and potential density (σ_θ) at St. E in the Suruga Bay between April 2000 and July 2002. The profiles in February 2001 are only shown for the upper 200 m due to the error on CTD below 200 m.

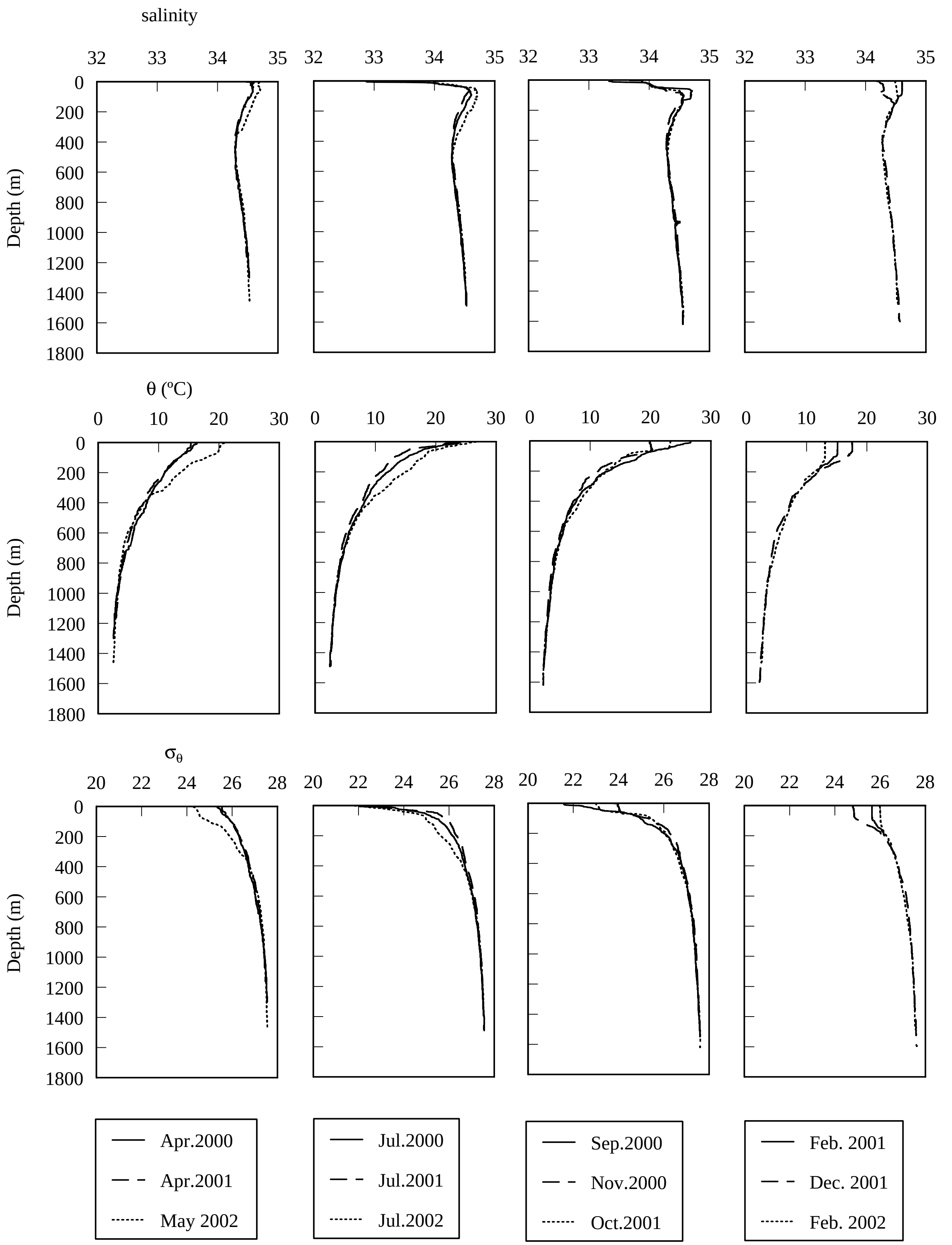

Fig. 2-2d. Vertical profiles of salinity, potential temperature (θ) and potential density (σ_θ) at St. 2 in the Suruga Bay between April 2000 and July 2002. The profiles in February 2001 are only shown for the upper 200 m due to the error on CTD below 200 m.

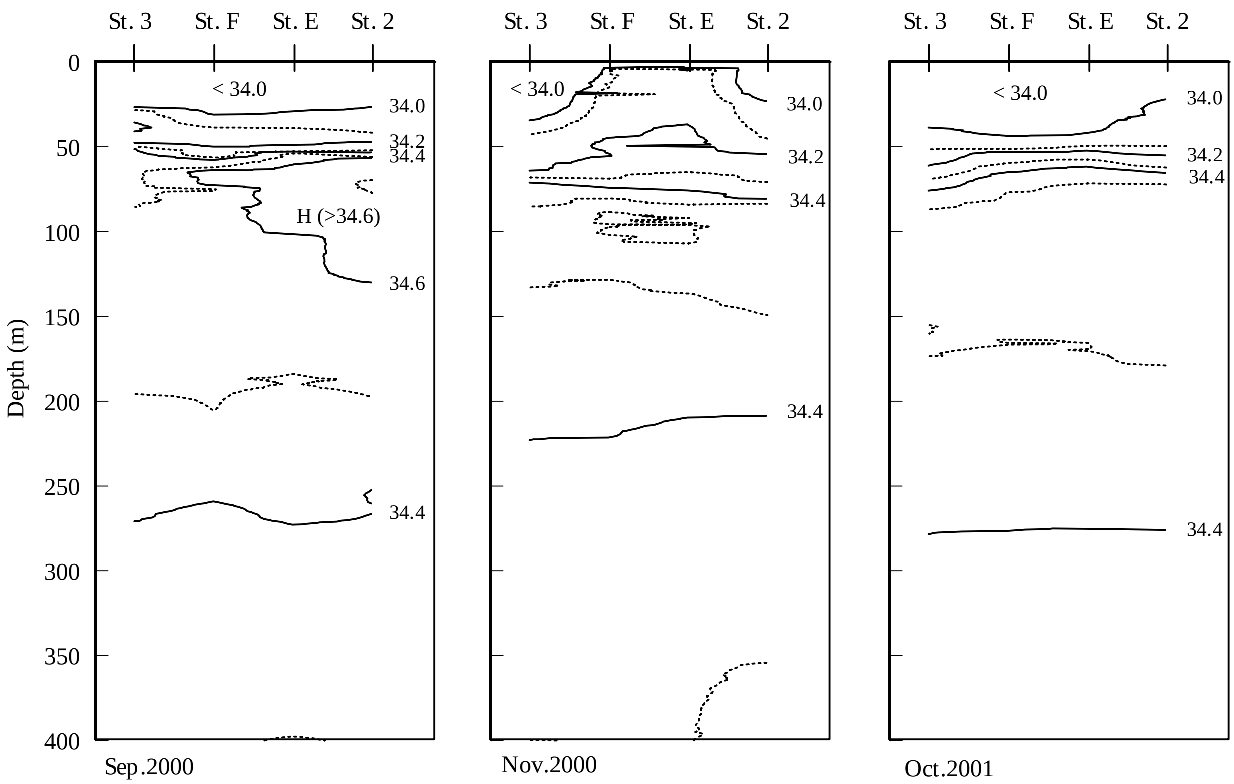

Fig. 2-3. Vertical sections of salinity along the east-west transect in the Suruga Bay in September 2000, November 2000 and October 2001. Counter interval is salinity = 0.1 and contours of the salinity lower than 34.0 were omitted.

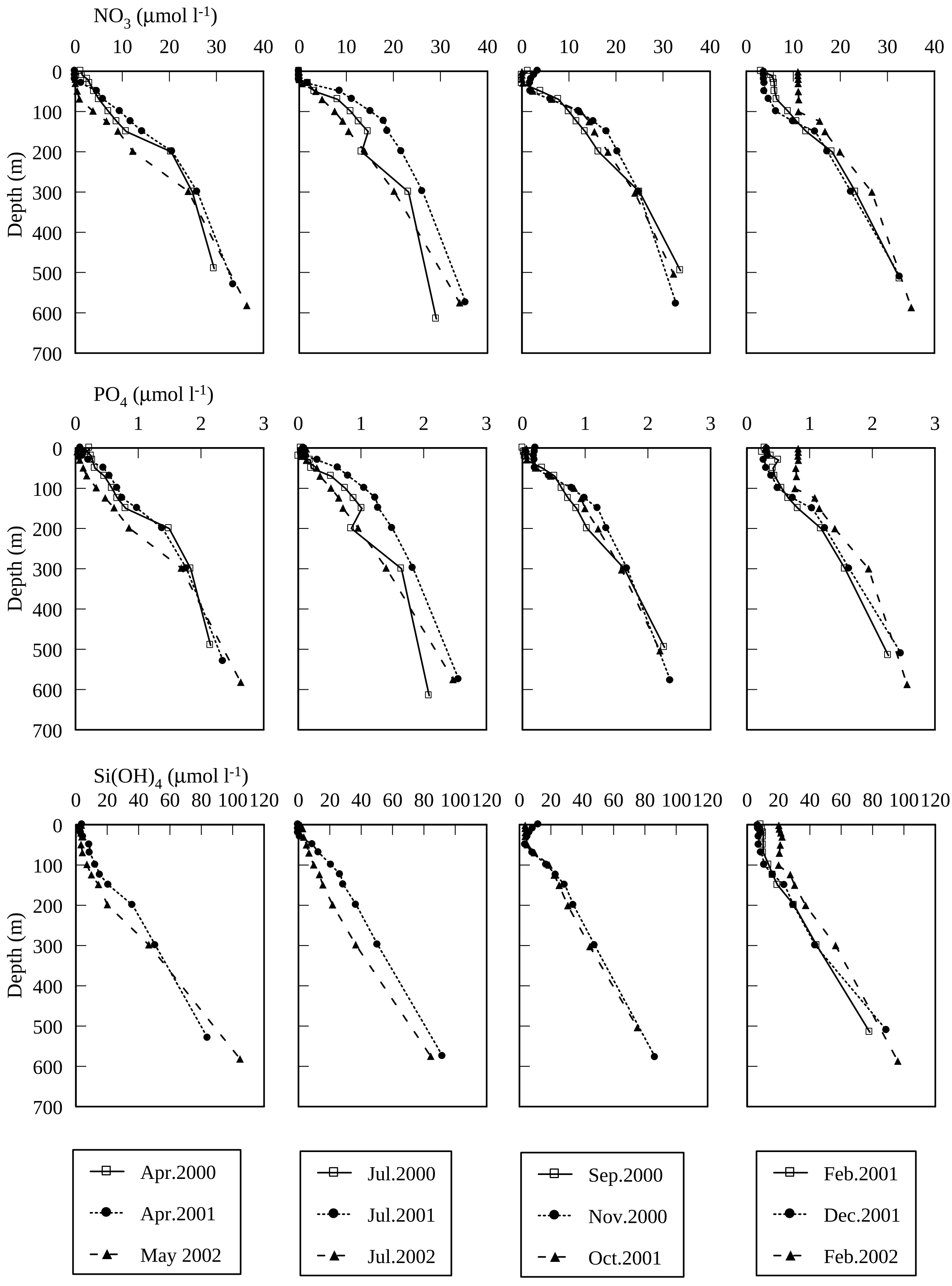

Fig. 2-4a. Vertical profiles of nutrients [NO_3, PO_4 and $Si(OH)_4$] concentrations at St. 3 in the Suruga Bay between April 2000 and July 2002. $Si(OH)_4$ was not measured in April, July and September 2000.

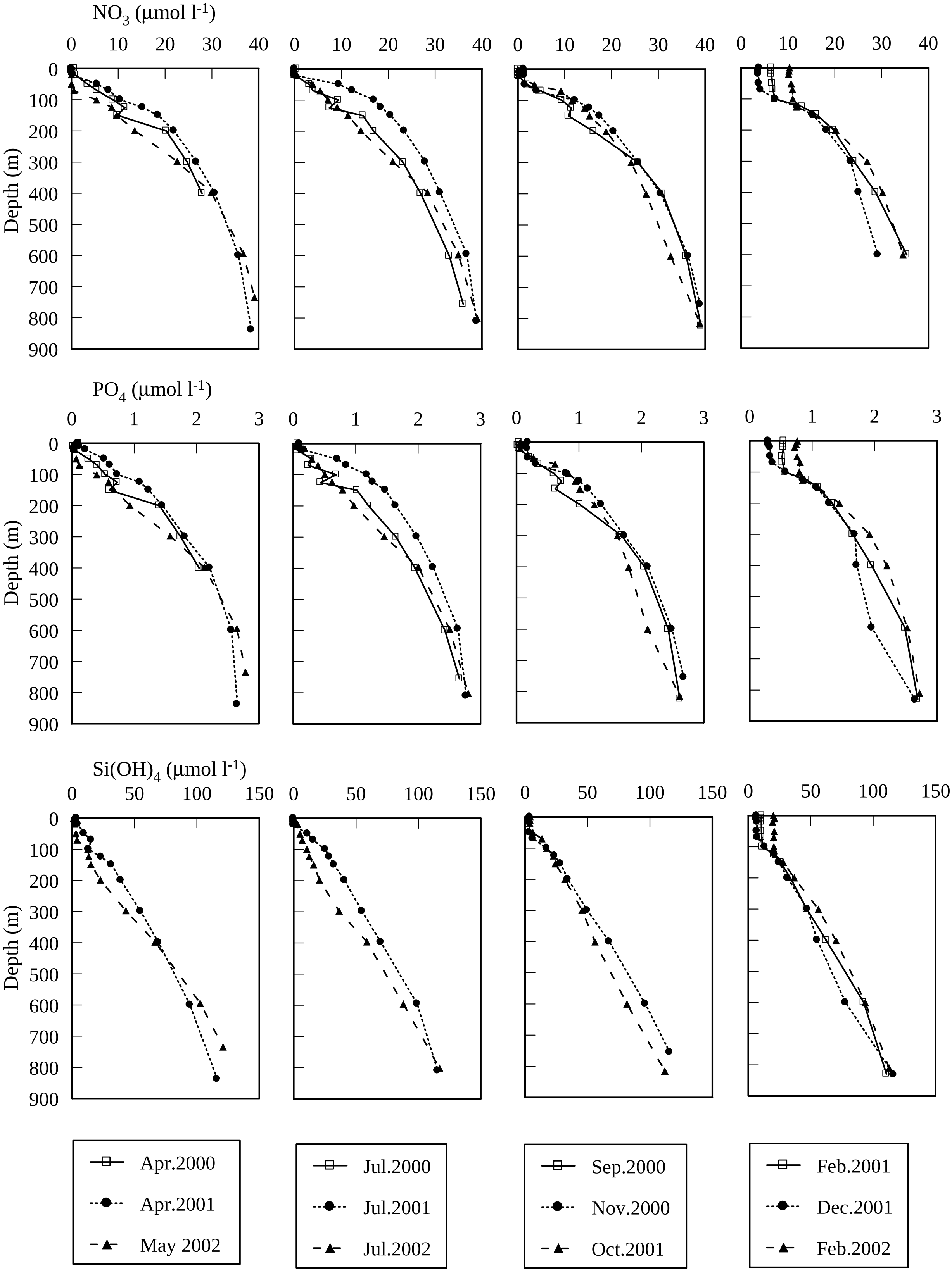

Fig. 2-4b. Vertical profiles of nutrients [NO_3, PO_4 and $Si(OH)_4$] concentrations at St. F in the Suruga Bay between April 2000 and July 2002. $Si(OH)_4$ was not measured in April, July and September 2000.

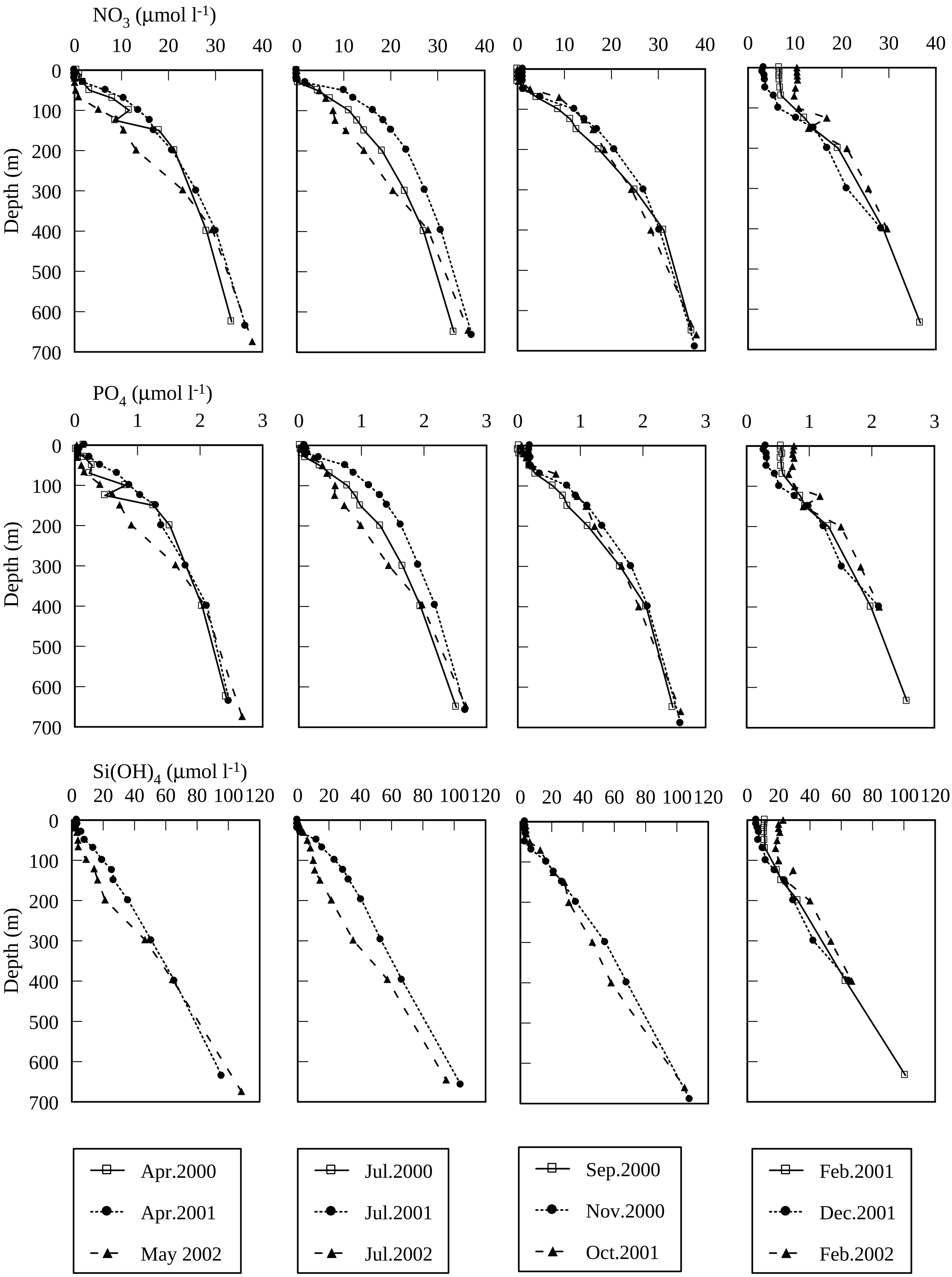

Fig. 2-4c. Vertical profiles of nutrients [NO_3, PO_4 and $Si(OH)_4$] concentrations at St. E in the Suruga Bay between April 2000 and July 2002. $Si(OH)_4$ was not measured in April, July and September 2000.

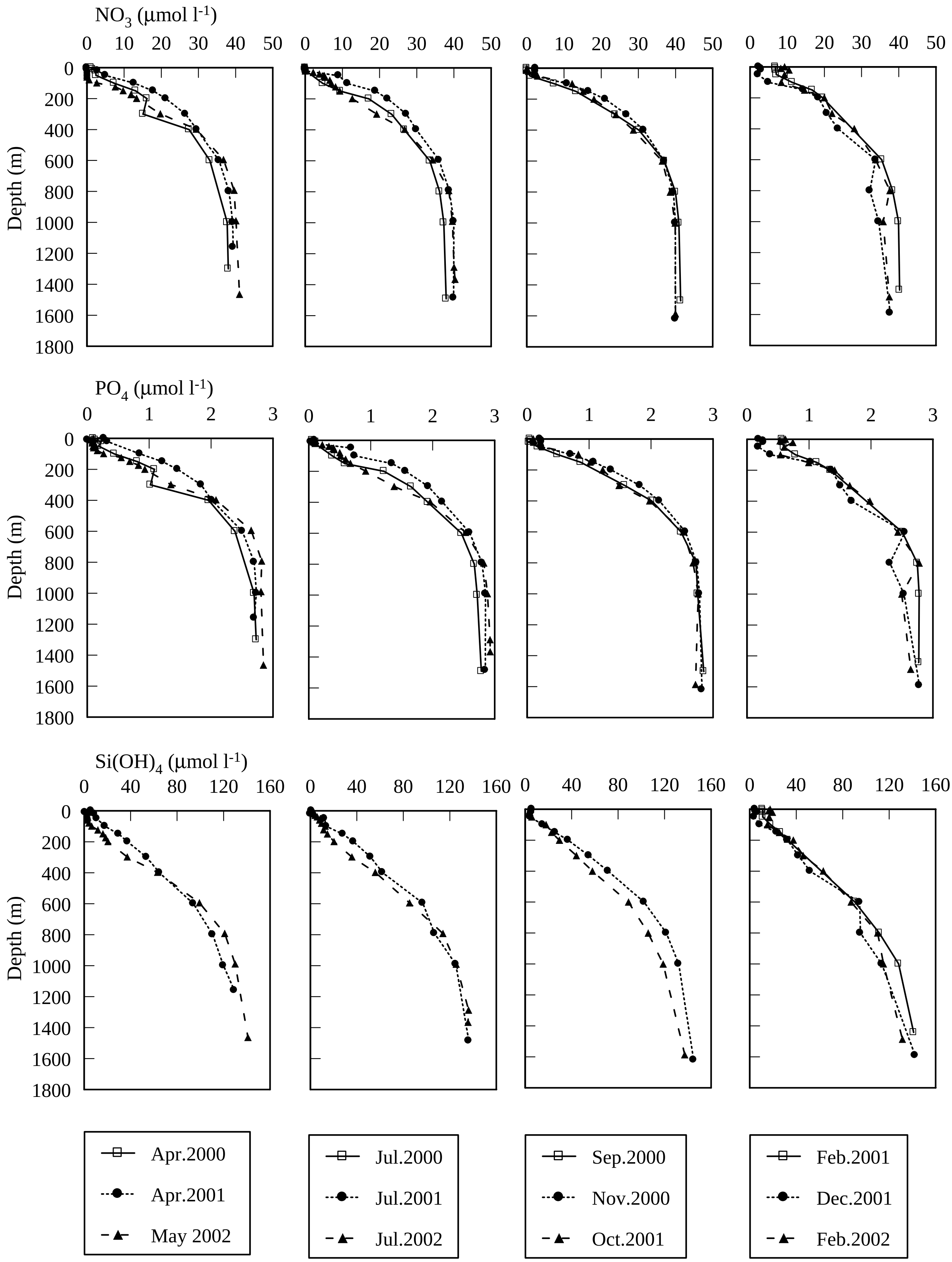

Fig. 2-4d. Vertical profiles of nutrient [NO_3, PO_4 and $Si(OH)_4$] concentrations at St. 2 in the Suruga Bay between April 2000 and July 2002. $Si(OH)_4$ was not measured in April, July and September 2000.

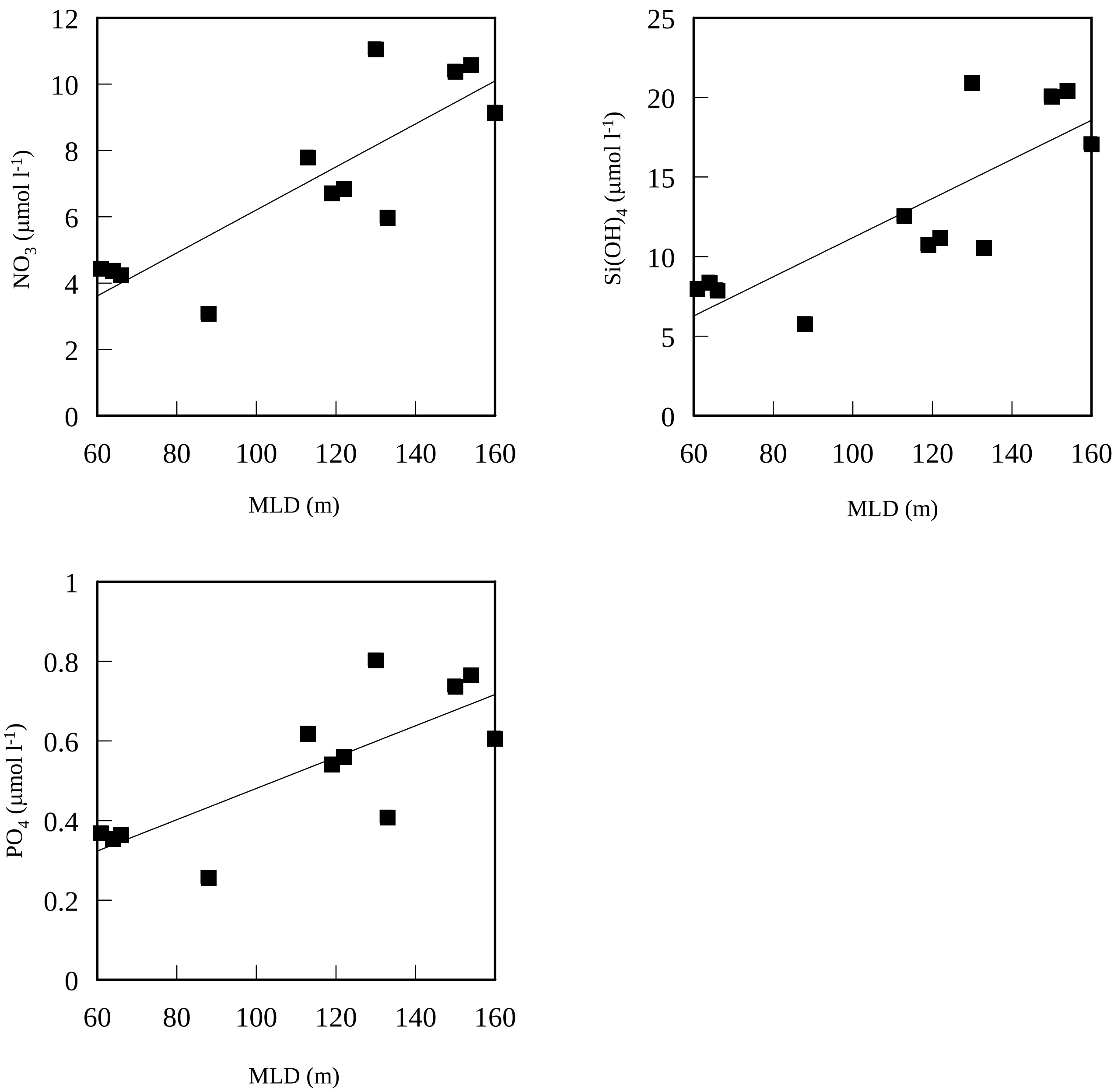

Fig. 2-5. Relationship between MLD and average concentration of nutrients NO_3, PO_4 and $Si(OH)_4$] in the upper 100 m in winter. Solid line indicates a linear regression between salinity and average nutrient concentrations.

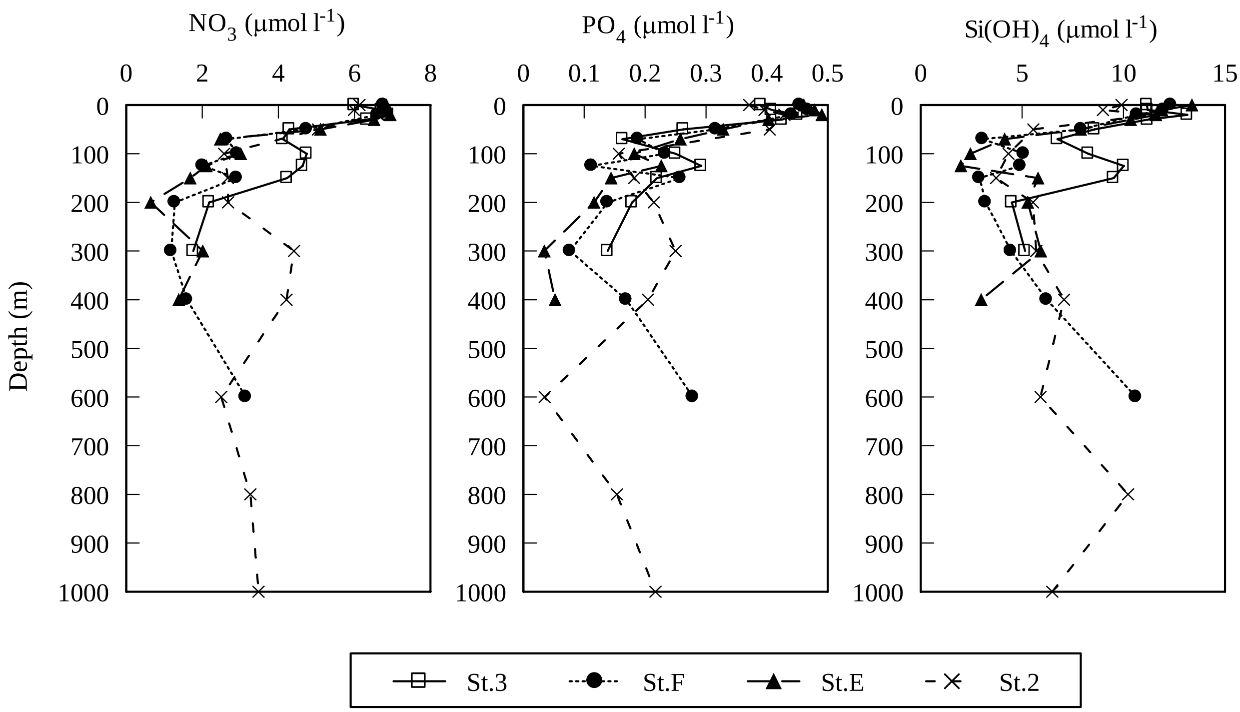

Fig. 2-6. Seasonal variation in nutrients [NO_3, PO_4 and $Si(OH)_4$] in the Suruga Bay.

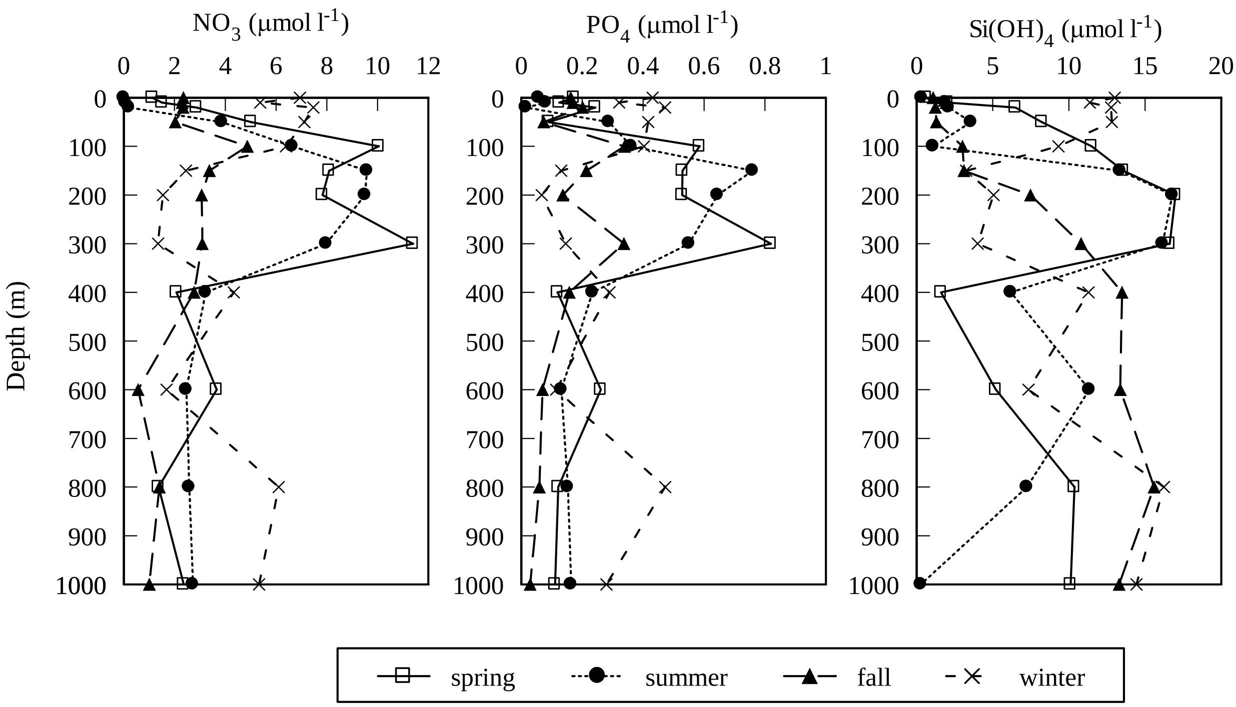

Fig. 2-7. The variation in nutrients [NO_3, PO_4 and $Si(OH)_4$] in each season at St. 2 in the Suruga Bay.

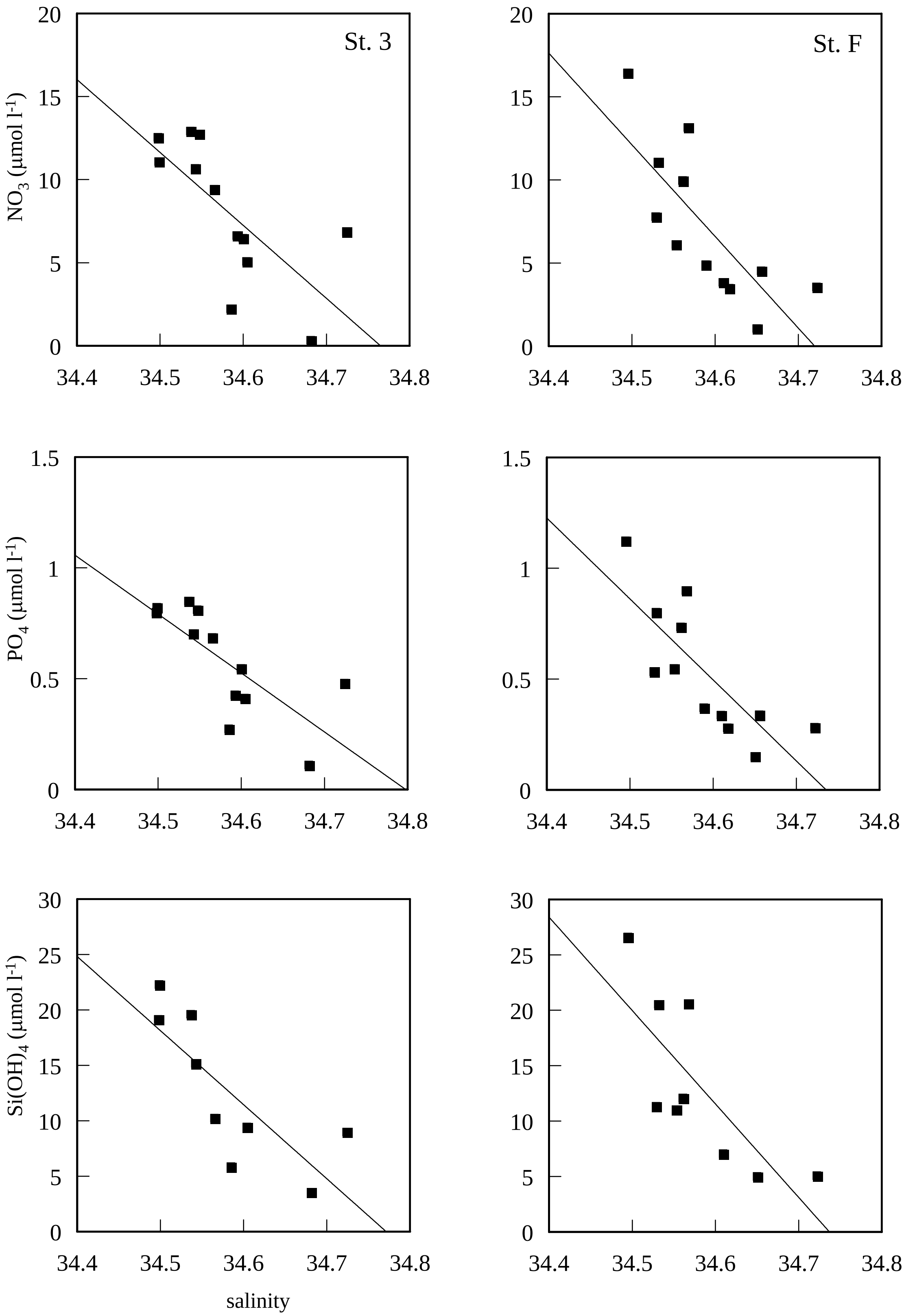

Fig. 2-8a. Relationship between salinity and nutrient concentrations [NO_3, PO_4 and $Si(OH)_4$] at the subsurface salinity maximum layer at St. 3 (left) and F (right) in the Suruga Bay. Solid line indicates a linear regression between salinity and nutrient concentrations.

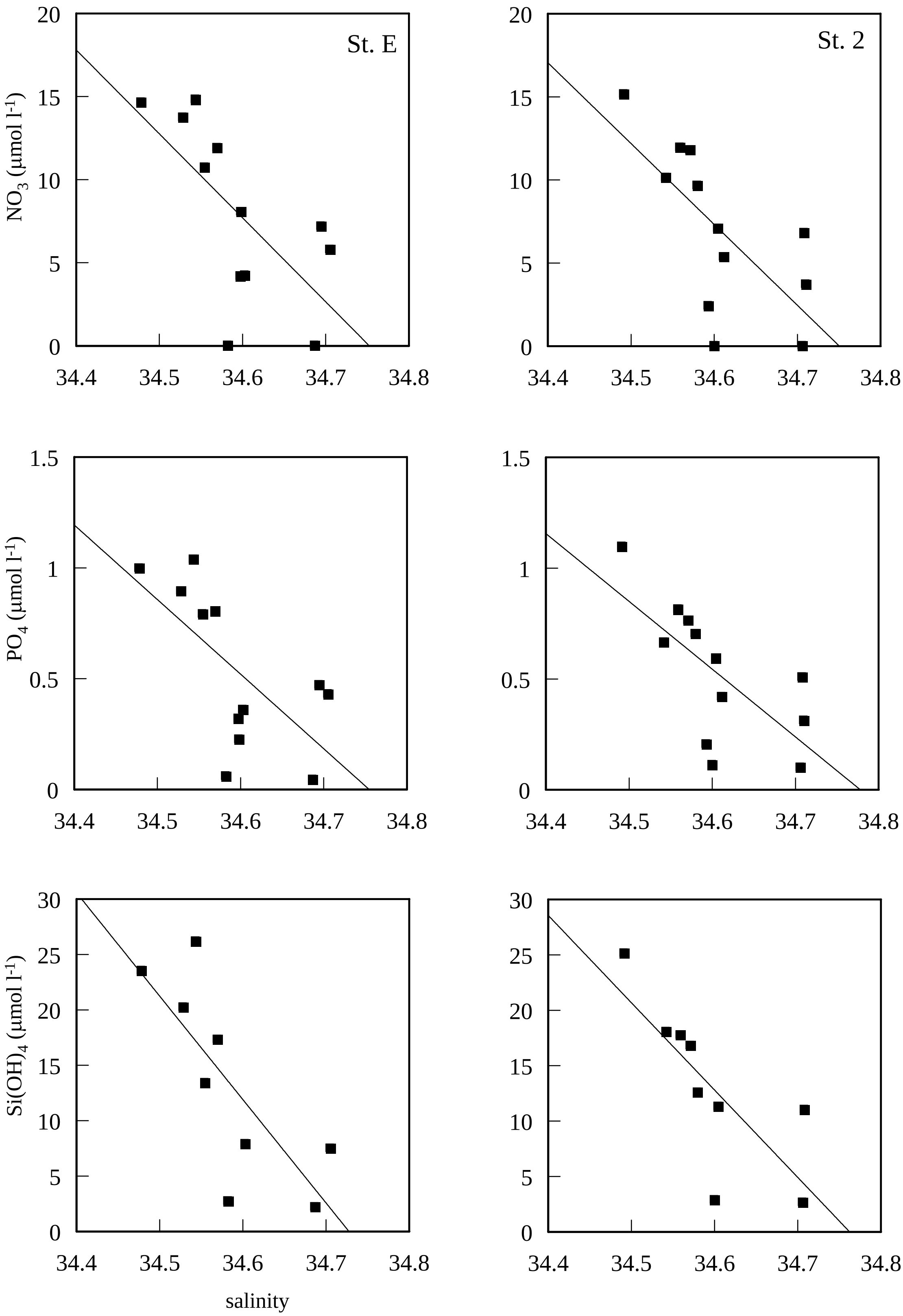

Fig. 2-8b. Relationship between salinity and nutrient concentrations [NO_3, PO_4 and $Si(OH)_4$] at the subsurface salinity maximum layer at St. E (left) and 2 (right) in the Suruga Bay. Solid line indicates a linear regression between salinity and nutrient concentrations.

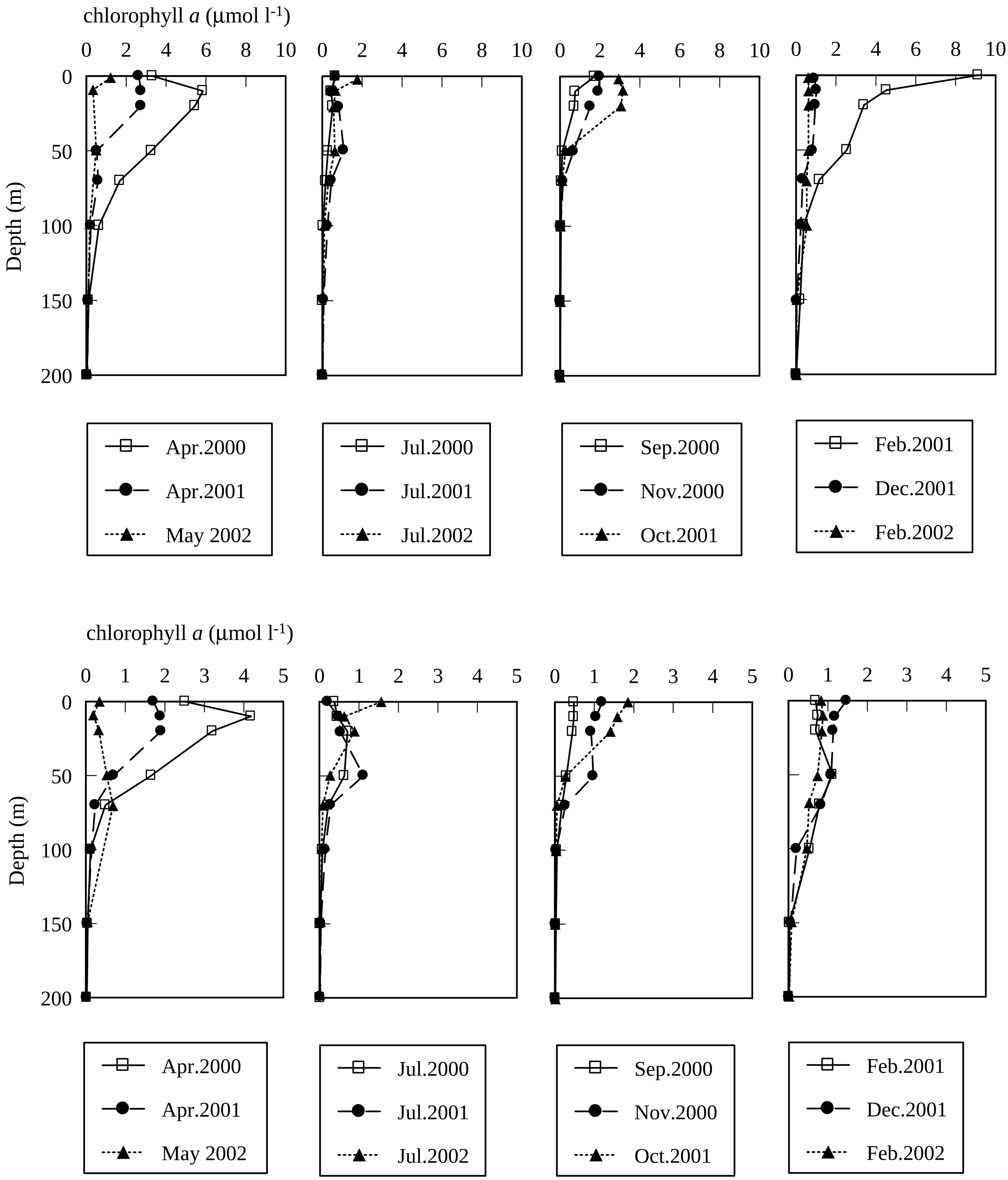

Fig. 2-9a. Vertical profiles of chlorophyll a concentration at St. 3 (upper) and F (lower) in the Suruga Bay between April 2000 and July 2002.

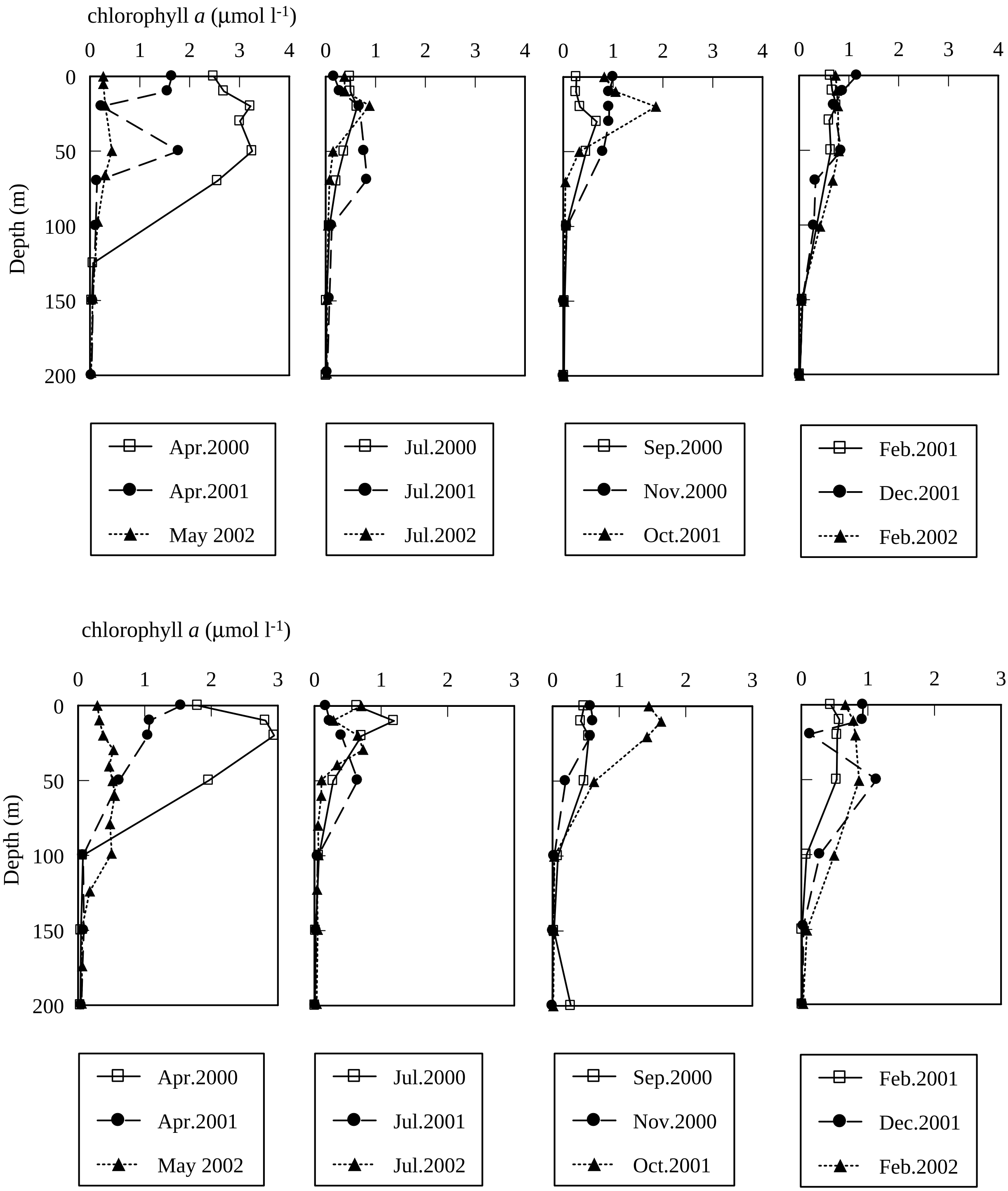

Fig. 2-9b. Vertical profiles of chlorophyll a concentration at St. E (upper) and 2 (lower) in the Suruga Bay between April 2000 and July 2002.

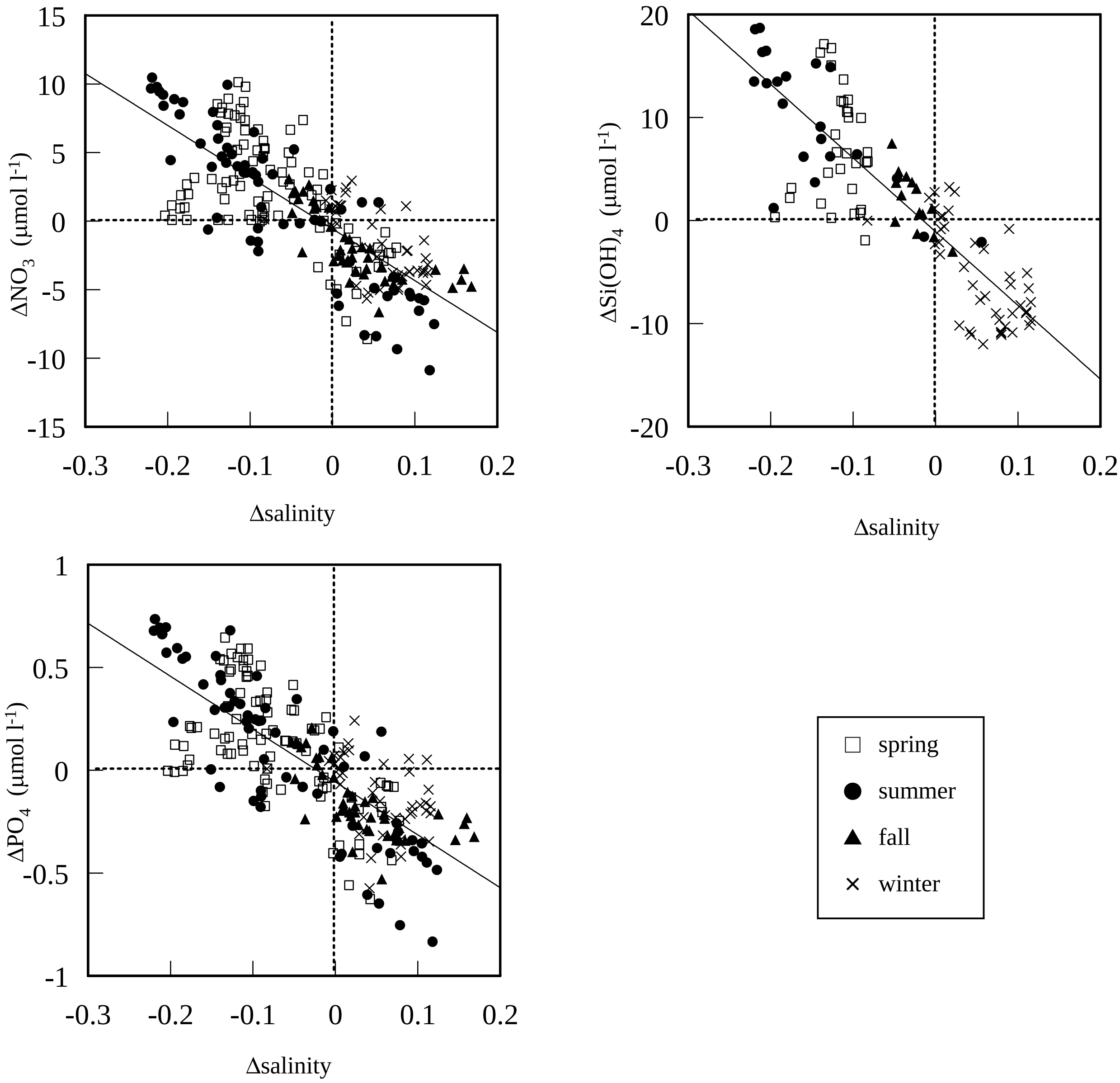

Fig. 2-10. Relationship between Δsalinity and Δnutrients [ΔNO_3, ΔPO_4 and $\Delta Si(OH)_4$] in the Offshore Water of the Suruga Bay. Δsalinity and Δnutrients represent the difference in salinity and nutrients between the sampling days in each season, respectively. Solid line indicates a linear regression line between Δsalinity and Δnutrients, when all the data were considered.

Chapter III: Nutrients and water structure in the vertical zonal cross-section from the center of the bay to the bay mouth in the Suruga Bay.

Introduction

In chapter II, an increasing intrusion of warm and saline water would bring about lower nutrients concentration in the Offshore Water in the Suruga Bay. This warm and saline water would be originated from the Kuroshio Water, and its appearance may be related with the approach of the Kuroshio axis to the Suruga Bay. Recent studies reported that Kyucho (stormy current) was observed in the Suruga Bay (Inaba and Katsumata, 2003; Inaba *et al.*, 2003). Kyucho is the suddenly intrusion of the warm water, which was originated from the Kuroshio, with high velocity near the bay coast at times (Matsuyama *et al.*, 1997, 1999). Kyucho in the Suruga Bay intruded along the west side of the Izu peninsula, and a part of intrusion water flows from east to west in the center of the bay (Inaba and Katsumata, 2003; Inaba *et al.,* 2003). The appearance of Kyucho in the Suruga Bay was caused by the approach of the Kuroshio and northward flow of the Kuroshio in the Irohzaki cape offing (Inaba *et al.,* 2003).

This phenomenon would give an important suggestion for circulation and distribution warm and saline water intruding to the Offshore Water. Furthermore, it is necessary to examine the variation in nutrient concentration caused by intrusion of warm and saline water.

In this chapter, nutrient concentrations and water structure was observed in vertical zonal cross-section from the center of the Bay to the bay mouth. Comparing these results with nutrients distribution and water structure in time series observation and its relationship, circulation and distribution of warm and saline water were investigated in the Suruga Bay.

Materials and Methods

Vertical zonal cross-section from the center of the bay to the bay mouth was observed in May 28, 2002, when two weeks after time series observation in May 14, 2002 (see chapter II). Sampling stations separated into two sections, which located from north to south (Fig. 3-1). The one section was composed of St. 2, St. 6 and St. 7, and the other was composed of St. E, St. 4, St. C and St. 5 (Fig. 3-1). Location of sampling stations and details of sampling depth was shows in Table 3-1. Temperature and salinity were measured by CTD every 1 dbar between the surface and the B-20.

Water samples were collected from 10 or 11 layers with 10-l Niskin bottles mounted on a CTD/Carousel water sampler system. Surface water samples were collected using a plastic bucket. Nutrients concentration [NO_3, PO_4, $Si(OH)_4$] was measured at all the stations. Method of analysis for nutrients was same as the previous chapter. Chlorophyll *a* concentrations was measured at St. 2, 5 and E from 0 to 200 m. Water samples were collected 6 or 7 layers (0, 10, 20, 50, 100, 150 and 200 m). Method of analysis for chlorophyll *a* was same as the previous chapter.

Results

Characteristics of the water structure at vertical zonal cross-section

Vertical profiles of salinity, θ and σ_θ at vertical zonal cross-section were shown in Figure 3-2. θ, salinity and σ_θ were similar distribution at 7 stations. In the surface layer, pycnocline was beginning to be formed. Table 3-2 shows mixed layer depth (MLD and salinity, nutrients [NO_3, PO_4 and $Si(OH)_4$] and chlorophyll *a* at 10 m in the north-south cross-section. MLD ranged from 16 to 27 m. In the surface water (10 m), θ was 19.82 - 20.27 (^oC), and salinity was 34.57 - 34.59 (Table 3-2). Salinity variation in north-south cross-section was relatively smaller than that in east-west cross-section (Sts. 3, F, E and 2) (Table 2-7).

The subsurface salinity maximum layer existed at 35 - 59 m, and salinity maximum was 34.62 - 34.65 (Table 3-3). Salinity at the subsurface salinity maximum layer was highest at St. 5, where located in most southern station in all stations, however the variation in salinity among all station was relatively small (0.03). Below the subsurface salinity maximum layer, there was little difference at all stations in θ, salinity and σ_θ, respectively (Fig. 3-2).

Characteristics of nutrients

Vertical profiles of nutrients [NO_3, PO_4 and $Si(OH)_4$] at vertical zonal cross-section were shown in Figure 3-3. In the surface layer (0 - 20 m), NO_3 was below detection limit (0.05 μmol l^{-1}) except for at 10 m at St. C (0.29 μmol l^{-1}). On the other hand, PO_4 and $Si(OH)_4$ were 0.05 - 0.29 μmol l^{-1} and 1.71 - 3.66 μmol l^{-1}, respectively, and were not below detection limit (Fig. 3-3). These results were similar to the result from April to October in the time series observation (Fig. 2-4).

In the subsurface salinity maximum layer, nutrient concentrations ranged from 1.87 - 5.14, 0.23 - 0.42 and 5.36 - 8.30 μmol l^{-1}, respectively for NO_3, PO_4 and $Si(OH)_4$ (Table 3-3). These nutrient concentrations were calculated by liner interpolation at the middle depth of the subsurface salinity maximum. Below the subsurface salinity maximum, nutrients concentration was mostly same tendency at all stations, respectively for NO_3, PO_4 and $Si(OH)_4$ (Fig. 3-3).

Characteristics of chlorophyll a

Figure 3-4 shows vertical profiles of chlorophyll *a* at St. 2, 5 and E. Chlorophyll *a* concentration marked a maximum from 0 to 50 m. Chlorophyll *a* concentrations from 0 to 50 m were ranged from 0.2 to 0.3 $\mu g\ l^{-1}$ at St. 2 and St. E and ranged from 0.3 to 0.7 $\mu g\ l^{-1}$ at St. 5 (Fig. 3-4). Below 100 m, chlorophyll *a* concentrations were below the detection limit (0.04 $\mu g\ l^{-1}$) at St. 2, 5 and E.

Discussion

Salinity variation in north-south cross-section was ranged from 34.57 to 34.59 at the surface water (10 m) (Table 3-2). The difference among Sts. 3, F, E and 2 in spring was ranged from 0.06 to 0.18 (Table 2-7), indicating that horizontal variation in water structure at the surface layer was smaller in north-south cross-section than in east-west cross-section. This reflects in the horizontal variation in MLD. The range of MLD was 16 - 27 m in north-south cross-section (Table 3-2), whereas it was 6 - 55 m at Sts. 3, F, E and 2 in spring (Table 2-3). In chapter II, variation in salinity at the surface layer was influenced by the intrusion of riverine water in east-west cross-section. These suggest that water structure in the surface layer would be hardly influenced by the intrusion of river water in north-south cross-section. On the other hand, the difference in chlorophyll *a* concentrations among St. 2, 5 and E was less than 0.1 μg l^{-1} at the surface water (10 m) (Table 3-2), and it was relatively smaller than that among St. 3, F, E and 2 in the time series observation (Table 2-7). The difference in nutrient concentration at the surface water (10 m) was 0.29 μmol l^{-1}, 0.08 μmol l^{-1} and 1.84 μmol l^{-1}, respectively for NO_3, PO_4 and $Si(OH)_4$, indicating that nutrient concentration at the surface water is less different between the center of the bay and the bay mouth. These results also suggest that the surface water in the north-south cross-section is little influenced by the intrusion of water with the higher concentration of nutrient and chlorophyll *a* such as river water. Nutrient distribution and phytoplankton biomass would be almost uniform at the surface layer in the center and bay mouth of the Suruga Bay, because of unvaried characteristics of water structure in the north-south cross section.

In the subsurface salinity maximum layer, salinity was ranged from 34.62 to 34.65 in north-south cross-section (Table 3-3) and relatively higher than in April 2000 and in April 2001 (Table 2-4). The difference in salinity maximum at the stations in north-south cross-section was 0.03. In the time series observation (chapter II), the difference in salinity maximum in each sampling date was 0.01 - 0.06 except for in September 2000 (Table 2-4), and it was mostly same as that in north-south cross-section. In September 2000, when the intrusion of saline water from east to west was observed (Fig. 2-3), the difference in the salinity maximum was 0.16, and larger that that in north-south cross-section (0.03). θ and depth at the subsurface salinity maximum layer was also mostly similar among 7 stations in north-south cross-section (Table 3-3). These results imply that horizontal variation in characteristics of θ and salinity at the subsurface salinity maximum in the north-south cross-section was little difference in the Suruga Bay. Recent studies (Inaba and Katsumata, 2003; Inaba *et al.,* 2003) reported about the Kyucho (stormy current) in the Suruga Bay, which intruded along the west side of the Izu peninsula and flowed counterclockwise in the center of the bay. The vertical section of salinity in September 2000 (Fig. 2-3) suggests that the water with the salinity > 34.6 intruded from east to west into the Suruga Bay, implying the counterclockwise circulation during its intrusion into the Suruga Bay. In the center of the bay, the branch of Kuroshio water may intrude mainly from east to west compared with the flow from the bay mouth to north.

To examine relationship between salinity and nutrients at the subsurface salinity maximum layer in the north-south cross-section, the scatter plot of salinity versus nutrient was constructed for the samples in the time series observation with in the north-south cross-section (Fig. 3-5). This plot was investigated at St. E and at St. 2, and among all stations in the time series observation and in the north-south cross-section. There were significantly negatively correlation between salinity and nutrients [NO_3, PO_4 and $Si(OH)_4$] at St. E and 2, respectively (r^2 = 0.45 - 0.61, n = 10 or 13, $P < 0.05$) (Table 3-4). Moreover, there were significantly negatively correlation between salinity and nutrients among all stations in the time series observation, which observation at Sts. 3, F, E and 2 from April 2000 to July 2002 (see chapter II), and in the north-south cross-section (r^2 = 0.52 - 0.61, n = 43 or 55, $P < 0.05$) (Table 3-4). These results suggest that the variation in salinity at the subsurface salinity maximum layer also influenced nutrient concentration in the north-south cross-section. To standardize the slope by nutrients concentration, we divided each slope by the average concentrations of NO_3, PO_4 and $Si(OH)_4$ at the subsurface salinity maximum. These ratios were similar among nutrients, and it ranged from -6.03 to -7.59 at St. E and St. 2 and among all stations. This result suggests that the salinity also influenced the nutrient ratio hardly. These characteristics of the relationship between salinity and nutrients in the north-south cross-section exhibited similar to those in the time series observations (Fig. 2-8). In the whole area of the Suruga Bay, including the cross-section from the center of the bay to the bay mouth, the variation in salinity at the subsurface salinity maximum layer would influence nutrient distribution.

Salinity at the subsurface salinity maximum at St. E and 2 was 34.63 and 34.62, respectively in May 28, 2002 in the north-south cross-section observation (Table 3-3), and that in May 14, 2002 in the time series observation was 34.69 at St. E and 34.71 at St. 2 (Table 2-4c, d). Decrease in the salinity maximum was 0.05 at St. E and 0.08 at St. 2 by 14 days, indicating a weak intrusion of saline water into the Suruga Bay in May 28, 2002 compared to that in May 14, 2002. The depth of the Offshore Water (salinity > 34.4) was at ca. 0 - 230 m in May 28, 2002 (Fig. 3-2), whereas it was at ca. 0 - 300 m in May 14, 2002 (Fig. 2-2c, d). In July 23, 2002 in the time series observation, salinity maximum was 34.71 at St. E and St. 2 (Table 2-4c, d) and depth of the Offshore Water was at ca. 30 - 330 m (Fig. 2-2c, d). These were mostly similar to the characteristics in May 14, 2002, except for that in the surface layer. These results suggest that an increasing intrusion of saline water continues from about two weeks to two months. This is supported by recently reports (Katsumata *et al.,* 1999; Inaba *et al.*, 2001). Katsumata *et al.* (1999) reported that in the Suruga Bay, the change of the 20-day period for the observed current at 20 - 200 m in the bay mouth could be related to frontal wave of the Kuroshio off the bay. At 300 m in the Suruga Bay, the change of 18-day period and 37-day period was predominant in temporal variation in current and the change of 25-day period was predominant in that of temperature, and these would be caused by the change of the position of the Kuroshio axis and frontal wave of the Kuroshio (Inaba *et al.,* 2001). It is possible that an increasing intrusion of saline water is the change of 20 - 40-day period.

To estimate the effect of the intrusion of saline water on nutrient distribution, it investigated the difference in integrated nutrients between May 28, 2002 and May 14, 2002. Nutrients were integrated from 0 to 200 m. Integrated nutrients [NO_3, PO_4 and $Si(OH)_4$] at St. E and 2 in May 28, 2002 and May 14, 2002 was shown in Table 3-5 with the salinity maximum and integrated chlorophyll *a*. Integrated NO_3 in May 28, 2002 was 1934 mmol m^{-2} at St. E and 2034 mmol m^{-2} at St. 2, and higher than that in May 14, 2002 (1116 mmol m^{-2} at St. E and 971 mmol m^{-2} at St. 2). Integrated PO_4 and $Si(OH)_4$ were also higher in May 28, 2002 than that in May 14, 2002 (Table 3-5). The difference in integrated NO_3 was 818 mmol m^{-2} at St. E and 1063 mmol m^{-2} at St. 2 (Table 3-5). It was equivalent to 42% (St. E) and 52% (St. 2) of integrated NO_3 in May 28, 2002, corresponding to 42% (St. E) and 50% (St. 2) for integrated PO_4 and 39% (St. E) and 48% (St. 2) for integrated $Si(OH)_4$. This result implies that decrease rate of nutrients in upper 200 m, which brought about an increasing intrusion of saline water to the Offshore Water, was 39 - 50% of nutrient budget without an increasing intrusion of saline water.

Integrated chlorophyll *a* in May 28, 2002 was 22 mg m^{-2} at St. E and 17 mg m^{-2} at St. 2, whereas those in May 14, 2002 were 37 mg m^{-2} at St. E and 60 mg m^{-2} at St. 2 (Table 3-5). Integrated chlorophyll *a* was lower in May 28, 2002 than that in May 14, 2002, whereas integrated nutrients were higher in May 28, 2002 than those in May 14, 2002. In May 14, 2002 and May 28, 2002, NO_3 concentration was mostly below the detection limit from 0 to 20 m (Figs. 2-4 and 3-3), suggesting that the productivity of phytoplankton is limited by NO_3. On the other hand, the depth of the mixed layer was 24 m at Sts. E and 2 in May 28, 2002 (Table 3-2), suggesting that pycnocline was beginning to be formed in the surface layer. The supply of nutrient by vertical mixing to the surface layer may decrease in May 28, 2002 rather than that in May 14, 2002. NO_3 depletion and less supply of nutrient by vertical mixing may bring about less phytoplankton biomass and production at the surface layer in May 28, 2002.

In summary, water structure and nutrients distribution was observed in vertical zonal cross-section from the center of the bay to the bay mouth. Horizontal variations in salinity, nutrients and chlorophyll *a* in the surface water were smaller than that in east-west cross section, suggesting uniform characteristics of water structure in the north-south cross section along the depth. In the subsurface salinity maximum layer, horizontal variations in water structure and nutrients concentration was mostly unvaried in zonal cross section from the center to the bay mouth in the Suruga Bay. This result implies that the Kuroshio water intrudes mainly from east to west compared with the flow from the bay mouth to north. Salinity maximum in May 28, 2002 was lower than salinity maximum in May 14, 2002. It is possible that an increasing intrusion of saline water is the change of 20 - 40-day period. Integrated nutrients in May 28, 2002 was 1.6 - 2.1 times as high as those in May 14, 2002, because of a weakness intrusion of saline water with lower nutrient concentration. On the other hand, integrated chlorophyll *a* was lower in May 28, 2002 (22 and 17 mg m^{-2}) than that in May 14, 2002 (37 and 60 mg m^{-2}). It can be explained that less phytoplankton biomass and production in May 28, 2002 is caused by NO_3 depletion and less supply of nutrient by vertical mixing.

Table 3-1. Location of sampling stations and details of the sampling depth in the north-south cross-section observation in May 28, 2002.

station	latitude (N)	longitude (E)	sampling depth											
St. 2	34° 51.0 ′	138° 38.0 ′	0 [a]	10	20	50	100	200	400	600	800	1000	1200	1385 [b]
St. 6	34° 45.5 ′	138° 38.0 ′	0 [a]	10	20	50	100	200	300	400	600	800	1041 [b]	
St. 7	34° 40.5 ′	138° 38.0 ′	0 [a]	10	20	50	100	150	200	300	400	600	765 [b]	
St. E	34° 51.0 ′	138° 33.0 ′	0 [a]	10	20	50	70	100	125	150	200	300	400	675 [b]
St. 4	34° 45.5 ′	138° 33.0 ′	0 [a]	10	20	50	70	100	125	150	200	300	400 [b]	
St. C	34° 40.5 ′	138° 33.0 ′	0 [a]	10	20	50	100	150	200	300	400	600	800	1335 [b]
St. 5	34° 35.0 ′	138° 33.0 ′	0 [a]	10	20	50	100	200	400	600	800	1000	1500	1763 [c]

a : water samples was collected using plastic bucket.
b : depth 20 m above the sea bottom [B-20].
c : deepest depth, which was able to collect water samples.

Table 3-2. Mixed layer depth (MLD) and salinity, nutrients [NO_3, PO_4 and $Si(OH)_4$] and chlorophyll *a* at 10 m in the north-south cross-section.

station	MLD (m)	salinity	NO_3 (μmol l^{-1})	PO_4 (μmol l^{-1})	$Si(OH)_4$ (μmol l^{-1})	chlorophyll *a* (μg l^{-1})
St. 2	24	34.56	0.00	0.12	2.12	0.2
St. 6	17	34.58	0.00	0.06	2.75	-
St. 7	20	34.57	0.00	0.07	2.68	-
St. E	24	34.58	0.00	0.07	3.66	0.2
St. 4	19	34.59	0.00	0.10	1.82	-
St. C	27	34.57	0.29	0.05	2.07	-
St. 5	16	34.55	0.00	0.08	2.48	0.3

- : Not determined

Table 3-3. Salinity, depth, θ, σ_θ and nutrients concentration in the subsurface salinity maximum layer in north-south cross-section. Depth, θ and σ_θ show a range of isohaline of the salinity maximum. Nutrients concentration was at the middle depth in the subsurface salinity maximum layer, and it was calculated by liner interpolation using the values at the above and below depths of the middle depth.

station	salinity maximum	range in the subsurface salinity maximum layer			NO_3	PO_4	$Si(OH)_4$
		depth (m)	θ (℃)	σ_θ	(μmol l^{-1})	(μmol l^{-1})	(μmol l^{-1})
St. 2	34.62	35 - 58	17.31 - 18.73	24.80 - 25.15	5.14	0.42	8.30
St. 6	34.63	35 - 49	17.89 - 18.75	24.79 - 25.01	4.45	0.36	7.01
St. 7	34.63	43 - 51	18.11 - 18.60	24.83 - 24.96	4.22	0.34	6.33
St. E	34.63	42 - 51	17.95 - 18.55	24.85 - 25.00	3.41	0.31	5.90
St. 4	34.64	40 - 59	17.94 - 18.80	24.79 - 25.00	1.87	0.23	7.82
St. C	34.64	46 - 51	17.83 - 18.19	24.95 - 25.04	3.62	0.34	6.83
St. 5	34.65	38 - 51	17.88 - 18.49	24.87 - 25.03	2.99	0.31	5.36

Table 3-4. Summary of liner regression fit to model y = *a* × salinity + *b* at the subsurface salinity maximum layer.

	y	slope (*a*)	intercept (*b*)	r^2	n	P^*
all stations	NO_3	-51.41	1785.73	0.52	55	< 0.05
	PO_4	-3.25	112.91	0.53	55	< 0.05
	$Si(OH)_4$	-83.27	2892.70	0.61	43	< 0.05
St. E	NO_3	-52.18	1813.06	0.46	13	< 0.05
	PO_4	-3.42	119.00	0.45	13	< 0.05
	$Si(OH)_4$	-96.17	3338.92	0.61	10	< 0.05
St. 2	NO_3	-49.02	1703.24	0.47	13	< 0.05
	PO_4	-3.08	107.04	0.47	13	< 0.05
	$Si(OH)_4$	-80.37	2793.49	0.60	10	< 0.05

*Test of the null hypothesis: a = 0.

Table 3-5. Salinity maximum, integrated nutrients [NO_3, PO_4 and $Si(OH)_4$] and integrated chlorophyll *a* at St. E and St. 2 in May 14, 2002 and May 28, 2002. Nutrients and chlorophyll *a* was integrated from 0 to 200 m.

station	date	salinity maximum	integrated nutrients NO_3 (mmol m^{-2})	PO_4 (mmol m^{-2})	$Si(OH)_4$ (mmol m^{-2})	integrated chlorophyll *a* (mg m^{-2})
St. E	May 14, 2002 (a)	34.69	1116	83	2048	37
	May 28, 2002 (b)	34.63	1934	144	3371	22
	b - a	0.05	818	61	1323	-15
St. 2	May 14, 2002 (a)	34.71	971	79	1847	60
	May 28, 2002 (b)	34.62	2034	157	3559	17
	b - a	0.08	1063	78	1712	-43

b - a : subtraction the data in May 14, 2002 from the data in May 28, 2002.

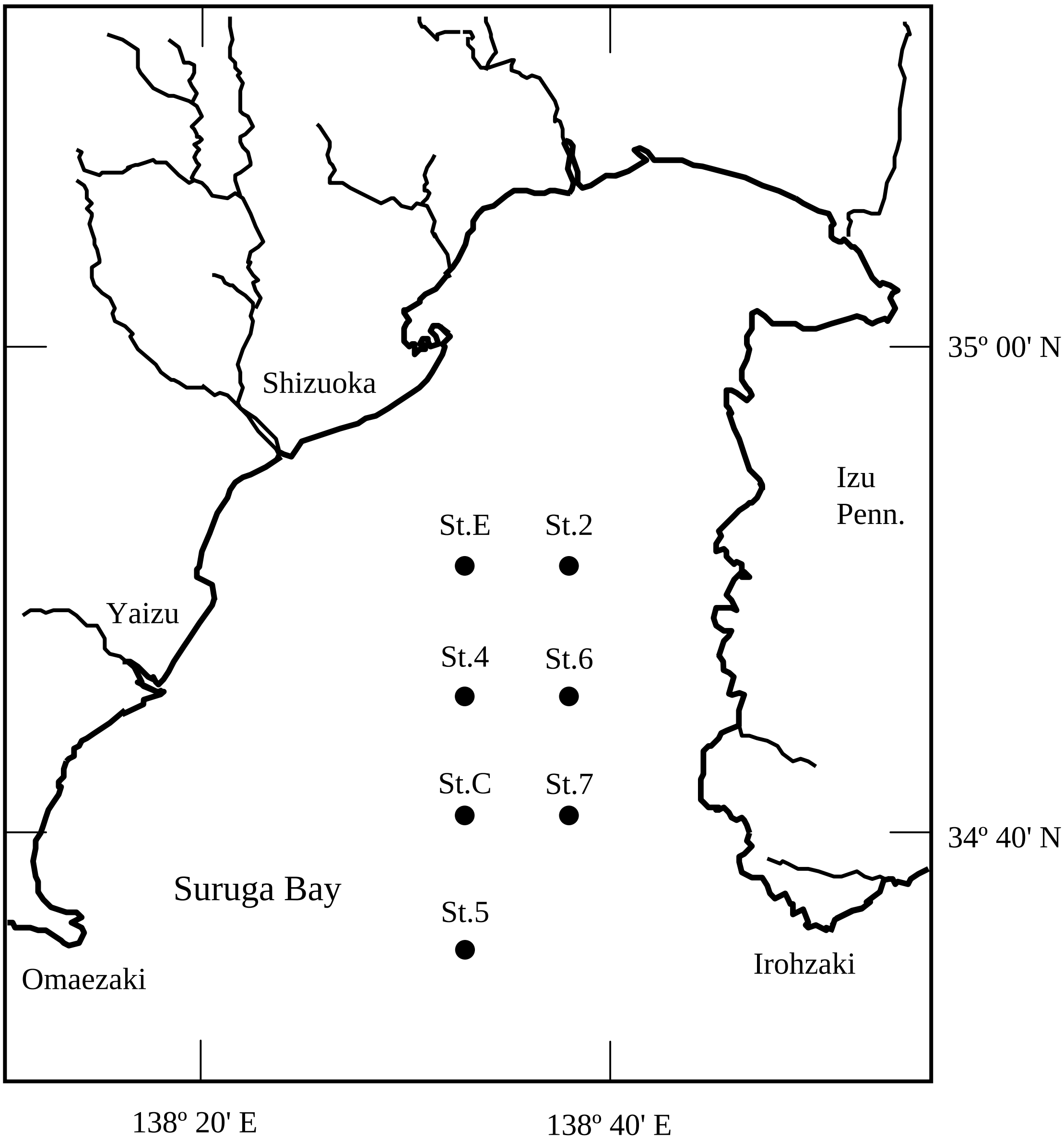

Fig. 3-1. Sampling station in the north-south cross-section in the Suruga Bay. Water depths were ca. 1600 m at St. 2, 1100 m at St. 6, 800 m at St. 7, 700 m at St. E, 400 m at St. 4, 1400 m at St. C and 2000 m at St. 5.

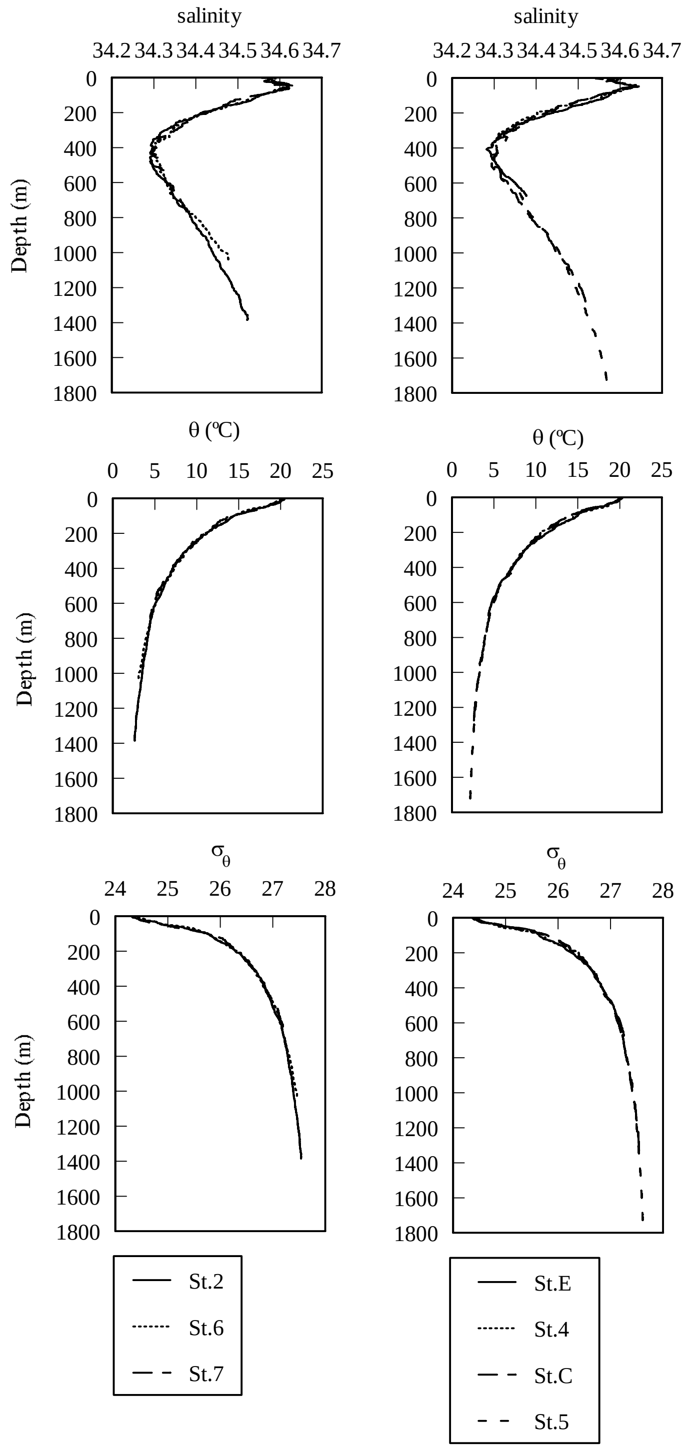

Fig. 3-2. Vertical profiles of salinity, θ and σ_θ in the north-south cross-section.

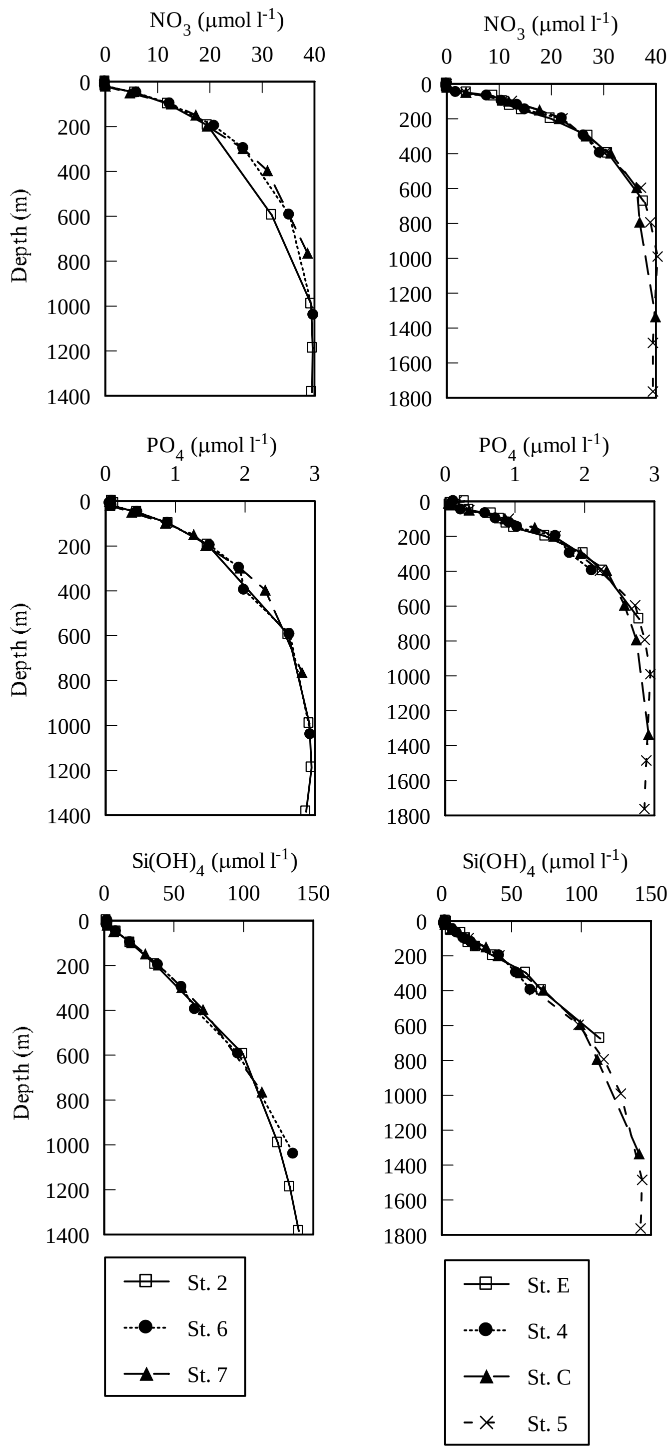

Fig. 3-3. Vertical profiles of NO_3, PO_4 and $Si(OH)_4$ in the north-south cross-section.

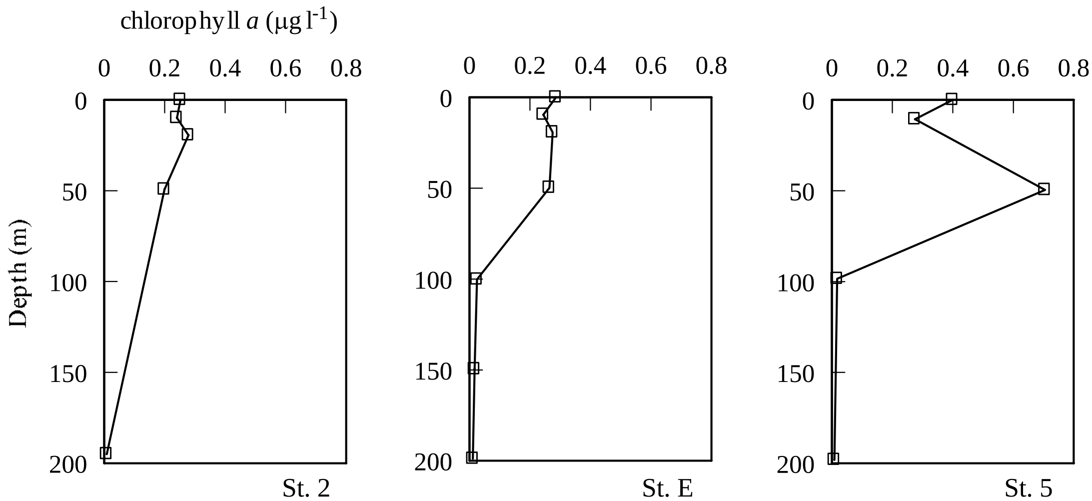

Fig. 3-4. Vertical profiles of chlorophyll *a* at St. 2, E and 5 in the north-south cross-section.

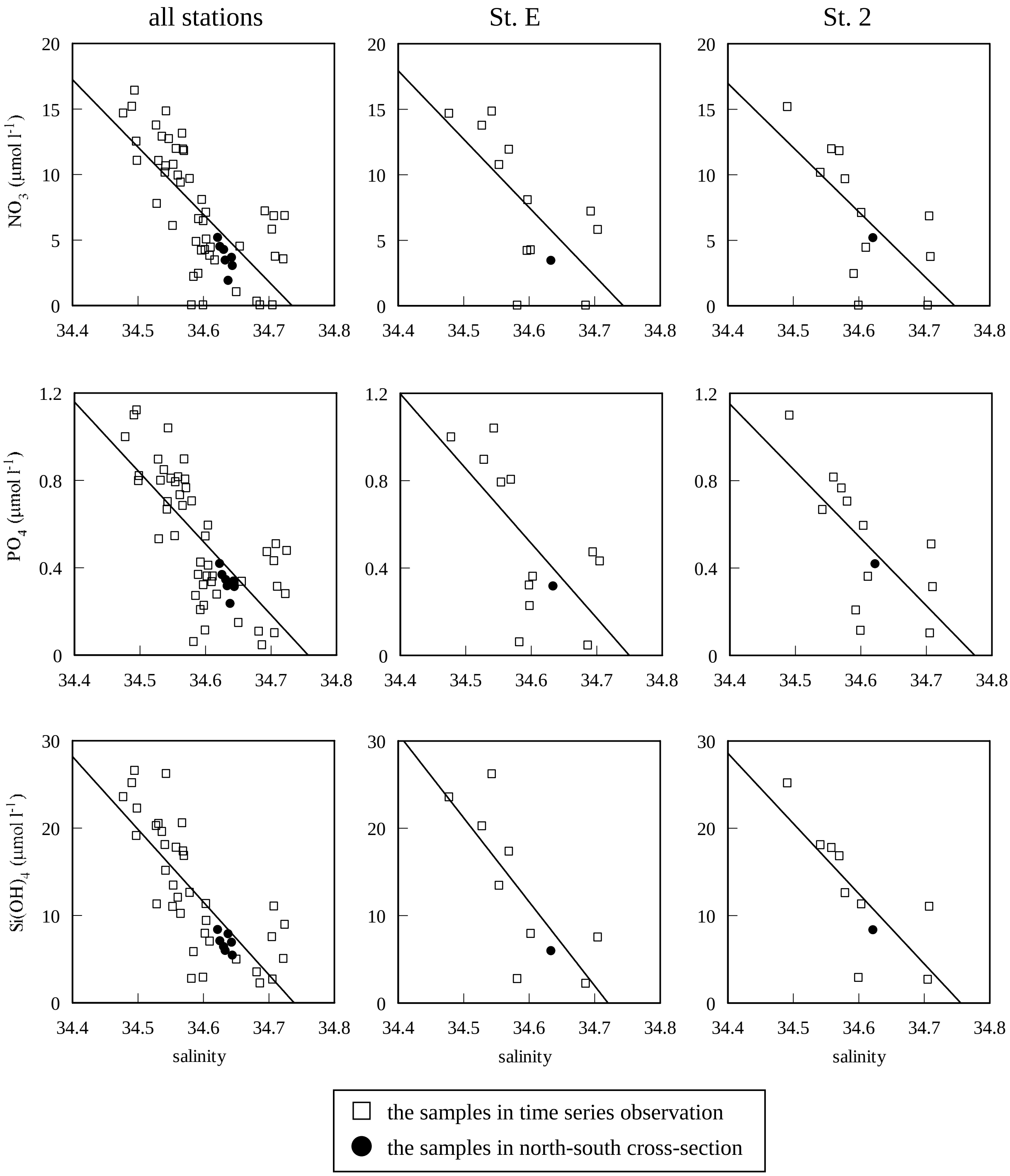

Fig. 3-5. The relationship between salinity and nutrients concentration at the subsurface salinity maximum layer. Data set is the samples in the time series observation with in the north-south cross-section. Solid lines indicate a linear regression between salinity and average nutrient concentrations.

Chapter IV: The path of the Kuroshio off the Honshu and the relation with water structure from April 2000 to July 2002 in the Suruga Bay.

Introduction

The Kuroshio has two steady flow patterns: one is "the large meander pattern (A pattern)", which flows through the Kii peninsula and Enshu-nada offing with large meander (Fig 4-1). The other is "the non large meander pattern", which flow near the southern coast of Honshu. "The non large meander pattern" is divided two patterns: one is "the small meander pattern" with small meander in off Enshu-nada, and it was classified 3 patterns (B, C and D pattern) by the location of the meander (Fig. 4-1). The other is "the strait pattern (N pattern)" without meander (Fig. 4-1). Previous studies reported about the fluctuation of Kuroshio in south coast of Honshu. Kimura and Sugimoto (1993) reported that the frontal wave of the Kuroshio was the change of 17 - 19-days period in off Cape Shionomisaki. About the influence of the variation in Kuroshio on the water characteristics in the southern coast of Honshu, Kasai *et al.* (1993) reported that the intrusion of the Kuroshio Water to Enshu-nada was the change of ca. 20-days period, which was related with the fluctuation in Kuroshio front, and 50-days period, which was related with the variation in the position of the Kuroshio axis. These effects of the Kuroshio Current would be related with the current and circulation in the Suruga Bay. In this study, one possibility that an increasing intrusion of warm and saline water is the change of ca. 20 - 40-days period was shown in chapter III.

In this chapter, it estimated the relationship between large variation in salinity at the salinity maximum layer in the Suruga Bay and the position of the Kuroshio axis. Moreover, the origin of the saline water intruded to the Suruga Bay was estimated by this relationship and nutrient concentration.

Results and Discussion

Data set of the paths of the Kuroshio Current from April 2000 to July 2002 referred from Quick Bulletin of Ocean Conditions by Japan Coastal Guard. Figure 4-2 shows the paths of the Kuroshio off the Honshu from April 2000 to July 2002. The distance of the Kuroshio axis from Cape Irohzaki [34° 36' (N) 138° 51' (E)] and Miyake Island [34° 4' (N) 139° 32' (E)] shows in Table 4-1. The paths of the Kuroshio showed various patterns from April 2000 to July 2002 (Fig. 4-2), and the large meander pattern was not shown during observation periods. The distance of the Kuroshio axis from

Cape Irohzaki ranged from 50 to 190 nm (nautical mile: 1 nm = 1852 m) (Table 4-1). In spring, the distance of the Kuroshio axis from Cape Irohzaki in May 2002, when the salinity maximum was higher in spring (Table 2-4), was 105 nm, and nearer than that in April 2000 (150 nm) and in April 2001 (140 nm). This characteristic was also shown in summer. The distance of the Kuroshio axis was nearer in July 2002 (50 nm) than that in July 2000 (140 nm) and in July 2001 (160 nm) (Table 4-1), and the salinity maximum was higher in July 2002 compared to that in July 2000 and in July 2001 (Table 2-4). The distance of the Kuroshio axis from Cape Irohzaki in spring and summer was significantly negatively correlated with the salinity maximum at St. 2 by Spearman's rank correlation (r_s = -0.97, n = 6, $P < 0.05$). This result suggests that approaching of the Kuroshio axis to the Suruga Bay caused to increase the value of the salinity maximum layer. In fall, the distance of the Kuroshio axis from Cape Irohzaki in September 2000, when the salinity maximum was highest in fall (Table 2-4), was 165 nm and further than that in November 2000 (85 nm) and in October 2001 (105 nm) (Table 4-1). However, path of the Kuroshio in September 2000 showed northward flow from the Hachijyo Island [33º 8' (N) 139º 46' (E)] to Miyake Island and meandered near Miyake Island (Fig. 4-2c). The distance of the Kuroshio axis from Miyake Island was nearer in September 2000 (20 nm) than that in November 2001 (65 nm) and in October

2001 (105 nm) (Table 4-1). The distance between Cape Irohzaki and Miyake Island was ca. 50 nm. As a result, the distance of the Kuroshio axis from the Suruga Bay was nearest in September 2000 (ca. 70 nm) compared to that in November 2001 (85 nm) and in October 2001 (105 nm). Inaba and Katsumata (2003) and Inaba *et al.* (2003) suggested that two possibilities were mentioned about the appearance of Kyucho (stormy current) in the Suruga Bay: One is the approach of the Kuroshio axis to the Suruga Bay. The other is the frontal wave related with northward flow of the Kuroshio in the Irohzaki cape offing. The latter suggests that higher salinity in September 2000 is brought about frontal wave of the Kuroshio related with northward flow in Cape Irohzaki offing. On the other hand, in winter, the distance of the Kuroshio axis from Cape Irohzaki was further in February 2001 (190 nm), when the salinity maximum was high, than in December 2001 (110 nm) and in February 2002 (75 nm) (Table 4-1). This result is not similar to the characteristics of the position of the Kuroshio axis in the other seasons.

The Kuroshio Water was relatively higher salinity compared to salinity in inshore area between the Kuroshio and the coast of Honshu such as Enshu-nada. Recent studies reported that salinity at the subsurface salinity maximum was ca. 34.8 near the Kuroshio axis (Komatsu and Kawasaki 2002) and ca. 34.6 in the Enshu-nada

(Kasai *et al.*, 2002). Nutrients concentration at the subsurface salinity maximum layer was lower near the Kuroshio axis than that in Enshu-nada. NO_3 concentration at the subsurface salinity maximum layer ranged from < 0.05 (below the detection limit) to 6.48 μmol l^{-1} from 50 to 150 m near the Kuroshio axis (Natori, 2004), and that in Enshu-nada ranged from 8.72 to 12.97 μmol l^{-1} from 50 to 100 m (Natori, unpublished). NO_3 concentration was higher in Enshu-nada than near the Kuroshio axis. This result supports that saline water intrude to the Suruga Bay is originated from Kuroshio Water, corresponding to an increasing intrusion of the saline water brought about lower nutrient concentration at the subsurface layer in the Suruga Bay (see chapter II). This is consistent with relationship between variation in salinity maximum in the Suruga Bay and path of the Kuroshio Current.

Conclusion

Path of the Kuroshio off Honshu has various patterns from April 2000 to July 2002. In spring and summer, the distance of the Kuroshio axis from Cape Irohzaki caused to the variation of the value in salinity maximum layer in the Suruga Bay, suggesting that an increasing intrusion of the saline water bring about approach of the Kuroshio axis to the Suruga Bay. In fall, higher salinity in the subsurface salinity maximum layer, which was observed in September 2000, may be caused by northward flow in Cape Irohzaki offing. On the other hand, saline water intruding to the Suruga Bay would be originated from Kuroshio Water, because of lower nutrient concentration near the Kuroshio axis compared to nutrient concentration in Enshu-nada. Since the path of the Kuroshio Current would be related with water structure and nutrient distribution in the Suruga Bay, the variation in the path of the Kuroshio Current would be important for estimation of phytoplankton production and organic matter distribution.

Table 4-1. The distance of the Kuroshio axis (nm) from Cape Irohzaki and Miyake Island, and the direction of the Kuroshio axis from Miyake Island. The direction of the Kuroshio axis from Cape Irohzaki was south throughout the observation periods. All data referred from Quick Bulletin of Ocean Conditions (Japan Coastal Guard, 2000, 2001, 2002).

		The difference of the Kuroshio axis (nm)		direction
season	date	Cape Irohzaki	Miyake Island	Miyake Island
spring	April 24, 2000	150	20	E
	April 25, 2001	140	30	SE
	May 14, 2002	105	25	E
summer	July 10, 2000	140	95	E
	July 11, 2001	160	60	ESE
	July 23, 2002	50	0	-
fall	September 20, 2000	165	20	SE
	November 27, 2000	85	65	E
	October 25, 2001	105	105	E
winter	February 19, 2001	190	50	E
	December 12, 2001	110	45	SSE
	February 20, 2002	75	0	-

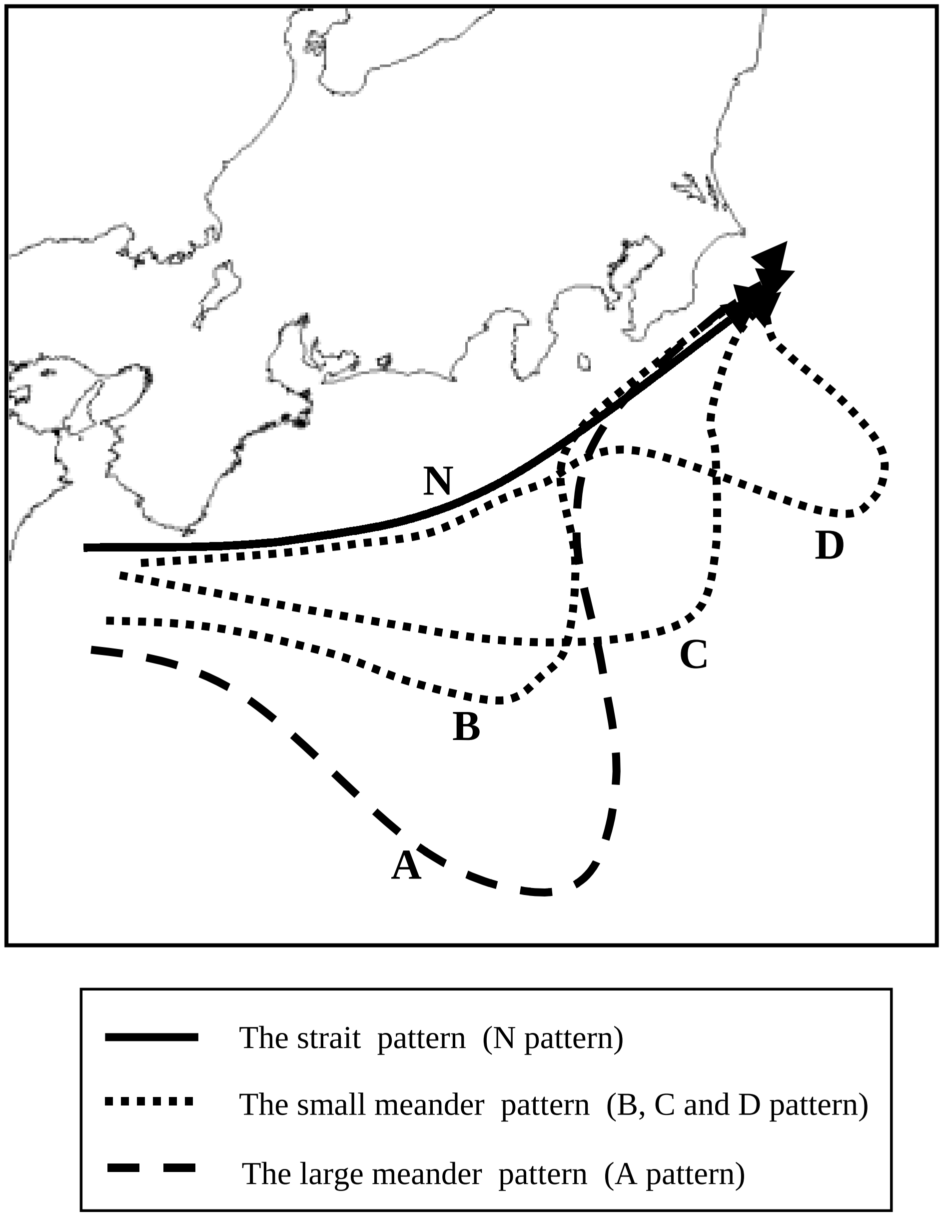

Fig. 4-1. Schematic view of typical paths of the Kuroshio.

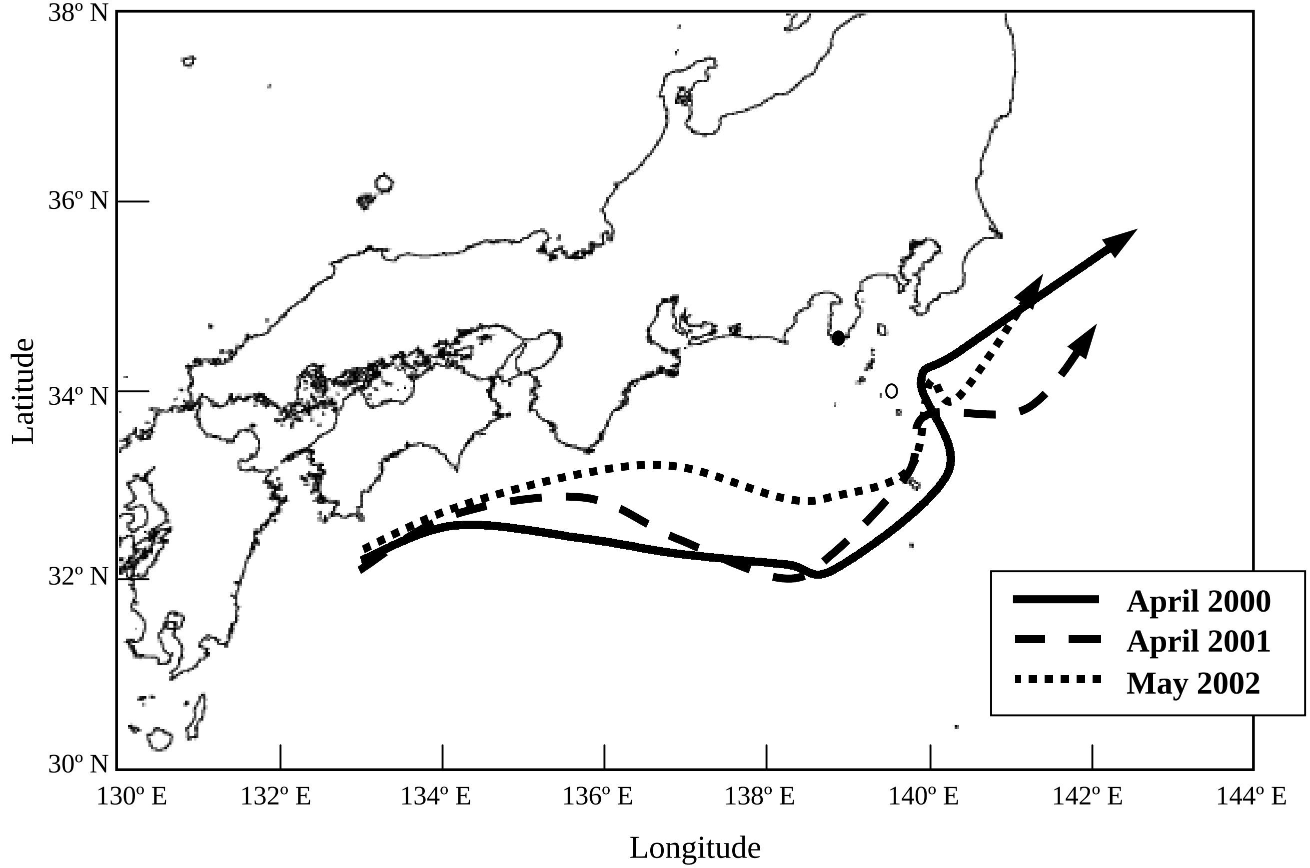

Fig. 4-2a. Paths of the Kuroshio off the Honshu in spring. Data of the Kuroshio axis referred from Quick Bulletin of Ocean Conditions (Japan Coastal Guard, 2000,2001,2002). Closed circle is the position of Cape Irohzaki, and open circle is the position of Miyake Island.

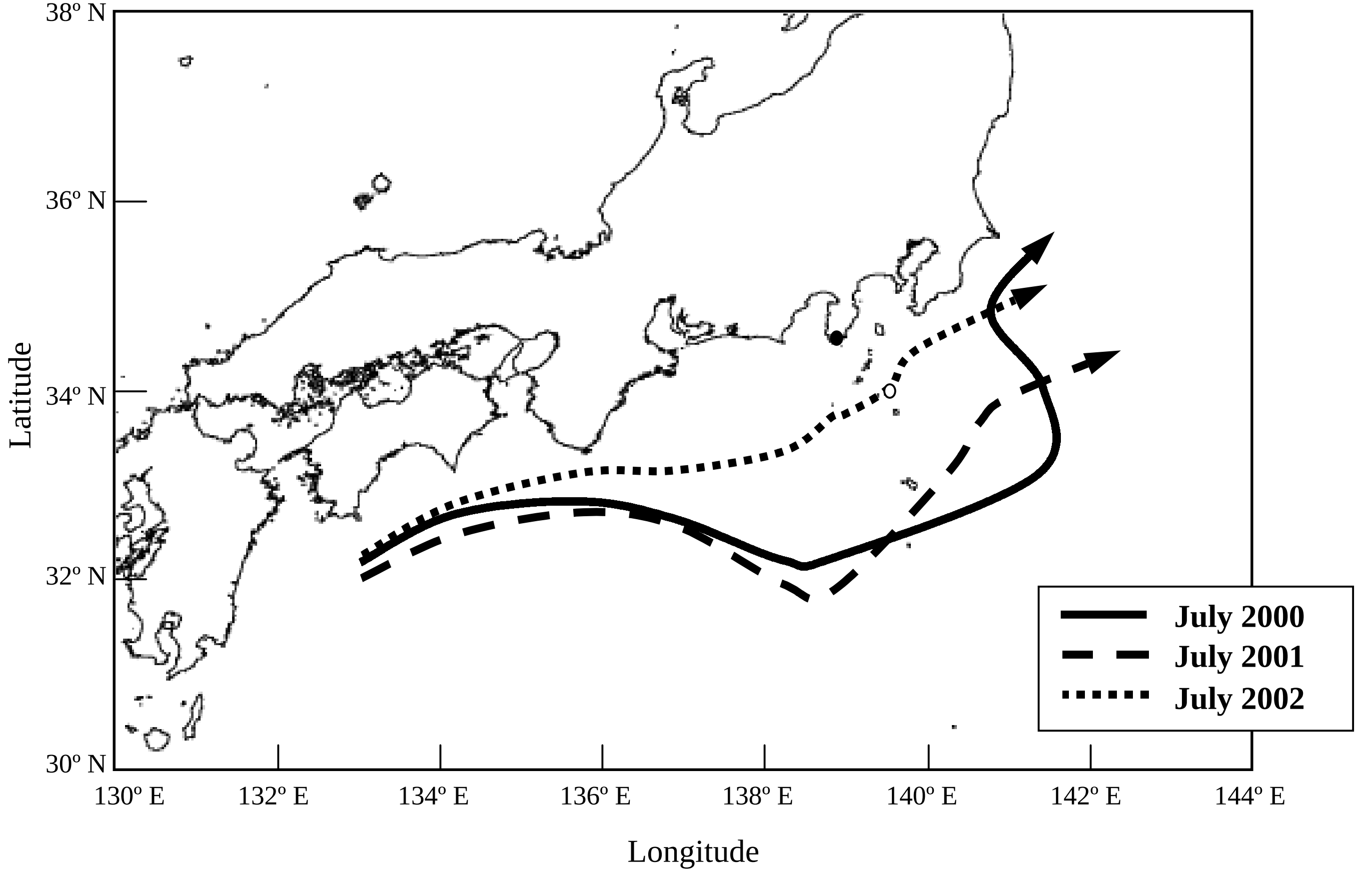

Fig. 4-2b. Paths of the Kuroshio off the Honshu in summer. Data of the Kuroshio axis referred from Quick Bulletin of Ocean Conditions (Japan Coastal Guard, 2000,2001,2002). Closed circle is the position of Cape Irohzaki, and open circle is the position of Miyake Island.

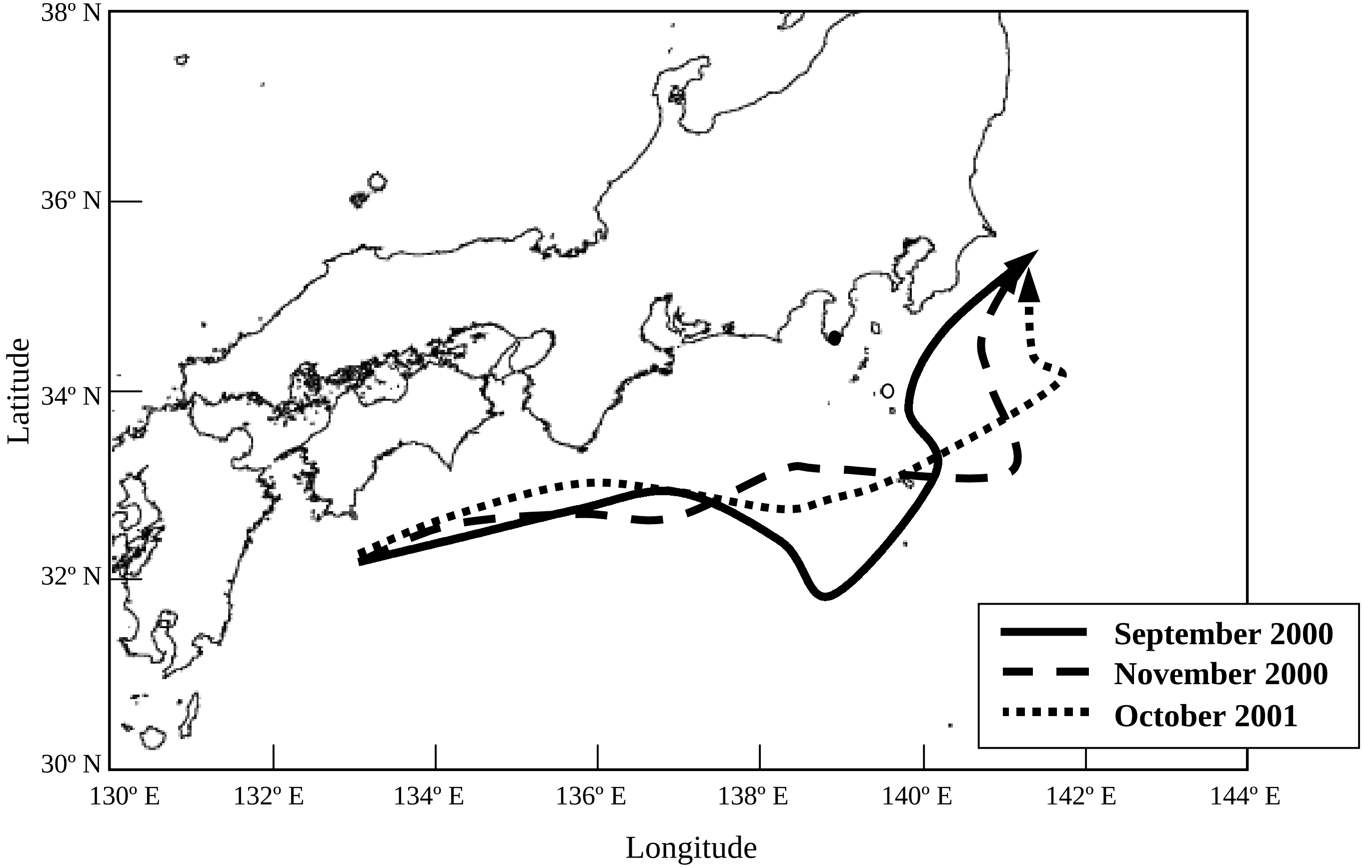

Fig. 4-2c. Paths of the Kuroshio off the Honshu in fall. Data of the Kuroshio axis referred from Quick Bulletin of Ocean Conditions (Japan Coastal Guard, 2000,2001). Closed circle is the position of Cape Irohzaki, and open circle is the position of Miyake Island.

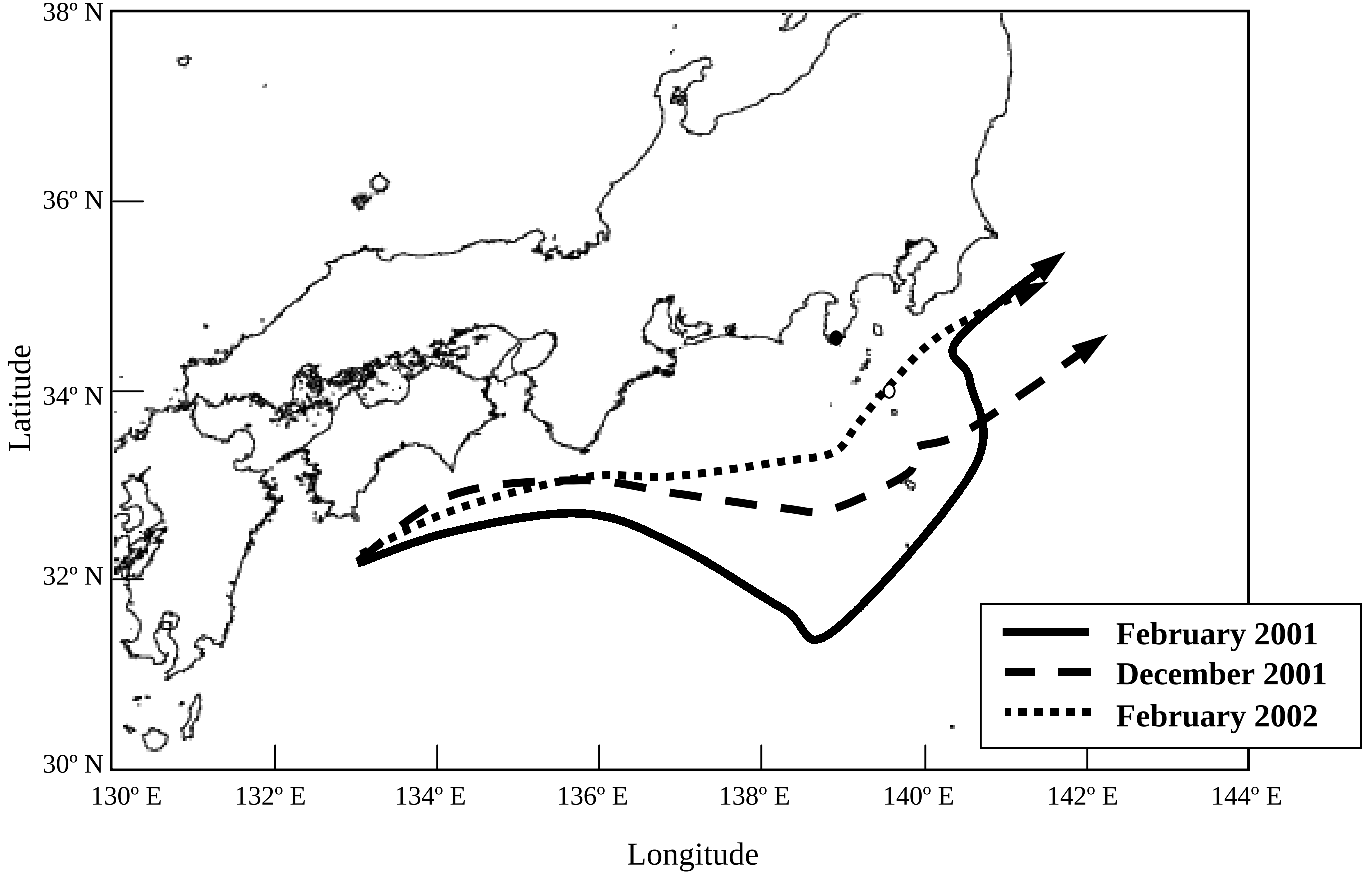

Fig. 4-2d. Paths of the Kuroshio off the Honshu in winter. Data of the Kuroshio axis referred from Quick Bulletin of Ocean Conditions (Japan Coastal Guard, 2001,2002). Closed circle is the position of Cape Irohzaki, and open circle is the position of Miyake Island.

Chapter V: Behavior of total nitrogen and phosphorus, and total organic nitrogen and phosphorus in the Suruga Bay.

Introduction

Total nitrogen (TN) and total phosphorus (TP) shows the sum of all forms of nitrogen (N) and phosphorus (P) in seawater. Previous studies (Karl *et al.*, 1993; Downing, 1997) focused mainly on the ecological N-to-P stoichiometry about TN and TP, with comparing to Redfield ratio (Redfield *et al.*, 1963). TN and TP are composed of inorganic matter (*i.e.*, nitrate, nitrite and ammonium for N and phosphate for P) and organic matter. Many studies reported the spatial variation in organic N and P (*e.g.*, Hopkinson *et al.*, 1997; Abell *et al.*, 2000; Loh and Bauer, 2000; Hung *et al.*, 2003). Recent studies (Hopkinson *et al.*, 1997; Loh and Bauer, 2000) suggests that organic P is more preferential degradation compared to organic N, based on the ratio of organic N and P increasing with depth. Since degradation experiment for organic N and P, the organic N and P were composed of labile, semi-labile and refractory pool (Hopkinson *et al.*, 2002), corresponding to organic carbon (Kirchman *et al.*, 1993, Carlson and Ducklow, 1995).

In this chapter, the temporal variation in TN and TP was observed in the Suruga Bay. The variation in total organic nitrogen (TON) and phosphorus (TOP) was also investigated. Moreover, the characteristics of TON and TOP was determined with particular reference to semi-labile TON and TOP.

Materials and Methods

Total nitrogen (TN) and total phosphorus (TP) samples were collected at St. 2 (Fig. 2-1) from April 2000 to July 2002. Details of the sampling depth were same as nutrient samples (Table 2-2). Water samples were collected into 100 ml polyethylene bottles from the Niskin bottles and kept in freezer (-30 °C) until the analysis. Concentrations of TN and TP were measured using alkaline persulfate oxidation method (Koroleff, 1983; Natori, 2004). Precision of TN and TP analysis were ±2.2 % and ±2.6 %, respectively, estimated from coefficient of variation of the replicated analysis (n = 5) of the seawater samples which contained 28.2 μmol l^{-1} of TN and 1.84 μmol l^{-1} of TP. Detection limit was estimated by multiplying 3 by standard deviation (SD) of the replicated (n = 5) analyses of 3.5% NaCl solution and the values were 0.3 μmol $l^{-1}$and 0.07μmol l^{-1} for TN and TP, respectively.

Total organic nitrogen (TON) and phosphorus (TOP) were investigated in 0 -

200 m from April 2000 to July 2002. TON was calculated by subtracting concentration of dissolved inorganic nitrogen [NO_3 and nitrite (NO_2)] from TN concentration. NO_2 concentration was measured with TRACCS 2000 (BRAN+LUEBBE) (Hansen and Koroleff, 1999). NO_2 concentrations were ca. 0 - 1.0 μmol l^{-1} in this study. TON includes ammonium (NH_4), because NH_4 was not measured in this study. Previous study reported that NH_4 concentration was 0 - 1.7 μmol l^{-1} in the Suruga Bay (Toyota, 1985). TOP was calculated same as TON: subtracting concentration of dissolved inorganic phosphorus (PO_4) from TP concentration.

Results

Temporal distribution of TN and TP

Figure 5-1 shows vertical profiles of TN and TP at St. 2 in the Suruga Bay from April 2000 to July 2002. In the surface layer (0 - 20 m), TN and TP concentrations were lower in summer and fall, and higher in winter. In spring, TN concentration was 8.3 ± 2.7 μmol l^{-1} (average ± standard deviation, n = 9) and 0.42 ± 0.17 μmol l^{-1} (n = 9). In May 2002, TN concentration ranged from 4.6 to 6.0 μmol l^{-1} and lower than in April 2000 (7.9 - 9.9 μmol l^{-1}) and in April 2001 (9.2 - 12.5 μmol l^{-1}). TN was 6.6 ± 1.5 μmol l^{-1} (n = 9) in summer, and 6.7 ± 1.9 μmol l^{-1} (n = 9) in fall, and these were relatively lower than in spring. In winter, TN was 11.9 ± 2.7 μmol l^{-1} (n = 9), and highest compared to those in each season. TN concentration in winter was lower in February 2002 (4.6 - 6.0 μmol l^{-1}) than in February 2001 (10.1 - 11.6 μmol l^{-1}) and in December 2001 (9.5 - 10.2 μmol l^{-1}) (Fig. 5-1). TP concentration in the surface water established similar to that of TN: concentrations of TP were 0.42 ± 0.17 μmol l^{-1} (n = 9) in spring, 0.27 ± 0.11 μmol l^{-1} (n = 9) in summer, 0.24 ± 0.12 μmol l^{-1} (n = 9) in fall and 0.68 ± 0.18 μmol l^{-1} (n = 9) in winter (Fig. 5-1).

Temporal changes of TN and TP were mostly similar tendency to those of nutrients [NO_3, PO_4 and $Si(OH)_4$]. Seasonal variation in TN and TP was largest in the surface layer. Figure 5-2 shows seasonal variation in TN and TP. Seasonal variation in TN and TP was defined as difference between the maximum and the minimum of average concentration in each season, same calculation of nutrients (see chapter II). The seasonal variation in TN was 4.8 - 6.6 μmol l^{-1} in 0 - 50 m, whereas it ranged from 1.3 to 2.8 μmol l^{-1} in below 100 m (Fig. 5-2). The seasonal variation in TP was also higher in 0 - 50 m (0.39 - 0.48 μmol l^{-1}) compared to that in below 100 m (0.01 - 0.23 μmol l^{-1}) (Fig. 5-2).

The difference between the maximum and the minimum concentration of TN and TP in each season was large at the depths from 100 to 300 m in spring and summer

(Fig. 5-3). In spring, the range of TN was 5.6 - 10.1 μmol l^{-1} in 100 - 300 m, whereas it was 5.0 - 7.2 μmol l^{-1} in 0 - 50 m and 0.5 - 2.9 μmol l^{-1} in 400 - 1000 m. The range of TN in summer was also highest in 100 - 300 m than in 0 - 50 m and in 400 - 1000 m (Fig. 5-3). However, the range of TN in fall was hardly different from the surface layer to the deep layer (0.4 - 4.4 μmol l^{-1}) (Fig. 5-3). In winter, the range of TN was widely varied in 0 - 50 m (5.2 - 8.2 μmol l^{-1}) than in below 100 m (1.0 - 3.5 μmol l^{-1}) (Fig. 5-3). The range of TP was similar to the range of TN in each season (Fig. 5-3). As a result, the difference of TN and TP in each season was large in the subsurface layer (100 - 300 m) in spring and summer, and in the surface layer (0 - 50 m) in winter, corresponding to those of nutrients (Fig. 2-7).

Temporal distribution of TON and TOP

Figure 5-4 shows the vertical profiles of TON and TOP from 0 to 200 m at St. 2 in the Suruga Bay from April 2000 to July 2002. TON and TOP marked mostly maximum at the surface layer (0 - 20 m). TON concentration from 0 to 20 m in spring was 7.4 ± 2.5 μmol l^{-1} (average ± standard deviation, n = 9), and it was higher than that in summer (6.5 ± 1.6 μmol l^{-1}, n = 9), fall (5.8 ± 1.7 μmol l^{-1}, n = 6) and winter (5.6 ± 1.7 μmol l^{-1}, n = 9). TOP concentration from 0 to 20 m was also higher in spring (0.28 ±

0.10 μmol l^{-1}, n = 9) compared to that in the other seasons, which ranged from 0.09 to 0.20 μmol l^{-1} (average concentration, n = 5 - 9). On the other hand, TON and TOP concentrations below 100 m was mostly constant, respectively, throughout the sampling dates (Fig. 5-4). Average concentration of TON and TOP from 100 to 200 m were 4.3 ± 1.8 μmol l^{-1} (n = 32) and 0.13 ± 0.08 μmol l^{-1} (n = 32), respectively.

The ratio of TON in TN (TON/TN) and the rate of TOP in TP (TOP/TP) were shown in Table 5-1. When NO_3 was mostly depleted at the surface layer (0 - 20 m) from April to October except for April 2000 (Fig. 2-4), TON/TN and TOP/TP were 92 - 100% and 41 - 98%, respectively. It is consistent with the limitation of phytoplankton production by NO_3 (see chapter II). In November, NO_3 concentration at the surface layer was higher than those from April to October, and TON/TN and TOP/TP decreased to 67 - 73% and 20 - 47%, respectively (Table 5-1). NO_3 and PO_4 at the surface layer in winter were highest among other seasons, and TON/TN and TOP/TP were 29 - 76% and 2 - 43%, respectively (Table 5-1). These results suggest that from November to February, an increase of nutrients by vertical convection in late fall and winter was less related with an increase of phytoplankton productivity, because of limitation of phytoplankton productivity by other causes (relationship mixed layer depth and critical depth). On the other hand, TON/TN and TOP/TP in 100 m - 200 m were 2 - 68% and 2

- 43%, respectively (Table 5-1). This implies that most of TN and TP account for nutrients (NO_3 and PO_4) below the euphotic layer.

Discussion

Average concentrations in each season of TON in the surface layer (0 - 20 m) ranged from 5.6 to 7.4 μmol l^{-1} and those of TOP ranged from 0.09 to 0.28 μmol l^{-1} (Fig. 5-4). Natori *et al.* (2002) reported that particulate organic nitrogen (PON) and particulate organic phosphorus (POP) in the Suruga Bay was 0.4 - 1.4 μmol l^{-1} and 0.03 - 0.11 μmol l^{-1}, respectively at the surface layer, and it was < 0.1 μmol l^{-1} and < 0.02 μmol l^{-1}, respectively in 100 - 200 m. It indicates that most of TON and TOP occupies dissolved organic nitrogen (DON) and dissolved organic phosphorus (DOP), and the rate of DON and DOP was ca. 80 - 90% of TON and TOP. Abell *et al.* (2000) reports that PON or POP occupied < 10% of TON or TOP in the north Pacific subtropical gyre, suggesting that the proportions of particulate matter with regard to organic matter was relatively high in the Suruga Bay. Table 5-2 shows DON and DOP concentrations reported in the recent studies. DON and DOP (or TON and TOP) ranged from 1.5 to 14.3 μmol l^{-1} and from 0.02 to 0.42 μmol l^{-1}, respectively in the recent reports. In this study, TON ranged from 0.5 to 12.5 μmol l^{-1}, and TOP ranged from 0.02 to 0.47 μmol l^{-1}

(Fig. 5-4), and it was mostly same range as the recent reports. The highest TON and TOP was observed at 0 m in April 2001 (12.5 and 0.47 μmol l^{-1}, respectively). In April 2001, concentration of particle organic carbon and nitrogen was 30.1 and 4.8 μmol l^{-1}, respectively at 0 m, and it was highest concentration during time series experiment (unpublished data). Chlorophyll *a* was also high concentration (1.6 μg l^{-1}) at 0 m in St. 2 (Fig. 2-9b). These results suggest that higher phytoplankton production and biomass reflect on TON and TOP concentration, corresponding to relatively high contribution of particulate organic matter.

To estimate the characteristics of TON and TOP at the surface layer, semi-labile TON and TOP (S-TON, S-TOP, respectively) was calculated from 0 to 50 m. S-TON and S-TOP was examined by applying the concept suggested by Carlson and Ducklow (1995) (Fig. 5-5). For example, Ogawa (2001) reported that semi-labile dissolved organic matter (DOC), which was examined based on this concept, occupied 44% of DOC pool at the surface layer in northwest Pacific Ocean. However, recent report was few for semi-labile DON and DOP (or TON and TOP) (Aminot and Kérouel, 2004). In this study, refractory TON and TOP defined as average concentration of TON and TOP from 100 to 200 m. Hino (2004) reported that organic nitrogen concentration in degradation experiment slightly decreased by < 0.5 μmol l^{-1} at samples taken from 100 m and 200 m in the Suruga Bay, and it was smaller than those at the surface layer. It seems that organic matter below 100 m occupied mostly refractory organic matter. Average concentrations of TON and TOP from 100 to 200 m was 4.3 μmol l^{-1} and 0.13 μmol l^{-1}, respectively. If this average concentration is assumed to be a refractory TON and TOP, S-TON and S-TOP is consistent with the result of Natori (2004). Natori (2004) reported that TON and TOP concentration in degradation experiment at 35-day was 4.0 - 4.5 μmol l^{-1} and 0.10 - 0.15 μmol l^{-1} using samples taken from 20 m in the Suruga Bay, and it concentration was nearly constant among all seasons. This implies that degradation rate of S-TON and S-TOP, which was calculated in this study, is about 40 days or less.

S-TON and S-TOP was calculated by subtracting average concentration of TON and TOP between 100 m and 200 m from TON and TOP concentration at the surface layer (0 - 50 m). S-TON and S-TOP in 0 - 50 m varied from -1.06 to 8.23 μmol l^{-1} and from -0.11 to 0.34 μmol l^{-1}, respectively. To examine relationship between S-TON or S-TOP and chlorophyll *a*, integrated S-TON and S-TOP was calculated from 0 to 50 m. Integrated depth (0 - 50 m) was assumed to be the same as the depth of the euphotic layer. The depth of euphotic layer from September 2000 to July 2002 was 33 - 62 m (April and July 2000 was not measured), and it was calculated from transparency (12 -

23 m) (Shinomura *et al.*, in press). Table 5-3 shows integrated S-TON and S-TOP with integrated chlorophyll *a*. S-TON in February 2000 and S-TOP in July, September, November 2000 and February 2001 were observed minus value, because of lower concentration of TON and TOP compared with that in 100 - 200 m. These data do not use for in this discussion. S-TON varied from 42 to 177 mmol m^{-2} and the proportions of S-TON to TON was 16 - 45%. Recent studies report that labile and semi-labile TON was composed 20 - 39% of TON under the degradation experiment (Hopkinson *et al.*, 2002; Natori, 2004). These were consistent with the result of this study. There was a significantly correlation between integrated S-TON and integrated chlorophyll *a* (r_s = 0.67, n = 11, $P < 0.05$) by Spearman's rank correlation, implying an increase of S-TON was related with the magnitude of primary production. In spring, S-TON was smaller in May 2002 (42 mmol m^{-2}) than in April 2000 (167 mmol m^{-2}) and in April 2001 (177 mmol m^{-2}), implying that it caused by lower primary production in May 2002 compared to that in April 2000 and 2001 (*i.e.,* lower chlorophyll *a* concentration in May 2002; Fig. 2-9). It is consistent with the result of the positive correlation between Δ[NO_3-int] and Δ[chl.*a*-int] (Table 2-10). It is possible that an increasing intrusion of warm and saline water also influences on the magnitude of organic matter at the surface layer. On the other hand, S-TOP varied from 1.0 to 8.6 mmol m^{-2} and the proportions of S-TOP with

regard to TOP was 13 - 58% (Table 5-3). Natori (2004) reported that labile and semi-labile TOP was composed 30 - 50% of TOP in the Suruga Bay, corresponding with the result of this study, whereas Hopkinson *et al.* (2002) reported that the proportions of S-TOP to TOP was 82% in the middle Atlantic bight. The variation in S-TOP was not clearly compared to that of S-TON. Also, S-TOP was not significantly correlated with integrated chlorophyll *a* (r_s = -0.07, n = 8, $P > 0.05$). It is possible that variation in S-TOP is affected by relatively faster degradation of TOP than organic carbon and nitrogen (*e.g.,* Loh and Bauer, 2000, Kolowith *et al.*, 2001).

In summary, total nitrogen (TN) and total phosphorus (TP) concentration was observed at St. 2 in the Suruga Bay from April 2000 to July 2002, and total organic nitrogen (TON) and total organic phosphate (TOP) concentration was also investigated. TON and TOP concentration varied from 0.5 to 12.5 μmol l^{-1} and from 0.02 to 0.47 μmol l^{-1}, respectively. These results were consistent with the results of previous reports. Applying the concept suggested by Carlson and Ducklow (1995), semi-labile TON (S-TON) and TOP (S-TOP) was calculated. Integrated S-TON and S-TOP from 0 to 50 m was 42 - 177 mmol m^{-2} and 1.0 - 8.6 mmol m^{-2}, respectively. The proportion of S-TON with regard to TON was 16 - 45% and that of S-TOP was 13 - 58%. There was a significantly correlation between integrated S-TON and integrated chlorophyll *a* (r_s =

0.67, n = 11). This implies that S-TON is related with the variation in productivity of phytoplankton. It is possible that the variation in S-TON is also influenced by an increasing intrusion of warm and saline water. On the other hand, integrated S-TOP was not significantly correlated with integrated chlorophyll *a*. This result might be caused by the difference of characteristics of TON and TOP for degradation.

Table 5-1. The ratio of TON / TN and TOP / TP at St. 2 in the Suruga Bay.

range of depth (m)	period	TON/TN (%)		TOP/TP (%)	
		range	n	range	n
0 - 20	spring	69 - 100	9	40 - 98	9
	summer	95 - 100	9	45 - 92	9
	fall	67 - 100	9	20 - 76	8
	winter	29 - 76	9	3 - 64	9
	April to October*	92 - 100	20	41 - 98	20
100 - 200	all seasons	2 - 68	32	2 - 43	32

* : NO_3 depleted in the surface layer.

Table 5-2. Literature value of concentrations of dissolved organic nitrogen (DON) and dissolved organic phosphorus (DOP).

Location	depth (m)	DON (μmol l^{-1})	DOP (μmol l^{-1})	reference	
Suruga Bay	0-50		0.17 - 0.29	Yanagi *et al*. (1992)	
	0-1000		0.06 - 0.29	Yanagi *et al*. (1992)	
Suruga Bay	0-200	3.7 - 6.0	0.11 - 0.25	Natori (2004)	
Northern shelf, Spain	0-80	4.58 ± 0.2		Bode *et al*. (2001)	a
	0-80	7.78 ± 0.23		Bode *et al*. (2001)	a
Middle Atlantic Bight	0-1500	3.5 - 14.3	0.01 - 0.42	Hopkinson *et al*. (2002)	
George Bank	0-1500	2.5 - 5.0	0.02 - 0.17	Hopkinson *et al*. (1997)	
NW Mediterranean Sea	0-120	4.5 - 5.5	0.06 - 0.1	Rainbault *et al*. (1999)	b
North Pacific Ocean subtropical gyre	0-50	5.0 - 7.5	0.1 - 0.35	Abell *et al*. (2000)	c
the eastern part, North Pacific Ocean	25-4000	1.5 - 4.5	0.01 - 0.2	Loh and Bauer (2000)	
the subtropical region, North Pacific Ocean	0-1000	2.0 - 9.0	0.07 - 0.40	Karl *et al*. (2001)	
the western part, North Pacific Ocean	0-200	3.6 - 4.8	0.09 - 0.16	Natori (2004)	
Atlantic Ocean		<3.0 - 11	<0.1 - 0.3	Vidal *et al*. (1999)	
Southern Ocean	0-5400	2.5 - 5.2	0.07 - 0.23	Loh and Bauer (2000)	

a : average concentration.

b :the range of the average value in each three station.

c : measured as TON and TOP.

Table 5-3. Integrated S-TON (semi-labile TON), S-TOP (semi-labile TOP) and chlorophyll *a* from 0 to 50 m at St. 2. S-TON / TON and S-TOP / TOP show the proportions of S-TON or S-TOP with regard to TON or TOP.

season	date	S-TON (mmol m^{-2})	S-TON / TON (%)	S-TOP (mmol m^{-2})	S-TOP / TOP(%)	chlorophyll *a* (mg m^{-2})
spring	April 24, 2000	167	43.5	4.3	40.4	125.4
	April 25, 2001	177	45.1	8.6	57.5	48.8
	May 14, 2002	42	16.3	3.2	33.0	21.1
summer	July 10, 2000	77	26.3	-	-	33.4
	July 11, 2001	46	17.7	5.3	45.3	20.9
	July 23, 2002	83	27.9	1.0	13.1	23.8
fall	September 20, 2000	111	33.8	-	-	24.6
	November 27, 2000	48	18.1	-	-	23.3
	October 25, 2001	49	18.4	3.5	35.0	62.0
winter	February 19, 2001	-	-	-	-	26.7
	December 12, 2001	129	37.3	8.1	55.9	33.6
	February 20, 2002	99	31.0	6.7	50.9	40.9

- : S-TON or S-TOP was not examined.

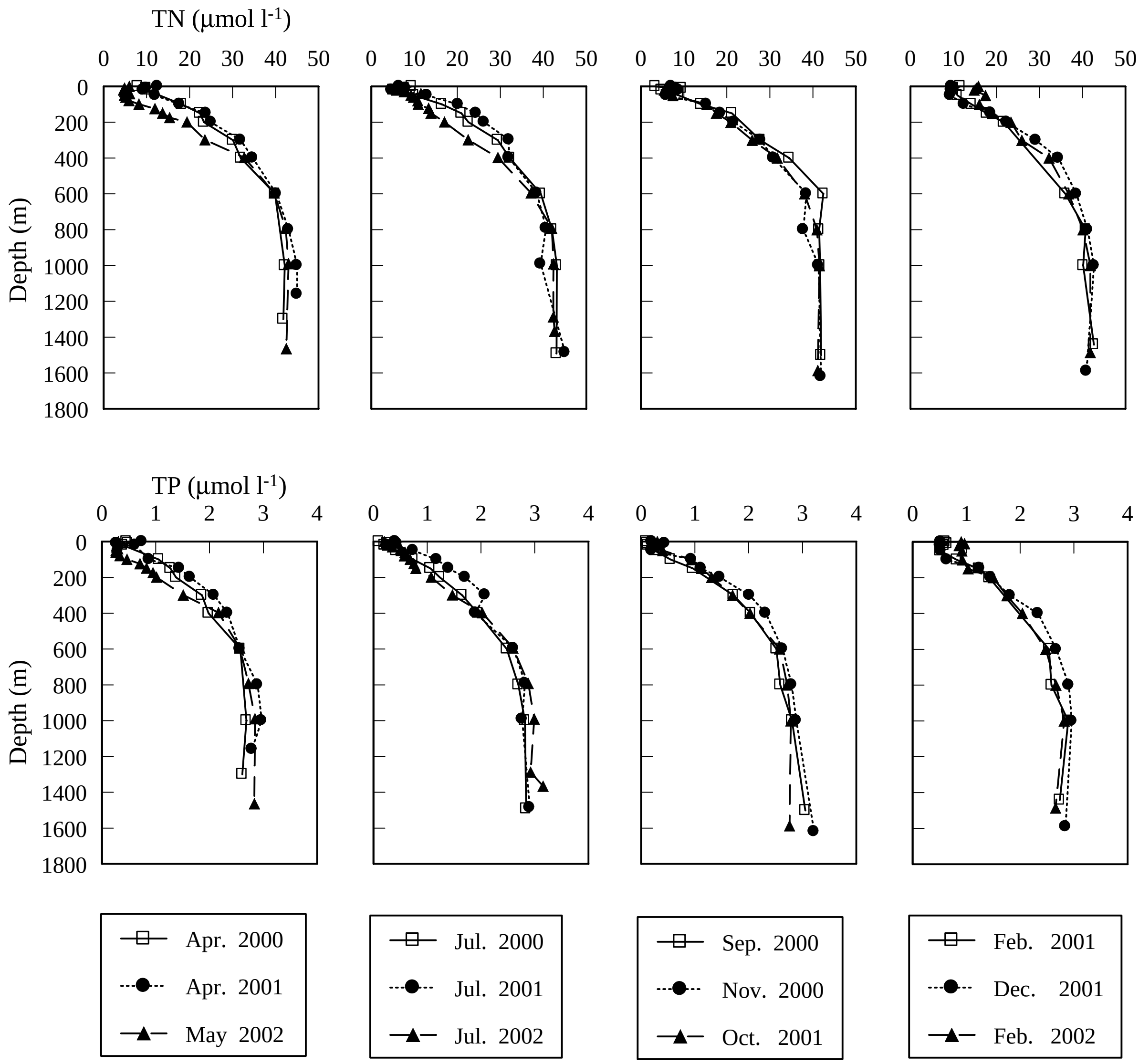

Fig. 5-1. Vertical profiles of TN (total nitrogen) and TP (total phosphorus) at St. 2 in the Suruga Bay from April 2000 to July 2002.

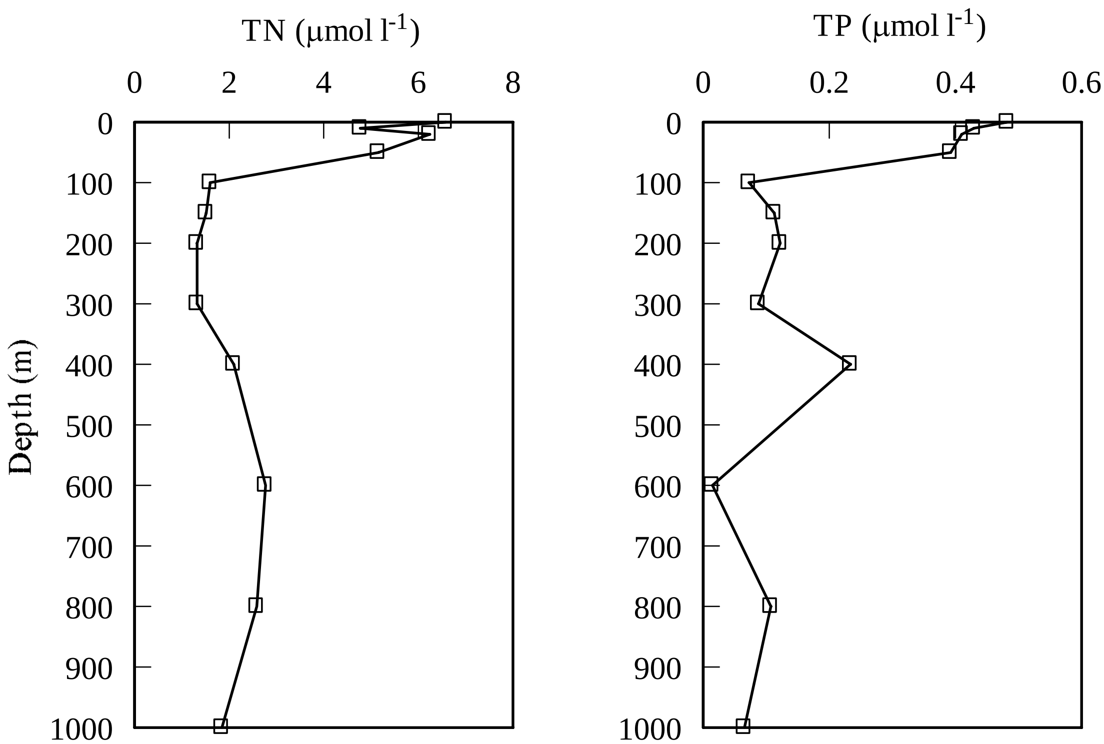

Fig. 5-2. Seasonal variation in TN and TP at St. 2.

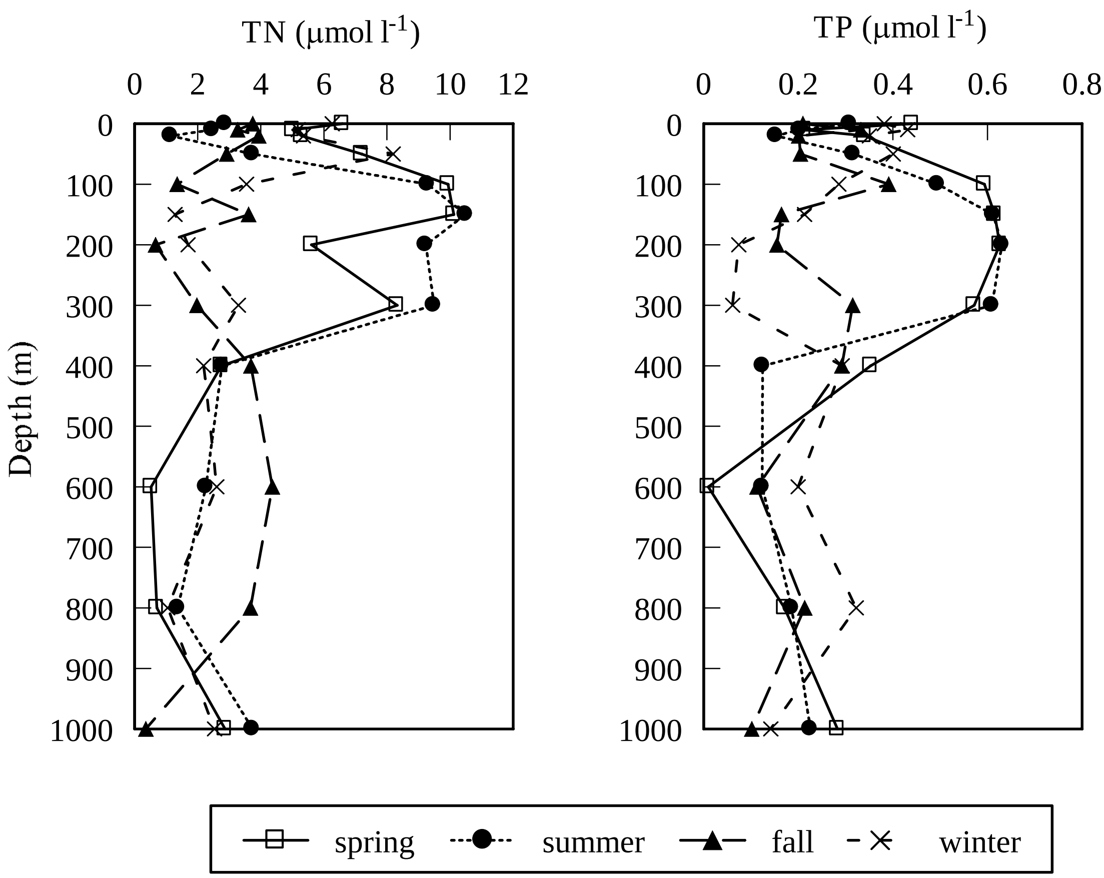

Fig. 5-3. The variation in TN and TP in each season at St. 2.

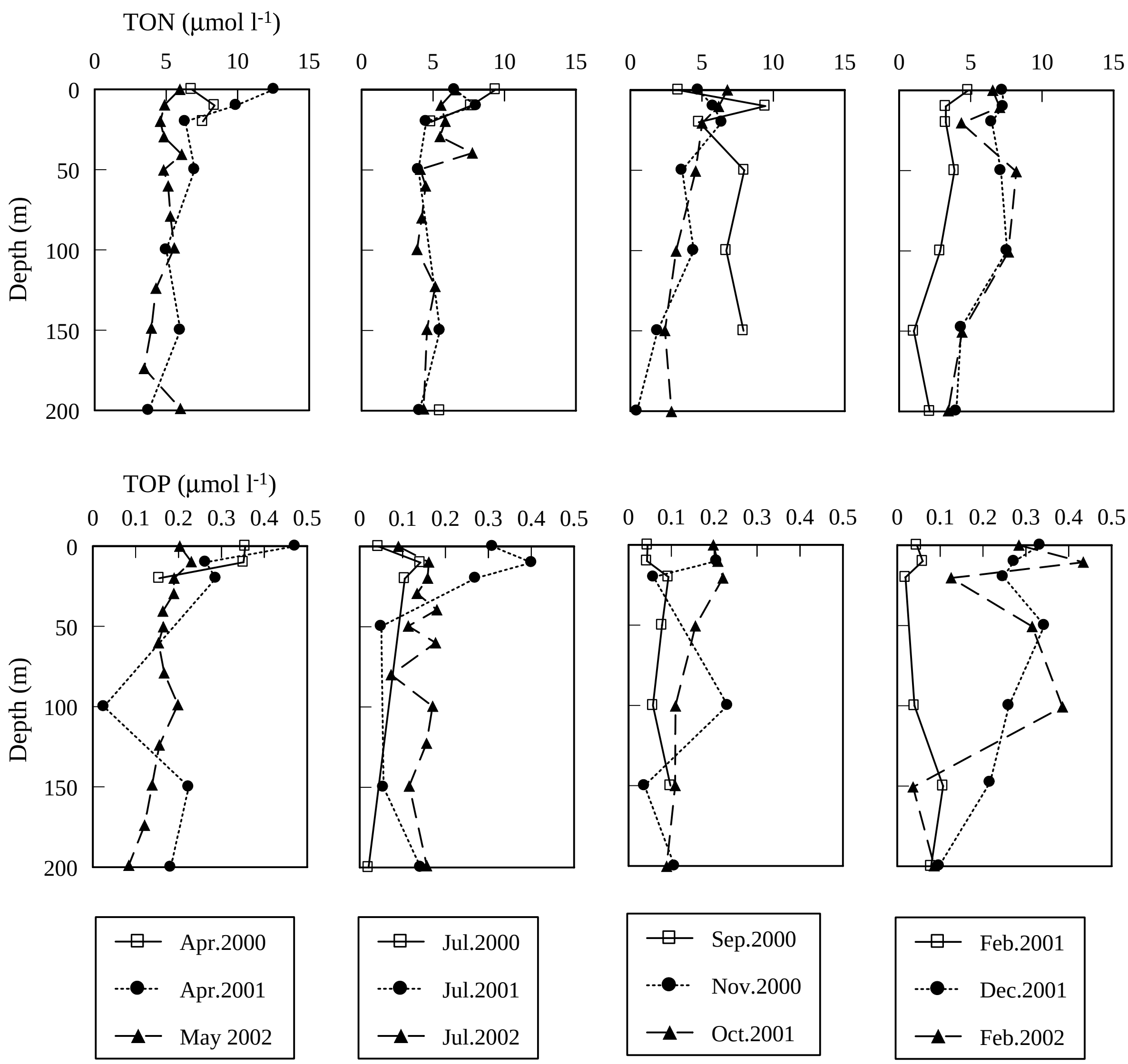

Fig. 5-4. Vertical profiles of TON (total organic nitrogen) and TOP (total organic phosphorus) at St. 2 in the Suruga Bay from April 2000 to July 2002.

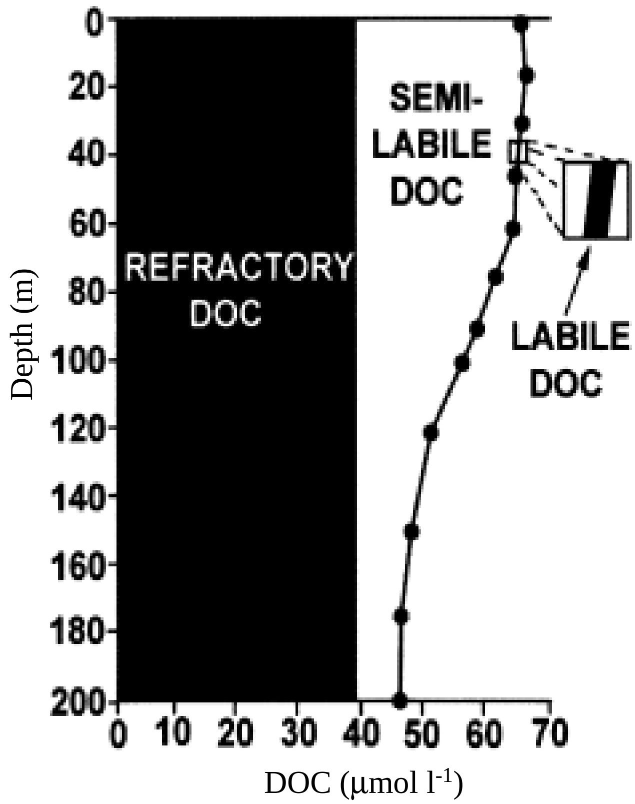

Fig. 5-5. Diagram of bulk DOC pool partitioned into refractory pool, semi-labile pool and labile pool. (from Carlson and Ducklow, 1995).

Chapter VI: Conclusion

In this thesis, the variation in nutrients and water structure was observed in the Suruga Bay from April 2000 to July 2002. Temporal variations in salinity and potential temperature (θ) were larger in the subsurface salinity maximum layer. Seasonal variation in nutrient (difference in average concentration of nutrients in each season) was larger in the surface layer (0 - 50 m) than in below 100 m. On the other hand, the variation in nutrients in each season (the range of the nutrients concentration in each season) was larger in the subsurface layer (100 - 300 m) for spring, summer and fall. In the subsurface salinity maximum layer, variation in nutrients concentration was related with that in salinity, suggesting the low nutrients concentration can be found in this layer when high salinity and θ exsisted. In the Offshore Water, which was characterized by salinity maximum, the difference in salinity between the sampling date in each season at the same station and depth was significantly negatively correlated with those of nutrients. This result suggests that an increasing intrusion of warm and saline water with low nutrient bring about low nutrient concentration in the Offshore Water. This phenomenon would be extremely related with the position of the

Kuroshio axis in the Suruga Bay offing. When salinity at the subsurface salinity maximum was high in spring and summer, the position of the Kuroshio axis was nearer to the Suruga Bay, suggesting that an increasing intrusion of saline water is caused by approaching of the Kuroshio axis to the Suruga Bay and the origin of the warm and saline water is the Kuroshio Water. In fall, higher salinity maximum, which was observed in September 2000, may be caused by northward flow in Cape Irohzaki offing. Furthermore, vertical section of salinity in September 2000 shows the counterclockwise circulation of the intrusion and extension of saline water. In north-south cross section, variation in salinity at the subsurface salinity maximum was smaller than that in September 2000. These results are consistent that an increasing intrusion of saline water would bring about the approach of the Kuroshio axis to the Suruga Bay. In May 2002, salinity maximum was 34.71 and decreased 34.62 after two weeks, whereas salinity maximum was 34.71 in July 2002. This implies that an increasing intrusion of the saline water is the changes of 20 - 40-days period. In this period, nutrient budget in 0 - 200 m increased ca. 1.6 - 2.0 times in two weeks. This suggests that about 50% of nutrient budget, in which salinity maximum was low, decreases by the effect of the increasing intrusion of warm and saline water to the Offshore Water.

In the surface layer, nitrate (NO_3) was mostly depleted from April to October, whereas phosphate (PO_4) and silicate [$Si(OH)_4$] were sufficient, suggesting the limitation of primary production by NO_3 in the Suruga Bay from spring to fall. Surface chlorophyll *a* was mostly higher at St. 3. St. 3 is closest to river mouth and the surface salinity was lowest at St. 3, suggesting the effect of riverine water on chlorophyll *a*. On the other hand, the difference in salinity maximum between the sampling dates in each season was negatively correlated with that in integrated chlorophyll *a* {Δ[chl. *a*-int]} and that in integrated nutrients {Δ[nutrients-int]}. Δ[chl. *a*-int] was positively correlated to Δ[NO_3-int], but there were no significant correlations between Δ[chl. *a*-int] and Δ[PO_4-int] or Δ[$Si(OH)_4$-int]. These results imply that an increasing intrusion of saline water in the Offshore Water would have resulted in the lower concentrations of chlorophyll *a* and nutrients in the upper 200 m and suggest that NO_3 regulates the total primary production.

TON and TOP concentration were consistent with the results of recent reports. Applying the concept suggested by Carlson and Ducklow (1995), semi-labile TON (S-TON) and TOP (S-TOP) was calculated. Integrated S-TON and S-TOP were a significant correlation between integrated S-TON and integrated chlorophyll *a*. The variation in S-TON may be influenced by an increasing intrusion of saline water. On the other hand, integrated S-TOP was not significantly correlated with integrated chlorophyll *a*. This result might be related with the difference of characteristics of TON and TOP for degradation.

In this thesis, it is first finding that large temporal variation in nutrients in the Offshore Water related with the variation in salinity. Because the Offshore Water accounts for the significant fraction of the total water volume of the Suruga Bay [15.1 - 25.0%; Nakamura (1982)], the various contribution of Kuroshio Water in the Offshore Water would have considerable effects on the nutrients dynamics and primary production in the Suruga Bay. Moreover, it is important to explain the biogeochemical cycle of nitrogen and phosphorus, which sustained the primary productivity in the Suruga Bay.

The result of this thesis would be not restrictive to estimate of biogeochemical cycle in the Suruga Bay. Previous studies that estimated influence of intrusion of the Kuroshio originated water in coastal area were mostly from physical viewpoint, and few from biogeochemical viewpoints. The result of this thesis indicates that the estimation of the effect of Kuroshio Current, which is due to the variation in the path of the Kuroshio Current, is important to the study of nutrients dynamics and phytoplankton productivity in the coastal area in the south coast of Japan.

Acknowledgement

I would like to express my thanks to Professor Yoshimi Suzuki, Department of Biology and Geoscience, Shizuoka University. He gave me opportunity to study in his laboratory, this subject, valuable scientific guidance and encouragement during this study. I wish to thank to Professor Hideki Wada and Doctor Rumi Sohrin, Department of Biology and Geoscience, Shizuoka University. They discussed with me and told me valuable guidance to this study. I also wish to express my thanks to Professor Yuzo Shioi (Department of Biology and Geoscience, Shizuoka University), Professor Takashige Sugimoto (Institute of Oceanic Research and Development, Tokai University), Doctor Akihiro Shiomoto (National Research Institute of Fisheries Science, Fisheries Research Agency) and Doctor Masayuki Minakawa (National Research Institute of Fisheries Science, Fisheries Research Agency). They will review this thesis and will tell me what I should express in this thesis.

I am supported and indebted by the staffs of Y. Suzuki laboratory, Department of Biology and Geoscience, Shizuoka University. Especially, the members of research team of the Suruga Bay; Miss Yoshiko Shinomura, Mr. Yuta Natori, Mr. Mamoru Hino and Miss Aya Haneda. They gave me many advices for this study and supports in research and analysis.

I thank the captain and the crew of R/V *Suruga-Maru*, and Mr. Yasumasa Igarashi, Mr. Yoshitsugu Hagiwara and Mr. Takayuki Hanai (Shizuoka Prefectural Fisheries Experiment Station) for their support in sampling for this study. The part pf this work was funded by the Japan Ministry of Education, Culture, Sports, Science and Technology (Grant-in-Aid for Scientific Research 12793001).

Finally, I sincerely thank to my parents, sister and younger brother from the bottom of my heart for their support and encouragement.

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Appendix 1. θ, salinity, σ_θ, nutrients [NO_3, PO_4, $Si(OH)_4$] and chlorophyll *a* data in April 2000.

station	Depth (m)	θ (℃)	salinity	σ_θ	NO_3	PO_4	$Si(OH)_4$	chlorophyll *a*
St. 3	2				1.19	0.22		3.3
	10	15.10	34.37	25.47	1.50	0.19		5.8
	20	14.91	34.45	25.57	2.59	0.25		5.4
	30	14.93	34.50	25.60	3.07	0.27		
	50	14.87	34.56	25.67	4.04	0.31		3.3
	70	14.74	34.57	25.70	5.07	0.46		1.7
	100	14.43	34.59	25.79	7.09	0.58		0.6
	125	14.01	34.58	25.86	8.84	0.67		
	150	13.42	34.55	25.96	10.86	0.80		0.1
	200	11.01	34.41	26.32	20.40	1.49		0.0
	300	9.02	34.33	26.59	24.88	1.84		
	490	7.22	34.30	26.84	29.52	2.15		
St. F	0				0.64	0.11		2.5
	10	15.23	34.44	25.49	0.31	0.02		4.2
	20	15.22	34.46	25.51	0.83	0.04		3.2
	50	14.78	34.58	25.70	3.47	0.27		1.7
	70	14.41	34.59	25.79	5.44	0.41		0.5
	100	13.59	34.55	25.93	8.83	0.54		0.1
	125	13.21	34.53	25.99	11.41	0.73		
	150	12.34	34.49	26.13	9.84	0.60		0.0
	200	10.93	34.40	26.32	20.24	1.41		0.0
	300	9.17	34.34	26.57	24.72	1.74		
	400	7.75	34.30	26.76	27.87	2.04		
	600	6.06	34.31	27.00				
	800	4.58	34.36	27.22				
St. E	0				0.45	0.14		2.5
	10	15.24	34.49	25.53	1.06	0.02		2.7
	20	15.18	34.50	25.55	0.91	0.06		3.2
	30	15.11	34.50	25.56	1.79	0.15		3.0
	50	15.04	34.51	25.59	3.20	0.28		3.3
	70	14.31	34.60	25.81	8.10	0.23		2.6
	100	13.49	34.56	25.95	11.62	0.81		
	125	12.54	34.50	26.10	8.68	0.48		0.1
	150	11.79	34.45	26.21	18.02	1.26		0.0
	200	10.65	34.39	26.36	21.32	1.52		
	300	9.22	34.34	26.56				
	400	7.61	34.30	26.78	28.14	2.03		
	625	5.64	34.32	27.06	33.45	2.42		
St. 2	0				1.13	0.10		1.8
	10	15.35	34.55	25.55	1.51	0.13		2.8
	20	15.34	34.55	25.56	2.31	0.23		2.9
	50	14.75	34.58	25.71	2.47	0.18		2.0
	100	13.44	34.54	25.95	7.30	0.44		0.1
	150	11.95	34.46	26.18	13.13	0.81		0.0
	200	11.05	34.41	26.31	16.15	1.09		0.0
	300	9.29	34.33	26.55	15.11	1.02		
	400	8.09	34.31	26.72	27.50	1.96		
	600	5.79	34.31	27.04	33.07	2.39		
	800	4.15	34.39	27.28				
	1000	3.14	34.46	27.44	37.73	2.69		
	1300	2.53	34.52	27.55	38.03	2.73		

unit. NO_3, PO_4, $Si(OH)_4$: µmol l^{-1}; chlorophyll *a* : µg l^{-1}

Appendix 2. θ, salinity, σ_θ, nutrients [NO_3, PO_4, $Si(OH)_4$] and chlorophyll *a* data in July 2000.

station	Depth (m)	θ (℃)	salinity	σ_θ	NO_3	PO_4	$Si(OH)_4$	chlorophyll *a*
St. 3	2				0.00	0.04		0.7
	10	22.36	33.80	23.21	0.00	0.05		0.4
	20	21.09	34.27	23.92	0.00	0.01		0.5
	30	20.06	34.49	24.36	1.87	0.19		
	50	18.01	34.56	24.94	3.26	0.21		0.3
	70	16.57	34.57	25.29	8.17	0.53		0.2
	100	15.06	34.58	25.64	10.98	0.75		0.0
	125	14.01	34.56	25.84	12.69	0.89		
	150	13.18	34.52	25.99	14.64	1.02		0.0
	200	11.92	34.45	26.18	13.26	0.85		0.0
	300	9.67	34.35	26.50	23.23	1.65		
	615	5.64	34.31	27.05	29.12	2.09		
St. F	0				0.43	0.07		0.4
	10	22.13	33.82	23.29	0.00	0.08		0.5
	20	21.46	34.01	23.62	0.00	0.06		0.7
	50	19.04	34.55	24.67	3.17	0.30		0.6
	70	16.94	34.57	25.20	3.92	0.24		0.2
	100	15.45	34.59	25.56	9.34	0.69		0.1
	125	14.44	34.56	25.76	7.46	0.44		
	150	13.71	34.54	25.89	14.61	1.02		0.0
	200	12.28	34.47	26.12	16.89	1.21		0.0
	300	9.68	34.35	26.50	23.17	1.65		
	400	8.17	34.31	26.71	26.92	1.95		
	600	5.73	34.31	27.04	33.03	2.43		
	755	4.63	34.35	27.20	35.98	2.66		
St. E	0				0.00	0.02		0.5
	10	22.04	33.75	23.26	0.00	0.03		0.5
	20	21.66	33.91	23.49	0.00	0.05		0.6
	30	21.27	34.06	23.71	0.27	0.11		
	50	18.28	34.59	24.89	4.49	0.34		0.4
	70	17.07	34.58	25.18	7.10	0.50		0.2
	100	15.11	34.56	25.61	11.12	0.78		0.1
	125	14.19	34.54	25.80	12.90	0.90		
	150	13.36	34.52	25.95	14.40	0.99		0.0
	200	11.93	34.45	26.18	18.18	1.30		0.0
	300	9.73	34.35	26.49	23.06	1.66		
	400	8.15	34.31	26.71	27.04	1.95		
	650	5.60	34.31	27.06	33.45	2.52		
St. 2	0				0.00	0.05		0.6
	10	21.92	33.75	23.30	0.07	0.11		1.2
	20	21.24	34.07	23.73	0.23	0.10		0.7
	50	18.01	34.54	24.92	9.75	0.70		0.3
	100	15.42	34.60	25.57	4.75	0.38		0.1
	150	13.48	34.53	25.93	9.45	0.58		0.0
	200	12.10	34.47	26.16	17.13	1.21		0.0
	300	9.67	34.36	26.50	23.29	1.65		
	400	8.18	34.31	26.70	26.67	1.92		
	600	5.60	34.30	27.05	33.51	2.46		
	800	4.30	34.37	27.25	36.15	2.67		
	1000	3.48	34.43	27.38	37.27	2.72		
	1492	2.46	34.53	27.56	37.91	2.79		

unit. NO_3, PO_4, $Si(OH)_4$: μmol l^{-1}; chlorophyll *a* : μg l^{-1}

Appendix 3. θ, salinity, σ_θ, nutrients [NO_3, PO_4, $Si(OH)_4$] and chlorophyll *a* data in September 2000.

station	Depth (m)	θ (℃)	salinity	σ_θ	NO_3	PO_4	$Si(OH)_4$	chlorophyll *a*
St. 3	2	26.48	32.76	21.20	1.32	0.00		1.7
	10	26.51	32.94	21.33	0.00	0.03		0.8
	20	26.38	33.77	21.99	0.00	0.04		0.7
	30	25.13	34.14	22.65	0.00	0.06		
	50	21.43	34.31	23.85	4.00	0.32		0.1
	70	18.32	34.48	24.80	7.80	0.51		0.1
	100	17.03	34.53	25.15	9.99	0.63		0.1
	125	16.14	34.54	25.36	11.65	0.73		
	150	14.93	34.54	25.64	13.43	0.86		0.0
	200	13.21	34.49	25.96	16.30	1.03		0.0
	300	9.56	34.36	26.53	25.03	1.62		
	495	6.54	34.30	26.93	33.69	2.26		
St. F	0				0.00	0.04		0.5
	10	26.51	33.30	21.59	0.00	0.02		0.5
	20	26.62	33.86	21.98	0.00	0.04		0.4
	50	22.96	34.18	23.33	1.92	0.21		0.3
	70	20.32	34.63	24.40	4.93	0.36		0.2
	100	17.52	34.51	25.02	9.38	0.60		0.1
	125	16.21	34.54	25.35	11.43	0.72		
	150	15.01	34.54	25.62	10.83	0.62		0.0
	200	13.69	34.50	25.87	16.20	1.02		0.0
	300	9.67	34.36	26.51	25.68	1.68		
	400	7.58	34.31	26.79	30.96	2.05		
	600	5.55	34.32	27.07	35.96	2.43		
	824	4.41	34.37	27.24	39.11	2.62		
St. E	0				0.00	0.02		0.3
	10	26.57	33.41	21.66	0.00	0.01		0.3
	20	26.50	33.83	22.00	0.00	0.03		0.3
	30	24.64	34.00	22.70	0.00	0.16		0.7
	50	22.56	34.22	23.47	1.50	0.19		0.5
	70	20.72	34.66	24.31	4.11	0.29		
	100	18.29	34.65	24.94	8.70	0.56		0.1
	125	16.27	34.54	25.33	11.32	0.73		
	150	15.52	34.54	25.51	12.64	0.80		0.0
	200	12.78	34.48	26.03	17.34	1.12		0.0
	300	9.75	34.36	26.49	24.99	1.64		
	400	7.63	34.30	26.78	31.14	2.05		
	650	5.22	34.33	27.12	37.13	2.48		
St. 2	0				0.00	0.05		0.5
	10	26.61	33.39	21.63	0.00	0.06		0.4
	20	25.42	33.97	22.44	0.00	0.03		0.5
	50	22.94	34.24	23.38	0.87	0.17		0.5
	100	18.35	34.70	24.96	7.32	0.49		0.1
	150	15.40	34.56	25.54	13.25	0.86		0.0
	200	12.96	34.49	26.01				
	300	9.87	34.37	26.48	23.77	1.57		
	400	7.71	34.30	26.77	30.12	2.01		
	600	5.52	34.32	27.07	37.01	2.49		
	800	4.09	34.38	27.29	39.99	2.73		
	1000	3.45	34.43	27.39	40.91	2.75		
	1502	2.32	34.55	27.58	41.37	2.85		

unit. NO_3, PO_4, $Si(OH)_4$: μmol l^{-1}; chlorophyll *a* : μg l^{-1}

Appendix 4. θ, salinity, σ_θ, nutrients [NO_3, PO_4, $Si(OH)_4$] and chlorophyll *a* data in November 2000.

station	Depth (m)	θ (℃)	salinity	σ_θ	NO_3	PO_4	$Si(OH)_4$	chlorophyll *a*
St. 3	2				3.42	0.21	12.23	2.0
	10	19.56	33.51	23.74	2.68	0.20	8.69	1.9
	20	19.71	33.77	23.91	2.03	0.19	6.53	1.5
	30	19.89	33.90	23.96	1.79	0.20	5.29	
	50	20.31	34.17	24.05	1.87	0.20	3.84	0.7
	70	19.67	34.34	24.35	6.13	0.43	8.43	0.2
	100	16.62	34.52	25.23	12.11	0.79	17.30	0.0
	125	14.56	34.51	25.69	15.28	1.00	23.33	
	150	12.64	34.47	26.05	18.06	1.20	29.03	0.0
	200	11.53	34.42	26.23	20.36	1.34	34.52	0.0
	300	9.56	34.34	26.51	24.86	1.67	48.08	
	578	5.57	34.32	27.07	32.81	2.36	86.63	
St. F	0				1.27	0.18	3.95	1.2
	10	20.13	34.10	24.04	1.35	0.16	3.86	1.0
	20	20.27	34.17	24.06	1.37	0.17	4.07	0.9
	50	20.32	34.21	24.08	1.52	0.18	3.38	1.0
	70	19.89	34.31	24.27	4.06	0.31	6.19	0.3
	100	16.03	34.50	25.36	12.23	0.79	17.42	0.0
	125	14.10	34.50	25.78	15.30	1.01	23.70	
	150	13.27	34.48	25.94	17.47	1.15	28.47	0.0
	200	11.43	34.42	26.25	20.47	1.36	34.37	0.0
	300	9.37	34.34	26.54	25.73	1.73	49.85	
	400	7.51	34.30	26.80	30.54	2.10	67.39	
	600	5.36	34.33	27.10	36.39	2.49	96.30	
	755	4.09	34.39	27.29	38.91	2.68	115.86	
St. E	0				1.21	0.20	3.16	1.0
	10	20.24	34.19	24.09	1.20	0.19	3.17	0.9
	20	20.24	34.19	24.09	1.20	0.18	3.11	0.9
	30	20.24	34.19	24.09	1.19	0.21	3.64	0.9
	50				1.26	0.20	3.07	0.8
	70	19.57	34.35	24.39	4.94	0.36	7.29	
	100	16.35	34.49	25.28	12.18	0.79	16.78	0.1
	125	14.47	34.52	25.72	14.33	0.93	21.54	
	150	13.30	34.48	25.93	17.02	1.12	26.84	0.0
	200	11.42	34.42	26.25	20.67	1.36	35.68	0.0
	300	9.10	34.33	26.58	26.91	1.82	54.37	
	400	7.57	34.30	26.79	30.27	2.08	68.05	
	690	4.62	34.36	27.21	37.85	2.60	108.34	
St. 2	0				2.35	0.21	5.78	0.6
	10	19.84	33.88	23.95	2.30	0.23	5.64	0.6
	20	19.98	33.95	23.97	2.34	0.23	5.35	0.6
	50	20.20	34.14	24.06	2.30	0.23	4.43	0.2
	100	16.52	34.57	25.30	10.86	0.70	15.05	0.0
	150	13.33	34.50	25.94	16.63	1.08	25.86	0.0
	200	11.33	34.41	26.26	21.13	1.36	36.97	0.0
	300	8.71	34.32	26.63	26.87	1.82	54.86	
	400	7.20	34.29	26.83	31.43	2.13	71.39	
	600	5.18	34.33	27.12	36.97	2.56	102.30	
	800	3.83	34.40	27.33	39.41	2.74	121.48	
	1000	3.19	34.46	27.44	39.96	2.78	132.09	
	1620	2.22	34.56	27.60	39.97	2.82	144.98	

unit. NO_3, PO_4, $Si(OH)_4$: $\mu mol\ l^{-1}$; chlorophyll *a* : $\mu g\ l^{-1}$

Appendix 5. θ, salinity, σ_θ, nutrients [NO_3, PO_4, $Si(OH)_4$] and chlorophyll *a* data in February 2001.

station	Depth (m)	θ (℃)	salinity	σ_θ	NO_3	PO_4	$Si(OH)_4$	chlorophyll *a*
St. 3	2				3.16	0.29	8.79	9.1
	10	15.02	34.53	25.61	5.33	0.25	9.78	4.5
	20	15.01	34.54	25.61	5.82	0.39	10.41	3.4
	30	15.01	34.55	25.62	5.99	0.50	10.29	
	50	15.04	34.57	25.64	6.06	0.42	10.21	2.6
	70	15.10	34.60	25.65	6.50	0.45	10.41	1.2
	100	14.82	34.57	25.68	8.93	0.56	13.86	0.4
	125	14.57	34.55	25.72	10.75	0.67	16.47	
	150	14.06	34.52	25.81	12.77	0.82	19.49	0.2
	200	12.44	34.46	26.09	18.25	1.18	30.02	0.0
	300	10.85	34.38	26.32	23.25	1.57	44.49	
	515	7.07	34.57	27.07	32.64	2.26	78.19	
St. F	0				6.51	0.55	10.70	0.7
	10	15.13	34.61	25.64	6.54	0.54	10.42	0.7
	20	15.11	34.61	25.65	6.48	0.54	10.42	0.7
	50	15.08	34.61	25.65	6.67	0.52	10.52	1.1
	70	15.07	34.61	25.66	6.77	0.53	10.75	0.8
	100	15.02	34.60	25.66	7.26	0.56	11.47	0.5
	125	14.08	34.53	25.81	13.05	0.91	20.60	
	150	13.11	34.49	25.98	16.09	1.10	25.90	0.0
	200	11.74	34.43	26.20	19.77	1.32	33.68	0.0
	300	10.45	34.71	26.65	24.08	1.65	46.85	
	400	8.77	34.34	26.64	28.74	1.95	62.37	
	600	5.83	34.53	27.21	35.36	2.49	92.43	
	829	4.50	34.46	27.31	37.75	2.69	110.62	
St. E	0				6.68	0.55	11.40	0.6
	10	15.18	34.60	25.63	6.80	0.55	11.15	0.7
	20	15.12	34.60	25.64	6.72	0.58	10.95	0.7
	30	15.10	34.60	25.64	6.77	0.55	10.97	0.6
	50	15.09	34.60	25.65	6.92	0.56	11.09	0.6
	70	15.08	34.60	25.65	7.11	0.58	11.42	
	100	15.07	34.60	25.65				
	125	14.30	34.54	25.77	12.05	0.86	19.06	
	150	13.77	34.52	25.86	13.78	0.94	21.84	0.1
	200	12.01	34.44	26.16	19.18	1.31	32.34	0.0
	300	10.02	34.36	26.45				
	400	8.13	34.32	26.72	28.78	1.99	62.93	
	634	5.37	34.79	27.46	36.70	2.56	100.93	
St. 2	0				6.78	0.56	10.91	0.4
	10	15.14	34.60	25.64	6.86	0.58	11.18	0.6
	20	15.14	34.60	25.64	6.87	0.57	11.29	0.5
	50	15.12	34.60	25.64	7.08	0.59	11.27	0.5
	100	14.61	34.56	25.72	11.34	0.78	18.00	0.1
	150	13.06	34.49	25.99	16.74	1.13	26.44	0.0
	200	11.86	34.44	26.18	19.55	1.35	32.84	0.0
	300	9.58	35.11	27.11				
	400	8.33	35.08	27.29				
	600	6.13	34.34	27.02	35.41	2.50	90.46	
	800	4.58	34.42	27.27	38.35	2.75	111.43	
	1000	3.54	34.53	27.46	39.93	2.78	128.09	
	1442	2.52	34.55	27.57	40.22	2.77	141.03	

unit. NO_3, PO_4, $Si(OH)_4$: $\mu mol\ l^{-1}$; chlorophyll *a* : $\mu g\ l^{-1}$

Appendix 6. θ, salinity, σ_θ, nutrients [NO_3, PO_4, $Si(OH)_4$] and chlorophyll *a* data in April 2001.

station	Depth (m)	θ (℃)	salinity	σ_θ	NO_3	PO_4	$Si(OH)_4$	chlorophyll *a*
St. 3	2				0.00	0.08	4.17	2.6
	10	16.08	34.46	25.32	0.00	0.14	3.08	2.8
	20	16.00	34.50	25.37	0.00	0.12	3.34	2.8
	30	15.88	34.57	25.45	1.34	0.21	4.78	
	50	15.05	34.54	25.61	4.67	0.45	8.75	0.5
	70	14.54	34.51	25.69	5.98	0.55	9.05	0.6
	100	13.97	34.52	25.83	9.53	0.67	12.60	0.2
	125	13.62	34.52	25.89	11.83	0.75	15.54	
	150	13.02	34.50	26.00	14.29	0.99	20.92	0.1
	200	11.07	34.41	26.30	20.66	1.39	36.28	0.1
	300	8.84	34.32	26.61	25.99	1.77	50.81	
	530	5.95	34.31	27.01	33.65	2.36	84.16	
St. F	0				0.00	0.11	3.59	1.7
	10	16.28	34.51	25.31	0.00	0.12	3.64	1.9
	20	16.09	34.55	25.38	0.36	0.22	4.69	1.9
	50	15.09	34.51	25.57	5.50	0.52	9.64	0.7
	70	14.53	34.53	25.71	7.98	0.62	15.46	0.2
	100	13.65	34.52	25.89	10.44	0.73	13.28	0.1
	125	13.12	34.50	25.98	15.21	1.09	23.31	
	150	11.77	34.44	26.20	18.53	1.23	31.74	0.0
	200	10.53	34.38	26.38	21.92	1.45	39.15	0.0
	300	8.66	34.32	26.64	26.68	1.81	55.06	
	400	7.17	34.29	26.84	30.65	2.21	69.35	
	600	5.22	34.33	27.12	35.70	2.56	94.53	
	839	3.81	34.41	27.34	38.43	2.65	116.27	
St. E	0				0.00	0.16	3.39	1.6
	10	16.33	34.50	25.29	0.00	0.08	3.74	1.6
	20	15.95	34.58	25.44	0.00	0.06	2.71	0.2
	30	15.15	34.51	25.56	1.87	0.24	6.28	
	50	14.35	34.52	25.75	6.65	0.41	8.38	1.8
	70	13.79	34.53	25.87	10.53	0.68	13.92	0.1
	100	13.18	34.50	25.97	13.64	0.88	19.59	0.1
	125	12.69	34.48	26.05	16.08	1.05	25.81	
	150	12.29	34.46	26.12	16.93	1.30	26.89	0.1
	200	11.04	34.41	26.31	20.83	1.39	36.16	0.0
	300	8.73	34.32	26.63	25.96	1.77	50.96	
	400	7.28	34.29	26.82	30.12	2.11	65.69	
	636	4.92	34.34	27.16	36.43	2.46	95.88	
St. 2	0				0.00	0.27	5.96	1.5
	10	16.27	34.60	25.38	0.00	0.00	0.77	1.1
	20	15.75	34.57	25.48	2.87	0.33	8.85	1.1
	50	15.33	34.57	25.57	5.02		10.89	0.6
	100	13.42	34.51	25.93	12.69	0.85	17.97	0.1
	150	12.20	34.46	26.13	17.85	1.22	29.69	0.1
	200	10.90	34.40	26.33	21.22	1.46	37.48	0.0
	300	8.84	34.32	26.62	26.51	1.84	53.71	
	400	7.54	34.29	26.78	29.58	2.01	64.79	
	600	5.29	34.32	27.10	35.52	2.50	94.04	
	800	4.00	34.40	27.31	38.22	2.69	110.59	
	1000	3.27	34.45	27.42	39.22	2.73	119.81	
	1160	2.96	34.48	27.48	39.33	2.70	129.17	

unit. NO_3, PO_4, $Si(OH)_4$: μmol l^{-1}; chlorophyll *a* : μg l^{-1}

Appendix 7. θ, salinity, σ_θ, nutrients [NO_3, PO_4, $Si(OH)_4$] and chlorophyll *a* data in July 2001.

station	Depth (m)	θ (℃)	salinity	σ_θ	NO_3	PO_4	$Si(OH)_4$	chlorophyll *a*
St. 3	0	24.92	33.17	21.99	0.00	0.09	0.00	0.7
	11	21.86	34.01	23.51	0.00	0.07	0.00	0.4
	21	19.51	34.30	24.36	0.00	0.13	0.00	0.8
	30	17.63	34.51	24.99	1.87	0.31	1.10	
	49	16.34	34.56	25.33	8.65	0.64	9.07	1.1
	70	15.37	34.54	25.54	11.25	0.80	12.98	0.5
	100	13.52	34.50	25.90	15.21	1.06	20.91	0.3
	124	12.40	34.46	26.09	18.02	1.23	26.69	
	149	11.91	34.44	26.17	18.80	1.28	28.74	0.1
	200	10.91	34.40	26.33	21.76	1.50	36.87	0.0
	299	8.86	34.33	26.61	26.20	1.83	50.57	
	575	5.58	34.32	27.07	35.42	2.56	92.00	
St. F	0				0.00	0.10	0.00	0.2
	10	22.21	33.91	23.33	0.00	0.11	0.00	0.5
	21	19.29	34.29	24.40	0.00	0.17	0.00	0.5
	50	16.02	34.54	25.39	9.45	0.71	11.27	1.1
	70	14.75	34.53	25.67	12.35	0.85	15.86	0.3
	100	12.86	34.47	26.01	16.96	1.18	25.43	0.1
	124	12.22	34.45	26.12	18.43	1.28	28.69	
	149	11.67	34.42	26.21	20.49	1.48	32.48	0.0
	199	10.21	34.36	26.42	23.42	1.64	40.83	0.0
	299	8.51	34.31	26.65	27.89	1.98	54.86	
	398	7.30	34.29	26.82	31.09	2.24	69.88	
	595	5.14	34.33	27.13	36.77	2.64	98.96	
	810	4.05	34.38	27.29	38.89	2.77	115.38	
St. E	0				0.00	0.09	0.00	0.2
	10	23.36	34.07	23.13	0.00	0.10	0.00	0.3
	20	19.58	34.29	24.33	0.00	0.14	0.00	0.7
	30	17.63	34.48	24.96	1.89	0.32	1.89	
	50	15.96	34.52	25.39	10.06	0.75	12.22	0.8
	69	14.96	34.52	25.62	12.09	0.88	15.82	0.8
	100	13.19	34.48	25.95	16.27	1.13	23.75	0.1
	124	12.35	34.45	26.09	18.50	1.30	29.24	
	148	11.58	34.42	26.22	20.12	1.41	32.74	0.1
	198	10.35	34.36	26.40	23.38	1.63	40.68	0.0
	297	8.66	34.31	26.63	27.29	1.91	53.14	
	397	7.39	34.28	26.80	30.71	2.18	66.72	
	658	4.77	34.34	27.18	37.29	2.66	104.29	
St. 2	0				0.00	0.10	0.95	0.2
	10	23.06	34.06	23.21	0.00	0.03	1.19	0.2
	20	21.45	34.10	23.69	0.22	0.09	0.00	0.4
	50	16.15	34.53	25.35	9.00	0.69	12.09	0.7
	100	13.28	34.50	25.95	11.39	0.74	13.81	0.0
	150	12.03	34.45	26.15	18.90	1.34	28.01	0.0
	200	10.80	34.39	26.34	22.18	1.56	37.12	0.0
	298	8.75	34.32	26.62	27.19	1.93	51.85	
	398	7.79	34.30	26.76	29.90	2.16	62.07	
	596	5.10	34.33	27.14	35.98	2.60	96.69	
	792	4.21	34.38	27.28	38.73	2.80	106.77	
	991	3.37	34.45	27.41	40.00	2.85	125.14	
	1486	2.58	34.53	27.54	39.92	2.85	136.29	

unit. NO_3, PO_4, $Si(OH)_4$: μmol l^{-1}; chlorophyll *a* : μg l^{-1}

Appendix 8. θ, salinity, σ_θ, nutrients [NO_3, PO_4, $Si(OH)_4$] and chlorophyll *a* data in October 2001.

station	Depth (m)	θ (℃)	salinity	σ_θ	NO_3	PO_4	$Si(OH)_4$	chlorophyll *a*
St. 3	2	23.35	33.79	22.92	0.00	0.06	3.64	2.9
	9	23.26	33.78	22.94	0.00	0.07	3.63	3.2
	20	23.25	33.79	22.95	0.00	0.07	3.73	3.1
	29	23.25	33.80	22.96	0.20	0.07	3.58	
	50	23.19	34.07	23.17	2.30	0.21	5.00	0.3
	70	21.52	34.27	23.80	6.32	0.45	9.61	0.1
	100	16.11	34.52	25.36	12.52	0.82	18.90	0.0
	125	14.88	34.51	25.63	14.30	0.93	22.16	
	151	14.21	34.50	25.76	15.41	1.00	25.32	0.0
	201	12.63	34.47	26.06	18.30	1.21	30.85	0.0
	303	10.14	34.38	26.44	24.01	1.58	44.89	
	504	6.79	34.31	26.91	32.24	2.19	75.22	
St. F	0				0.00	0.06	4.09	1.9
	10	23.29	33.94	23.05	0.07	0.08	3.88	1.6
	20	23.26	33.94	23.06	0.06	0.06	3.71	1.4
	50	22.47	34.17	23.46	3.48	0.27	6.30	0.3
	70	18.47	34.47	24.75	9.20	0.62	13.51	0.1
	101	16.22	34.55	25.35	11.64	0.84	17.52	0.0
	125	14.77	34.52	25.66	14.27	0.94	22.93	
	150	13.93	34.52	25.83	15.32	1.02	24.19	0.0
	201	12.45	34.46	26.08	18.85	1.25	31.92	0.0
	300	10.07	34.38	26.45	24.19	1.62	45.61	
	401	8.35	34.32	26.69	27.40	1.80	56.05	
	600	5.21	34.34	27.13	32.62	2.10	81.59	
	816	4.01	34.40	27.31	38.88	2.61	111.97	
St. E	0				0.00	0.06	2.95	0.8
	10	23.36	33.91	23.01	0.00	0.07	3.46	1.0
	20	23.28	33.94	23.05	0.01	0.10	3.59	1.9
	30	23.27	33.96	23.07	0.24	0.14	3.81	
	50	23.00	34.09	23.25	2.69	0.24	5.98	0.3
	70	18.58	34.49	24.74	8.88	0.61	12.65	0.0
	100	15.85	34.55	25.44				
	126	14.36	34.54	25.76	14.24	0.95	20.92	
	150	13.68	34.50	25.87	16.11	1.09	28.12	0.0
	200	12.44	34.46	26.09	18.50	1.23	30.94	0.0
	299	10.07	34.38	26.45	24.27	1.66	45.98	
	400	8.41	34.33	26.68	28.40	1.93	57.94	
	660	4.51	34.37	27.23	38.09	2.60	104.89	
St. 2	0				0.00	0.10	4.70	1.4
	10	23.28	33.89	23.01	0.00	0.10	3.70	1.6
	21	23.27	33.93	23.05	0.45	0.10	4.12	1.4
	51	22.17	34.15	23.53	2.90	0.24	5.73	0.6
	100	15.93	34.55	25.42	12.19	0.83	18.06	0.0
	150	14.00	34.52	25.82	15.14	1.02	22.76	0.0
	200	12.63	34.47	26.06	18.06	1.22	29.50	0.0
	300	10.23	34.38	26.43	23.98	1.48	44.06	
	400	8.40	34.32	26.68	28.66	1.98	57.90	
	600	5.41	34.31	27.08	36.45	2.52	88.92	
	801	4.37	34.38	27.25	38.58	2.68	105.89	
	1001	3.51	34.44	27.39	39.90	2.76	118.79	
	1587	2.20	34.57	27.61	39.99	2.72	137.34	

unit. NO_3, PO_4, $Si(OH)_4$: μmol l^{-1}; chlorophyll *a* : μg l^{-1}

Appendix 9. θ, salinity, σ_θ, nutrients [NO_3, PO_4, $Si(OH)_4$] and chlorophyll *a* data in December 2001.

station	Depth (m)	θ (℃)	salinity	σ_θ	NO_3	PO_4	$Si(OH)_4$	chlorophyll *a*
St. 3	2	17.40	34.14	24.76	3.83	0.33	7.01	0.9
	10	17.35	34.14	24.77	3.82	0.33	7.26	1.0
	20	17.34	34.14	24.78	3.82	0.34	8.83	1.0
	30	17.34	34.15	24.78	3.96	0.27	7.59	
	50	17.36	34.18	24.80	3.92	0.31	7.63	0.8
	70	17.18	34.25	24.90	4.83	0.40	9.09	0.3
	100	16.87	34.32	25.02	6.40	0.50	11.08	0.2
	125	16.21	34.39	25.23	10.02	0.74	16.64	
	151	13.97	34.49	25.80	14.70	1.05	24.01	0.0
	200	12.61	34.46	26.05	17.30	1.25	29.65	0.0
	300	10.10	34.36	26.44	22.33	1.63	43.62	
	511	5.91	34.33	27.03	32.70	2.46	89.05	
St. F	0				3.85	0.30	6.77	1.5
	11	17.40	34.19	24.80	3.71	0.30	6.35	1.2
	20	17.42	34.27	24.86	3.69	0.33	7.13	1.1
	50	17.28	34.32	24.93	3.80	0.33	6.94	1.1
	70	17.26	34.31	24.93	4.17	0.37	7.35	0.8
	100	16.54	34.34	25.12	7.39	0.58	13.27	0.2
	125	15.59	34.44	25.41	11.96	0.86	21.42	
	150	13.83	34.49	25.83	15.24	1.07	24.75	0.1
	200	12.06	34.44	26.14	18.27	1.28	31.46	0.0
	300	9.62	34.35	26.51	23.45	1.69	47.38	
	400	7.64	34.31	26.79	25.13	1.72	55.28	
	600	5.11	34.35	27.15	29.24	1.96	77.87	
	832	3.94	34.41	27.32	36.74	2.65	116.44	
St. E	0				3.41	0.31	5.90	1.2
	10	17.60	34.30	24.84	3.13	0.28	5.92	0.9
	20	17.60	34.31	24.85	3.59	0.32	6.73	0.7
	30	17.58	34.31	24.85	3.66	0.33	7.59	
	50	17.51	34.31	24.86	3.75	0.32	7.14	0.8
	70	17.09	34.32	24.98	5.55	0.46	9.97	0.3
	100	16.60	34.35	25.12	6.54	0.53	11.91	0.3
	125	15.85	34.39	25.32	10.31	0.77	17.67	
	150	14.22	34.47	25.73	14.03	0.99	24.00	0.1
	200	12.13	34.44	26.13	16.93	1.24	29.58	0.0
	301	9.60	34.34	26.51	21.10	1.53	42.39	
	400	7.45	34.27	26.78	28.40	2.12	64.98	
	649	4.50	34.37	27.23				
St. 2	0				2.34	0.19	4.57	0.9
	10	17.61	34.29	24.83	2.90	0.26	4.89	0.9
	20	17.61	34.29	24.83	3.00	0.27	6.74	0.1
	50	17.61	34.29	24.83	2.15	0.18	3.90	1.1
	100	16.77	34.29	25.02	4.95	0.38	8.68	0.3
	148	14.06	34.48	25.77	14.29	1.03	23.19	0.0
	200	11.94	34.43	26.16	18.41	1.36	32.44	0.0
	301	9.35	34.33	26.54	20.70	1.51	41.88	
	400	7.41	34.28	26.79	23.69	1.69	51.94	
	601	5.12	34.34	27.14	33.79	2.55	94.56	
	800	4.05	34.40	27.30	32.24	2.31	95.19	
	1001	3.37	34.45	27.41	34.60	2.53	113.65	
	1590	2.22	34.56	27.61	37.68	2.78	142.25	

unit. NO_3, PO_4, $Si(OH)_4$: μmol l^{-1}; chlorophyll *a* : μg l^{-1}

Appendix 10. θ, salinity, σ_θ, nutrients [NO_3, PO_4, $Si(OH)_4$] and chlorophyll *a* data in February 2002.

station	Depth (m)	θ (℃)	salinity	σ_θ	NO_3	PO_4	$Si(OH)_4$	chlorophyll *a*
St. 3	2	13.23	34.49	25.96	11.00	0.82	20.24	0.6
	11	13.06	34.49	25.99	10.99	0.82	20.54	0.6
	20	13.05	34.49	25.99	11.04	0.82	21.50	0.6
	31	13.04	34.49	25.99	11.02	0.82	22.28	
	51	13.03	34.49	26.00	11.07	0.78	21.14	0.6
	71	13.01	34.49	26.00	11.16	0.79	20.56	0.5
	101	12.94	34.48	26.00	11.08	0.77	20.06	0.5
	124	12.56	34.47	26.07	15.60	1.08	27.56	
	150	12.00	34.44	26.16	16.73	1.15	30.30	0.0
	200	11.28	34.40	26.26	19.90	1.40	37.36	0.0
	300	8.54	34.31	26.65	26.71	1.94	56.47	
	587	5.22	34.34	27.13	35.08	2.56	96.17	
St. F	0				10.35	0.76	20.03	0.8
	10	13.16	34.52	25.99	10.24	0.74	21.29	0.9
	21	13.09	34.52	26.00	10.15	0.72	19.43	0.8
	51	13.06	34.52	26.01	10.69	0.76	20.80	0.7
	69	13.07	34.53	26.02	10.96	0.81	20.39	0.5
	100	13.04	34.53	26.02	11.03	0.80	20.46	0.5
	126	13.00	34.52	26.03	11.83	0.85	21.44	
	150	12.51	34.49	26.09	15.44	1.10	28.02	0.1
	200	10.97	34.39	26.31	20.23	1.44	36.82	0.0
	301	8.48	34.31	26.66	26.91	1.92	56.18	
	401	7.05	34.28	26.84	30.23	2.20	70.25	
	600	5.40	34.33	27.10	34.59	2.52	93.68	
	811	4.10	34.40	27.30	37.42	2.72	112.83	
St. E	0				10.42	0.76	22.83	0.7
	10	13.17	34.49	25.97	10.43	0.74	19.97	0.8
	20	13.16	34.49	25.97	10.51	0.73	19.94	0.8
	31	13.09	34.48	25.98	10.54	0.76	20.70	
	51	13.08	34.48	25.98	10.10	0.73	19.01	0.8
	70	13.09	34.49	25.98	9.82	0.67	17.99	0.7
	101	13.12	34.51	25.99	10.83	0.76	19.92	0.4
	125	12.95	34.51	26.03	16.77	1.17	29.25	
	151	12.32	34.46	26.11	12.91	0.91	24.59	0.0
	201	10.64	34.38	26.36	21.08	1.51	40.00	0.0
	301	8.92	34.32	26.60	25.66	1.82	53.30	
	400	7.28	34.28	26.82	29.60	2.12	66.72	
	656	5.02	34.34	27.15				
St. 2	0				9.28	0.62	17.57	0.7
	11	13.06	34.49	25.99	8.27	0.53	16.27	0.8
	20	13.06	34.50	26.00	10.48	0.74	19.51	0.8
	51	13.05	34.51	26.01	9.27	0.60	16.71	0.9
	101	13.07	34.54	26.02	8.40	0.54	15.19	0.5
	151	12.52	34.48	26.08	14.65	0.99	25.48	0.1
	200	11.15	34.40	26.28	19.96	1.41	37.49	0.0
	300	9.32	34.33	26.55	22.05	1.66	45.89	
	400	7.61	34.29	26.77	28.03	1.98	63.23	
	600	5.72	34.32	27.05	33.73	2.43	87.21	
	800	4.32	34.38	27.26	37.61	2.78	110.02	
	1000	3.31	34.46	27.42	35.81	2.50	115.10	
	1486	2.47	34.54	27.56	37.45	2.64	131.39	

unit. NO_3, PO_4, $Si(OH)_4$: μmol l^{-1}; chlorophyll *a* : μg l^{-1}

Appendix 11. θ, salinity, σ_θ, nutrients [NO_3, PO_4, $Si(OH)_4$] and chlorophyll *a* data in May 2002.

station	Depth (m)	θ (℃)	salinity	σ_θ	NO_3	PO_4	$Si(OH)_4$	chlorophyll *a*
St. 3	1	20.64	34.27	24.04	0.05	0.04	3.55	1.2
	9	20.29	34.65	24.42	0.00	0.02	2.88	0.3
	20	20.07	34.63	24.46	0.00	0.04	3.21	
	30	19.95	34.66	24.52	0.00	0.07	3.86	
	50	19.00	34.64	24.75	0.39	0.12	3.30	0.5
	69	18.76	34.62	24.80	0.87	0.18	4.17	
	99	17.74	34.60	25.04	3.76	0.33	7.08	0.2
	124	16.78	34.60	25.26	6.64	0.47	9.93	
	149	15.70	34.58	25.49	9.06	0.61	14.41	
	199	14.23	34.55	25.79	12.21	0.85	20.10	0.0
	298	9.84	34.37	26.49	24.00	1.69	46.56	
	582	4.97	34.34	27.16	36.47	2.63	104.71	
St. F	0				0.00	0.04	1.33	0.3
	9	20.53	34.65	24.35	0.00	0.03	2.12	0.2
	19	20.54	34.65	24.35	0.00	0.05	1.74	0.3
	50	19.76	34.61	24.53	0.00	0.07	3.24	0.5
	71	19.09	34.64	24.73	0.53	0.12	4.08	0.7
	101	17.02	34.61	25.22	5.37	0.40	12.65	
	124	15.93	34.59	25.45	8.61	0.59	13.48	
	149	15.27	34.57	25.58	9.69	0.67	15.13	0.0
	199	13.73	34.53	25.88	13.51	0.93	22.81	
	298	10.40	34.39	26.41	22.57	1.58	43.13	
	398	7.61	34.30	26.78	29.87	2.13	66.52	
	594	4.95	34.34	27.16	36.71	2.65	102.68	
	735	3.72	34.42	27.35	39.09	2.78	121.05	
St. E	0				0.00	0.03	3.32	0.3
	5	20.72	34.68	24.33	0.00	0.03	1.66	0.3
	19	20.36	34.68	24.43	0.00	0.04	2.18	0.3
	30	20.18	34.68	24.47	0.00	0.04	3.24	
	50	19.35	34.65	24.67	0.22	0.10	3.86	0.4
	66	18.78	34.63	24.80	0.82	0.15	4.04	0.3
	97	17.55	34.61	25.09	5.05	0.40	9.15	0.2
	121	15.99	34.59	25.43	8.81	0.60	14.21	
	149	15.22	34.57	25.59	10.40	0.71	16.49	0.1
	198	13.99	34.53	25.83	13.10	0.90	21.23	0.0
	297	10.23	34.38	26.43	22.99	1.61	46.70	
	396	7.85	34.30	26.75	29.30	2.07	64.26	
	674	4.51	34.36	27.22	37.83	2.67	108.32	
St. 2	0				0.00	0.10	6.59	0.3
	10	20.42	34.68	24.41	0.00	0.06	2.81	0.3
	20	20.30	34.69	24.45	0.00	0.08	2.35	0.4
	30	20.02	34.69	24.52	0.00	0.08	2.70	0.5
	40	19.96	34.70	24.55	0.00	0.13	3.13	0.5
	50	19.89	34.69	24.56	0.00	0.10	2.66	0.5
	60	19.81	34.68	24.57	0.00	0.10	2.58	0.6
	79	18.94	34.63	24.76	0.60	0.16	4.06	0.5
	99	18.04	34.62	24.98	2.65	0.26	6.48	0.5
	124	16.54	34.60	25.32	7.65	0.55	11.80	0.2
	149	15.18	34.57	25.60	9.76	0.69	16.12	0.1
	174	14.46	34.56	25.75	11.89	0.83	18.51	0.1
	199	13.82	34.53	25.87	13.39	0.93	20.48	0.1
	298	11.15	34.42	26.30	19.77	1.35	37.10	
	397	7.81	34.30	26.75	29.42	2.08	63.18	
	595	5.11	34.33	27.14	36.74	2.65	99.25	
	792	3.83	34.41	27.33	39.59	2.82	120.95	
	990	3.26	34.46	27.43	40.09	2.81	129.93	
	1465	2.53	34.53	27.55	41.04	2.84	141.02	

unit. NO_3, PO_4, $Si(OH)_4$: μmol l^{-1}; chlorophyll *a* : μg l^{-1}

Appendix 12. θ, salinity, σ_θ, nutrients [NO_3, PO_4, $Si(OH)_4$] and chlorophyll *a* data in July 2002.

station	Depth (m)	θ (℃)	salinity	σ_θ	NO_3	PO_4	$Si(OH)_4$	chlorophyll *a*
St. 3	2	26.62	32.19	20.73	0.00	0.13	1.72	1.8
	10	24.95	33.90	22.53	0.00	0.06	2.67	0.7
	21	24.26	34.03	22.83	0.00	0.06	0.86	0.6
	31	22.68	34.45	23.61	0.60	0.13	3.31	
	50	20.44	34.60	24.34	3.52	0.30	5.11	0.6
	70	19.55	34.64	24.61	4.86	0.35	6.69	0.3
	100	17.81	34.69	25.08	7.52	0.52	9.69	0.1
	124	16.76	34.65	25.30	9.22	0.65	13.34	
	149	16.01	34.64	25.47	10.48	0.71	15.55	
	199	14.19	34.54	25.80	13.89	0.95	21.74	0.0
	298	11.39	34.43	26.26	20.15	1.40	36.51	
	575	5.96	34.31	27.02	34.08	2.47	84.35	
St. F	0				0.00	0.07	0.33	1.6
	10	24.50	34.05	22.78	0.00	0.05	1.43	0.6
	20	23.37	34.48	23.43	0.49	0.13	3.31	0.9
	50	20.52	34.70	24.40	3.88	0.30	5.20	0.3
	70	19.14	34.67	24.74	5.44	0.40	6.88	0.1
	99	18.06	34.60	24.95	7.11	0.50	10.66	0.1
	123	17.01	34.65	25.25	9.07	0.62	12.47	
	149	16.00	34.63	25.46	11.37	0.79	16.14	0.0
	198	14.10	34.56	25.83	14.12	0.97	20.74	0.0
	298	11.33	34.43	26.27	20.98	1.46	36.49	
	396	8.27	34.32	26.70	28.38	2.00	58.68	
	596	5.72	34.32	27.05	34.96	2.51	87.92	
	802	3.76	34.42	27.35	39.03	2.80	116.97	
St. E	0				0.00	0.12	0.02	0.4
	10	24.85	33.84	22.51	0.00	0.06	0.91	0.4
	19	23.35	34.12	23.17	0.00	0.09	1.90	0.9
	30	21.75	34.49	23.90	2.01	0.23	3.59	
	50	19.90	34.65	24.52	4.81	0.38	6.12	0.1
	69	18.96	34.66	24.78	6.17	0.45	8.03	0.1
	100	17.78	34.66	25.07	7.69	0.58	9.90	0.0
	124	17.26	34.66	25.20	8.12	0.57	10.81	
	149	16.19	34.63	25.42	10.43	0.73	14.18	0.0
	198	14.45	34.57	25.76	14.27	0.99	21.48	0.0
	298	11.33	34.43	26.27	20.45	1.43	35.37	
	396	8.41	34.33	26.68	27.92	1.97	57.26	
	645	5.13	34.34	27.14	36.47	2.66	94.83	
St. 2	0				0.00	0.11	1.29	0.7
	10	24.53	33.97	22.71	0.00	0.07	3.09	0.3
	20	23.47	34.11	23.13	0.03	0.10	2.10	0.7
	29	22.07	34.36	23.72	2.17	0.22	4.07	0.7
	39	20.97	34.61	24.21	3.80	0.33	5.88	0.3
	50	19.60	34.67	24.62	5.13	0.40	8.51	0.1
	60	19.00	34.66	24.77	5.33	0.41	7.86	0.1
	80	18.38	34.69	24.94	6.61	0.50	9.52	0.1
	100	18.16	34.69	25.00	7.04	0.51	12.72	0.1
	123	17.44	34.67	25.16	8.19	0.59	11.35	0.0
	149	16.55	34.66	25.36	9.31	0.67	14.64	0.0
	199	14.93	34.55	25.64	12.67	0.92	20.32	0.0
	298	11.80	34.44	26.20	19.21	1.38	35.69	
	397	8.82	34.34	26.63	26.75	1.96	55.88	
	595	6.05	34.31	27.00	34.29	2.53	85.34	
	792	4.21	34.39	27.28	38.62	2.82	114.02	
	991	3.42	34.45	27.41	39.58	2.88	125.43	
	1288	2.78	34.51	27.51	40.02	2.93	136.14	
	1366	2.72	34.51	27.52	40.29	2.93	135.72	

unit. NO_3, PO_4, $Si(OH)_4$: μmol l^{-1}; chlorophyll *a* : μg l^{-1}

Appendix 13. θ, salinity, σ_θ, nutrients [NO_3, PO_4, $Si(OH)_4$] and chlorophyll *a* data in September 2002.

station	Depth (m)	θ (℃)	salinity	σ_θ	NO_3	PO_4	$Si(OH)_4$	chlorophyll *a*
St. 3	2	26.18	33.46	21.82	0.00	0.07	1.38	1.7
	10	26.31	33.69	21.96	0.00	0.08	4.20	1.1
	19	26.72	33.91	21.99	0.00	0.10	3.04	1.1
	29	24.30	34.28	23.01	2.03	0.21	4.35	
	50	20.67	34.56	24.25	5.49	0.40	7.94	0.1
	69	19.49	34.63	24.62	6.81	0.49	8.89	0.1
	100	16.87	34.64	25.27	10.22	0.71	13.70	0.0
	124	15.05	34.59	25.65	12.68	0.88	18.06	
	148	14.24	34.55	25.79	14.08	0.99	20.74	0.0
	198	13.01	34.50	26.00	25.77	1.80	50.37	0.0
	298	9.22	34.34	26.57	25.71	1.80	49.19	
	575	5.26	34.33	27.12	36.35	2.61	96.05	
St. F	0				0.00	0.07	2.42	2.0
	9	26.11	33.75	22.06	0.00	0.07	1.81	1.4
	20	25.86	33.96	22.30	0.05	0.09	2.66	1.5
	48	21.36	34.54	24.05	4.44	0.36	5.87	0.2
	69	19.76	34.61	24.53	6.45	0.47	9.25	0.1
	100	16.60	34.64	25.34	10.37	0.72	13.43	0.0
	122	15.21	34.59	25.62	12.86	0.88	18.26	
	149	13.81	34.54	25.87	14.90	0.93	21.95	0.0
	198	11.39	34.42	26.26	20.06	1.31	32.19	0.0
	298	8.96	34.33	26.60	26.63	1.82	51.44	
	396	7.44	34.30	26.81	31.86	2.02	66.39	
	594	5.43	34.33	27.09	36.06	2.55	92.54	
	803	3.68	34.43	27.36	39.47	2.66	119.99	
St. E	0				0.00	0.07	3.14	0.5
	9	25.65	34.08	22.45	0.00	0.09	2.86	0.7
	19	24.54	34.32	22.97	1.20	0.16	3.52	0.7
	30	21.98	34.52	23.86	4.16	0.34	5.58	
	49	20.33	34.61	24.38	5.80	0.42	8.65	0.2
	69	18.49	34.64	24.88	7.93	0.56	10.29	0.1
	98	16.59	34.63	25.33		0.72	13.95	0.0
	124	15.72	34.61	25.52	11.49	0.79	15.49	
	149	14.67	34.57	25.72	13.62	0.93	19.53	0.0
	198	12.05	34.45	26.16	18.64	1.28	29.34	0.0
	294	9.26	34.35	26.57	26.03	1.81	49.71	
	396	7.47	34.30	26.80	30.56	2.13	64.40	
	645	4.97	34.34	27.16	37.01	2.60	99.45	
St. 2	0				0.00	0.07	6.24	0.5
	10	25.68	34.19	22.52	0.00	0.09	4.68	0.5
	20	24.16	34.38	23.13	1.31	0.20	5.12	0.5
	30	22.54	34.53	23.71	3.44	0.29	6.61	0.3
	40	21.70	34.59	23.99	4.95	0.37	9.93	0.2
	50	20.21	34.63	24.43	5.96	0.44	9.22	0.1
	59	19.75	34.65	24.57	6.22	0.47	8.05	0.1
	80	18.39	34.65	24.91	7.92	0.58	13.27	0.1
	99	17.23	34.65	25.19	9.16	0.64	12.08	0.0
	124	16.22	34.62	25.41	9.30	0.67	12.89	0.1
	149	14.20	34.55	25.80	14.38	1.00	22.14	0.0
	200	12.61	34.47	26.06	15.81	1.10	22.94	0.0
	299	9.70	34.37	26.51	24.51	1.73	46.56	
	397	7.69	34.30	26.77	29.75	2.10	64.81	
	595	5.47	34.31	27.08	35.98	2.56	90.84	
	793	4.21	34.39	27.28	38.73	2.76	111.37	
	991	3.32	34.46	27.42	39.80	2.82	125.30	
	1514	2.28	34.56	27.60	39.90	2.79	138.08	
	1593	2.23	34.57	27.61	39.74	2.79	139.88	

unit. NO_3, PO_4, $Si(OH)_4$: μmol l^{-1}; chlorophyll *a* : μg l^{-1}

Appendix 14. θ, salinity, σ_θ, nutrients [NO_3, PO_4, $Si(OH)_4$] and chlorophyll *a* data in November 2002.

station	Depth (m)	θ (℃)	salinity	σ_θ	NO_3	PO_4	$Si(OH)_4$	chlorophyll *a*
St. 3	2	16.39	34.50	25.28	5.65	0.45	10.20	1.5
	10	16.42	34.50	25.27	5.02	0.37	10.92	1.3
	20	16.42	34.50	25.27	5.73	0.45	12.31	1.2
	30	16.38	34.55	25.31	6.97	0.53	12.37	
	50	15.36	34.59	25.58	12.00	0.82	17.89	0.1
	69	15.04	34.58	25.64	11.83	0.80	20.18	0.1
	99	14.16	34.55	25.81	14.03	0.97	21.64	0.1
	124	14.01	34.54	25.83	13.32	0.88	22.16	
	149	13.22	34.51	25.97	15.70	1.09	25.66	0.0
	199	12.71	34.49	26.05	16.67	1.20	28.18	0.0
	299	9.61	34.36	26.52	24.42	1.73	48.00	
	576	5.55	34.32	27.08	34.52	2.53	93.54	
St. F	0				4.15	0.34	8.36	0.9
	10	17.36	34.56	25.10	4.14	0.33	8.77	0.9
	19	17.35	34.56	25.10	4.78	0.39	9.94	0.9
	50	15.51	34.57	25.53	9.99	0.73	17.68	0.3
	69	15.15	34.57	25.61	11.00	0.80	18.28	0.2
	99	14.41	34.56	25.76	13.95	0.97	22.61	0.1
	123	13.66	34.53	25.90	15.09	1.04	24.20	
	146	13.41	34.52	25.94	12.39	0.83	24.97	0.1
	197	12.31	34.47	26.12	14.93	1.02	30.51	0.0
	297	9.65	34.36	26.51	24.51	1.73	50.42	
	396	7.71	34.31	26.77	28.26	2.00	67.44	
	595	5.28	34.33	27.11	33.88	2.41	98.34	
	814	3.99	34.41	27.31	37.21	2.66	119.27	
St. E	0				2.58	0.24	6.13	0.8
	10	17.73	34.55	25.00				
	20	17.25	34.58	25.14	3.27	0.28	8.21	0.5
	30	17.04	34.59	25.20	4.04	0.44	9.45	
	50	16.52	34.59	25.31	3.88	0.37	7.98	0.6
	70	15.74	34.59	25.50	8.49	0.57	19.03	0.1
	99	14.33	34.56	25.78		0.97	22.88	0.1
	124	13.78	34.54	25.88	13.86	0.92	24.23	
	148	13.15	34.51	25.98	16.11	1.13	26.02	0.0
	197	11.85	34.45	26.19	17.28	1.20	31.83	0.0
	297	9.47	34.35	26.53	23.82	1.68	48.83	
	397	7.55	34.31	26.80	29.83	2.15	67.25	
	610	5.43	34.32	27.09	35.03	2.52	94.45	
St. 2					1.58	0.23	4.82	0.8
	10	18.49	34.55	24.81	3.13	0.34	8.52	0.7
	20	18.49	34.55	24.81	3.18	0.33	7.47	0.8
	30	18.47	34.54	24.81	3.11	0.35	7.10	0.6
	40	18.40	34.54	24.83	3.50	0.37	8.27	0.6
	50	17.82	34.53	24.96	5.57	0.49	11.29	0.4
	59	16.47	34.58	25.32	7.80	0.64	13.38	0.4
	79	15.27	34.58	25.59	10.35	0.78	18.35	0.2
	100	14.92	34.57	25.66	10.95	0.82	20.20	0.2
	125	13.98	34.54	25.84	13.03	0.97	22.17	0.0
	149	13.29	34.51	25.96	15.30	1.08	26.61	0.0
	198	12.22	34.47	26.13	17.53	1.28	31.43	0.0
	296	9.76	34.36	26.50	23.22	1.69	45.98	
	397	7.56	34.30	26.79	29.49	2.19	67.44	
	594	5.31	34.33	27.11	35.49	2.64	97.36	
	793	3.96	34.41	27.32	38.05	2.84	113.05	
	988	3.20	34.47	27.44	39.00	2.84	126.88	
	1284	2.65	34.52	27.53	38.38	2.77	127.74	
	1364	2.56	34.53	27.55	38.06	2.76	127.84	

unit. NO_3, PO_4, $Si(OH)_4$: μmol l^{-1}; chlorophyll *a* : μg l^{-1}

Appendix 15. θ, salinity, σ_θ, nutrients [NO_3, PO_4, $Si(OH)_4$] and chlorophyll *a* data in February 2003.

station	Depth (m)	θ (℃)	salinity	σ_θ	NO_3	PO_4	$Si(OH)_4$	chlorophyll *a*
St. 3	2	17.01	34.75	25.32	3.39	0.32	5.19	0.7
	10	16.99	34.75	25.32	3.47	0.27	5.08	0.5
	20	16.86	34.74	25.35	3.55	0.28	5.05	0.5
	29	16.85	34.74	25.35	3.50	0.27	5.07	
	50	16.84	34.74	25.36	3.57	0.28	5.05	0.7
	69	16.83	34.74	25.36	3.55	0.28	4.90	0.5
	99	16.01	34.66	25.48	6.78	0.49	9.30	0.1
	124	15.13	34.61	25.65	8.42	0.59	12.08	
	149	14.56	34.62	25.77	8.48	0.59	12.77	0.2
	199	13.35	34.53	25.96	14.30	0.99	22.31	0.0
	298	10.94	34.40	26.32	20.53	1.43	36.15	
	535	6.13	34.30	26.98	29.94	2.21	74.45	
St. F	0				2.99	0.27	6.84	1.4
	10	17.02	34.74	25.32	2.98	0.27	6.12	0.7
	19	16.99	34.75	25.32	3.00	0.26	5.35	0.7
	48	16.82	34.74	25.36	3.54	0.29	6.21	0.4
	68	16.82	34.74	25.36	3.56	0.30	5.91	0.4
	99	15.88	34.66	25.52	7.13	0.51	10.48	0.1
	124	14.95	34.61	25.68	7.21	0.52	11.84	
	150	14.46	34.60	25.78	10.23	0.71	15.61	0.1
	198	13.01	34.50	26.01	15.35	1.06	25.14	0.0
	297	10.67	34.39	26.36	21.12	1.49	36.52	
	397	8.55	34.32	26.65	27.17	1.92	57.01	
	595	5.61	34.31	27.06	34.94	2.49	87.20	
	793	3.91	34.40	27.32	38.88	2.77	111.59	
St. E	0				3.18	0.26	5.69	0.5
	10	17.13	34.72	25.27	3.17	0.27	6.46	0.6
	20	17.09	34.71	25.27	3.33	0.27	6.35	0.5
	30	17.06	34.71	25.28	3.64	0.27	5.78	
	50	16.51	34.68	25.38	5.79	0.42	8.16	0.1
	69	15.80	34.65	25.52	7.87	0.56	11.55	0.1
	100	15.34	34.62	25.60		0.68	14.57	0.0
	124	15.22	34.62	25.63	9.28	0.64	14.03	
	148	14.72	34.62	25.75	8.32	0.59	12.89	0.2
	198	12.80	34.49	26.04	15.93	1.08	24.61	0.1
	297	10.07	34.37	26.45	22.88	1.60	44.42	
	397	7.92	34.30	26.74	28.66	2.04	59.68	
	664	5.06	34.33	27.14	36.32	2.62	93.35	
St. 2	0				3.49	0.30	5.72	0.6
	10	16.64	34.73	25.39	3.69	0.32	6.18	0.6
	20	16.63	34.73	25.40	3.81	0.33	6.03	0.5
	29	16.60	34.72	25.40	4.38	0.35	6.88	0.4
	40	16.19	34.68	25.46	6.20	0.46	9.74	0.3
	50	15.98	34.68	25.50	6.42	0.48	9.54	0.3
	61	15.59	34.64	25.57	7.48	0.54	10.68	0.1
	79	15.28	34.63	25.63	6.62	0.49	10.29	0.2
	100	14.96	34.64	25.70	7.12	0.52	11.25	0.2
	124	14.59	34.64	25.78	7.76	0.56	11.75	0.2
	149	14.15	34.59	25.84	10.49	0.74	15.78	0.1
	198	12.69	34.48	26.06	15.86	1.11	24.84	0.0
	298	10.29	34.37	26.41	22.34	1.59	40.36	
	397	7.80	34.27	26.73	28.82	1.94	60.04	
	594	5.67	34.30	27.04	35.42	2.40	90.10	
	793	4.21	34.38	27.27	39.15	2.66	114.31	
	991	3.60	34.43	27.37	39.76	2.67	125.45	
	1425	2.69	34.52	27.53	39.49	2.74	135.95	
	1504	2.48	34.54	27.56	40.34	2.64	143.97	

unit. NO_3, PO_4, $Si(OH)_4$: $\mu mol\ l^{-1}$; chlorophyll *a* : $\mu g\ l^{-1}$

Appendix 16. θ, salinity, σ_θ, nutrients [NO_3, PO_4, $Si(OH)_4$] and chlorophyll *a* data in May 2003.

station	Depth (m)	θ (℃)	salinity	σ_θ	NO_3	PO_4	$Si(OH)_4$	chlorophyll *a*
St. 3	0				0.00	0.00	1.86	0.5
	10	20.18	34.60	24.41	0.00	0.04	3.15	0.7
	20	19.25	34.56	24.62	0.09	0.07	3.02	1.0
	30	18.95	34.58	24.72	0.45	0.09	4.76	
	50	18.51	34.59	24.84	0.90	0.08	3.14	0.4
	70	17.53	34.62	25.10	3.43	0.24	7.09	0.2
	99	16.33	34.63	25.39	6.57	0.46	9.90	0.1
	124	15.83	34.62	25.50	7.99	0.52	12.53	
	149	15.39	34.60	25.58	8.87	0.56	14.04	0.1
	199	14.09	34.56	25.83	12.47	0.84	19.27	0.0
	299	9.74	34.36	26.49	23.84	1.65	45.71	
	555	6.08	34.29	26.98	33.80	2.45	84.16	
St. F	0				0.00	0.06	2.01	0.5
	10	20.61	34.66	24.34		0.04	2.84	0.7
	20	20.23	34.63	24.42	0.08	0.04	2.17	0.7
	50	18.53	34.56	24.81	0.80	0.11	4.00	0.4
	70	17.41	34.57	25.09	2.74	0.21	5.31	0.2
	100	16.53	34.64	25.35	6.38	0.43	9.90	0.1
	123	16.08	34.63	25.45	7.23	0.49	10.64	
	150	15.35	34.61	25.59	9.16	0.63	13.19	0.1
	199	13.48	34.53	25.93	14.55	0.99	23.10	0.0
	298	9.91	34.36	26.47	23.50	1.64	44.45	
	397	7.71	34.29	26.76	13.04	0.92	24.15	
	595	5.93	34.30	27.01	34.20	2.45	85.36	
	744	4.88	34.33	27.16	37.02	2.71	101.57	
St. E	0				0.00	0.07	2.28	0.6
	10	20.12	34.63	24.45	0.06	0.07	4.00	0.7
	20	18.99	34.47	24.62	1.03	0.11	3.36	0.5
	30	18.98	34.47	24.63	0.26	0.08	4.49	
	50	18.56	34.52	24.77	0.64	0.10	2.20	0.4
	70	17.72	34.60	25.04	2.72	0.23	4.10	0.2
	100	16.57	34.63	25.33	5.84	0.41	7.59	0.1
	124	16.03	34.63	25.46	7.55	0.52	10.52	
	149	15.43	34.61	25.58	9.39	0.61	13.54	0.1
	199	13.65	34.54	25.91	13.71	0.92	20.96	0.0
	298	9.98	34.36	26.46	23.26	1.55	43.23	
	398	7.72	34.30	26.76	28.56	2.03	63.83	
	665	5.23	34.32	27.11	35.92	2.58	94.51	
St. 2	2	21.39	34.76	24.21	0.15	0.09	3.21	0.4
	10	21.17	34.75	24.26	0.13	0.09	2.53	0.5
	20	20.03	34.65	24.49	0.30	0.11	2.97	0.8
	30	19.45	34.57	24.58	0.37	0.09	2.52	0.7
	39	19.48	34.61	24.60	0.24	0.10	3.14	0.7
	50	19.18	34.64	24.70	0.51	0.12	3.18	0.9
	59	18.75	34.61	24.79	1.14	0.15	3.91	0.4
	79	17.92	34.60	24.99	2.63	0.23	5.53	0.3
	99	16.90	34.62	25.25	4.89	0.36	6.90	0.2
	123	16.22	34.62	25.41	6.91	0.50	12.14	0.1
	149	15.28	34.61	25.61	9.30	0.64	13.40	0.1
	199	13.53	34.54	25.93	13.93	0.93	21.20	0.0
	298	10.16	34.37	26.43	23.35	1.61	44.91	
	496	6.90	34.29	26.87	31.64	2.28	74.08	
	793	4.37	34.37	27.24	38.49	2.75	110.78	
	990	3.47	34.44	27.39	39.70	2.83	126.78	
	1435	2.47	34.54	27.57	40.00	2.87	141.09	

unit. NO_3, PO_4, $Si(OH)_4$: μmol l^{-1}; chlorophyll *a* : μg l^{-1}

Appendix 17. θ, salinity, σ_θ, nutrients [NO_3, PO_4, $Si(OH)_4$] and chlorophyll *a* data in July 2003.

station	Depth (m)	θ (℃)	salinity	σ_θ	NO_3	PO_4	$Si(OH)_4$	chlorophyll *a*
St. 3	0				0.00	0.44	0.74	0.8
	10	21.15	34.18	23.83	0.00	0.48	3.70	1.5
	20	19.19	34.53	24.61	3.44	0.64	6.10	1.5
	30	18.65	34.57	24.78	4.75	0.71	6.44	
	50	16.99	34.61	25.22	7.44	0.88	10.81	0.2
	70	15.51	34.59	25.55	10.23	1.04	15.13	0.1
	99	14.20	34.54	25.79	13.31	1.22	20.24	0.1
	124	12.98	34.50	26.01	16.29	1.41	25.43	
	149	11.93	34.45	26.18	18.34	1.48	30.73	0.0
	198	10.67	34.40	26.37	21.52	1.70	38.52	0.0
	298	8.74	34.32	26.63	26.29	2.06	52.95	
	571	5.72	34.31	27.04	34.44	2.60	86.00	
St. F	0				0.00	0.44	0.26	0.8
	10	20.55	34.33	24.11		0.46	1.74	1.9
	20	19.87	34.40	24.34	1.70	0.58	5.29	1.9
	50	16.29	34.61	25.38	8.71	0.94	13.32	0.1
	70	15.10	34.57	25.62	10.02	1.04	14.90	0.1
	99	13.84	34.53	25.86	14.39	1.29	22.67	0.0
	124	12.73	34.49	26.05	15.94	1.38	25.62	
	149	12.12	34.46	26.15	18.31	1.53	31.36	0.0
	199	10.72	34.40	26.36	21.26	1.69	38.95	0.0
	297	8.52	34.32	26.66	27.11	2.05	55.71	
	397	7.19	34.30	26.84	30.70	2.34	69.60	
	595	5.34	34.32	27.10	35.27	2.70	96.14	
	799	4.36	34.37	27.25	37.78	2.82	105.35	
St. E	0				0.00	0.44	1.20	0.5
	10	20.90	34.03	23.79	0.00	0.47	0.79	1.3
	19	19.03	34.53	24.66	2.67	0.61	7.62	1.3
	30	18.46	34.58	24.83	5.28	0.75	7.83	
	50	16.22	34.56	25.36	6.29	0.90	10.26	0.1
	69	14.74	34.57	25.70	11.56	1.11	16.59	0.0
	99	13.67	34.53	25.89	14.36	1.29	22.40	0.0
	124	12.82	34.49	26.04	16.60	1.39	26.79	
	148	11.73	34.44	26.21	18.85	1.57	32.43	0.0
	199	10.42	34.39	26.40	21.77	1.73	40.98	0.0
	298	8.70	34.32	26.64	26.72	2.06	58.64	
	397	7.19	34.29	26.84	26.40	2.12	61.77	
	645	5.01	34.33	27.14	32.60	2.54	90.97	
St. 2	2	21.35	34.01	23.65	0.00	0.03	0.53	0.9
	10	20.90	34.20	23.92	0.07	0.04	1.81	1.2
	20	19.95	34.33	24.27	1.10	0.10	2.62	1.9
	30	18.30	34.52	24.83	4.23	0.33	7.60	1.4
	40	17.87	34.57	24.98	5.91	0.42	9.38	0.6
	51	17.01	34.54	25.16	7.17	0.52	11.82	0.6
	60	15.89	34.53	25.42	9.91	0.69	16.96	0.4
	80	14.70	34.54	25.69	12.19	0.81	21.60	0.1
	100	13.99	34.53	25.83	13.29	0.91	23.55	0.1
	125	13.21	34.50	25.97	11.10	0.84	19.94	0.0
	149	12.13	34.47	26.15	17.90	1.22	32.18	0.0
	200	11.05	34.42	26.32	20.17	1.40	38.27	0.0
	298	8.85	34.33	26.62	26.00	1.81	55.44	
	496	6.29	34.29	26.96	32.55	2.29	82.64	
	793	4.06	34.39	27.30	37.75	2.67	118.25	
	991	3.23	34.46	27.44	38.90	2.72	133.84	
	1426	2.63	34.52	27.54	38.70	2.71	141.07	

unit. NO_3, PO_4, $Si(OH)_4$: μmol l^{-1}; chlorophyll *a* : μg l^{-1}

Appendix 18. θ, salinity, σ_θ, nutrients [NO_3, PO_4, $Si(OH)_4$] and chlorophyll *a* data in October 2003.

station	Depth (m)	θ (℃)	salinity	σ_θ	NO_3	PO_4	$Si(OH)_4$	chlorophyll *a*
St. 3	0				0.54	0.08	6.94	0.8
	9	22.47	33.97	23.30	0.52	0.09	6.73	0.8
	19	22.48	33.97	23.30	0.69	0.10	7.39	0.8
	30	22.48	33.97	23.30	0.53	0.10	6.31	
	49	21.59	34.21	23.74	3.13	0.27	7.68	0.3
	69	19.40	34.37	24.44	7.68	0.54	11.95	0.1
	100	16.30	34.48	25.29	11.84	0.84	18.10	0.0
	123	15.08	34.51	25.58	13.51	0.95	25.42	
	150	13.85	34.49	25.83	15.38	1.07	26.32	0.0
	200	12.02	34.45	26.16	18.78	1.31	33.43	0.0
	299	8.86	34.34	26.63	25.96	1.85	54.82	
	476	6.09	34.31	27.00	33.06	2.42	84.31	
St. F	0				0.41	0.10	4.08	0.6
	11	22.41	34.16	23.47	0.46	0.18	4.09	0.7
	20	22.42	34.16	23.47	0.42	0.13	4.14	0.5
	50	22.15	34.36	23.70	1.80	0.21	4.94	0.3
	70	19.45	34.41	24.46	6.91	0.47	10.69	0.1
	101	16.33	34.49	25.28	11.86	0.77	18.08	0.0
	125	15.52	34.59	25.54	11.96	0.81	18.16	
	150	14.22	34.55	25.79	14.13	0.91	22.03	0.0
	198	12.03	34.45	26.16	18.89	1.29	32.87	0.0
	298	8.54	34.33	26.67	26.93	1.87	56.48	
	397	7.05	34.30	26.86	30.77	2.20	71.65	
	595	5.16	34.33	27.13	35.76	2.57	94.55	
	842	3.70	34.42	27.35	38.62	2.64	117.24	
St. E	0				0.52	0.11	4.78	0.4
	10	22.32	34.16	23.49	0.54	0.09	5.28	0.4
	20	22.31	34.16	23.50	0.49	0.09	4.72	0.4
	30	22.39	34.23	23.53	0.55	0.10	4.11	
	50	22.03	34.21	23.61	2.67	0.23	6.61	0.2
	70	19.52	34.48	24.49	7.39	0.49	14.02	0.1
	100	16.05	34.57	25.41	11.30	0.77	17.20	0.0
	125	14.64	34.52	25.68	14.03	0.93	22.60	
	150	13.63	34.52	25.90	15.25	1.04	24.67	0.0
	200	11.99	34.45	26.17	19.06	1.28	33.54	0.0
	299	9.19	34.35	26.58	25.29	1.69	51.08	
	396	7.55	34.30	26.79	29.41	2.05	65.25	
	634	5.23	34.33	27.11	35.61	2.51	94.31	
St. 2	2	22.42	34.17	23.47	0.39	0.08	4.41	0.4
	10	22.43	34.17	23.47	0.49	0.10	5.83	0.4
	20	22.42	34.17	23.47	0.52	0.09	5.18	0.4
	30	22.36	34.18	23.50	0.61	0.10	8.94	0.4
	40	22.54	34.34	23.56	0.74	0.11	3.54	0.5
	50	22.07	34.25	23.63	1.97	0.17	5.06	0.3
	60	21.56	34.32	23.83	3.69	0.29	6.71	0.2
	80	18.39	34.59	24.86	8.27	0.57	12.54	0.1
	101	16.54	34.58	25.30	10.50	0.72	15.91	0.0
	124	15.04	34.51	25.59	13.63	0.96	22.32	0.0
	150	14.58	34.54	25.71	13.92	0.95	22.63	0.0
	200	12.13	34.45	26.14	16.32	1.13	29.51	0.0
	298	9.35	34.36	26.56	24.69	1.75	50.02	
	496	6.05	34.31	27.00	33.06	2.25	86.15	
	793	4.20	34.38	27.27	37.60	2.70	114.45	
	990	3.41	34.45	27.41	38.54	2.78	128.98	
	1088	3.14	34.47	27.45	38.71	2.77	133.06	
	1188	2.93	34.49	27.49	38.96	2.79	136.47	
	1286	2.74	34.51	27.52	38.61	2.78	131.05	
	1486	2.43	34.54	27.57	38.90	2.78	143.96	

unit. NO_3, PO_4, $Si(OH)_4$: μmol l^{-1}; chlorophyll *a* : μg l^{-1}

Appendix 19. θ, salinity, σ_θ, nutrients [NO_3, PO_4, $Si(OH)_4$] and chlorophyll *a* data in February 2004.

station	Depth (m)	θ (℃)	salinity	σ_θ	NO_3	PO_4	$Si(OH)_4$	chlorophyll *a*
St. 3	0				8.93	0.67	16.74	
	9	13.60	34.63	25.99	8.95	0.67	15.91	
	20	13.57	34.63	25.99	9.15	0.68	16.78	
	30	13.56	34.63	25.99	9.28	0.67	16.25	
	50	13.55	34.63	26.00	9.33	0.68	18.26	
	70	13.52	34.63	26.00	9.61	0.71	18.61	
	99	13.35	34.61	26.02	10.11	0.74	17.28	
	124	12.88	34.54	26.06	14.23	1.01	24.30	
	148	12.53	34.50	26.10	16.54	1.17	29.73	
	198	10.69	34.39	26.36	21.65	1.54	43.11	
	297	9.14	34.33	26.57	25.23	1.81	50.23	
	538	6.12	34.32	27.00	33.16	2.44	84.64	
St. F	0				8.28	0.63	13.96	
	11	13.65	34.62	25.97	8.34	0.65	15.53	
	20	13.58	34.62	25.98	8.65	0.63	14.54	
	49	13.57	34.62	25.99	8.90	0.64	14.03	
	69	13.56	34.62	25.99	8.93	0.66	15.79	
	99	13.57	34.63	25.99	9.28	0.69	15.96	
	124	12.85	34.52	26.06	14.50	1.03	26.73	
	149	12.41	34.49	26.11	17.02	1.17	29.70	
	198	11.15	34.41	26.29	20.32	1.44	39.05	
	298	9.18	34.33	26.57	24.54	1.69	46.77	
	397	7.46	34.31	26.81	29.85	2.15	67.89	
	595	5.35	34.34	27.11	35.11	2.56	95.02	
	793	4.35	34.38	27.26	37.41	2.76	113.76	
St. E	0				8.40	0.66	15.74	
	10	13.58	34.62	25.98	9.01	0.66	14.20	
	19	13.58	34.62	25.98	9.07	0.67	15.59	
	30	13.58	34.62	25.98	9.11	0.68	16.13	
	49	13.57	34.62	25.98	9.28	0.69	19.59	
	69	13.55	34.61	25.98	9.67	0.71	15.06	
	100	13.57	34.62	25.99	9.20	0.67	14.64	
	123	13.54	34.62	25.99	9.87	0.74	16.05	
	149	12.66	34.50	26.07	16.36	1.16	27.33	
	199	11.26	34.42	26.28	19.87	1.38	35.16	
	298	8.90	34.32	26.61	26.09	1.84	49.13	
	397	7.67	34.31	26.78	29.10	2.13	63.85	
	645	4.65	34.36	27.21	36.83	2.71	102.53	
St. 2	2	13.66	34.62	25.97	7.88	0.60	14.86	2.6
	10	13.63	34.62	25.97	7.95	0.60	13.51	3.1
	20	13.62	34.62	25.97	8.29	0.61	14.80	
	30	13.61	34.62	25.98	8.63	0.64	14.22	2.8
	40	13.61	34.62	25.98	8.64	0.63	14.37	2.4
	50	13.61	34.62	25.98	8.44	0.62	13.59	2.3
	61	13.57	34.62	25.98	9.30	0.67	14.48	2.1
	80	13.46	34.60	26.00	10.11	0.73	17.19	1.1
	99	12.92	34.53	26.05	14.51	1.01	23.67	0.5
	124	12.39	34.48	26.11	17.38	1.20	29.65	0.1
	149	11.90	34.46	26.19	18.60	1.29	32.29	0.0
	199	10.75	34.40	26.35	21.67	1.48	37.15	0.0
	299	8.42	34.33	26.68	19.31	1.37	35.00	
	495	5.99	34.31	27.01	34.47	2.45	85.67	
	793	4.02	34.40	27.30	39.09	2.81	113.32	
	992	3.44	34.45	27.40	39.81	2.88	123.35	
	1089	3.29	34.46	27.43	39.96	2.89	128.04	
	1189	3.12	34.48	27.46	39.89	2.87	128.94	
	1288	2.89	34.50	27.50	40.04	2.88	133.58	
	1425	2.56	34.53	27.55	39.98	2.87	135.32	

unit. NO_3, PO_4, $Si(OH)_4$: μmol l^{-1}; chlorophyll *a* : μg l^{-1}

Appendix 20. θ, salinity, σ_θ, nutrients [NO_3, PO_4, $Si(OH)_4$] and chlorophyll *a* data in May 2004.

station	Depth (m)	θ (℃)	salinity	σ_θ	NO_3	PO_4	$Si(OH)_4$	chlorophyll *a*
St. 2	3	19.28	34.12	24.28	0.24	0.11	2.32	1.0
	2	19.31	34.07	24.23	0.00	0.09	2.23	0.9
	19	16.57	34.62	25.32	5.79	0.43	8.87	0.4
	30	16.00	34.62	25.46	6.97	0.47	10.12	0.1
	39	15.53	34.61	25.55	8.43	0.56	12.58	0.3
	50	15.18	34.60	25.63	10.11	0.65	14.48	0.2
	60	14.99	34.59	25.66	10.10	0.65	14.88	0.2
	79	14.42	34.57	25.76	11.98	0.78	18.38	0.2
	99	13.82	34.54	25.87	13.18	0.87	20.76	0.2
	123	12.83	34.50	26.04	15.46	1.05	25.25	0.1
	149	12.37	34.49	26.12	16.40	1.10	27.62	0.1
	149	12.26	34.48	26.14	16.41	1.01	26.33	0.0
	197	11.27	34.43	26.28	19.46	1.21	32.71	0.1
	297	9.06	34.33	26.58	25.33	1.67	49.03	
	396	7.23	34.30	26.83	30.28	1.96	66.17	
	496	5.99	34.30	27.00	33.29	2.18	79.87	
	793	3.95	34.40	27.31	38.24	2.42	112.79	
	991	3.30	34.46	27.42	38.90	2.46	120.64	
	987	3.33	34.45	27.42	38.73	2.61	125.77	
	1086	3.14	34.47	27.45	38.94	2.52	126.39	
	1187	2.98	34.49	27.48	38.54	2.59	128.58	
	1286	2.82	34.50	27.51	38.76	2.56	130.31	
	1417	2.61	34.53	27.54	38.75	2.62	131.66	
	1437	2.62	34.52	27.54	38.97	2.61	134.86	

unit. NO_3, PO_4, $Si(OH)_4$: μmol l^{-1}; chlorophyll *a* : μg l^{-1}

Appendix 21. θ, salinity, σ_θ, nutrients [NO_3, PO_4, $Si(OH)_4$] and chlorophyll *a* data in November 2004.

station	Depth (m)	θ (℃)	salinity	σ_θ	NO_3	PO_4	$Si(OH)_4$	chlorophyll *a*
St. 2	13	22.40	33.84	23.23	0.13	0.06	2.64	1.5
	21	22.42	33.85	23.23	0.30	0.07	3.51	1.4
	31	22.62	33.99	23.28	0.84	0.10	3.68	0.7
	42	21.98	34.35	23.73	3.52	0.25	4.67	0.1
	50	21.51	34.38	23.89	4.50	0.31	5.62	0.0
	61	20.60	34.47	24.20	5.81	0.39	6.94	0.0
	72	19.50	34.60	24.59	7.02	0.47	7.23	0.0
	91	17.57	34.64	25.10	9.13	0.62	9.76	0.0
	111	16.62	34.62	25.32	10.30	0.70	11.18	0.0
	135	15.79	34.59	25.48	11.59	0.79	12.79	0.0
	161	14.41	34.55	25.76	13.78	0.95	18.60	0.0
	160	14.26	34.54	25.78	13.74	0.93	16.09	0.0
	208	11.97	34.43	26.16	18.34	1.24	23.11	0.0
	308	9.23	34.32	26.55	25.14	1.79	39.43	
	408	6.93	34.27	26.86	30.50	2.22	56.54	
	506	5.91	34.30	27.01	33.99	2.37	66.95	
	804	3.51	34.44	27.39	38.68	2.71	96.97	
	1001	2.95	34.49	27.48	39.33	2.83	101.64	
	1002	3.11	34.48	27.46	39.06	2.82	102.62	
	1102	2.72	34.51	27.52	39.51	2.83	106.35	
	1200	2.52	34.54	27.56	39.39	2.80	109.82	
	1298	2.39	34.55	27.58	39.18	2.81	108.83	
	1397	2.35	34.56	27.59	39.08	2.80	109.03	
	1499	2.32	34.56	27.60	39.09	2.81	108.84	

unit. NO_3, PO_4, $Si(OH)_4$: μmol l^{-1}; chlorophyll *a* : μg l^{-1}