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Dynamics of pelagic variables in two contrasting coastal systems in the western Hokkaido coast off Otaru port, Japan

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A B S T R A C T

Human impact on adjacent coastal waters, leading to alteration in nutritional environment and hence affecting phytoplankton biomass (Chlorophyll *a*), will probably be enhanced by the nearby presence of ports. The main goal of this study is to assess the influence of nearby presence of port on phytoplankton biomass build-up and the physical–chemical environmental characteristics in two contrasting coastal systems (Otaru port, S-IN and an exposed coastal area, S-OUT) in the western Hokkaido coast off Otaru port, Japan. Sampling was conducted on "bi-weekly and monthly" basis during the period of September 2006–December 2007 and data comprising 11 pelagic variables were obtained. In most instance, phytoplankton biomass, nutrients' (NH_4, NO_3, PO_4, and $Si(OH)_4$) concentrations and nutrients' molar ratios were higher at the Otaru port location. Physical parameters (temperature, salinity, hydrogen ion concentration (pH), photosynthetically active radiation (PAR) and dissolved oxygen, (DO)) were not significantly different ($P > 0.05$) between the two locations. With the exception of salinity, pH and DIC, all variables measured showed significant variation ($P < 0.05$) with season. While the coefficient of variation (CV) of physical parameters and phytoplankton biomass were relatively higher in Otaru port location (S-IN), the exposed coastal location (S-OUT) showed a higher variation in chemical parameters. Other variables showed different patterns between the two locations. We conclude that ports, due to its activities and restricted circulation favour high nutrient loading and phytoplankton biomass build-up in adjacent coastal systems, thus, suggesting the need for continuous field observation data in order to advance our knowledge on possible future human impact on coastal environment and the need to monitor and control port activities.

1. Introduction

Human impact on the continental margins is increasing with expanding urbanization and the conflicting demands of tourism, aquaculture, water diversions, wind parks and other developments such as ports. Nutrient delivery to coastal areas has increased in the recent years as a consequence of human activity, mainly agricultural practices and sewage discharges particularly affecting enclosed bays and lagoons (Kormas et al., 2001; Hung and Kuo, 2002; Muslim and Jones, 2003; Newton et al., 2003; Zaldivar et al., 2003). Adjacent coastal waters are also inevitably affected by the nearby presence of ports which can be considered as a transition zone between the natural environment and the area impaired by port activities. Sea ports are very complex systems with a wide range of environmental issues: releases to water, waste water, noise, dredging, waste production, fishing activity, maintenance operations, recreational activity and storage, loading and unloading of oil products amongst others (Darbra et al., 2004, 2005; Peris-Mora et al., 2005). With regard to their ecological profiles, ports are particularly critical environments on account of the type of activities conducted in ports and their surroundings; moreover, they are also subject to the risk of further pollution from accidental causes. There is therefore the need for in-depth scientific knowledge of the ecological characteristics of port areas, as well as adjacent marine zones, in order to identify both internal and external risk areas and to plan prevention and clean-up measures that can guarantee a reliable safety margin.

Otaru is a port town of about 145,000 population located on the Sea of Japan side of western Hokkaido, facing to Ishikari Bay (Fig. 1). Otaru port is an important port on the Sea of Japan coast. Extensive work for port improvement and expansion, as well as the creation of new ports raises a series of problems involved in the safeguarding of

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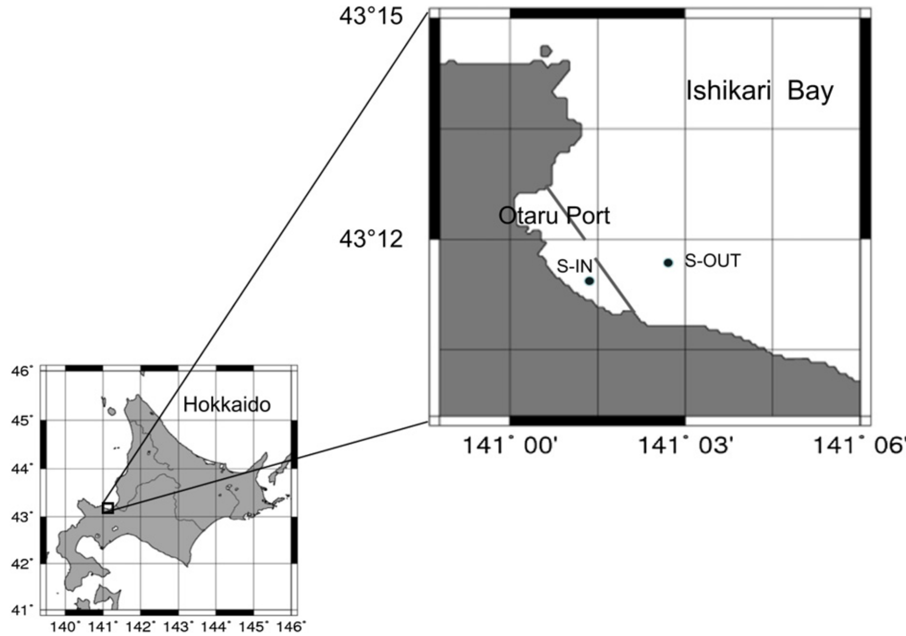

Fig. 1. Study area showing the sampling locations, S-IN and S-OUT in Ishikari Bay.

coastal zones. Since this has direct impact on the coastal ecosystems, anthropogenic influence (port activities) on some pelagic variables (physical, chemical and biological components) in the Ishikari Bay is hereby investigated. We carried out a bi-weekly and monthly sampling at two sampling stations in the Ishikari Bay, one in Otaru port/harbour and the other at an exposed coastal area from September 2006 to December 2007. The out-port station (hereafter, S-OUT) with high tidal influence is assumed to have a higher water turnover rate compared with the in-port station (hereafter, S-IN).

In order to measure anthropogenic influence on a certain ecosystem, a good knowledge of the system natural variability is a necessary requisite. Variability and unsteadiness are intrinsic properties of coastal ecosystems, where the action of natural forcing factors is difficult to isolate from anthropogenic ones. Phytoplankton appears very sensitive to climatic changes and could be used as a proxy of the variations occurring in the environment. Also, phytoplankton responds rapidly to pulsed nutrient inputs that might otherwise go undetected by regular nutrient sampling (Brando et al., 2006). Thus, monitoring can provide information on physico-chemical factors, and measurement that reveal the overall condition of the ecosystem (e.g. Chlorophyll *a*). Chlorophyll *a* concentrations are an indicator of phytoplankton abundance and biomass in coastal and estuarine waters and have been extensively used in measuring trophic status and water quality (ANZECC/ARMCANZ, October 2000). Extremely high levels often indicate eutrophication, and low levels often suggest oligotrophic condition. However, elevated Chlorophyll *a* concentrations are not necessarily unfavorable condition. It is the long-term persistence of elevated levels that is a problem (Ward et al., 1998).

The aim of this study is to investigate the impacts of human induced activities (port and urban sewage discharge) on oceanographic parameters, especially nutrient concentrations and phytoplankton biomass build-up. This would help to monitor water and ecosystem quality in the coastal zone and the sporadic nutrient supply to the ocean area resulting in temporal increases in phytoplankton biomass. Also, we intend to aggregate the temporal dynamic environmental signal of port activities through observed variations in pelagic variables in Otaru port (S-IN) and an exposed coastal area (S-OUT).

2. Materials and methods

2.1. Study area and sampling

Two stations were studied in Ishikari Bay (western coast of Hokkaido): one inside the Otaru port/harbour (S-IN: 43°11.3′N, 141°1.1′E) and the other outside the port (S-OUT: 43°11.4′N, 141°2.3′E, Fig. 1). These stations are located about 30 km westward from Ishikari River mouth and river plume extends northeastward in the Ishikari Bay (Agboola et al., 2009). Thus, we assumed, at least, a little or no influence from the Ishikari River. Water samples were collected in 10 l acid clean cowboys and 5 l Niskin bottle. Physical parameters (temperature, salinity, PAR, and depth) were measured in situ by deploying a CTD profiler (AST-1000PK, Alec Electronics Co. Ltd.) and a PAR sensor (LI-193SB, Li-Cor).

2.2. Chlorophyll a and nutrient analyses

Chemical parameters (O_2, pH, NO_3^-, NH_4^+, PO_4^-, $Si(OH)_4$ and DIC) and phytoplankton biomass (Chlorophyll *a*) were determined. Sub-samples for nutrients (NO_3^-, NH_4^+, PO_4^-, and $Si(OH)_4$) were collected in 5 ml spit tubes and stored frozen at −30 °C prior to measurement using a nutrient analyzer (QuAAtro, BRAN + LUBBE). Phytoplankton biomass (Chlorophyll *a*) was measured at S-IN and S-OUT locations by filtering 150 ml of sub-sample through Whatman GF/F (25 mm diameter, nominal pore size 0.7 μm) using parallel filtration under low vacuum pressure (<250 mg Hg) or gravity. After filtration, Chlorophyll *a* was immediately extracted by immersing the filter in *N*,*N*-dimethylformamide (Suzuki and Ishimaru, 1990), and preserved at −30 °C until on shore analysis by fluorometry. Chlorophyll *a* concentrations were determined using HITACHI F2000 fluorescence spectrophotometer, according to the method of Parsons et al. (1984).

2.3. Statistical analysis

Physical, chemical and biological data were classified into spring (March, April and May), summer (July and August), autumn (September, October and November) and winter (December, January and February) and were compared for stational and seasonal variability using a two-way analysis of variance (ANOVA), whereas, Duncan multiple range test was used for separation of means. Pearson Product Moment Correlation's coefficient was used to evaluate associations between variables. The coefficient of variation (CV) was used to compare the variability of measured parameters at S-IN and S-OUT locations.

3. Results

3.1. Seasonal variation of environmental variables

The range of temperature, salinity, dissolved oxygen (DO) and pH variables over 16 months (September 2006–December 2007) is presented in Fig. 2. Temperature vertical profile across the sampling period was homogenous in the two stations (Fig. 3a and b), whereas salinity profile showed intermittent mixing of bottom waters to the surface especially in S-OUT in autumn (Fig. 3c and d). Mean surface temperature varied from 4.1–4.7 °C in winter to 21.5–21.7 °C in summer (Fig. 4a). In contrast, salinity mean values were nearly equal in S-IN and S-OUT across the seasons with a maximum value of 33.4 (Fig. 4b). Dissolved oxygen (DO) peaked in spring (Fig. 4c), coinciding with the minimum DIC value (Fig. 4d) across the seasons in both stations. Seasonal pH values were highest in spring (7.99 ± 0.29) and summer (8.11 ± 0.22) especially in S-IN (Fig. 4e), establishing the corresponding relationship between dissolved inorganic carbon (DIC) and pH as observed by the lower DIC concentration in the same seasons. Although, temperature, salinity, DO and pH were not significantly different between stations ($P > 0.05$), temperature and DO were significantly different across seasons ($P < 0.0001$).

Photosynthetically active radiation (PAR) ranged from 150 μmol $m^{-2}\,s^{-1}$ in S-IN and S-OUT in winter to 2210 μmol $m^{-2}\,s^{-1}$ and 2400 μmol $m^{-2}\,s^{-1}$, respectively, at S-IN and S-OUT in spring. There was no significant variation in PAR values between stations ($P > 0.05$) but PAR values were significantly lower in winter compared to other seasons ($P < 0.005$)

3.2. Seasonal variation of nutrient concentrations and ratios

Nutrients' concentrations were higher in S-IN compared with S-OUT over the 16 months sampling period (Table 1 and Fig. 5). The two stations showed similar seasonal trend in NH_4, DIN and PO_4 concentrations with a sharp peak in January (winter). However, NO_3 and $Si(OH)_4$ concentration across the sampling period showed both similar and varied trends in both stations. All nutrients

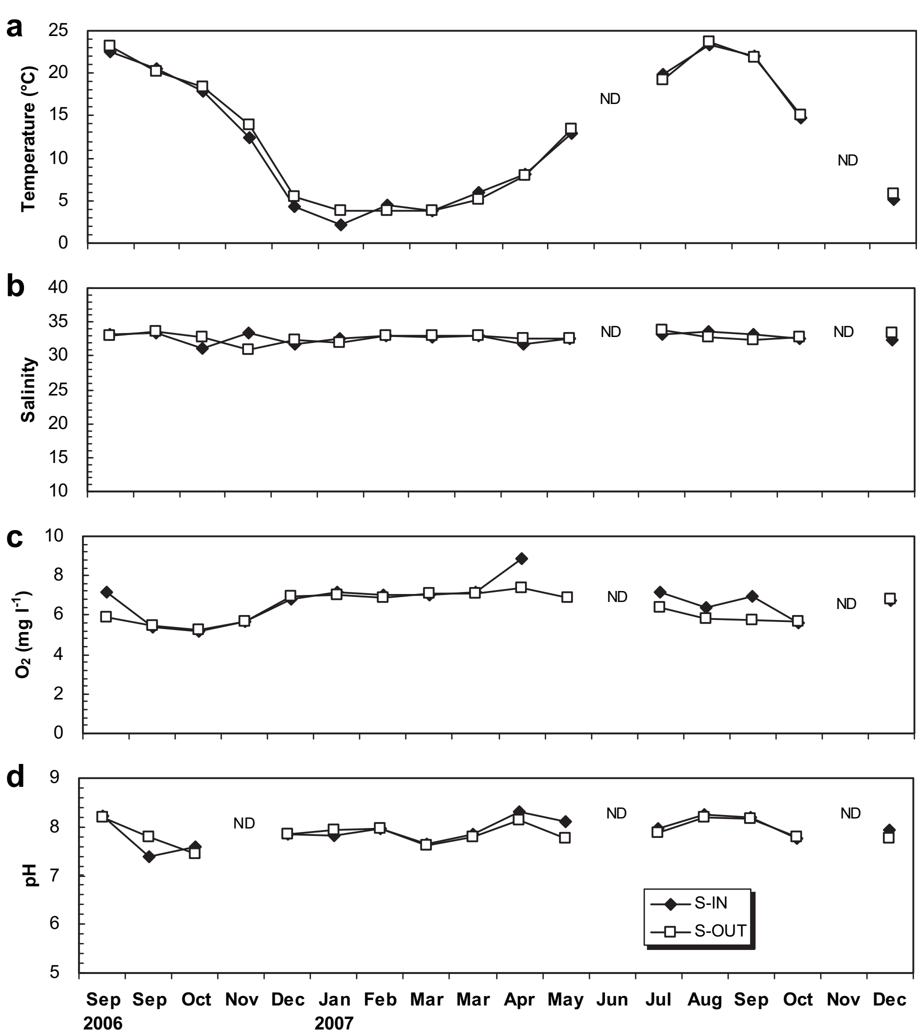

Fig. 2. Temporal variation of some physico-chemical parameters in surface waters from S-IN and S-OUT stations during sampling in Ishikari Bay. ND means no data. Repeated month implies bi-weekly sampling.

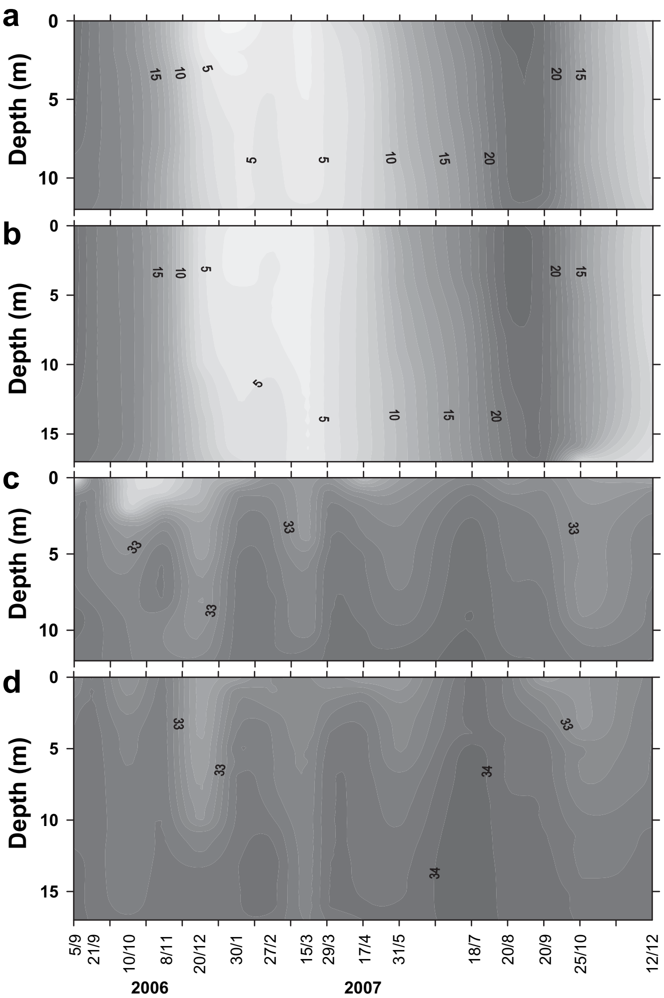

Fig. 3. Vertical profiles of temperature and salinity in S-IN (a and b) and S-OUT (c and d), respectively, during the time series observation in Ishikari Bay.

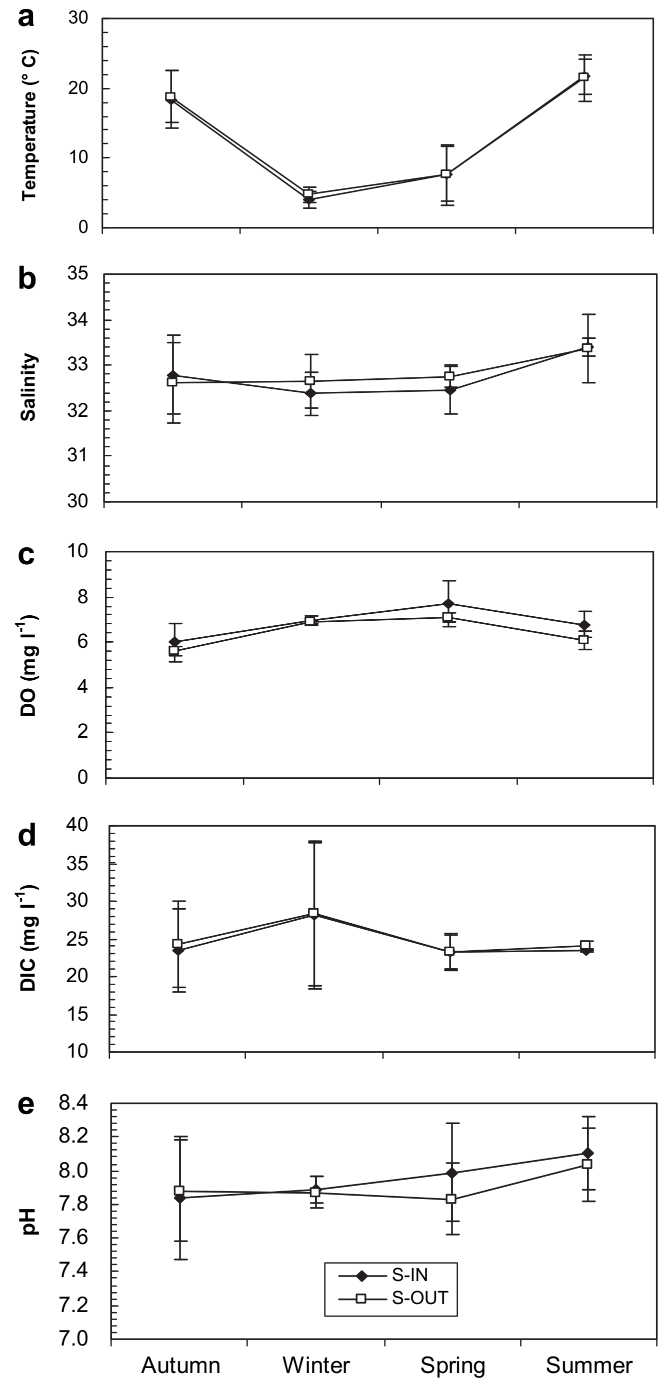

Fig. 4. Mean ± SD of seasonal temperature (a), salinity (b), DO (c), DIC (d) and pH (e) in S-IN and S-OUT during the sampling period (September 2006–December 2007) in Ishikari Bay.

especially NH_4 and PO_4 showed relatively higher values in S-IN compared with S-OUT in December 2007. While all nutrients showed highly significant variation ($P < 0.001$) across seasons, there was no significant variation between stations ($P > 0.05$).

Dissolved inorganic nitrogen (DIN: $NO_3^- + NO_2^- + NH_4^+$) concentrations during the sampling period ranged from 0.015 to 47 μM (Fig. 5): the highest values in winter, almost depleted through the summer. DIN concentration was dominated by NH_4^+: a minimum value of 0 μM in autumn and summer and a maximum of 40.1 μM in winter. Average ammonium concentration was significantly higher ($P < 0.005$) at S-IN (7.78 ± 11.20 μM) than at S-OUT (4.23 ± 6.11 μM).

The minimum (0.03 μM) and the maximum (1.31 μM) of phosphate concentration was observed at S-IN in summer and winter, respectively. Average phosphate concentration was significantly higher ($P < 0.001$) at S-IN (0.45 ± 0.39 μM) compared with S-OUT (0.31 ± 0.24 μM). Silicic acid concentration showed some dissimilar peaks at both stations across the sampling seasons, showing abrupt fall (from 32.3 μM to 1.2 μM) in summer like other nutrients. Similarly, average concentration was significantly higher ($P < 0.005$) at S-IN (14.20 ± 10.03 μM) than at S-OUT (10.12 ± 7.29 μM).

Nutrients concentrations generally increased during the winter mixing period and decreased during the stratification period in summer; however, nutrients rarely showed complete depletion even in summer.

DIN:P ratio was on average (±SD) higher at S-IN (28.2 ± 28.8) than at S-OUT (19.1 ± 11.8) with relatively high ratios in winter and spring. At both stations in autumn and summer, these ratios are lower than the Redfield ratios of 16:1 (Redfield et al., 1963). Si:P ratios were relatively high across the season at both stations. While highest seasonal average was recorded at S-IN (65.7 ± 27.5) in spring, S-OUT (28.4 ± 15.1) had lowest seasonal average in autumn. Unlike other molar ratios, Si:N ratio was on average (±SD) higher at S-OUT (8.5 ± 17.6) than at S-IN (6.2 ± 9.4). However, average Si:N molar ratios were <1.3 at S-IN and <2.5 at S-OUT in winter and

Table 1
Minimum and maximum nutrient concentrations (DIN, PO_4, and SiO_2) and ratios (N:P, Si:P and Si:N) during autumn (September–November; $n = 6$), winter (from December to February; $n = 4$), spring (from March to May; $n = 4$) and summer (July–August; $n = 2$) at S-IN and S-OUT.

		Autumn		Winter		Spring		Summer	
		S-IN	S-OUT	S-IN	S-OUT	S-IN	S-OUT	S-IN	S-OUT
DIN	Min	0.15	0.02	12.88	8.99	5.16	0.77	0.06	0.12
	Max	16.30	7.86	46.67	29.84	10.19	14.27	0.21	1.57
PO_4	Min	0.10	0.10	0.50	0.44	0.05	0.11	0.03	0.04
	Max	0.69	0.35	1.31	0.49	0.41	0.40	0.08	0.06
$Si(OH)_4$	Min	3.62	1.00	16.00	14.08	4.48	4.10	1.23	1.22
	Max	25.60	13.15	32.28	22.12	14.89	20.38	6.12	2.82
N:P	Min	0.25	0.07	25.60	20.56	24.88	6.82	2.20	2.90
	Max	23.67	28.16	35.53	29.19	105.29	41.58	2.57	26.80
Si:P	Min	5.98	4.94	19.77	19.60	36.36	29.84	46.70	28.89
	Max	47.53	52.17	42.14	50.61	91.30	59.38	73.22	47.99
Si:N	Min	1.50	1.26	0.56	0.67	0.87	1.43	21.23	1.79
	Max	24.13	66.67	1.57	2.46	1.55	5.36	28.50	9.96

spring seasons. While all nutrient ratios except Si:N showed highly significant variation ($P < 0.001$) across seasons, there was no significant variation ($P > 0.05$) between stations.

3.3. *Seasonal variation of phytoplankton biomass (Chlorophyll a)*

Phytoplankton biomass (Chlorophyll *a*) ranged from 0.20 to 24.58 $\mu g\, l^{-1}$ at S-IN and from 0.21 to 15.48 $\mu g\, l^{-1}$ at S-OUT over 16 months sampling period (Fig. 6a). Chlorophyll *a* concentration peaked (24.58 $\mu g\, l^{-1}$) in September (autumn) with a corresponding draw down in nutrients' concentration, whereas in January (winter) when nutrients concentrations were highest, lowest Chlorophyll *a* values (0.20 $\mu g\, l^{-1}$) were due to limited light conditions. The mean Chlorophyll *a* biomass was <1.0 $\mu g\, l^{-1}$ in winter and >2.0 $\mu g\, l^{-1}$ in other seasons at both stations (Fig. 6b). Although, there was no significant variation ($P > 0.05$) in Chlorophyll *a* concentration with the observed stations, variations across seasons were significant ($P < 0.05$). Using the Duncan Multiple range test, Chlorophyll *a* concentration in winter, spring and

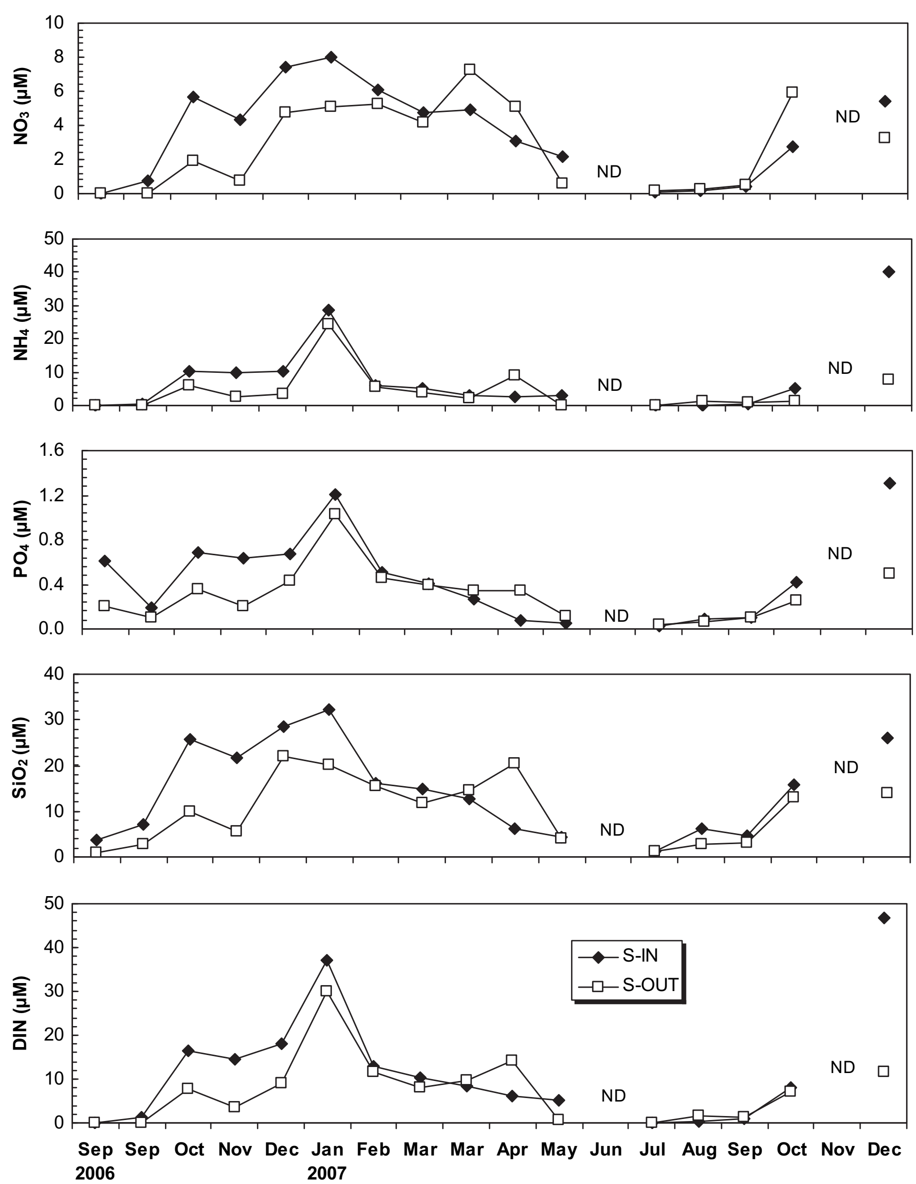

Fig. 5. Variations of nutrient's concentration in S-IN and S-OUT during the sampling period in Ishikari Bay. ND means no data. Repeated month implies bi-weekly sampling.

summer seasons was not significantly different at 5% probability level. Also, at this probability level, Chlorophyll *a* concentrations in spring, summer and autumn were not significantly different. However, Chlorophyll *a* concentrations were generally higher in S-IN compared with S-OUT, suggesting eutrophication tendency in port location (S-IN).

Chlorophyll *a* concentration in the system increased with corresponding decreased concentration of DIN and PO_4 (Fig. 8a and b). The fitted exponential model is of the form:

$$y = A\exp^{bx} \quad (1)$$

where *A* and *b* are constants that do not depend on DIN or PO_4 but may depend on other physical, chemical or biological processes. Fig. 8a and b reveals that the average Chlorophyll *a* concentration in S-IN (DIN, 5.34 $\mu g\ l^{-1}$; PO_4, 6.43 $\mu g\ l^{-1}$) is intrinsically higher than that of S-OUT (DIN, 4.61 $\mu g\ l^{-1}$; PO_4, 6.37 $\mu g\ l^{-1}$). Also, *b*, the rate of decrease in Chlorophyll *a* concentration given the DIN concentration of the system is higher for S-OUT ($b = -0.12$) than for S-IN ($b = -0.08$). Similarly, the rate of decrease in Chlorophyll *a* concentration given the PO_4 concentration of the system is also higher for S-OUT ($b = -3.85$) that for S-IN ($b = -2.47$).

3.4. Intercorrelation of Chlorophyll a with other variables

We evaluate the relations between Chlorophyll *a* and other variables using Pearson Product Moment Correlation's coefficient. In Otaru port location (S-IN), Chlorophyll *a* only showed strong correlation with temperature ($r = 0.674$; $P = 0.01$; $n = 16$), nitrate ($r = -0.705$, $P = 0.01$; $n = 16$) and silicate ($r = -0.617$; $P = 0.05$; $n = 16$), whereas, in S-OUT, Chlorophyll *a* showed strong correlation with temperature ($r = 0.706$; $P = 0.01$; $n = 16$), pH ($r = 0.614$; $P = 0.01$; $n = 16$), phosphate ($r = -0.526$; $P = 0.05$; $n = 16$), nitrate ($r = -0.628$, $P = 0.01$; $n = 16$) and silicate ($r = -0.631$, $P = 0.01$; $n = 16$). Since most nitrogen loading into aquatic systems has often been implicated with anthropogenic influence, stronger correlation between nitrate and Chlorophyll *a* in S-IN may suggest some influence from port activity.

4. Discussion

Our results clearly show that over the 16 months sampling period most of the pelagic variables had higher values or concentrations at S-IN than at S-OUT. Temperature and salinity profiles at both stations did not suggest freshwater influence; salinity profile (Fig. 3c and d) depicts higher water column stratification in S-IN than at S-OUT. Surface water pH values at both stations were within the range of natural water pH values of 6.5–8.5.

Since the pelagic environment in Otaru port is not in a continual state of flux compared to the exposed coastal area of the Ishikari Bay, introduction of excess organic matter may result in a depletion of oxygen from the aquatic system. Across the sampling periods, dissolved oxygen levels were >6.0 mg l^{-1} at more than 60% of our observations. Low dissolved oxygen concentrations can increase mortality, reduce growth rates and alter the distribution and behavior of aquatic organisms, all of which can produce significant changes in the overall estuarine food web (Breitburg, 2002). Also, prolonged exposure to low dissolved oxygen levels (less than 5–6 mgl^{-1} oxygen) may not directly kill organism, but will increase susceptibility to other environmental stresses (Wazniak, 2002).

Phytoplankton assimilate available nutrients over their lifetime, whereas water column inorganic nutrient concentrations are notoriously variable over much shorter time scales (Brando et al., 2006). Nutrient concentration varied across the sampling period with elevated concentration at S-IN compared to S-OUT. Elemental ratios give information about nutrient limiting phytoplankton growth. Seasonal Si:N:P molar ratio from the study (Fig. 7a and b) showed varied limiting trends. Mean Si:N molar ratio was <1.3 in S-IN in winter and spring seasons. When the Si:N atomic ratio is near 1:1, aquatic food webs leading from diatoms (which require silicate) to fish may be compromised and the frequency or size of

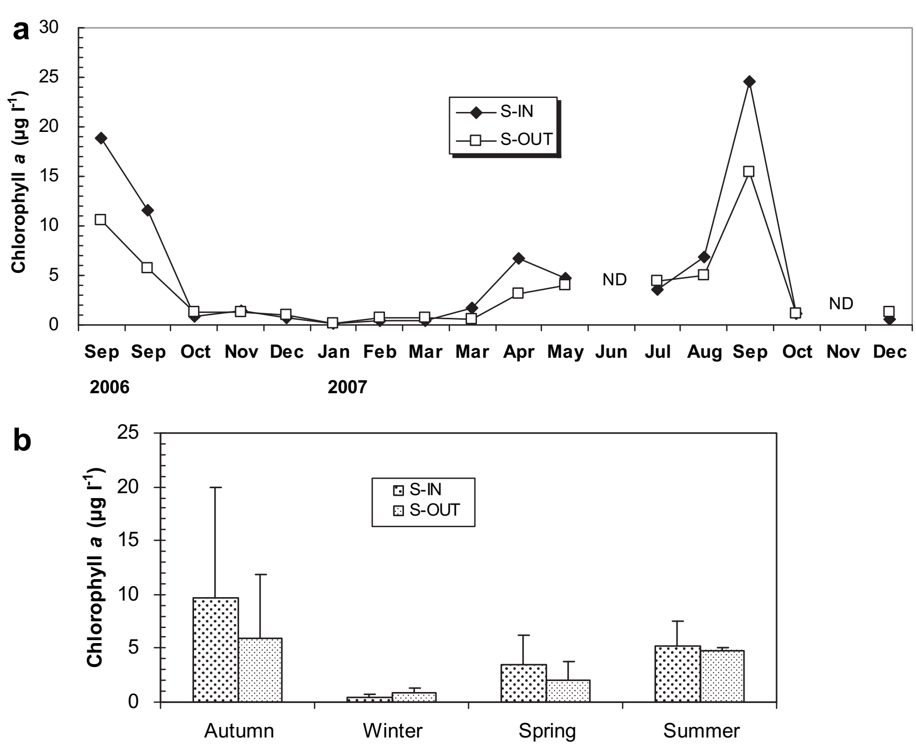

Fig. 6. Variations of Chlorophyll *a* concentration (a) and mean ± SD seasonal variation of Chlorophyll *a* during the sampling period (September 2006–December 2007).

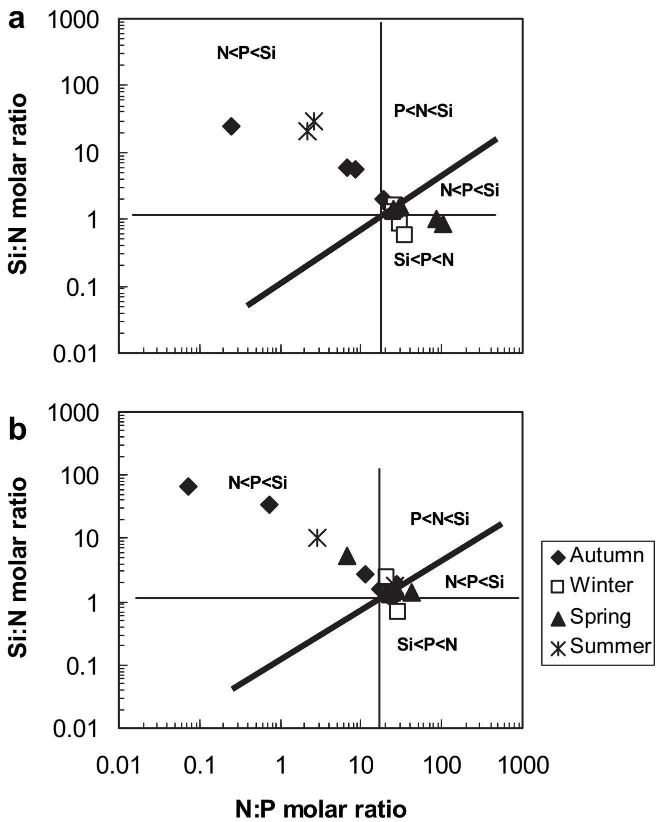

Fig. 7. Seasonal Si:N:P molar ratios in S-IN (a) and S-OUT (b). Vertical and horizontal lines: Redfield et al. (1963) ratio (N:P) and Brzezinski (1985) ratio (N:Si), respectively. Diagonal line: aggregated ratio (Si:N:P = 16:16:1).

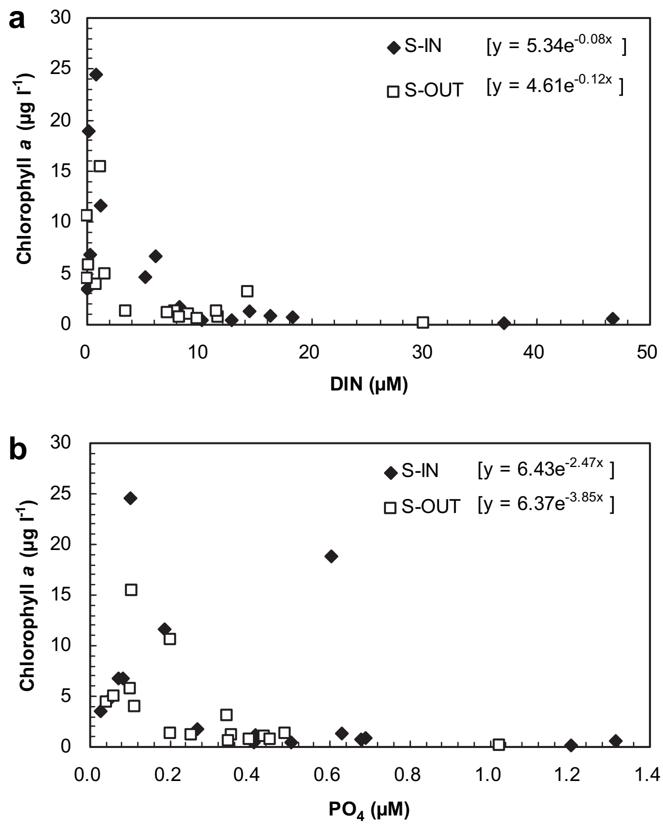

Fig. 8. The relationship between Chlorophyll *a* and dissolved inorganic nitrogen (DIN) (a) and Chlorophyll *a* and PO_4 (b) in S-IN and OUT across the sampling period (September 2006–December 2007) described by an exponential model.

harmful or noxious algal blooms may increase. Using the atomic Si:N:P ratio of 16:16:1 (Redfield et al., 1963; Brzezinski, 1985; Rahm et al., 1996) as a criterion for balanced nutrient composition, one can distinguish the Otaru port location (S-IN) and the exposed coastal area (S-OUT) with close Si:N:P molar ratio of 32:26:1 and 33:23:1, respectively, as higher than the Redfield molar ratios. While PO_4 maintained similar ratio, $Si(OH)_4$ and DIN had 2 and 1.5 order of increase, respectively.

Due to the influences of human activities, within only a few decades, numerous previously pristine, oligotrophic estuarine and coastal waters have undergone a transformation to more mesotrophic and eutrophic conditions (Nixon, 1995; Paerl, 1997). Eutrophic waters could change the molar ratios among key limiting nutrients, change the nutrients balance, and cause environmental deterioration (Turner and Rabalais, 1994; Shen, 2001).

According to Nixon (1992), elevated concentrations of Chlorophyll *a* can reflect an increase in nutrient loads and increasing trends can indicate eutrophication of aquatic ecosystems. Anthropogenic discharges typically have a high nitrogen:phosphorus ratio (N:P) because of the preferential removal of P in sewage treatment (Flynn, 2002). In this study, for example, elevated concentration of Chlorophyll *a* corresponded with lower DIN and PO_4 concentration (Fig. 8) and vice versa. Aquatic systems tend to have a high phytoplankton biomass, but low concentrations of dissolved inorganic nitrogen due to phytoplankton uptake. Thus, one may suggest that human activity (port) which may impact on nutrient load has effect on Chlorophyll *a* concentration in this system. However, as there were no increasing trends in Chlorophyll *a* concentration over the sampling period, it may be suggested that asides from nutrient load, season also played significant role in the observed autotrophic biomass. Also, the Chlorophyll *a* biomass was highest in summer–autumn due to thermohaline stratification, high nutrients, temperature, and light availability. The classical spring bloom of temperate areas was not observed at this time series station.

The condition of restricted circulation prevailing inside Otaru port (S-IN) induced increased phytoplankton biomass concentration compared to the exposed coastal area of Ishikari Bay. Moreover, against an expected low dissolved oxygen (O_2) concentration in the port station (S-IN) due to low water turnover rate and high biological degradation, higher phytoplankton biomass compared with S-OUT station may have produced an increase in dissolved oxygen (O_2) concentration especially in autumn, spring and summer seasons in S-IN.

About 73% (8 out of 11) measured variables revealed higher CV for S-IN (Table 2). With exception of PO_4 all other nutrients had higher variation at S-OUT. Against an expected higher variability at

Table 2
Coefficient of variation (CV, %) of some pelagic variables in S-IN and S-OUT stations across the sampling period in Ishikari Bay.

Variables	CV, %	
	S-IN	S-OUT
Temperature (°C)	61.6	59.5
Salinity	2.1	2.0
pH	3.3	2.7
DO (mg l^{-1})	13.9	11.0
DIC (mg C l^{-1})	24.1	23.3
PAR (μmol m^{-2} s^{-1})	53.4	51.9
NH_4 (μM)	143.4	143.7
PO_4 (μM)	87.2	78.6
SiO_2 (μM)	70.6	72.0
NO_3 (μM)	77.0	90.0
Chlorophyll *a* (μg l^{-1})	137.4	118.1

S-OUT, a typical exposed coastal environment, the higher variability at the port station (S-IN) may be attributed to a complex of factors. The port is by definition an area protected from wave action and therefore of reduced water circulation and even more so in case of microtidal environment. However, water in this port is subjected to stirring due to large vessels and wind driven circulation especially in summer–autumn and winter.

While it is evident from measured variables that concentrations or values were higher at S-IN than at S-OUT, this study did not reveal any significant change in coastal water quality as a result of port activity. Sea traffic operations at the Otaru port remain relatively moderate, so anthropogenic loading of nutrients to the coastal area may be limited. However, locally elevated nutrient concentrations observed in the coastal areas (Otaru port) around the conurbation of the city of Otaru may suggest discharge of urban sewage and industrial wastes. One of the operational bioindicators for coastal management as suggested by Håkanson and Blenckner (2008) is Chlorophyll *a* concentration. They suggest Chlorophyll *a* mean values greater than 1.5 mg m^{-3} for the growing season as "critical" and as "alarm" when greater that 2.5 mg m^{-3}. Seasonal mean value of Chlorophyll *a* at S-IN location was greater than 2.5 $\mu g\,l^{-1}$ in autumn, spring and summer seasons. Although, these limits meant as reference values indicating the "state of alert" when there is a change in Chlorophyll *a* concentration, they may not be related to seasonal but to long-term changes in coastal ecosystems. There is therefore, the need for continuous field observation data in order to advance our knowledge on possible future human impact on coastal environment and the need to monitor and control port activities.

5. Conclusion

In a coastal sea such as the Ishikari Bay, where ecosystem boundaries correspond adequately to political frontier, and where conservation need not be reconciled with multiple economic interests, adequate control through surveillance and prevention measures based on scientific knowledge of the problems involved may be required. Control of port and adjacent marine ecosystem's environmental quality is a guarantee against further degradation and eliminates pollution. This could also facilitate more effective intervention policies that aim to perform reliable environmental impact assessment of proposed port structure expansion and modification.

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