Hydrobiologia **512:** 215–229, 2004.
P.O. Ang, Jr. (ed.), Asian Pacific Phycology in the 21st Century: Prospects and Challenges.

The effects of nutrients and their ratios on phytoplankton abundance in Junk Bay, Hong Kong

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Key words: eutrophication, nutrients, N:P ratio, phytoplankton, harmful algal bloom, Junk Bay, Hong Kong

Abstract

Eutrophication has been considered to be undoubtedly one of the key factors stimulating phytoplankton growth, since it involves the enrichment of a water mass with both inorganic and organic nutrients supporting plant growth. Nutrient enrichment as a result of anthropogenic activity occurs in estuaries and coastal waters as well as in lakes and freshwater impoundments, and blooms of phytoplankton are one of the effects of such an accelerated process of nutrient enrichment. This paper presents the results of a two-year survey of the nutrients and phytoplankton at 3 stations in Junk Bay, Hong Kong, carried out from 1997 to 1998. The relationships between nitrogen, phosphorus, and their ratio, with phytoplankton abundance have been studied. The results show that the highest nitrogen concentration was in Station 2 which is close to a sewage input, whereas the highest phosphorus concentration was in Station 1 which is close to a landfill area. The mean N:P ratios at the three stations were between 8 and 14. The diatoms were the dominant group during most of the year but it seems that diatoms were more sensitive than dinoflagellates and other algal groups to the increase in nutrients.

Introduction

After almost a century of study, the term 'eutrophication' can be defined in terms of both systems naturally enriched by nutrients, e.g. upwelling in the sea, or so-called natural eutrophication, and environments polluted by anthropogenic activities such as sewage discharge, or so-called cultural eutrophication. Most recent studies have focused on cultural eutrophication. Coastal marine waters, particularly embayments and estuaries, are typically more fertile than the open ocean. The urbanization of coastal marine and estuarine areas results in a dramatic increase in population, so that eutrophication by anthropogenic activities such as urban waste and sewage discharge, increasing use of agricultural fertilizers, freshwater runoff, riverine nutrient inputs, coastline construction, tourism, mariculture, etc., are now the major causes in the world of environmental pollution. Many estuaries and coastal waters are eutrophic because of the large amounts of inorganic nutrients (primarily nitrogen and phosphorus) and organic matter they receive from anthropogenic activities. It is a widespread phenomenon in coastal areas and estuaries all around the world. Well-known examples from elsewhere in the world are Chesapeake Bay (Fisher, et al., 1992), the Baltic Sea (Larsson et al., 1985), Narragansett Bay (Nixon, 1997), the Black Sea (Mee, 1992), the Dutch Wadden Sea (De Jonge & Raaphorst, 1995), Mediterranean Sea (Stirn, 1988), the North Sea (Paetsch & Radach, 1997), Skagerrak and Kattegat (Rosenberg et al., 1996), and the Seto Inland Sea (Yamanaka, 1983).

Phytoplankton primary production in both fresh water and marine ecosystems is basically controlled by three factors: nutrient availability, light availability, and the response of the algae to nutrients and light (Kelly & Naguib, 1984). The direct effect of nutrient enrichment is phytoplankton 'population explosions' (or algal blooms). The decomposition of these blooms depletes dissolved oxygen in the water column, resulting in invertebrate, fish and even marine mammal kills (Hallegraeff, 1993). Some algae can produce toxins which can be hazardous to humans through the food web (Yasumoto, 1990; Baden et al., 1993), and the resulting harmful algal blooms (HABs) in coastal waters and embayments have increased in the last few decades (Anderson, 1989; Hallegraeff, 1993). Eutrophication of coastal waters, which has been reported all around the world (Smayda, 1990), is one of the major reasons, at least in the case of some specific blooms, such as *Phaeocystis* (Riegman, et al. 1992), *Chattonella* (Amano, et al. 1998), *Aureococcus anophagefferens* Hargraves *et* Seiburth (brown tide) (Keller & Rice, 1989), *Heterosigma akashiwo* Hada (Honjo, 1993), and *Chrysochromulina polylepis* Manton *et* Parke (Maestrini & Granéli, 1991).

In Hong Kong, Tolo Harbour is a well-known example of the effects of cultural eutrophication. Urbanization of the area since the mid-1970s resulted in mass loadings of livestock wastes and domestic sewage. In the period 1976–1985, nutrient loading increased more than two-fold, and the frequency of red tide occurrences markedly increased during this period (Lam & Ho, 1989).

Junk Bay is one of those enclosed small bays in Hong Kong facing pollution problems. Land development, including house construction and reclamation, is under way in Tseung Kwan O, Tseng Lan Shue, Ma Yau Tong, Sheung Lau Wan, Chik Sha, Tiu Keng Leng and Hang Hau. A new town is being constructed to house more and more residents in the near future. In order to provide land for urbanization, major coastal land reclamation schemes were undertaken in Tiu Keng Leng, which is just beside the western side of the inner bay. To the eastern side of the inner bay, there is an effluent discharge tunnel which receives sewage and runoff. In 1989, the first toxic algal bloom in Hong Kong, caused by *Alexandrium catenella* (Whedon *et* Kofoid) E. Balech, was recorded in Junk Bay. Other harmful algal species were also found in the bay (Lu & Hodgkiss, 1999). Because of the increasing water pollution and nutrient loading, Junk Bay was included in one of the 10 gazetted water control zones set up by the Environmental Protection Department of the Hong Kong Government (EPDHK, 1990).

In addition to sewage effluents, landfill leachates are another source of nutrient enrichment of seawater. A case study conducted in Hong Kong (Chu et al., 1994) revealed that the principal pollutant in the leachate was ammoniacal nitrogen. The ammoniacal nitrogen concentration in leachate samples from Junk Bay reached 594–1610 mg l^{-1} (mean 1040 mg l^{-1}). The concentration of nitrate/nitrite nitrogen and phosphorus were relatively low in the leachates, but still contributed to the enrichment of the seawater.

The objectives of this study were to understand the present status of water enrichment by anthropogenic activities such as land reclamation and effluent discharge, to understand phytoplankton population dynamics and their relationship to nutrient levels and their ratios, and finally to try to find a linkage between algal blooms and nutrient enrichment.

Description of sites studied

Junk Bay is located to the south of the Kowloon Peninsula, facing Hong Kong Island and the South China Sea (Fig. 1). Three representative stations were chosen for the study: S1 (station 1) located in the west side of the inner bay and surrounded by reclamation and a new housing construction area; S2 (station 2) located in the east side of the inner bay and close to an effluent discharge tunnel; and S3 (station 3) is a station located in the outer bay. The depths of the three stations were 6, 8, and 15 m, respectively.

Materials and methods

Sampling

Sampling was undertaken every 10 days (three times a month) from January to December 1997. Water samples were taken from surface (0.5 m below surface) and bottom (0.5 m above bottom) levels from 3 stations. Water samples were collected using a 3-l Van Dorn-type water sampler. To minimize changes in nutrient concentration, all samples were stored in a cooler with enough dry ice immediately after sample collecting, and the nutrients were measured within 3 h of sampling.

Phytoplankton

Water and net phytoplankton samples were collected for quantitative and qualitative analysis respectively. Water samples were collected at each station using a water sampler and 2 l of water were then concentrated to about 50 ml by filtering through a 10 μm mesh size sieve. Net trawls were made using a 10 μm mesh size phytoplankton net at each station. Samples were preserved immediately after sampling using acidic

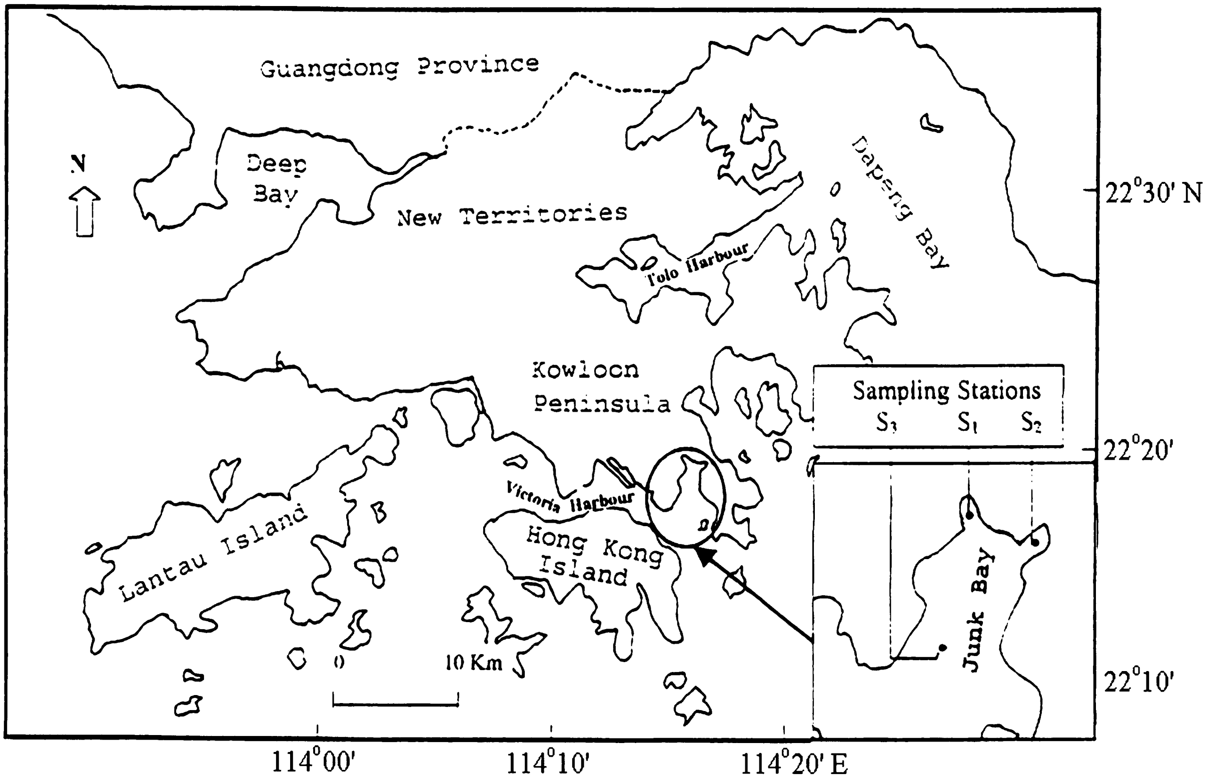

Figure 1. Map showing position of Junk Bay and the sampling stations.

Lugol's solution (Sournia, 1978). Some live phytoplankton samples were also kept for observation of fragile species. Sample processing, storage and concentration followed Sournia (1978). Water samples for quantitative analysis were finally concentrated to 15 ml by sedimentation. A Sedgwick–Rafter counting cell was used for cell counting and a 1 ml concentrated phytoplankton sample was pippetted into the counting chamber and then allowed to stand for 10 min, to permit settling of the phytoplankton before counting with an Olympus inverted microscope (Model IX50-S8F2). The total number of cells of individual species collected at each depth of each station was quantified and the phytoplankton abundance was expressed as number of cells per l sample.

Nutrient analysis

The nutrients in this study were mainly dissolved inorganic nitrogen (DIN), including ammonium-nitrogen (NH_4-N), nitrate-nitrogen (NO_3-N) and nitrite-nitrogen (NO_2-N), and dissolved inorganic phosphorus (DIP), including phosphate-phosphorus (PO_4-P).

The method for analysis of nutrients used in this study was based on the transformation, through a chemical reaction of the substance to be analyzed, to another compound which can be measured colorimetrically within the wavelength range of the visible spectrum. The steps followed Parsons et al. (1984) and Grasshoff (1976). The spectrophotometer employed in this study was a Philips PYE Unicam (Model PU8600). As a general rule, all samples were analyzed as soon as possible after collection and especially when the concentration was expected to be low.

Other Oceanographic parameters such as water depth, water temperature, dissolved oxygen, and salinity were measured *in situ*. The readings of water temperature and dissolved oxygen were taken directly from a YSI Dissolved Oxygen Meter (Model 59) and salinity (in parts per thousand) was measured using an ATAGO Hand Refractometer.

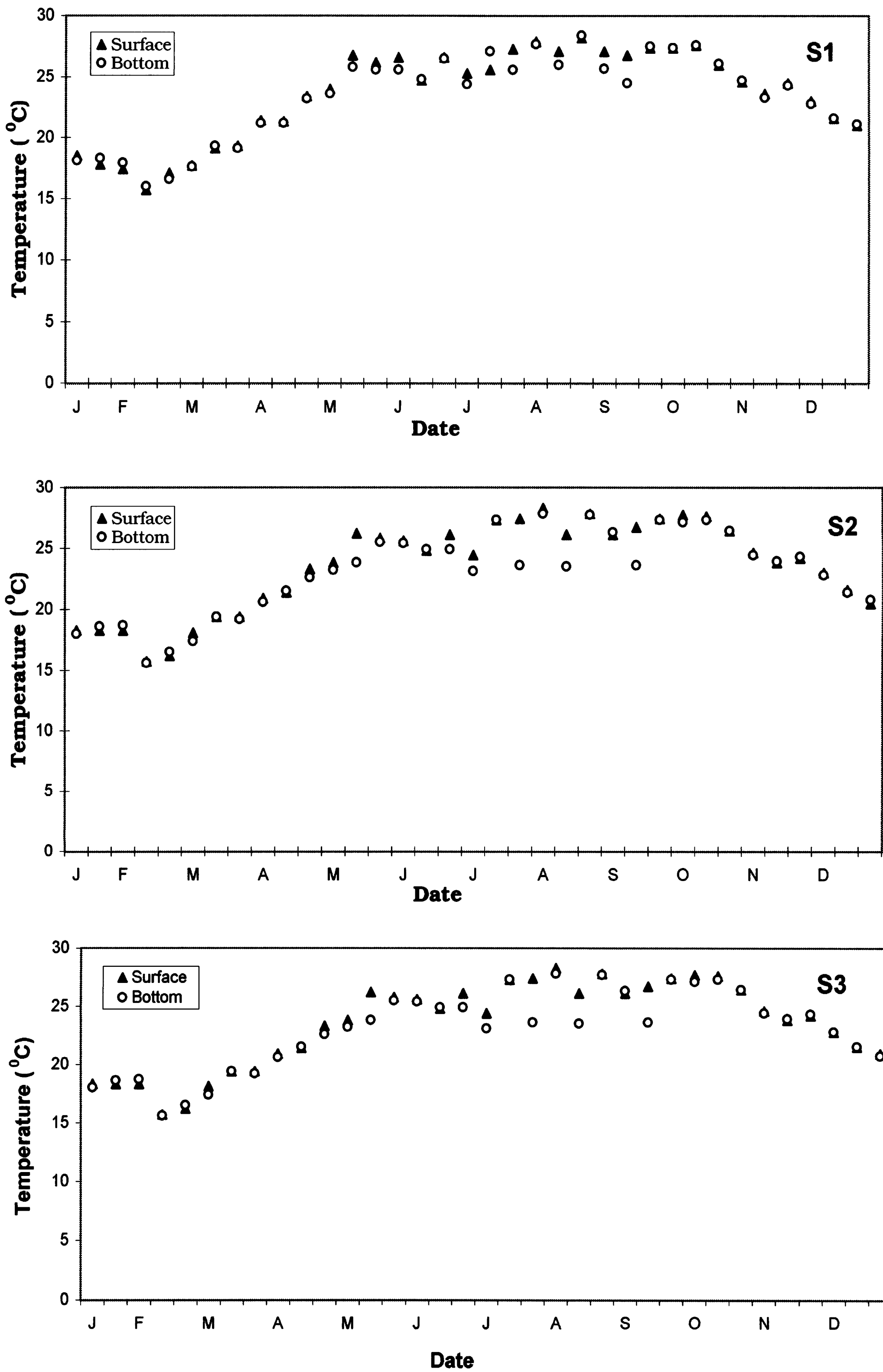

Figure 2. Seasonal variation of water temperature at the 3 sampling stations in Junk Bay in 1997.

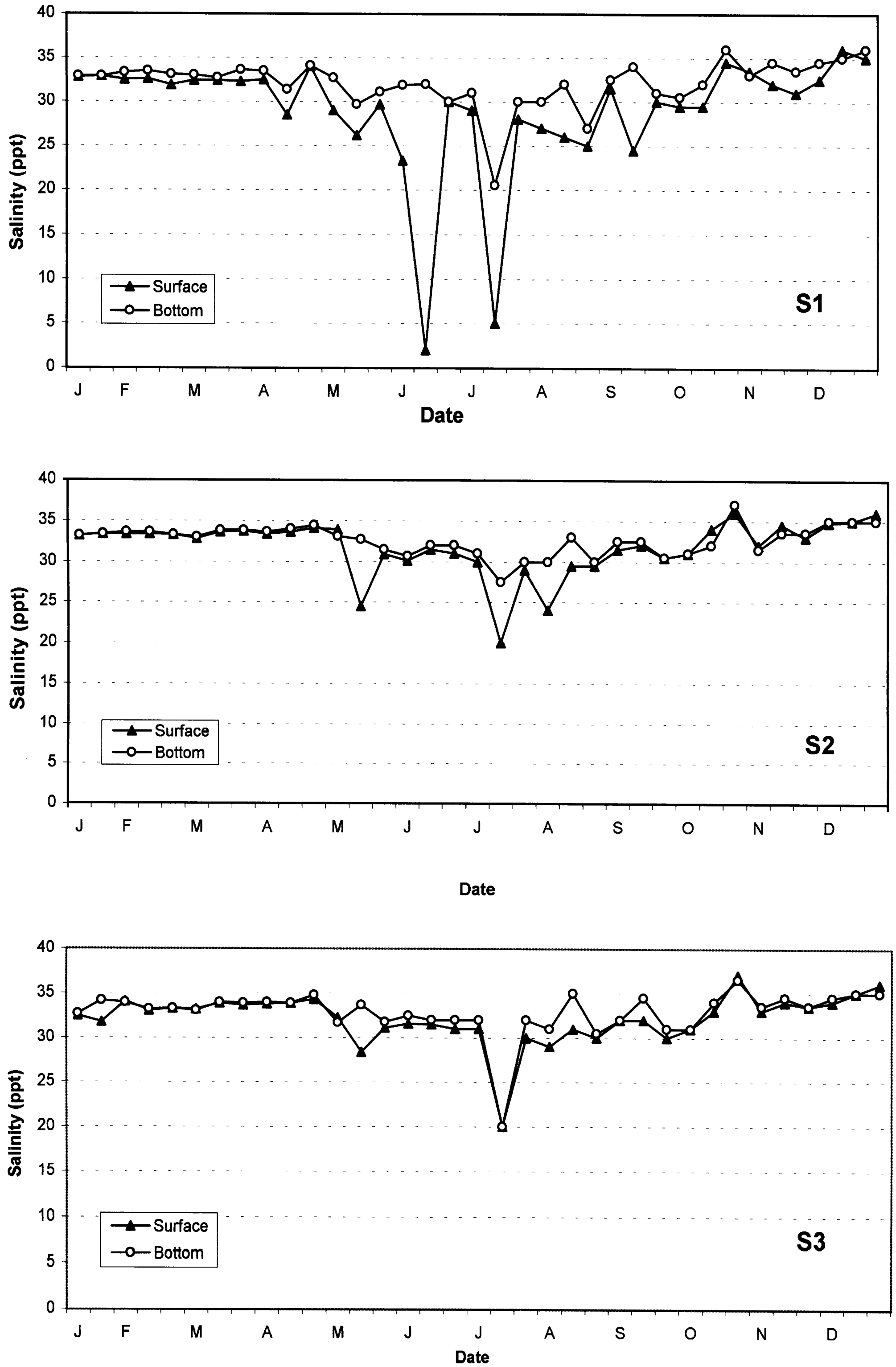

Figure 3. Seasonal variation of salinity at the 3 sampling stations in Junk Bay in 1997.

Results

Physical characters

The annual average water temperature at the 3 sampling stations ranged between 23.11 °C and 24.28 °C. The lowest and highest water temperatures during the study period were 15.6 °C (in March) and 28.9 °C (in August), respectively (Fig. 2). The annual average salinity at the 3 sampling stations ranged from 28.5‰ to 32.7‰. The lowest and highest salinity recorded during the study period was 5.0‰ in the inner bay (station 1) and 37.0‰ in the outer bay (station 3), respectively. The salinity was almost stable, except from June to August during the rainy season (Fig. 3). The annual average dissolved oxygen at the 3 stations ranged between 6.88 mg l^{-1} and 7.69 mg l^{-1}. The lowest and highest values during the study period were 3.02 and 11.94 mg l^{-1}, respectively. The annual average Secchi disc depth at the 3 stations ranged between 1.25 m and 2.96 m. The lowest and highest values during the study period were 0.3 m and 4.8 m, respectively. Because of the relatively shallow water depth (6–15 meters), as well as flushing by tides and currents, no thermal stratification occurred in Junk Bay.

Nutrients and their ratios

The summary of the annual average and the range of concentrations for all nutrients are listed in Table 1. DIN ($DIN=NH_4+NO_2+NO_3$) in the water column of the three stations ranged from a low of 0.007 (surface-station 3) to a high of 8.579 mg l^{-1} (bottom-station 2). The highest annual average concentration (0.97 mg l^{-1}) was in the surface water of station 2, which was close to an effluent discharge tunnel, and the lowest value was 0.2 mg l^{-1} in the surface water of station 3, which is the offshore station. Figure 4 shows the DIN in the surface and bottom waters of the three stations. It indicates that the DIN was highest from July to September, especially in stations 1 and 2, which are nearshore stations, station 1 receiving land runoff from a landfill construction site and station 2 receiving effluents from a discharge tunnel. This might have resulted from heavy summer rainfall (Fig. 8), which would bring more land runoff (and thus wastes) to these coastal waters. The differences of DIN between surface and bottom water at station 1 and station 2 were significant ($p<0.05$), but were not significant at station 3. Among the three forms of nitrogen (NH_4, NO_2 and NO_3), NH_4-N was the major element. It comprised 65% (station 1) to 84% (station 2) of the total DIN.

Phosphate (PO_4-P) concentrations in Junk Bay ranged from almost non-detectable (station 3) to 0.151 mg l^{-1} (surface-station 2). Annual variation of phosphate at the three sampling stations is shown in Figure 5. The highest annual mean phosphate concentration was in the surface water of station 1 (0.036 mg l^{-1}), and the lowest was in the bottom water at station 3 (0.023 mg l^{-1}) (Table 1). The phosphate concentrations in bottom waters were relatively stable, with average values ranging from 0.020 to 0.027 mg l^{-1}. Statistical analysis showed that the phosphate concentrations in the surface water were significantly higher than at the bottom in station 1 ($P<0.05$), but there were no significant differences at stations 2 and 3.

Overall, comparing the offshore station (station 3) with the nearshore stations (station 1 and station 2), the concentrations of DIN and phosphate in station 3 were significantly lower than at stations 1 and 2 ($P<0.05$), with the highest annual mean DIN concentration in station 2 and highest annual mean phosphate concentration in station 1 (Table 1). DIN concentrations in Junk Bay fluctuated widely (from 0.007 to 8.579 mg l^{-1}), with higher concentration in summer from June to September (Fig. 4). Whereas phosphate concentrations did not vary significantly (except some of those at station 1), and there was no clear seasonal trend (Fig. 5).

With the exception of the surface water at station 2, where the annual average N:P (DIN to PO_4-P) ratio (atomic) was 31.9, the ratios at each depth of each of the other stations were all less than the Redfield Ratio of 16 (Table 1). The annual N:P ratio data (Fig. 6) indicated that the ratios were usually higher than the Redfield ratio in the Summer months of May to September, and less than the Redfield ratio for most time of the other months. The N:P ratio (atomic) shows that Junk Bay, like most other marine waters, is generally nitrogen limited. The only exception was in the surface water at station 2, where 60% of the samples were higher than the Redfield ratio, and were thus phosphorus limited. This coincided with the high inputs of nitrogen at this station.

Phytoplankton abundance

The annual variation in total phytoplankton abundance is given in Figure 7. The highest annual average phytoplankton abundance (1.07×10^7 cells l^{-1}) was in the surface water of station 3, whereas station 2 had the

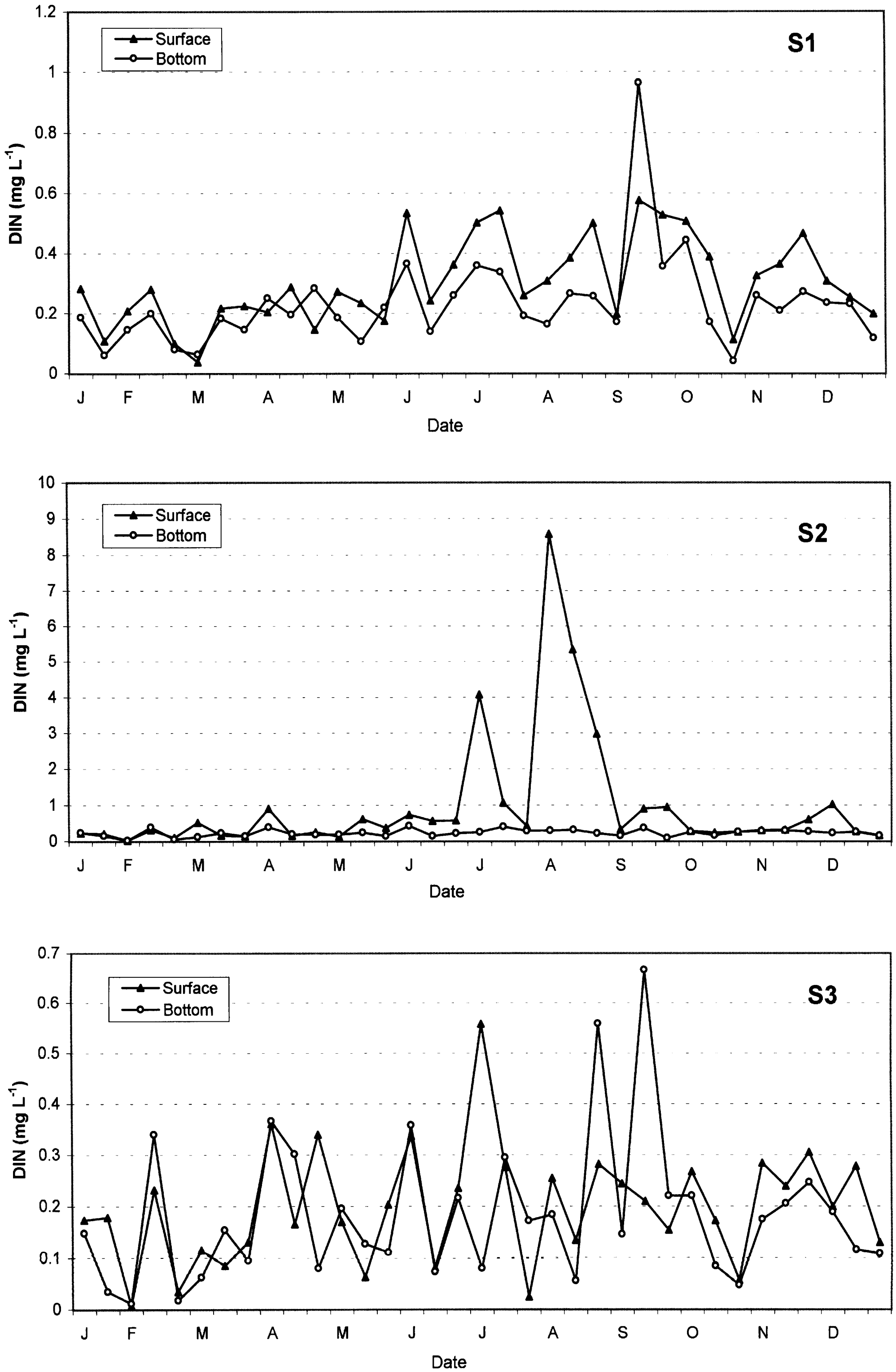

Figure 4. Seasonal variation of dissolved inorganic nitrogen (DIN) at the 3 sampling stations in Junk Bay in 1997.

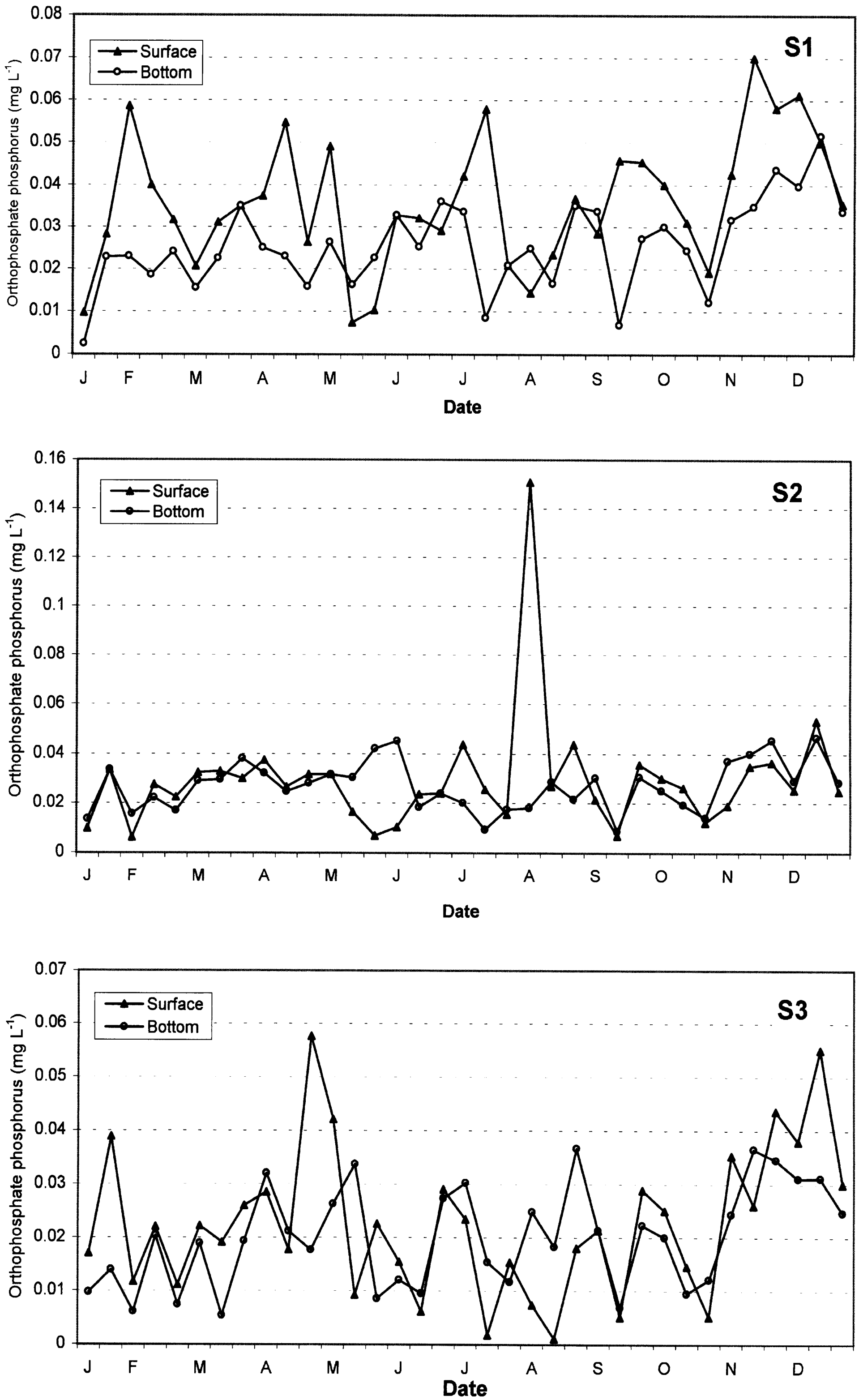

Figure 5. Seasonal variation of phosphate-phosphorus at the 3 sampling stations in Junk Bay in 1997.

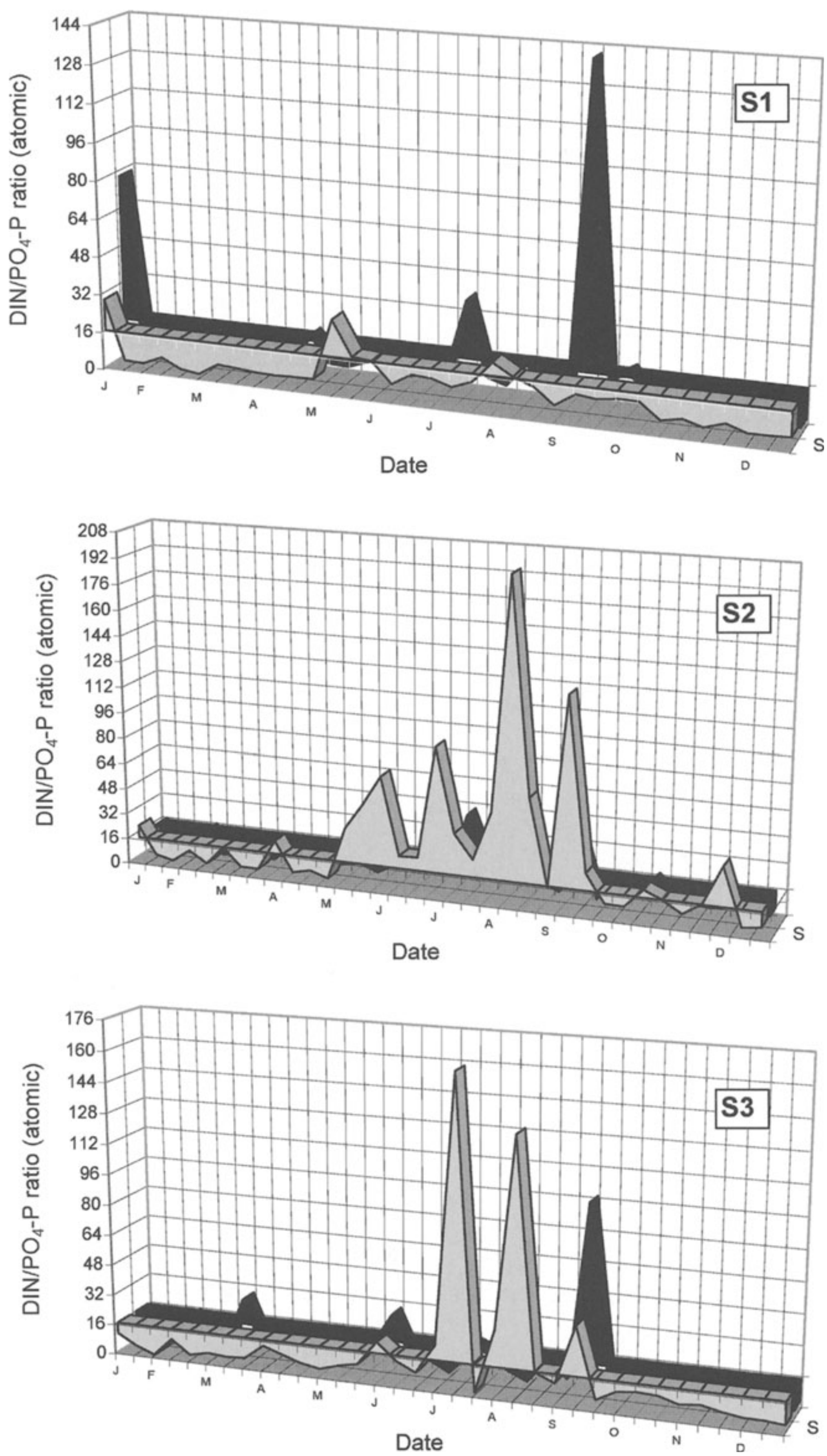

Figure 6. Seasonal variation of N:P ratio (atomic) at the 3 sampling stations in Junk Bay in 1997 (Solid area = bottom water; stippled area = surface water).

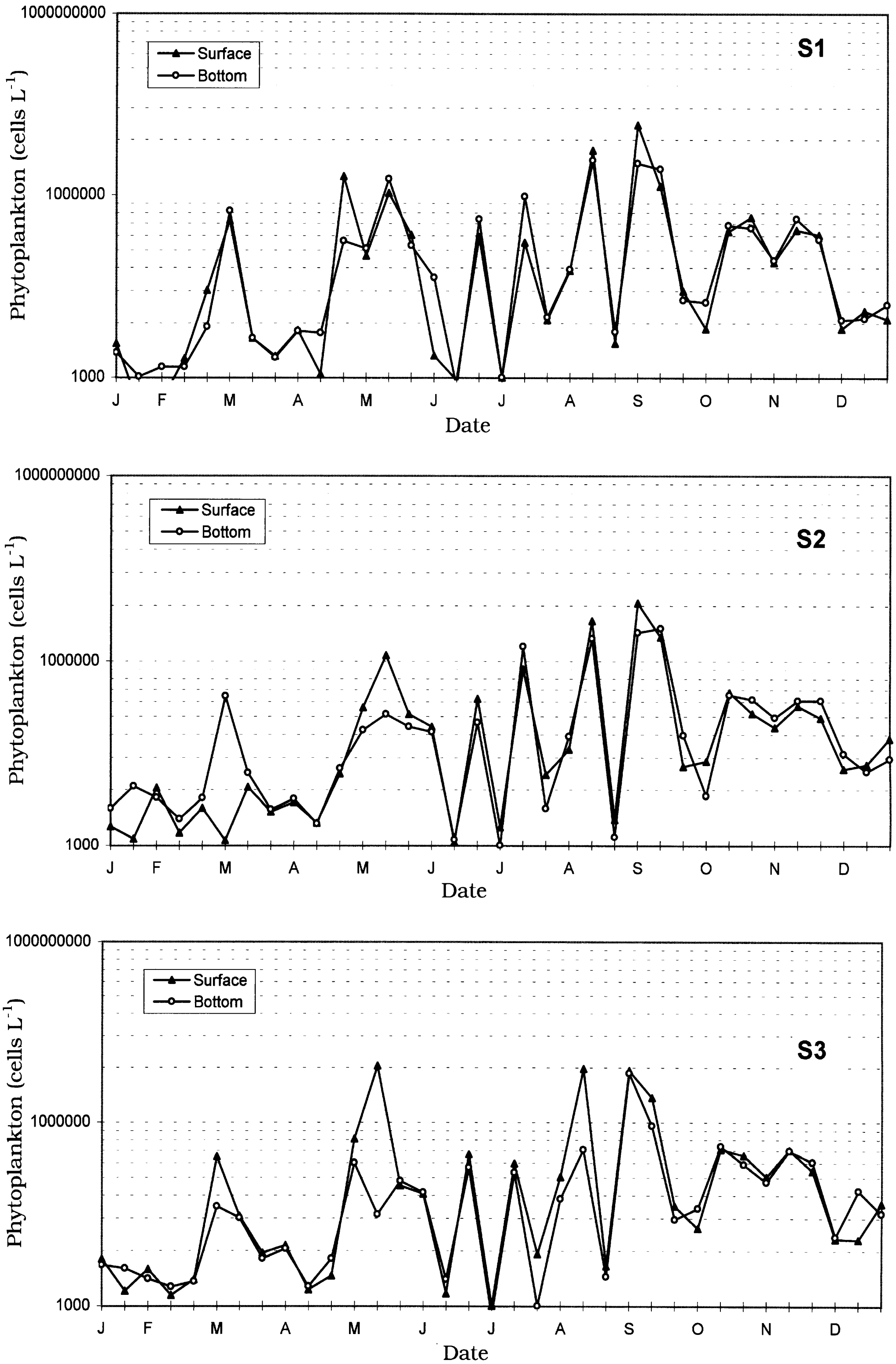

Figure 7. Seasonal variation of phytoplankton numbers at the 3 sampling stations in Junk Bay in 1997.

Table 1. Mean and range (in brackets) of nutrient concentrations and phytoplankton abundance in Junk Bay, Hong Kong

Measurements	Station 1		Station 2		Station 3	
	Surface	Bottom	Surface	Bottom	Surface	Bottom
NH_4-N (mg l^{-1})	0.197	0.156	0.811	0.155	0.151	0.135
	(0.026~0.431)	(0.007~0.60)	(0.014~8.364)	(0.001~0.28)	(0.001~0.485)	(0.001~0.662)
NO_2-N (mg l^{-1})	0.0133	0.0131	0.0186	0.0093	0.0075	0.0067
	(0~0.0374)	(0~0.10)	(0~0.114)	(0~0.044)	(0~0.054)	(0~0.054)
NO_3-N (mg l^{-1})	0.095	0.0616	0.1145	0.0555	0.0392	0.0413
	(0.0003~0.47)	(0.0001~0.35)	(0.0002~0.93)	(0.0001~0.31)	(0.0001~0.213)	(0.0001~0.32)
DIN (mg l^{-1})	0.304	0.232	0.97	0.226	0.20	0.184
	(0.038~0.576)	(0.04~0.963)	(0.134~8.579)	(0.023~0.423)	(0.007~0.558)	(0.011~0.666)
PO_4-P (mg l^{-1})	0.036	0.026	0.03	0.027	0.023	0.020
	(0.007~0.07)	(0.0024~0.052)	(0.006~0.151)	(0.008~0.046)	(0.001~0.058)	(0.005~0.037)
N/P Ratio	10.1	14.6	31.9	10.6	15.14	11.84
	(1.8~31.6)	(2.6~77.6)	(3.4~199.0)	(1.5~46.1)	(0.6~162.5)	(2.0~98)
Phytoplankton	9.64×10^5	5.38×10^5	7.12×10^5	4.36×10^5	1.07×10^6	3.32×10^5
abundance	(333~	(695~	(1135~	(1000~	(1490~	(1000~
(cells l^{-1})	1.4×10^7)	3.69×10^6)	8.75×10^6)	3.39×10^6)	8.58×10^6)	6.46×10^6)

lowest value (7.12×10^5 cells l^{-1}) among the surface waters of the three stations (compare this with the fact that the highest nitrogen concentration was at this station). Phytoplankton abundance was higher in the summer than in other seasons (Fig. 7). The dominant phytoplankton groups in Junk Bay were diatoms, and then dinoflagellates. The chlorophyceae, cryptophyceae, cynobacteria, dictyophyceae, and raphidophyceae were minor groups. The diatom species were dominant almost year round, usually making up more than 90% of the total abundance. The abundance of dinoflagellate was relatively higher in the Spring than in other seasons.

The dominant taxa during the study period were: *Skeletonema costatum*, (Grev.) Cleve *Asterionella japonica* Cleve, *Chaetoceros* spp. *Cylindrotheca closterium* (Ehrenberg) Lewin *et* Reimann, *Bacillaria paxillifera* (Müller) Hendey, *Pseudonitzschia* spp. *Thalassiosira mala* Takano, *T. rotula*, Meunier *Thalassionema nitzschioides* (Grunow) Grunow *ex* Hustedt, *Prorocentrum micans* Ehrenberg, *P. minimum* (Pavillard) Schiller, *P. triestinum,*Schiller and*Ceratium furca* Ehrenberg (Claparede *et* Lachmann). Toxic species were also recorded (Lu & Hodgkiss, 2004).

Discussion

Eutrophication

The term 'eutrophication' is complicated, and so far there have been about a dozen different definitions. However, it is clear that the most common single factor causing eutrophication in coastal marine ecosystems is an increase in the amounts of nitrogen and phosphorus they receive, and one of its effects may increase the productivity of the ecosystem. Nixon (1995) proposed a definition and trophic classification standard for eutrophication based on organic matter supply. He emphasized that "eutrophication is a process, not a trophic state". Based on this, as well as the results of the present study, we can say that Junk Bay is now experiencing eutrophication. A long term environment monitoring program carried out by the Environmental Protection Department (EPD) of the Hong Kong S.A.R. Government revealed that there was a significantly increasing trend for PO_4-P and NH_4-N over the 10 years from 1988 to 1997 (EPDHK, 1998). Junk Bay is a nitrogen limited water, and thus, the enrichment of nitrogen is the most important contribution to this water. Normally, nitrogen is supplied to coastal waters by riverine and land runoff, precipitation, atmospheric resources (nitrogen fixation), offshore waters (upwelling), and waste effluents. The most important nitrogen inputs to Junk Bay are land runoff and waste effluents. Because no river enters the bay, and the cynobacterial population in the bay is a minor group, riverine input and nitrogen fixation in the bay are not important. Nutrient enrichment of the inner bay was higher than that of the outer bay. As well as groundwater, landfill leachate is an important source of nutrients. One of the surveys conducted in Junk Bay (Cheung et al., 1997) showed the nutrient enrichment contributed by landfill leachate. The present study also revealed that phosphorus was highest at station 1, and this is probably from landfill leachate and runoff from the naked land flushing.

Even though there are no detailed data concerning either inputs of leachate and runoff from landfill construction to station 1, or the effluents to station 2, the two nearshore stations were heavily affected by land runoff and effluents, especially the surface waters and the average N and P values in the surface waters of these two stations were higher than at station 3, the outer bay station. The highest values were all found in summer, when there were heavy rainstorms in this subtropical area (Fig. 8). The heavy rain flushed the naked land of the landfill area in station 1, and a large amount of land runoff, as well as effluents, were discharged from the tunnel in station 2. This resulted in the concentration of N and P in these two stations being even higher. The data also show that the deeper waters were less affected by runoff. The differences between N and P at the three stations were not, however, statistically significant.

Nutrients and phytoplankton

Phytoplankton growth depends largely on the availability of inorganic nutrients. Thus, nutrient enrichment results in an increase of phytoplankton productivity and population selection. A good example is in Tolo Harbour, which is the most heavily polluted embayment in Hong Kong, and where the relationship between eutrophication and phytoplankton has been well studied (Hodgkiss & Chan, 1983, 1987; Chan & Hodgkiss, 1987). The same result was also shown in Tai Tam Bay, Hong Kong (Chan et al., 1991; Chiu et al., 1994).

Junk Bay is another example where high nutrient levels have resulted in high phytoplankton abundance. From the point of view of seasonal dynamics, the highest phytoplankton numbers coincided with the highest nutrient enrichment in summer. One explanation for higher diatom abundance (over 90% all over the year) and lower abundance of other algal groups is that diatoms are more sensitive to nutrient enrichment than the others. Studies have shown that diatoms have high growth rates under nutrient-rich conditions (Eppley, 1977), compared to the generally lower growth rates of dinoflagellates. Experimental study from Sweden has also indicated that river water draining from forest areas (containing rich humic and fulvic acids) can stimulate dinoflagellate bloom such as *Prorocentrum minimum*, whereas the river water draining from agricultural soils (containing rich inorganic N and P) stimulates diatom blooms (Granéli & Moreira, 1990). The higher concentrations of inorganic N and P in Junk Bay may result in the higher abundance of diatoms. Unfortunately, there is a lack of long term phytoplankton data from this bay and so algal population succession and species selection under different nutrient status conditions remains unclear.

Nutrients affect not only phytoplankton numbers, but also toxin production by some algal species. In the case of *Alexandrium tamarense* (Lebour) Balech, *Pseudo-nitzschia pungens f. multiseries* (Hasle) and *Chrysochromulina polylepis* it has been proven that the cells increase their toxin content considerably when grown in a P-deficient (excess nitrogen) medium and in the stationary phase (Anderson et al., 1990; Carlsson et al., 1990; Bates et al., 1991). Laboratory experiments also showed that *Prorocentrum lima* increased its toxin production when grown under nitrogen limited conditions (McLachlan et al., 1994). There were many toxic species recorded in Junk Bay (Lu & Hodgkiss, 2003), although there were no toxic blooms recorded during the study. The production of toxins and their relationship with nutrients needs to be further studied.

N/P ratio, phytoplankton biomass and population composition

Response of the phytoplankton to nutrients is considerably influenced by its physiological state when the nutrients are in short supply. It has been demonstrated that algae increase their uptake rates for NH_4^+ when N starved and for PO_4^{3-} when P starved. Redfield (1958) reported atomic ratios of available nitrogen to phosphorus of 15:1 in seawater, depletion of nitrogen and phosphorus in the ratio of 15:1 during phytoplankton growth, and ratios of 16:1 for laboratory analyses of phytoplankton. This ratio was subsequently called the Redfield ratio. It is now agreed that freshwater (especially lake) phytoplankton growth is limited primarily by phosphorus, and marine phytoplankton growth by nitrogen (Dugdale, 1967; Hecky & Kil-

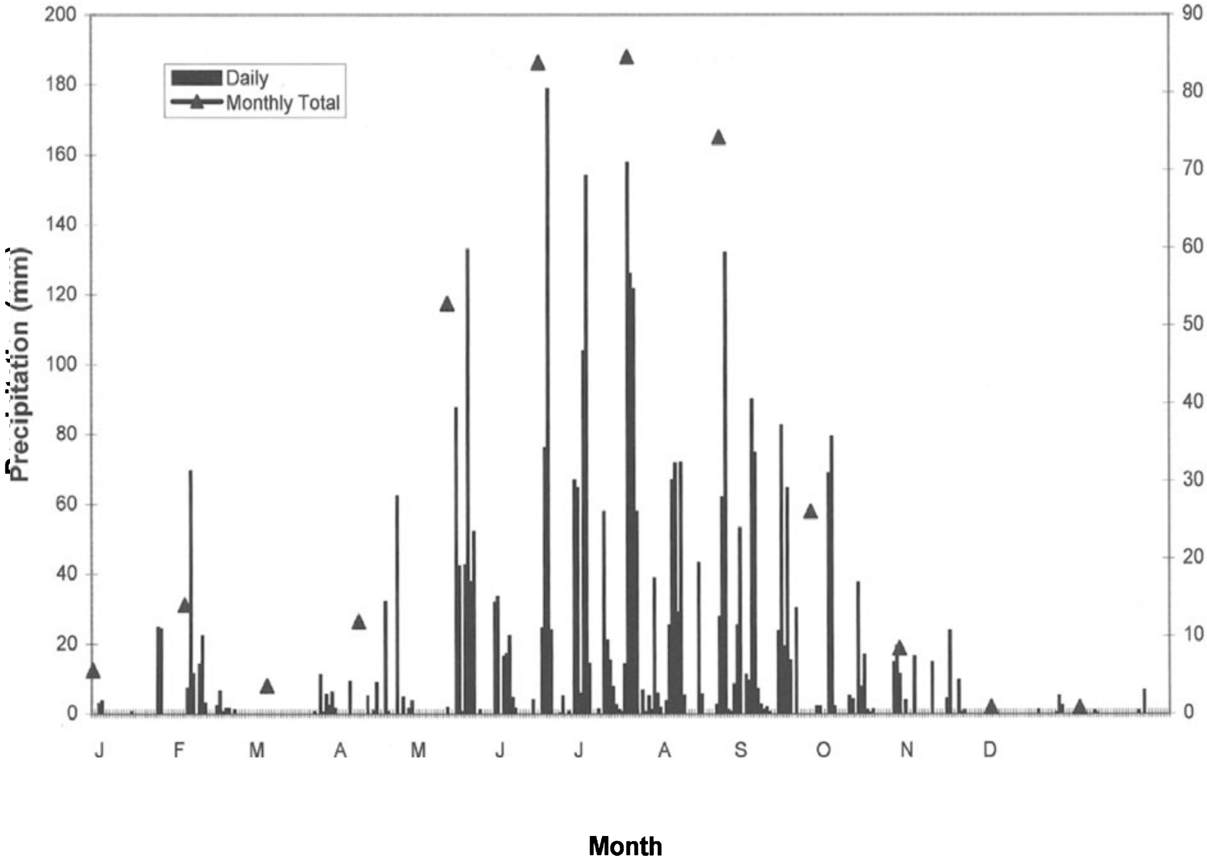

Figure 8. Annual precipitation in the Junk Bay area (from the Hong Kong Observatory).

ham, 1988). This means that N:P values are normally more than the Redfield ratio in freshwater, and less in seawater. Ryther & Dunstan (1971) indicated that 'although there is no indication of any normal or optimal nitrogen to phosphorus ratio in algae, values between 5:1 and 15:1 are most commonly encountered and an average ratio of 10:1 is therefore a reasonable working value'. Hodgkiss & Ho (1997) experimentally determined the optimal N:P ratio for various algal species. Most of the values on their list are within the range 5:1 to 15:1. In Junk Bay, 71%, 26%, and 60% of the samples had N:P ratios between 5:1 and 15:1 at stations 1, 2 and 3, respectively. Conversely 60 percent of the samples at station 2 had an N:P ratio larger than 15:1 and this is probably the reason why the higher nitrogen concentration at station 2 resulted in the lower phytoplankton numbers (phosphorus limited). Comparing with stations 1 and 2, the station 3 (surface water) has a favourable annual mean N:P ratio (15.14). It might be one of the reasons that station 3 has a lower nutrient level but higher phytoplankton abundance.

The nutrient supply and its ratios have a decisive effect on the species composition of the phytoplankton since different algal species have different nutrient requirements. Although the optimal nutrient requirement for each algal species is not well-known, diatoms as a group have an obligate requirement for silica, and many blue-green bacteria can fix molecular nitrogen, making them potentially superior competitors under low nitrogen conditions (Granéli et al., 1990). A good example are the nitrogen fixing cynobacteria, *Nodularia spumigena* Mertens, *Aphanizomenon flos-aquae* (L.) Ralfs *ex* Bornet *et* Flahault *Anabaena lemmermanni* (Skuja) Cronberg *et* Komárek in the Baltic, which usually develop blooms in late summer when DIN is low in surface water (Granéli & Granéli, 1982). On the other hand, dinoflagellates may show stronger competition under nutrient deficient conditions, because of their diurnal migrations to deeper nutrient-rich layers (Granéli & Moreira, 1990). In Junk Bay, the phosphorus level is relatively stable year round, whereas the nitrogen level is highest in the Summer and lowest in the Spring. Diatom numbers were highest in the summer, whereas the population diversity and numbers of dinoflagellates were higher in the Spring, showing, therefore, that their relative abundance is closely related to the nutrient ratio in Junk Bay.

Acknowledgements

We are grateful to Miss Lo Gar Yee for kindly assisting in some sampling and nutrient analysis.

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