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The Impact of Sewage Discharge on the Macroalgae Community in the Yellow Sea Coastal Area Around Qingdao, China

Dongyan Liu · Jie Bai · Shuqun Song · Jing Zhang · Ping Sun · Ying Li · Gang Han

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Abstract The dynamics of macroalgal communities and the impact of sewage on their growth were studied in the tidal zone around Zhanqiao Pier of the Qingdao coastal area, in the northwest of the Yellow Sea, China, from September 2001 to September 2003. The tidal zone of the study area is divided into western and eastern sections by the Zhanqiao Pier. Inorganic nitrogen and phosphorus in seawater showed higher concentrations on the eastern side of Zhanqiao Pier than on the western side, because a sewer drains into the eastern side. The macroalgal communities on each side of the Pier showed an obvious difference due to the effect of this sewage discharge. A total of 47 macroalgal species including 10 greens, 11 browns and 26 reds was identified in this study. The species composition and biomass indicated higher values in the nutrient-rich area on the eastern side of Zhanqiao Pier compared with the nutrient-poor area on the western side of Zhanqiao Pier. Some ephemeral and filamentous species dominated seasonally on the eastern side of Zhanqiao Pier, in contrast to the western side where slow-growing species dominated throughout the year. Nutrient gradients and temperature were considered the main factors affecting the distribution of macroalgae communities in time and space. The results are consistent with the common observation that nutrient-poor areas are dominated by slow-growing rather than ephemeral algal species. Moreover, the species diversity in the whole study area had declined when compared to previous records.

Keywords Macroalgae · Sewage · Intertidal · Zhanqiao pier bay · Yellow sea · China

1 Introduction

Marine macroalgae dominate primary production in many coastal ecosystems such as rocky shores,

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D. Liu · S. Song · Y. Li
College of Marine Life Science,
Ocean University of China,
5 Yushan Road,
Qingdao 266003, China

D. Liu (✉) · P. Sun
School of Earth and Environmental Sciences,
University of Wollongong,
Wollongong, NSW 2522, Australia
e-mail: dl988@uow.edu.au

J. Bai
College of Environmental Science and Engineering,
Ocean University of China,
5 Yushan Road,
Qingdao 266003, China

J. Zhang
State Key Lab of Estuarine and Coastal Research,
East China Normal University,
3663 Zhongshan Road North,
Shanghai 200062, China

G. Han
Institute of Oceanology, The Chinese Academic of Science,
Qingdao 266071, China

estuaries and coral reefs (Alongi 1998). They only cover <2% of the ocean surface, but contribute about 10% of the primary production of the ocean (Duarte and Cebrián 1996). Macrophytes are not only an important primary producer but also an excellent water quality indicator in coastal areas (Levine 1984). Many studies have indicated that pollution and trophic changes interact strongly with the biotic communities, and with associated macrophytes in particular, can result in the abnormal growth of nuisance seaweeds and the decline of species diversity (Orth and Moore 1983; Twilley et al. 1985; Taylor et al. 1995; Sfriso and Macromini 1996a).

The Shandong Peninsula, which has a high population density and rapid economic development, is surrounded by the Yellow Sea. In the last decade, pollution of the shoreline has increased with the development of tourism and sewage discharge along coastal areas, and the nutrient loading to the coastal seawater has dramatically increased (Shen 2001). Macroalgae communities in the coastal area respond to environmental deterioration, and this will be reflected in the species composition and biomass. Little research has been carried out in the coastal area of the Yellow Sea. The Zhanqiao Pier Bay, a typical intertidal area that has been affected significantly by sewage discharge, was chosen for this maroalgae community study. The study was aimed to investigate the community composition and biomass of the marine benthic algae around Zhanqiao Pier Bay, and to evaluate the impact of sewage on the community structure.

2 Materials and Methods

2.1 Study Sites

The field observations were carried out on the rocky intertidal shores around Zhanqiao Pier Bay, Qingdao, a coastal city adjacent to the western Yellow Sea, China (Fig. 1). Two sections, each with three sites were designated in the intertidal zone (A1, B1, C1, A2, B2, C2). A1, B1 and C1 sites were in the upper landward intertidal zone, while A2, B2 and C2 were in the lower seaward zone. Sampling site locations were confirmed by means of GPS (Global Position System) measurements. These sites covered almost the whole upper and lower intertidal zone.

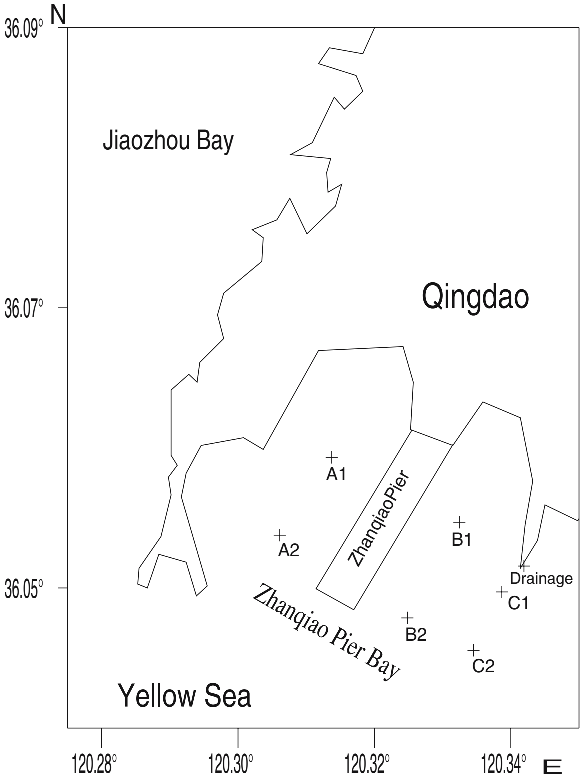

Fig. 1 Map of Zhanqiao Pier Bay and locations of the six sampling sites

The Zhanqiao Pier is located in the north of Qingdao, facing south-west into the open Yellow Sea. It was built in 1931 with a width of 8 m and 440 m in length, thus the intertidal area of the Bay is divided two parts by the Zhanqiao Pier (Fig. 1). In the early 1990s, sewage and stormwater drains were constructed on the eastern side of Zhanqiao Pier Bay and resulted in the eutrophication of coastal seawater in that area (Yin and Lu 2000). Thus, it was supposed that the marine benthic algae community on the east and west sides of Zhanqiao Pier might have different characteristics due to the different degree of exposure to sewage discharge. A comparative investigation between the nutrient rich and nutrient poor sites was carried out from 2001 to 2003.

2.2 Macroalgal Biomass and Species Composition Determination

The marine benthic algae biomass was sampled monthly from 2001 to 2003 by means of a 0.5×0.5 m quadrat at each site. A series of five plots of 0.5×0.5 m were randomly placed at each site, at the landward and seaward intertidal areas. The algae in the grid were collected, and their fresh weights (fwt) were measured using an electronic balance. Macroalgal species were collected from the whole intertidal area and their composition was identified based on a standard taxonomy book (Tseng 1983).

2.3 Seawater Analyses

Water temperature and salinity were monitored using temperature and conductivity probes. Nutrient concentrations including ammonium, nitrate plus nitrite, and phosphate were measured in filtered seawater samples using a Skalar Autoanalyer (Model: SAN $^{\mathrm{Plus}}$).

2.4 Statistical Analyses

The Coverage of macroalgae was calculated using the equation (Saito and Atobe 1971):

$$C = \frac{\sum(\mathrm{Mi}*fi)}{\sum f}$$

where Mi=mid point percentage of Class i. f is the frequency.

Community data were analyzed using a one-way analysis of variance (ANOVA). Significant differences in physico-chemical parameters were tested according to one-way ANOVA (SPSS 13.0 edition Statistical software, copyright SPSS Inc.)

3 Results

3.1 Seawater Analysis

The Yellow Sea is a typical temperate coastal water body. In the field observations, the air temperature showed an obvious seasonal feature, with a range of 3.8±1.2°C in winter to 32±1.6°C in summer, and the water temperature ranged from 6.1±1.3°C in winter to 27±1.1°C in summer, and the surface water salinity ranged from 27±0.32 in summer to 31.8±0.54 in winter, being affected mainly by rainfall and irradiation (Fig. 2).

In contrast, the nutrient concentrations in time and space differed significantly (DIN: $F_{0.05,5}=160.18$, $p=0.000<0.001$; DIP: $F_{0.05,5}=23.91$, $p=0.000<0.001$) (Fig. 3). In Section 1, the sequence of significant differences was C1>B1>A1, and dissolved inorganic nitrogen ($\mathrm{DIN} = \mathrm{NO}_3^- + \mathrm{NO}_2^- + \mathrm{NH}_4^+$) and dissolved inorganic phosphate (DIP) showed the highest annual mean values at site C1 with 50.7±7.9 and 0.93±0.12 μmol/L, respectively; the annual mean values of DIN and DIP at site B1 were 36.8±4.4 and 0.75±0.18 μmol/L, respectively; the lowest annual mean values of DIN and DIP occurred at site A1 with 23.1±3.8 and 0.51±0.13 μmol/L, respectively. The concentrations of DIN and DIP and their differences between sites in Section 2 were significantly lower than those in Section 1. However, the sequence of significant differences still showed C2>B2>A2, and the annual mean values of DIN at site C2, B2 and A2 were 30±2.1, 26.4±3.71 and 18.3±3.2 μmol/L, respectively, and for DIP were 0.62±0.1, 0.66±0.18 and 0.41±0.14 μmol/L, respectively.

The observed results indicated that the nutrient concentrations on the eastern side of Zhanqiao Pier were obviously higher than those on the western side of Zhanqiao Pier. Moreover, the concentration of DIN differed more obviously between two sites than the concentration of DIP. Otherwise, the annual variation of nutrient concentrations demonstrated that DIN and

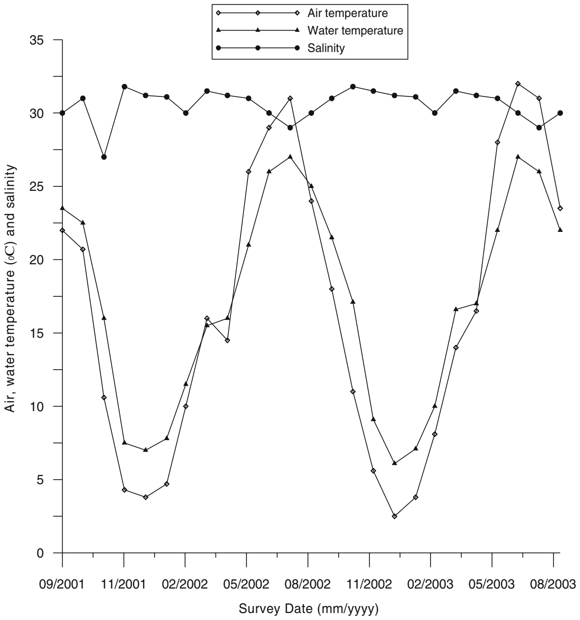

Fig. 2 The monthly variations of air temperature, water temperature and salinity in Zhanqiao Pier Bay during this study period

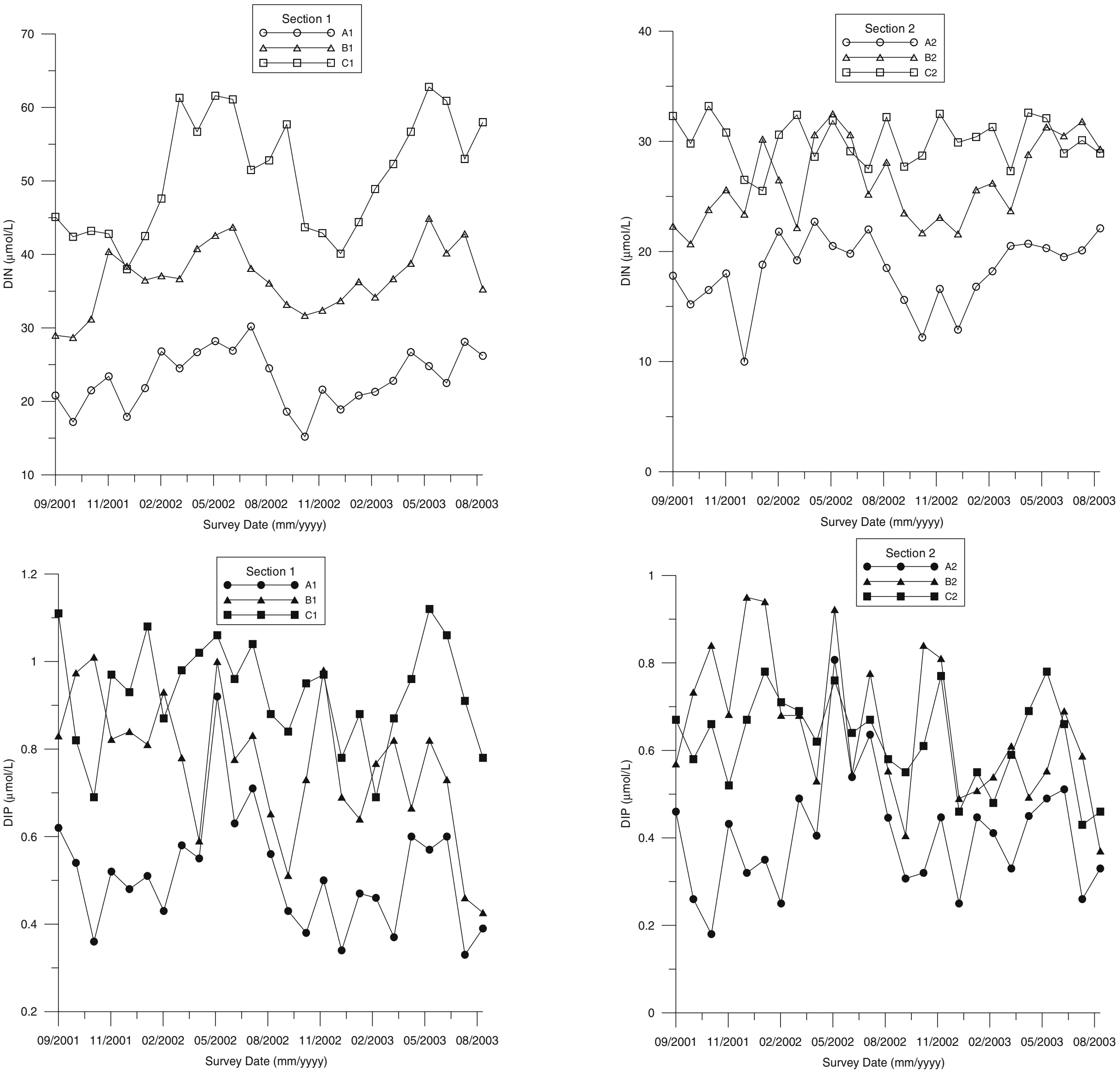

Fig. 3 The monthly variations of DIN and DIP at different sites during this survey in Zhanqiao Pier Bay

DIP were lower in winter and higher in summer compared with other seasons (Fig. 3). For example, in summer, the mean values of DIN at sites A1, B1 and C1 reached 28.4, 41.5 and 58.1 μmol/L, respectively; however, in winter, their mean values were only 20.4, 34.1 and 42.5 μmol/L, respectively. In summer, the mean values of DIP at sites A1, B1 and C1 were 0.75, 0.87 and 1.02 μmol/L, respectively; however, in winter, their mean values dropped to 0.44, 0.77 and 0.88 μmol/L, respectively.

3.2 Changes in Species Composition and Macroalgal Biomass

In this survey, a total of 47 species of marine benthic algae were found in the intertidal zone, including 10 green, 11 brown, and 26 red algae (Table 1). The species composition showed obvious differences in time and space. In autumn and winter, species numbers had a mean value of 14±2.1, while in spring and summer the community showed higher species richness with a

Table 1 A list of macroalgae species investigated monthly in Zhanqiao Pier Bay (EZP: Eastern side of Zhanqiao Pier; WZP: Western side of Zhanqiao Pier; +: presence; −: absence)

Year	2001–2002		2002–2003	
Species	EZP	WZP	EZP	WZP
Chlorophyta				
Bryopsis corymbosa	+	+	+	+
B. plumosa	+	+	+	+
Chaetomorpha fascicularis	+	−	+	−
Cladophora albida	+	−	+	−
Codium fragile	+	+	+	+
Enteromorpha compressa	+	+	+	+
E. linza	+	+	+	+
E. intestinalis	+	+	+	+
Ulva pertusa	+	+	+	+
U. lacatuca	+	+	+	+
Phaeophyta				
Ectocarpus confervoides	+	−	+	−
Colpomenia. bullosa	+	−	+	−
Desmorestia viridis	+	−	+	−
Dictyota dichotoma	+	+	+	+
Laminaria japonica	+	+	+	+
Punctaria latifolia	+	+	+	+
Sargassum thunbergii	+	+	+	+
S. kjellmanianum	+	+	+	+
S. pallidum	+	+	+	+
S. yezoense	+	+	+	+
Undaria pinnatifida	+	+	+	+
Rhodophyta				
Acrosorium yendoi	+	+	+	+
Ceramium japonicum	+	−	+	−
C. kondoi	+	−	+	−
Chondrus ocellatus	+	+	+	+
Corallina officinalis	+	+	+	+
Dumontia simplex	+	+	+	+
Gelidium amansii	+	+	+	+
G. pusillum	+	+	+	+
Gloiopeltis jurcaio	+	+	+	+
Gracilaria verrucosa	+	+	+	+
G. asiatica	+	−	+	−
G. textorii	+	+	+	+
G. sjoestedtii	−	+	−	+
Grateloupia filicina	+	+	+	+
G. okamurai	−	+	−	+
G. proliongata	−	+	−	+
Gymnogongrus flabelliformis	+	+	+	+
Lomentaria hakodatensis	+	+	+	+
Porphyra marginato	+	+	+	+
P. yezoensis	+	+	+	+
Polysiphonia japonica	+	+	+	+
Rhodomela confervoides	−	+	−	+
Heterosiphonia pulchra	+	−	+	−
Hyalosiphonia caespitosa	+	−	+	−
Halymenia sinensis	+	+	+	+
Symphyocladia latiuscula	+	+	+	+
Total numbers	43	37	43	37

mean value 25±3.5. There were more species present on the eastern side of Zhanqiao Pier than the western side (Table 1). For example, *Chaetomorpha fascicularis*, *Cladophora albida*, *Ectocarpus confervoides*, *Desmorestia viridis*, *Ceramium japonicum*, *C. kondoi*, *Rhodomela confervoides* and *Heterosiphonia pulchra* were only observed on the eastern side of Zhanqiao Pier.

The mean coverage of dominant species showed significant differences between sites and over time in the Zhanqiao Pier coastal areas. The distribution across the intertidal area indicated that the landward tidal zones were dominated by green algae, such as *Ulva pertusa*, *Enteromorpha intestinalis*, and *Codium fragile* (Fig. 4a). At site A1, the dominant species were *U. pertusa*, *E. intestinalis* and *C. fragile*, and their mean coverage values were 7.2–32.7, 0.1–14.7 and 0–2.7, respectively; at site B1, the dominant species were *U. pertusa*, *E. intestinalis*, *Ch. fascicularis*, *C. albida*and *B. plumose*, and their mean coverage values were increased to 17.2–42.7, 0.1–15.3, 0–4.3, 0–7.8 and 0–17.6, respectively; at site C1, the dominant species were composed of *U. pertusa*, *E. intestinalis*, *Ch. fascicularis*, *C. albida* and *B. plumosa*, and their mean coverage values were even higher at 17.2–57.8, 0–18.2, 0–4.7, 0–5.6 and 0–21.3, respectively.

Some seasonal changes were observed among dominant species. *U. pertusa* was dominant the whole year round; *E. intestinalis* dominated in spring and summer; *C. fragile*, *C. albida*and *Ch. fascicularis* became the overwhelming species in spring and summer, and *B. plumosa* increased dramatically from spring to autumn (Fig. 4a).

For the seaward tidal zones, the dominant species turned out to be brown and red algae including *Sargassum thunbergii*, *D. viridis*, *Corallina officinalis*, and *Heterosiphonica pulchra* etc. (Fig. 4b). At site A2, the dominant species were composed of slow-growing algae including *S. thunbergii*, *C. officinalis*, *G. flabelliformis* and *G. sjoestedtii*, and their mean coverage values were 11.1–39.7, 0.7–14.7, 0–12.2 and 0–4.6, respectively; at site B2, the dominant species were slow-growing and filamentous species *S. thunbergii*, *D. viridis*, *G. sjoestedtii* and *H. pulchra*, and their mean coverage values were 6.2–32.5, 0–11.5, 0–12.1 and 1.3–11.2, respectively; at site C2, the dominant species were *S. thunbergii*, *D. viridis*, *G.. sjoestedtii* and *H. pulchra*, and their mean coverage values were 7.2–27.8, 0–15.7, 0–10.1 and 1–12.1, respectively. The slow-growing species, *S. thunbergii*, dominated the seaward intertidal section the whole year round, and *C. officinalis* and *G. flabelliformis*, were only dominant seasonally on the western side. However, *H. pulchra*and *D. viridis* were only found and became dominant on the eastern side of Zhanqiao Pier. *H. pulchra* was overwhelming the whole year round and *D. viridis* dominated only in spring and summer.

The biomass of marine benthic algae showed a typical seasonal change in coastal areas around Zhanqiao Pier during this survey (Fig. 5). A higher biomass occurred in the late spring and summer, and a lower biomass occurred in the late autumn and winter, as would be expected when the macroalgae community was composed mainly of temperate species. In the landward intertidal section, the macroalgal biomass was mainly contributed by green algae such as *U. pertusa*, *E. intestinalis*, *C. fragile*, *B. plumose* and *C. fascicularis*. The biomass changed with seasons and sites; they were 0.29–1.57 kg m^{-2} fwt at site C1, 0.16–0.91 kg m^{-2} fwt at site B1, and 0.13–0.56 kg m^{-2}

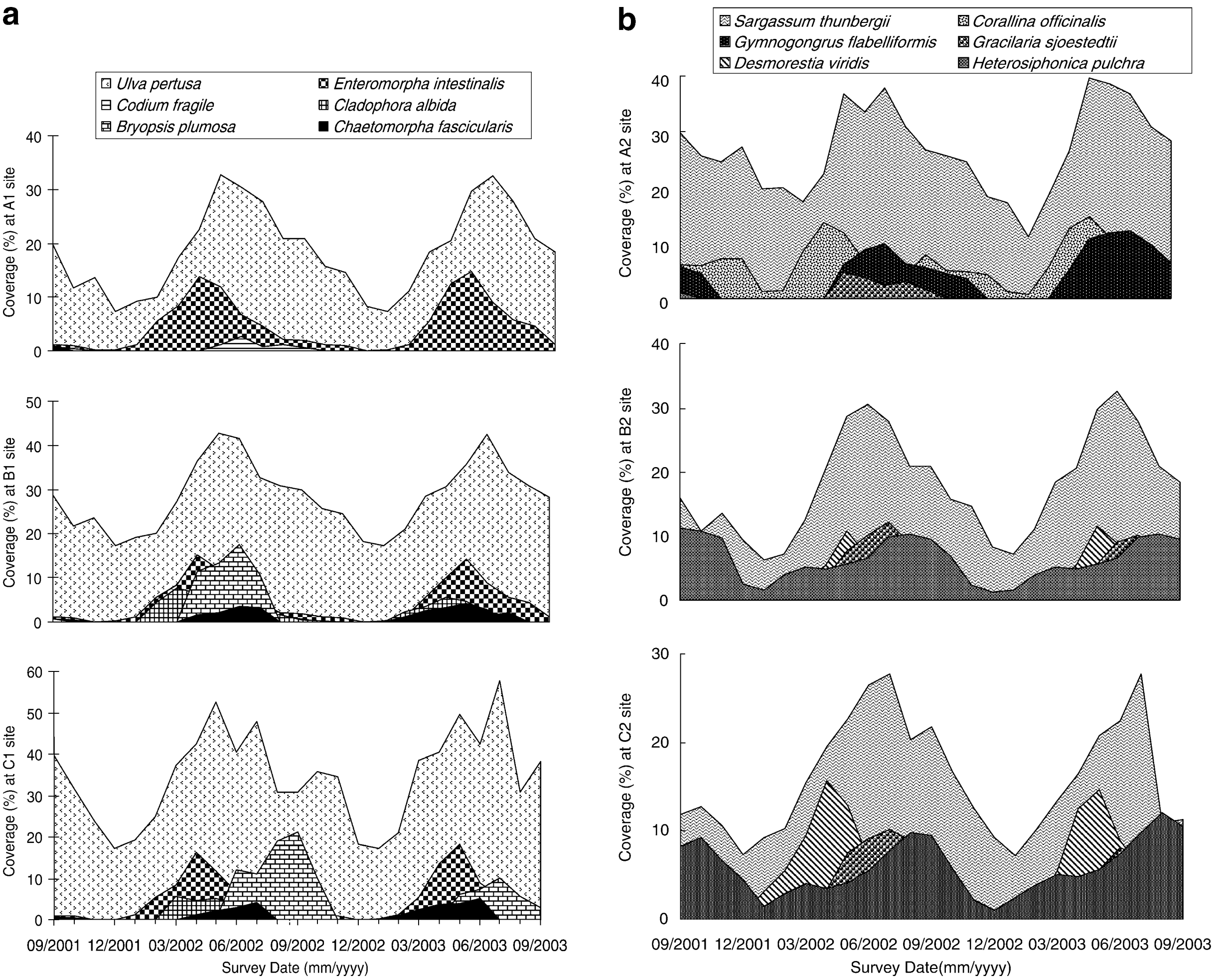

Fig. 4 **a** The monthly variations of macroalgae biomass in Section 1 during this survey in Zhanqiao Pier Bay. **b** The monthly variations of macroalgae biomass in Section 2 during this survey in Zhanqiao Pier Bay

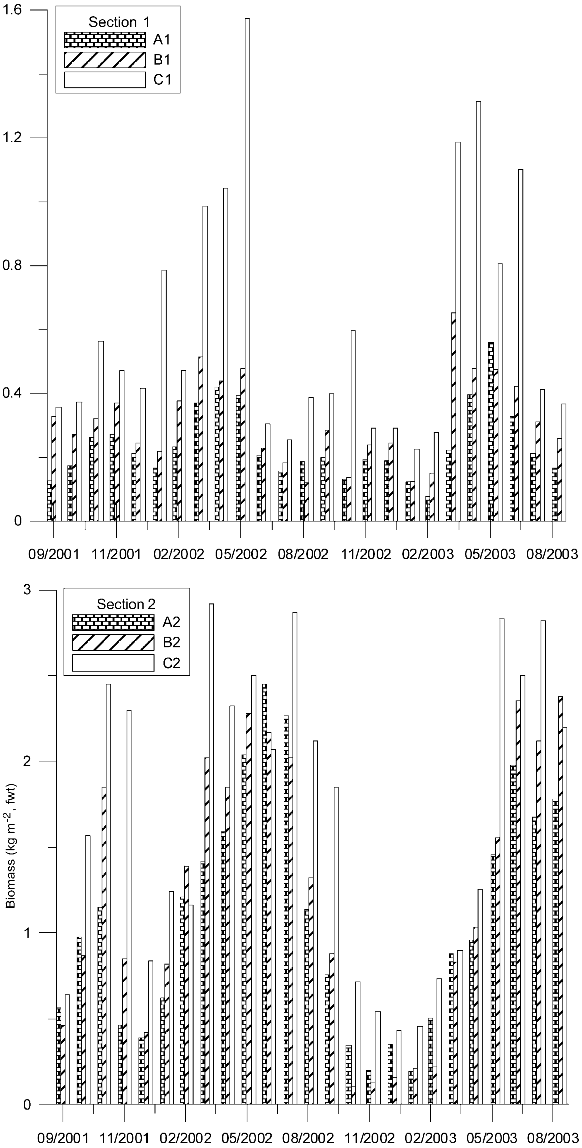

Fig. 5 The monthly variations in coverage of dominant species around Zhanqiao Pier Bay

fwt at site A1, respectively (Fig. 5). In the seaward section, the macroalgae biomass was composed mainly of brown and red algae, including *S. thunbergii*, *D. viridis*, *C. officinalis*, *G. flabelliformis*, *G. sjoestedtii* and *H. pulchra*. The biomass ranged from 0.43–5.50 kg m^{-2} fwt at site C2, 0.11–3.17 kg m^{-2} fwt at site B2 and 0.16–3.54 kg m^{-2} fwt at site A2 with seasonal changes, respectively (Fig. 5). The results demonstrated that the marcoalgae biomass on the eastern side of Zhanqiao Pier was significantly higher than that on the western side ($F_{0.05,5}=23.92$, $P=0.000<0.001$), especially at the sites C1 and C2.

4 Discussion

Several factors possibly impacted on the growth of maroalgae in Zhanqiao Pier Bay, including temperature, substrata, tidal movement and nutrients. Zhanqiao Pier Bay is adjacent to the Yellow Sea which is characterized by very cold, dry winters and wet, warm summers. This dramatic seasonal change in temperature is a result of the cold Siberian winds in winter and warm summer monsoon conditions (Wu and Long 1995). Macroalgae showed distinct changes in biomass and species composition, which can be related to these climatic conditions. For example, a high biomass occurred in Zhanqiao Pier Bay in the late spring and summer when the temperature ranged from 10 to 27°C. It has been reported previously that 10–25°C is an optimal temperature range for the growth and reproduction of temperate seaweeds (Lüning 1990).

Unlike some coastal areas of the world (Croley and Dawes 1970; Davison and Pearson 1996), mass bleaching and death of macroalgae during summer has not been recorded in Zhanqiao Pier Bay. This bay has regular semidiurnal tides with two high and two low tides every day. The annual average tidal range is 2.8 m, and the speed of tidal current is much faster during the rising tide than the ebb tide (Ding 1986). As a result, tidal amplitude and frequency shorten the exposure time of macroalgae to the air. In addition, the humid and foggy weather in this region during summer reduces the effect of desiccation.

Zhanqiao Pier Bay is protected from high seas and has a gently sloping shoreline, which dissipates the energy of waves and tides. This allows filamentous and turf algae to dominate, rather than larger, more robust algae. In addition, substrates in the Zhanqiao Pier Bay are highly variable, characterized by areas of sand, stones and rocks. This also provides a wide range of substrate conditions for the attachment of algae of different morphologies. As a result, the macroalgae in Zhanqiao Pier Bay displayed a high diversity in morphology, including species exhibiting a range of growth forms, such as, filamentous (e.g., *Chaetomorpha*); flat sheet-like (e.g., *Ulva*); coarse branching stipes (e.g., *Sargassum*); thick leathery blades (e.g., *Laminaria*); and, encrusting prostrate thalli (e.g., *Corallina*).

In the last decade, pollution of the Chinese coastal areas has increased with the development of tourism and sewage discharge. Nutrient loading to the coastal seawater has been much higher than before (Wu 1999; Shen 2001). Thus, high DIN and DIP concentrations were detected in Zhanqiao Pier Bay during this study. Nutrient concentrations showed significant differences between the western and eastern sides of Zhanqiao Pier, especially at site C1, where the nutrient concentrations were much higher than at other sites. The sewage drain constructed near to site C1 in the 1990s is the main reason for higher nutrient concentrations on the eastern side of Zhanqiao Pier. In summer, increased tourists and rainfall brought abundant nutrients from the land into the sea, and resulted in higher nutrient concentrations than in other seasons. These factors are enhancing the speed of coastal eutrophication. Nutrient availability for biological uptake is an important factor controlling algae species composition and biomass in shallow coastal waters, and various algae show the different growth strategies, life forms and distribution along nutrient gradients (Sand-Jensen and Borum 1991; Duarte 1995; Borum 1996). The results of this research show that the macroalgal community structure is different under nutrient-rich and nutrient-poor conditions.

Firstly, the biomass of maroalgae along the nutrient gradients obviously demonstrated that higher biomass on the eastern side of Zhanqiao Pier was produced compared with the biomass on the western side, for example, the annual data showed that the average biomasses at sites B1 and C1 (nutrient-rich area) were higher by 38 and 158% respectively than those at site A1 (nutrient-poor area). However, few macroalgae bloom events have been reported in this area. The semi-diurnal tides may enhance the transportation of nutrients out of the area, reducing the environmental pressure. Another possible reason for this is that the foreshore cleaners frequently remove the macroalgae during the tourism season. Temperature is another important factor affecting the seasonal variation of biomass. In the warm and wet weather (i.e., spring and summer), the macroalgae reproduced and flourished more than in the dry and cold winter.

Secondly, the species composition in the landward intertidal areas showed the distinctive eutrophication characteristics. The dominant species *U. pertusa* and *E. intestinalis* belong to the typical r-selected pioneering species, and increased nutrient concentrations can result in “green tides” (Merrill and Fletcher 1991). These species demonstrated higher biomass during this survey, for example, at site C1, the highest biomass and coverage reached 1.57 kg m^{-2} fwt and 76%, respectively, in summer. Otherwise, *C. albida* and *Ch. fascicularis* were growing well near to the nutrient-rich sites B1 and C1 during this survey, the highest coverage reached 7.8 and 4.7%, respectively on the eastern side of Zhanqiao Pier. Some researchers have reported that these species have formed massive macroalgal blooms under nutrient-rich conditions (Bach and Josselyn 1978; Birch et al. 1981; Lapointe and O’Connell 1989).

In the seaward section, the slow-growing species, such as *S. thunbergii*, *C. officinalis* and *G. flabelliformis*, dominated at site A2 the whole year round, but at sites B2 and C2, not only slow-growing species *S. thunbergii*, but some filamentous and ephemeral species like *C. albida*, *Ch. fascicularis* and *H. pulchra*, became dominant on the eastern side of Zhanqiao Pier. The available studies show that large, slow-growing macroalgae are able to grow under low nutrient concentrations relative to fast-growing species, because fast-growing species tend to require relatively high external concentrations of inorganic N to saturate their growth (Borum 1996; Pederson and Borum 1997). Some in-situ experimental results have also proved that short-lived, opportunistic and filamentous algae have rather high nutrient uptake rates, that are related to their thin morphology and higher relative surface areas compared to large and thick algae (Wallentinus 1984; Hein et al. 1995). Otherwise, *D. viridis,* known to have an extremely low pH due to a high sulfuric acid concentration in cell sap, was only present on the eastern side of Zhanqiao Pier and became quite dominant in late spring. Previous research showed that this species can grow well in low pH and nutrient-rich environments (Wirth and Rigg 1973; Meusse 1956; Maclintock et al. 1982). The massive production of *D. viridis* is a possible indication of seawater acidification on eastern side of Zhanqiao Pier.

There are few data sets available about the macroalgal community from the area around Zhanqiao Pier Bay to compare with this work. Based on the limited historical record, however, macroalgae in this area showed a decline in species diversity (Tseng and Cheng 1954; Tseng and Chang 1962; Zheng and Liu 1985; Zhang 1993; Liu et al. 1999). There were more than 70 macroalgae species found in this area before the 1990s, using similar sites and same methods as in these studies. For example, an annual survey in the same area from 1981 to 1982 showed that 83 species of benthic algae were found including 13 Chlorophyta, 16 Phaeophyta and 54 Rhodophyta (Zheng and Liu 1985); another survey in Zhanqiao Pier Bay from 1988 to 1989 found 78 species of benthic algae including 14 Chlorophyta, 19 Phaeophyta and 44 Rhodophyta (Zhang 1993). However, the survey results in 1998–1999 (Liu et al. 1999) and this survey results in 2001–2003 located no more than 60 macroalgae species. For red algae especially, species decline was particularly steep. Another important reason for the changes may be that the firm substrate in the Zhanqiao Pier coastal area has decreased significantly because of construction and building of new touring facilities in recent years. Substrate is one of the important abiotic factors affecting the species growth, productivity and diversity because many macroalgae prefer to grow on a firm substrate (Dahl 1973; Dawes 1998).

Finally, this study has illustrated the annual characteristics of macroalgae in Zhangqiao Pier Bay, and compared the differences in macroalgal communities between the two sides of Zhanqiao Pier resulting from the effect of sewage discharge. It has been shown that the biomass and species composition have a consistent relationship with exotic nutrient sources. Macroalgal biomass and species composition are seen in this study as sensitive indicators of the degree of coastal eutrophication. Nutrient concentrations demonstrated an obvious effect on the selective distribution of slow-growing and fast-growing macroalgae, as has been shown in other studies.

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