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Estimating areal carbon fixation of intertidal macroalgal community based on composition dynamics and laboratory measurements*

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Abstract The community dynamics and potential carbon fixation of intertidal macroalgae were investigated monthly from April 2014 to April 2015 in the northwest coast of Yellow Sea. Seasonal variations in biomass and carbon fixation were presented and showed close relationship with community structure. The carbon fixation rate ranged from 0.48±0.13 mg C/(g_{FW}·d) to 4.35±0.12 mg C/(g_{FW}·d). *Sargassum thunbergii*, *Chondrus ocellatus* and *Ulva intestinalis* were three most influential species which contributed 27%, 21.9% and 18.5% variation of carbon fixation rate, respectively. Standing carbon stocks ranged from 7.52 g C/m^2 to 41.31 g C/m^2, and estimated carbon stocks varied from 11.77 g C/m^2 to 96.49 g C/m^2. The larger difference between estimated and standing carbon stocks implied that more fixed carbon was exported from the community in summer and autumn than in winter. This study suggested that intertidal macroalgal community could provide a potential function in carbon fixation of coastal ecosystem.

Keyword: carbon fixation; carbon stock; community composition; intertidal macroalgae; Yellow Sea

1 INTRODUCTION

Marine vegetation as a potential sink for anthropogenic C emissions, defined as "Blue Carbon" by Nellemann et al. (2009), has been studied increasingly in recent years. Algae and higher marine plants such as mangroves and seagrasses play a critical role to CO_2 removal and carbon sequestration or storage (Gao and McKinley, 1994; Duarte et al., 2005, 2010; Bouillon et al., 2008; Kennedy et al., 2010; Mcleod et al., 2011). With high productivity as great as or greater than the most productive land plants, macroalgae have great potential for biomass production and CO_2 bioremediation (Gao and McKinley, 1994; Muraoka, 2004; Chung et al., 2011). Besides, massive cultivated macroaglae along coast area in East Asia countries, such as China, Japan, Korea, Malaysia and Indonesia, and recently developing area in Chile, also provide environmental and economic function in carbon cycle (Chung et al., 2013). Nearly 0.7 million tons of carbon is removed from the sea each year globally within commercially harvested seaweeds (Turan and Neori, 2010). However, a rigorous assessment of the CO_2 fixation and fluxes that are driven by macroalgae beds in coastal ecosystem, especially by the intertidal macroalgae, is neglected and received little consideration within the context of CO_2 sequestration (Chung et al., 2013).

To determine the carbon fixation of macroalgae, two strategies were generally applied in its estimation: one is using the accumulated carbon content of macroalgae, especially for cultivated macroalge (Tsai et al., 2005; Renaud and Luong-Van, 2006; Delille et al., 2009); the other is based on the carbon fixation rate of macroaglal photosynthesis. The latter mainly evaluated by DIC (dissolved inorganic carbon) concentrations (Beardall and Roberts, 1999; Middelboe et al., 2007), O_2 evolution (Mercado et al.,

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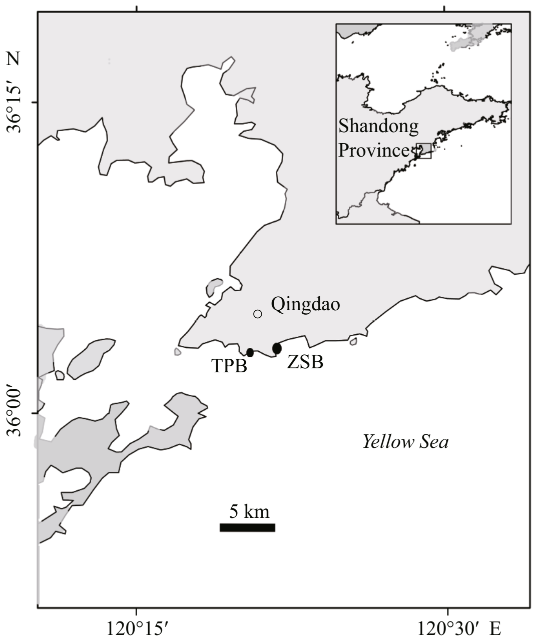

Fig.1 Sampling sites in the northwestern coast of Yellow Sea

One in Taiping Bay (TPB) and another in Zhanshan Bay (ZSB).

1998), and photosynthetic electron transport rate (ETR) of PSII (Franklin and Badger, 2001; Longstaff et al., 2002). Recently, a flowing-through system was developed by Gao et al. (2012) based on measurement of differences in dissolved O_2 concentrations or total alkalinity, which made the estimation on photosynthetic or calcification rates more accurately for benthic organisms.

Most studies showed that the carbon content or carbon fixation rates of macroalgae varied among different species and seasons. Those species of genera *Sargassum*, *Ascophyllum* and *Fucus* in Phaeophyte, species of *Pyropia* and *Palmaria* in Rhodophyte, and genera *Ulva* in Chlorophyte ranked the highest level of photosynthetic and CO_2 assimilation rates in their respective Phyta (Chung et al., 2011). And obviously seasonal variation in carbon content of individual species was presented along with their biomass variation (Tsai et al., 2005; Delille et al., 2009). In addition, a survey of chemical composition in 30 common species of tropical Australian marine macroalgae (Renaud and Luong-Van, 2006) showed that there was no single trend in the change of carbohydrate content for individual species of different seasons. For instance, among 9 species collected in both summer and winter, carbohydrate content was significantly higher for 3 species in summer, but 2 species of rhodophytes had significantly higher content in winter, while all other species had no temporal variation in carbohydrate content. Therefore, the estimation of carbon fixation by macroalgae should be carried on all the year round based on species composition and on community level.

In this study, aimed to explore the potential function of intertidal macroalgal community in carbon fixation of coastal ecosystem, we combined the field investigation and laboratory experiments to estimate carbon fixation rate and standing carbon stocks on community level. The investigation were carried on intertidal macroalgae in northwestern coasts of Yellow sea, through monthly recording seasonal variations in biomass and community compositions, measuring community carbon fixation, analyzing the relationship of carbon fixation rates with community structures, and tracking the variation in carbon flow by comparison of standing carbon stock and estimated carbon stock.

2 MATERIAL AND METHOD

2.1 Study area and sampling

Macroalgal communities were sampled from rocky shores of Qingdao in Shandong Peninsula of China, along the northwestern coastline of Yellow sea. One site (TPB) was located in Taiping Bay (36°2′53″N, 120°20′49″E), where is all rocks down to the subtidal zone; the other site (ZSB) was located in Zhanshan Bay (36°3′11″N, 120°21′41″E), which was about 300 m width rocky area surrounded by sand flats from both sides facing open sea (Fig.1). The two bays are semi-enclosed and have irregular semi-diurnal tide, with typical characteristics of northern temperate monsoon and marine climate (Gao, 2002). Two main environmental factors, light intensity (PAR, photosynthetically available radiation) and sea surface temperature (SST) were obtained from the database of NASA (National Aeronautics and Space Administration, USA), selecting the monthly average in area of Lat (35.5°N, 36.5°N) and Lon (119°E, 121°E).

Sampling was carried out monthly from April 2014 to April 2015 in the intertidal zone of two sampling sites during the lowest tide period. Five quadrats (50 cm×50 cm) for each site were selected randomly with 50–100 m intervals in middle part of intertidal zone within range of ~100 m width and 200–300 m length along the coastline, and all the macroalgae in the 5 quadrats were collected together as one sample and transported to the laboratory subsequently.

2.2 Biomass and community composition

After cleaning, samples were classified by species and weighed immediately after removal the surface water to obtain the fresh weight (FW) of each species. The dry weight of each species (DW) was measured after drying at 80°C for at least 48 h in an oven. The monthly standing biomass was expressed by the total weight (FW or DW) per square meter. The species was identified morphologically according to Tseng (1983, 2009), Zheng (2001), and Xia (2011). Microstructure characteristics of the fresh fronds were observed under an Olympus CX31microscope (Olympus Co., Japan). The community composition was assessed by the proportion of fresh weight of individual species to total fresh weight of one sample.

2.3 Carbon fixation rate and carbon fixation

Carbon fixation rates were measured using the modified light and dark bottle technique. The replicates of macroalgae assemblage were composed of individual species according to the proportion of field samples. The incubation was last for 24 h under natural light and surrounding temperature with the density of one gram of the macroalgae assemblage per litre sea water (filtered by 0.45 μm membranes). Three parallel pairs of light and dark treatment and one blank (ck, without algae) were filled with filtered seawater. Dissolved oxygen (DO) was measured by an EcoSense DO200 Dissolved Oxygen Meter (sensitivity 0.01 mg/L) (YSI, America) at the beginning and the end of experiments. The carbon fixation rate (C_{FR}) was converted from oxygen evolution according to the following formula:

$C_{FR}=12\times(m_{O_2,i}-m_{O_2,ck})/32$, mg C/($g_{FW}$·d),

where 12 is the molar mass of C (12 g/mol); 32 is the molar mass of O_2 (32 g/mol); m_{O_2} is the amount of O_2 release ($m_{O_2,i}=\Delta DO_i\times V/m_{FW}$, V=system volume; m_{FW}=mass of tested assemblage; V/m_{FW}=1 L:1 g, i=individual experiment).

The carbon fixation (C_F) was calculated according to the following formula:

$C_F=C_{FR}\times FW_T$, g C/(m^2·d),

where FW_T is the total fresh weight of community per unit area.

2.4 Carbon stock

Triplicate dry samples of 22 dominant species were ground and kept dry before measurement. The carbon content of sample was measured by a CHONS elemental analyzer (Vario EL III, Hanau, Germany), and expressed by the C proportion (%) of dry weight.

Standing carbon stock (C_S) was the total carbon content of community per unit area, calculated by $C_S=\sum_{i=1}^{s}(C_i\times DW_i)$, g C/m^2, where C_i is the C content (%) of individual species, DW_i is the dry weight of individual species per unit area, s is total number of species.

Estimated carbon stock (C_E) of next month was the sum of standing carbon stock of present month and carbon fixation of average 30 days per month.

2.5 Statistical analysis

Monthly data of carbon fixation rate and carbon contents were evaluated by the Kolmogorov-Smirnov test to exam the normal distribution. For the data fitted normal distribution, one-way ANOVA and Tukey's honestly significant difference (HSD) test following Levene's test of homogeneity of variance were performed for multiple comparisons. For the data did not fit the normal distribution, the Kruskal-Wallis one-way ANOVA was performed. T-test was used to compare the difference between two sampling sites.

The relationship among carbon fixation rates, community compositions, light intensity (PAR) and seawater temperature (SST) were analyzed by Principal Component Analysis (PCA) using CANOCO 5, which were tested by Monte Carlo Permutation Test.

3 RESULT

3.1 Biomass

By one-year investigation, it showed that the biomass of macroalgal communities in Taiping and Zhanshan Bay had obviously seasonal variation with two distinct peaks in March and July, respectively (Fig.2). The evident difference between TPB and ZSB exhibited when the biomass of ZSB decreased rapidly in August then slightly increased in September, but the biomass of TPB kept decreasing steadily during this period. The maximum biomass of 675.7 g_{FW}/m^2 appeared in July at TPB and 601.1 g_{FW}/m^2 in March at ZSB, respectively. And the lowest biomass occurred in November at ZSB (208.0 g_{FW}/m^2) and in December at TPB (174.0 g_{FW}/m^2), respectively. There was obvious interannual difference presented between April 2014 and April 2015. Dry weight biomass was relatively low due to high water content of macroalgae but varied with generally consistent trend and amplitude of fluctuation as fresh weight biomass except period of July to October at TPB, where the dry weight biomass vibrate little but the fresh weight biomass decreased steadily.

3.2 Community composition

The community compositions of macroalgae were different seasonally and between two sites (Fig.3). During one-year investigation, total 21 and 23 species were collected at TPB and ZSB, respectively. *Ulva australis* and *U. intestinalis* were dominant at both sites especially in spring and summer, accounting for 52.8% (July), 56.2% (April, 2014) of community composition at TPB, and 58.6% (June), 40.2% (March) at ZSB, respectively. Besides, *Sargassum thunbergii* was abundant at TPB almost throughout the year with highest composition as 51.32% in May. *Corallina officinalis* was also common at ZSB and thrived in winter and early spring with maximal composition of 53.1% in March. On seasonally, *Monostroma grevillei* and *Pyropia yezoensis* only appeared in spring, and *Bryopsis hypnoides* merely grew in autumn. Generally, species of Chlorophyte, Rhodophyte and Phaeophyte were dominant in summer, autumn, and winter, respectively.

3.3 Carbon fixation rate and carbon fixation

The variation in carbon fixation rate of macroalgal communities were shown in Fig.4A. There was significant difference between two sites ($P<0.01$). The carbon fixation rate varied significantly in individual months ($P<0.05$) at both sites, and those of ZSB were always higher than those of TPB. It averaged 24.17 mg C/(g_{FW}·d) at TPB, varying from 0.48±0.13 mg C/(g_{FW}·d) (December) to 3.51±0.14 mg C/(g_{FW}·d) (May); averaged 35.86 mg C/(g_{FW}·d) at ZSB, changing from 1.26±0.12 mg C/(g_{FW}·d) (October) to 4.35±0.12 mg C/(g_{FW}·d) (May) at ZSB. On seasonally, carbon fixation rate was higher in spring and summer than in autumn and winter.

The variation of carbon fixation showed significant difference between two sites (Fig.4B, $P<0.01$ by *t*-test). Carbon fixation in individual months varied significantly ($P<0.05$) between 0.08±0.02 g C/(m^2·d) (December) and 1.56±0.07 g C/(m^2·d) (September) at TPB, and from 0.48±0.02 g C/(m^2·d) (December) to 2.13±0.10 g C/(m^2·d) (April) at ZSB. On a year scale, carbon fixations had relatively larger differences between two sites as 265.8 g C/(m^2·a) at TPB and 394.4 g C/(m^2·a) at ZSB. Calculated by multiplying carbon fixation rate with biomass, carbon fixation followed similar variation patterns with carbon fixation rate, excluding the reverse from May to June at both sites and January to March at TPB.

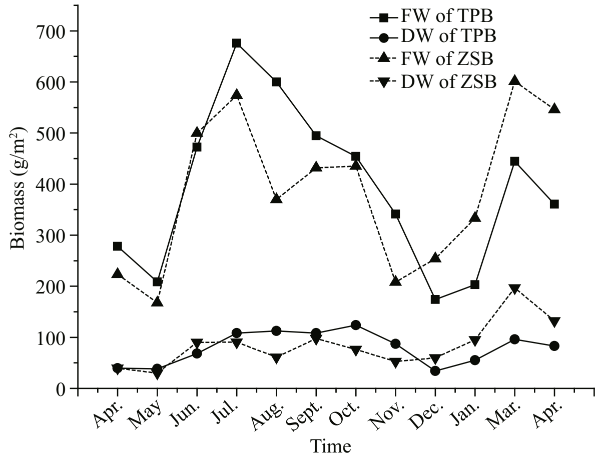

Fig.2 Seasonal variations in biomass (g/m²) of macroalgae communities at sampling sites

TPB: Taiping Bay; ZSB: Zhanshan Bay. DW: dry weight; FW: fresh weight.

3.4 Carbon fixation rate and community composition

The relationship between carbon fixation rates and community composition was analyzed by multivariate correlation analysis on 22 plots and 22 species along with two environmental factors of light intensity (PAR) and seawater surface temperature (SST, Fig.5). According to the results of PCA and Monte Carlo permutation test, three species contributed to the variation of carbon fixation rate significantly ($P<0.05$), i.e. *Sargassum thunbergii* (27%), *Chondrus ocellatus* (21.9%), *Ulva intestinalis* (18.5%). *Blidingia minima*, *Colpomenia sinuosa* and *Ulva australis* had positive relationships with carbon fixation rate, explaining 15.8%, 10.2% and 9.5% variation, respectively. *S. thunbergii* and *C. ocellatus* negatively related to carbon fixation rate. Light intensity was the main effect environmental factor on carbon fixation rate, explaining its 30.4% variation (Fig.5, $P<0.05$). But seawater surface temperature had no significant influence on carbon fixation rate (Fig.5). With regard to the relationship between community composition and environmental factors, *Ulva intestinalis*, *Ulva australis*, *Blidingia minima* and *Cladophora vagabunda* were closely related to light intensity (PAR) and temperature (SST), and *Grateloupia filicina* and *Bryopsis hypnoides* were negatively related to these two factors.

3.5 Carbon content and carbon stocks

The carbon content of 22 investigated species varied from 16.9%±1.0% to 35.2%±2.5% (Table 1).

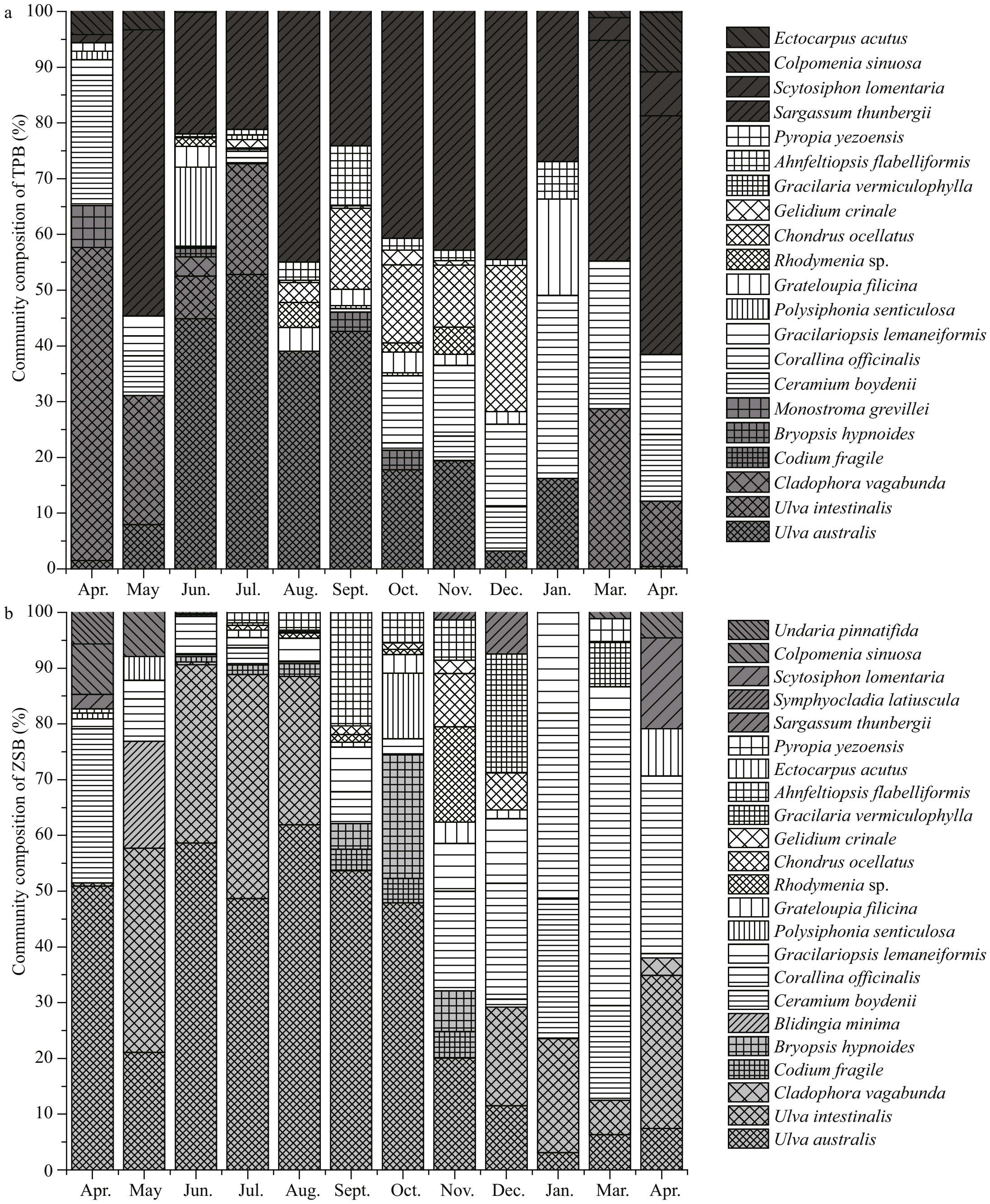

Fig.3 Seasonal variations in community compositions of two sampling sites

a. Taiping Bay (TPB); b. Zhanshan Bay (ZSB); base color of light grey: chlorophyte; white: rhodophyte; grey: phaeophyte

Carbon contents of species with less than 3.0% composition (*Gelidium crinale* and *Symphyocladia latiuscula*) were substituted by the average value of 22 species (28.9%±1.7%).

The standing carbon stocks varied seasonally, but averaged closely at two sites: average of 22.73 g C/m^2, ranging from 9.28 g C/m^2 (December) to 34.71 g C/m^2 (August) at TPB; and average of 21.18 g C/m^2, varying from 7.52 g C/m^2 (May) to 41.31 g C/m^2 (March) at ZSB (Fig.6). On one-year scale, the standing carbon stocks of were approximate for both sites (272.8, TPB and 254.2 g C/(m^2·a), ZSB). The estimated carbon stocks mainly followed the variation patterns of carbon fixation, with averages of 24.17 g C/m^2 (11.77g C/m^2 in January ~78.84 g C/m^2 in October) and 35.86 g C/m^2 (29.43 g C/m^2 in June ~96.49 g C/m^2 in April) at TPB and ZSB, respectively (Fig.6). On generally, the estimated carbon stocks were higher than standing carbon stocks, especially much higher in summer and autumn (July till to

Table 1 Carbon content of 22 species collected in one-year investigation

No.	Species	Carbon content (average±SD, %)
1	*Ulva australis*	27.4±3.4
2	*Ulva intestinalis*	28.3±3.0
3	*Monostroma grevillei*	33.1±0.4
4	*Blidingia minima*	25.8±0.1
5	*Codium fragile*	28.1±1.5
6	*Cladophora vagabunda*	30.8±2.3
7	*Bryopsis hypnoides*	30.7±2.1
8	*Pyropia yezoensis*	33.7±0.3
9	*Ceramium boydenii*	30.6±4.4
10	*Corallina officinalis*	18.1±0.8
11	*Gracilaria vermiculophylla*	30.7±0.1
12	*Gracilariopsis lemaneiformis*	35.2±2.5
13	*Chondrus ocellatus*	26.3±3.2
14	*Polysiphonia senticulosa*	29.1±0.1
15	*Grateloupia filicina*	31.9±1.5
16	*Ahnfeltiopsis flabelliformis*	31.8±1.9
17	*Rhodymenia sp.*	31.0±0.6
18	*Ectocarpus acutus*	25.8±0.8
19	*Scytosiphon lomentaria*	30.4±2.1
20	*Colpomenia sinuosa*	16.9±1.0
21	*Sargassum thunbergii*	33.5±4.5
22	*Undaria pinnatifida*	27.4±0.4
	Average	28.9±1.7

November) at both sites and in April (2015) at ZSB, but closed to or even lower in January, March and June at both sites and in April (2015) at TPB.

4 DISCUSSION

Globally, marine macrophytes (seaweeds and seagrasses) in the coastal regions account for ~1 Pg C/a productivity (Beardall and Raven, 2004; Chung et al., 2011). Marine macroalgae beds with high biomass, such as the kelps *Macrocystis* and *Laminaria*, are capable to drawdown C of ≥3 000 g C/(m^2·a) (Jackson, 1987; Gao and McKinley, 1994; Muraoka, 2004). A comparison of sustained productivities with 23 species of important phaeophyte and rhodophyte showed that most species produced less than 500 g C/(m^2·a) and only 7 species at the level in excess of 1 000 g C/(m^2·a) (Littler and Murray, 1974; Leigh et al., 1987; Gao and McKinley, 1994; Chung et al., 2011). In this study, the annual standing carbon stocks of the intertidal macroaglae community could be 263.5 g C/(m^2·a), and the yearly carbon fixation could reach 350.1 g C/(m^2·a). Although the results are lower

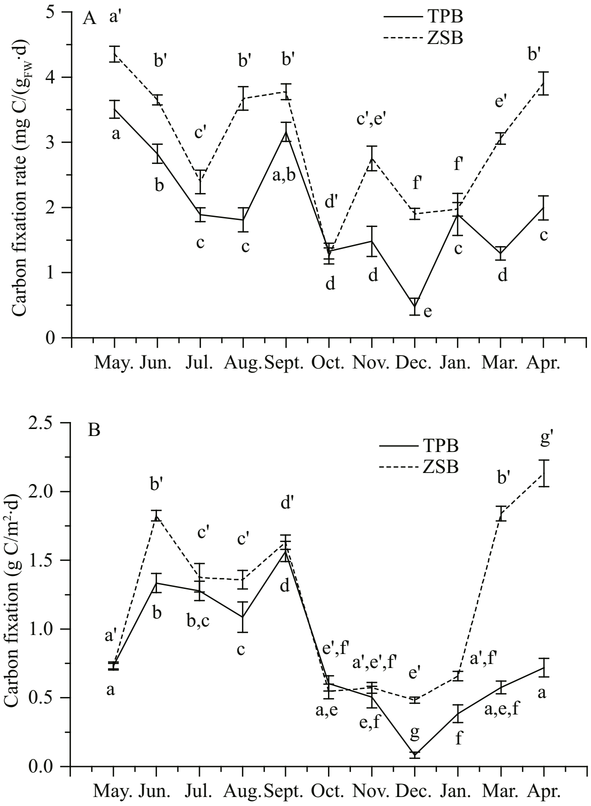

Fig.4 Seasonal variations in carbon fixation rate (A) and carbon fixation (B) of intertidal macroalgal communities

Different letters present statistically significant differences (P<0.05).

than productivity of single species and those kelp beds, it is still reasonable for macroaglal community which has less biomass and oscillating productivity due to vibrating environmental conditions in intertidal zones than in subtidal zones. Therefore, the results of this study are comparable and could be references for other studies or applications**.**

In the present study, carbon content and fixation varied significantly in individual months and sites, which had its origin in their difference and alternation of community compositions. Firstly, the species composition directly influences the community biomass which are basically responsible for carbon fixation. For example, the disappearing of *Pyropia yezoensis* thalli due to its metagenesis caused a decline of biomass in May at both sites; and the reduction of *Ulva intestinalis* in August contributed to the rapid decrease of biomass at ZSB. On the contrary, the thriving of *Ahnfeltiopsis flabelliformis* in September made the biomass slightly increase at ZSB, and the predominance of *Sargassum thunbergii* at TPB made community biomass varied smoothly in August and September. Secondly, the ability of individual species on carbon fixation strongly

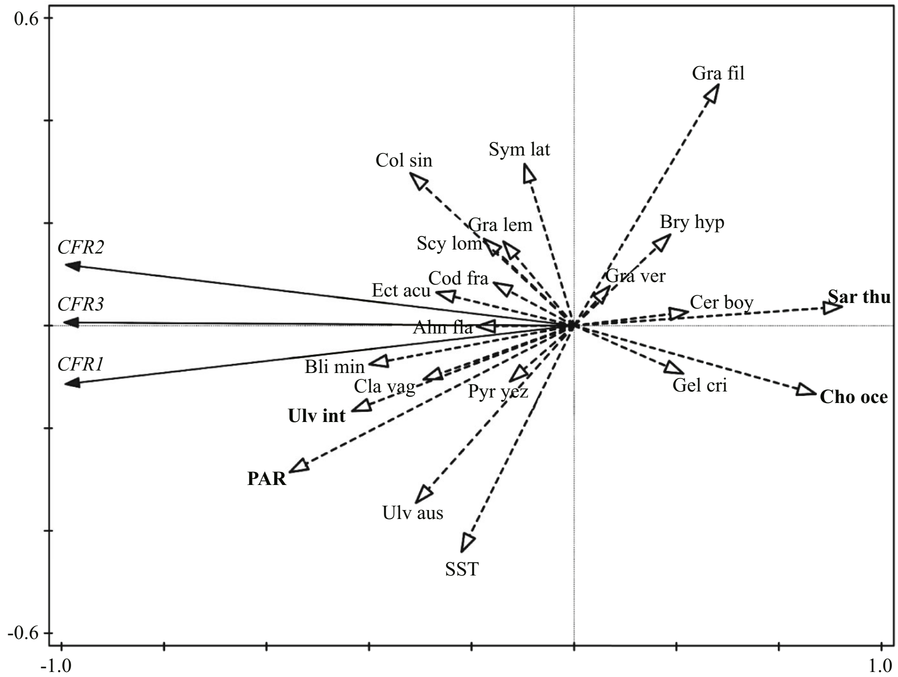

Fig.5 PCA (principal component analysis) of carbon fixation rates with species compositions, PAR and SST

CFR1, CFR2, and CFR3: three parallels of carbon fixation rate; PAR: photosynthetically available radiation; SST: sea surface temperature; species was presented by the first 3 letter of the scientific name. i.e. *Ulv aus*: *Ulva australis*; *Ulv int*: *Ulva intestinalis*; *Cer boy*: *Ceramium boydenii*; *Scy lom*: *Scytosiphon lomentaria*; *Col sin*: *Colpomenia sinuosa*; *Gra lem*: *Gracilariopsis lemaneiformis*; *Cla vag*: *Cladophora vagabunda*; *Cod fra*: *Codium fragile*; *Gra fil*: *Grateloupia filicina*; *Sar thu*: *Sargassum thunbergii*; *Cho oce*: *Chondrus ocellatus*; *Gel cri*: *Gelidium crinale*; *Bry hyp*: *Bryopsis hypnoides*; *Gra ver*: *Gracilaria vermiculophylla*; *Ahn fla*: *Ahnfeltiopsis flabelliformis*; *Ect acu*: *Ectocarpus acutus*; *Pyr yez*: *Pyropia yezoensis*; *Bli min*: *Blidingia minima*; *Sym lat*: *Symphyocladia latiuscula*.

determines the carbon fixation at community level. As summarized by Chung et al. (2011), *Sargassum muticum*, *S. thunbergii*, *Pyropia yezonensis* and *Ulva lactuca* could achieve high rates of CO_2 assimilation by 120, 50, 350 and 150 mg $CO_2/(g_{FW}·d)$, respectively. In this study, *Ulva intestinalis*, *U. australis*, *Blidingia minima* and *Colpomenia sinuosa*, which thrived in late spring or summer when light intensity was higher during the year, contributed higher carbon fixation for macroagal community. In addition, environmental factors, such as light intensity and temperature, control and affect the processes of primary production which in turn affect the carbon fixation of macroalgae (Bhatti et al., 2002). *Sargassum thunbergii* and *Chondrus ocellatus* which were more abundant in autumn and winter, limited by the low light intensity and surface temperature (less than half of spring and summer), presented a negative correlation with carbon fixation rate (Fig.5). Based on above variations, on community level, the carbon fixation and carbon stocks of intertidal macroagae exhibited distinctly temporal-spatial dynamics (Fig.6).

To evaluate the carbon fixation of intertidal macroalgal community, both main strategies were used in the present study. The standing carbon stocks were calculated based on carbon content of individual

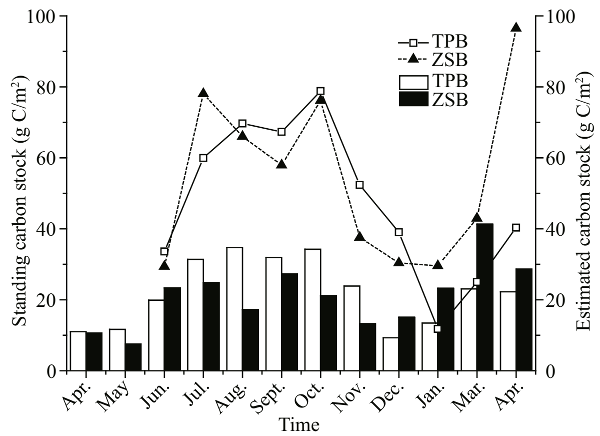

Fig.6 Seasonal variation in carbon stock of macroalgae communities

Column: standing carbon stock; line: estimated carbon stock.

macroalgae, but the carbon fixation was based on the carbon fixation rate of macroaglal community. Unlike the cultivated macroalgae which almost are harvested, the natural macroalgae inhibiting the intertidal zone are facing to more complex and faster alternation which lead to inevitable loses of its production. In fact, intertidal macroalgae often exposed in the air during low tide and performing different photosynthetic rate or mechanism from in water (Gao, 2014). That is also why in this study, the measurement of carbon fixation rate was carried on the 24 h incubation in sea water to avoid complex methods and get a comparative estimation. In previous studies, total carbon content of some typical macroalgae were used to show the potential significant affection to carbon absorption and storage in shallow coastal aquatic systems (Tsai et al., 2005; Delille et al., 2009), but their studies were carried out only on seaweed beds of single species, such as *Laurencia papillosa* and *Macrocystis pyrifera*. However, the carbon content was not only species-specific but also varied seasonally for individual species with no single trend (Tsai et al., 2005; Renaud and Luong-Van, 2006; Delille et al., 2009). Therefore, the strategy based on accumulated carbon content is more suitable for cultivated macroalgae or single species seaweed beds. On the contrary, the evaluation strategy based on community level would be more practically reflect their potential function in carbon fixation and sequestration.

With respect of the carbon flow, previous studies showed that the release of dissolved organic carbon (DOC) by living macroalgae could range from 0.5% up to 40% of total C fixed by photosynthesis (Khailov and Burlakova, 1969; Harlin and Craigie, 1975; Brylinsky, 1977; Penhale and Capone, 1981; Carlson and Carlson, 1984). Particulate organic carbon (POC) also takes away a part of C fixation, such as 19% for *Undaria pinnatifida* (Yoshikawa et al., 2001). In this study, by comparison of standing carbon stock and estimated carbon stock, the flux of fixed carbon could be tracked all year round and community level. For instance, during January to March and June when most macroalgae are in fast growth period, the estimated carbon stock was proximity to standing carbon stock. It could be deduced that the most photosynthetic product was used in growth and stored into thallus. In summer and autumn, there were big gaps between estimated and standing carbon stocks, it indicated that even with high carbon fixation rate, a certain amount of fixed carbon was released, decomposed or consumed from macroalgal community (ca. 56.3%). In addition, the stronger manual cleanup through anthropogenic activities in summer and autumn than in winter may also contribute to these gaps.

5 CONCLUSION

Combining field investigations with laboratory measurements, this study estimated areal carbon fixation of intertidal macroaglae community. It showed obvious seasonal variations in carbon fixation and its close relationship with community structure. Community carbon fixation rates varied from 0.48±0.13 mg C/(g_{FW}·d) to 4.35±0.12 mg C/(g_{FW}·d), significantly influencing by three species, *Sargassum thunbergii*, *Chondrus ocellatus*, and *Ulva intestinalis*. The standing carbon stock of macroalgal communities could account for 263.5 g C/(m^2·a) in the study area of intertidal zone in the northwestern coast of Yellow Sea. The results are reasonable and imply that this method can be used as an alternative to labor intensive measurements in situ. The estimated carbon stocks were generally higher than the standing carbon stocks, especially in summer and autumn, indicating that a certain amount of fixed carbon was exported from macroalgal community.

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