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Divergence of carbon dioxide fluxes in different trophic areas of Taihu Lake, China

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Abstract: Carbon dioxide partial pressures(pCO_2) and CO_2 fluxes on air-water interface in different trophic-level areas of Taihu Lake were calculated and corrected using alkalinity, pH, ionic strength, active coefficient, water temperature and wind speed on the basis of the data sets of monthly sampling in 1998. The mean values of pCO_2 in the hypertrophic, eutrophic, and mesotrophic areas are 1807.8 ± 1025.8(mean ± standard deviation) μatm, 416.3 ± 207.8 μatm, and 448.5 ± 194.0 μatm, respectively. A maximum and minimum pCO_2 values were found in the hypertrophic(4053.7 μatm) and the eutrophic(3.2 μatm) areas. There was about one magnitude order of difference in mean CO_2 fluxes between the hypertrophic area(27.3 ± 17.4 mmol/($m^2 \cdot d$)) and the eutrophic(1.99 ± 4.50 mmol/($m^2 \cdot d$)) and mesotrophic (2.22 ± 4.31 mmol/($m^2 \cdot d$)) areas. But there was no significant difference between eutrophic and mesotrophic areas in pCO_2 and the flux of CO_2. In respect to CO_2 equilibrium, input of the rivers will obviously influence inorganic carbon distribution in the riverine estuary. An exponential relationship between the pCO_2 values and chlorophyll-a concentrations was obtained($r = 0.8356$, $n = 60$) in eutrophic bay. Results suggested that lake ecosystems, also may be considered as unique aggregation, which can contain and be patient of different components that have their relative independence so long as its size enough to large. A productive lake, though it has positive fluxes of CO_2 to atmosphere during the most of time, is a huge and permanent sink of carbon in terrestrial ecosystems through receiving a great quantity of carbon materials via rivers, precipitation, and biological production.

Keywords: carbon dioxide flux; trophic difference; chlorophyll-a; Taihu Lake

Introduction

Carbon dioxide (CO_2) is a principal greenhouse gas and therefore their air-water exchanges are important problems in terrestrial ecosystems for climate change study (Frankignoulle, 1998; Chimel, 2001). The direction of CO_2 gas exchange(evasion or invasion) is dependent on the direction of the CO_2 concentration gradient between the air and the surface water; the magnitude of the exchange depends additionally on the gas exchange coefficient, k.

All of lakes in land, with its small area but large atmospheric CO_2 flux range, play an important role in evaluating land CO_2 fluxes(Meybeck, 1993). Therefore, the fluxes, sources, and mechanisms of CO_2 in lakes are studied and compared (Richey, 1978; Kling, 1992; Cole, 1994; Hope, 1996; Kelly, 2001). In these studies, each lake was usually considered as a homogenous water body regardless of its size. Actually some large lakes, especially induced largely by the mankind, possess the waters of different trophic levels and loading properties (Wang, 1998). There trophic status may fluctuate in response to changes in inputs of carbon and nutrients from the watershed due to disturbances such as those caused by fertilization, industrialization or urbanization, which can result in different phytoplankton productivity and carbonate equilibrium systems(Richey, 1978; Wetzel, 2001). Generally, the lowest CO_2 concentrations are observed during spring to autumn period when waters experience the highest algal activity (Neal, 1998).

This paper is based on data collected in the waters with different trophic levels in a large lake in China. The purpose of the paper is to quantify annual spatial and temporal changes of pCO_2 and divergence of CO_2 fluxes among the different trophic areas in the lake, in order to identify the major algal grown

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processes in photosynthesis, and to observe the response of dissolved inorganic carbon to the CO_2 flux changes. Furthermore, we evaluate the special behavior and relative importance of the riverine estuary and discuss the impact of carbon loading from rivers on the carbonate equilibrium in the different waters.

1 Materials and methods

1.1 Site description

Taihu Lake(31°15′N, 120°12′E), the third largest freshwater lake in China, locates in the Yangtze River Delta and is about 100 km^2 away from Shanghai Metropolis. Taihu catchment, an area of 36500 km^2, is one of the most developed regions in China. It is situated in temperate zone and the southeast monsoon zone with annual precipitation of 1200—1400 mm (Sun, 1993). Taihu Lake is a large, shallow and unstratified lake, with an area of 2338 km^2 and a mean depth of 1.89 m. Its water residence time is approximate 300 days. The north part of the lake is main water resource for Wuxi City, with population about 1.1 million.

Taihu Lake is developing in eutrophication, with mean pH of 8.3, and four large bays. There are two high productive lake areas, Meiliang Bay and Wulihu Lake, in the north part of the lake(Fig.1). Meiliang Bay often occurs algal bloom in summers since 1990s(Fan, 1996). It mainly receives input of surface runoff from farmland, and industrial discharge from a western river, Zhihugang River, whose total organic carbon input loading takes up about 17% of the whole external loading from the watershed(Huang, 2001), resulting in that the river estuary keeps heavy organic pollution in addition to eutrophication(Fan, 1998). Wulihu Lake, located near to the urban environment of Wuxi City and connecting with Meiliang Bay in the south, the west of which mainly receives the sewage of the city zone from a bi-directional river, Liangxihe River. Surrounding Wulihu Lake there are many scenic spots and hotels, generating high nitrogen, phosphorus, and organic carbon concentrations(Sun, 1993). The open lake, to the south of Meiliang Bay, is the main lake area.

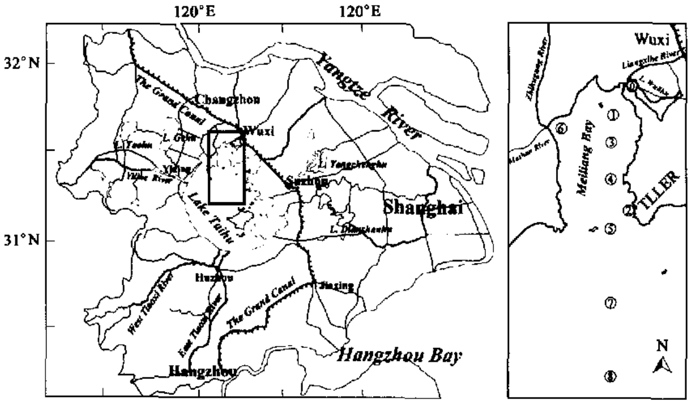

Fig.1 Map of Taihu Lake and its catchment showing the sampling sites 0—8. The point labeled "TLLER" marks the location of the Taihu Laboratory for Lake Ecosystem Research, in which all meteorological observation and analytical experiments were done in relation to this research

In order to make a comparison among the lake areas with different trophic situations, we located nine sites in the northern area of Taihu Lake(Fig.1), two sites, 0 and 6, are in west Wulihu Lake and the riverine estuary of Zhihugang River, respectively; site 1 to 5 are in the Meiliang Bay; the other two sites, 7 and 8, are in the open lake.

1.2 Sampling and analytical methods

Water samples were sampled at monthly interval from mid January to mid December 1998 and from 0.5 m depth under the water surface with a bilge sampler during 8:00—19:00 of the sampling day. The quantitative phytoplankton samples were collected from a screen of 40 μm mesh size, each 5 L, also using the bilge sampler. At each site, water temperature, pH, and electrical conductivity were measured in the field. All water samples were filtrated through glass filters(Whatman GF/C) on arriving the laboratory and kept refrigerated in the dark. Chlorophyll-a concentrations were determined using ethanol and corrected for phaeopigments using the technique developed by Marker(Marker, 1994).

Wind speed (10 meter), atmosphere pressure, temperature, and photosynthetic active radiation (PAR) were automatically recorded every 30 minutes with a meteorological observatory (MODAS) and precipitation was measured with a rain gauge in the Taihu Laboratory for Lake Ecosystem Research (TLLER; Fig.1).

pCO_2 was calculated for each sampling date from pH and alkalinity (Alk), with the appropriate corrections for temperature, ionic strength, following Wetzel and Likens(Wetzel, 1991) and Cole *et al.* (Cole, 1994). Alk was measured by Gran titration in an open vessel (precision ± 0.5%). pH was measured with an acidimeter using a gel-filled combination, temperature-compensating electrode. Calibration was done using two buffers(pH 6.86 and 9.18). Ionic strength was calculated from K^+, Na^+, Ca^{2+}, Mg^{2+}, NH_4^+, Cl^-, F^-, SO_4^{2-}, NO_3^-, HCO_3^-, CO_3^{2}, and SiO_3^{2-} according to Butler(Butler, 1991). NH_4^+ and NO_3^- were measured with a double tunnel autolyzer (Skalar-SA1000); dissolved inorganic carbon(DIC) was calculated with $[CO_2]$, $[HCO_3^-]$, and $[CO_3^{2-}]$. $[HCO_3^-]$ and $[CO_3^{2-}]$ were calculated from pH, Alk and the corrected carbonate first and second association constants(k_1 and k_2); all other ions were analyzed with an ionic colour spectrum meter(DX-100). We calculated activity coefficients for carbonate and bicarbonate following Butler(Butler, 1991).

1.3 Calculation of CO_2 flux

The rate of exchange of a gas between surface waters and the atmosphere depends on two main factors: the concentration gradient between the water and the air, and the gas exchange coefficient for a given gas at a given temperature, k(Wanninkhof, 1992). Then, k and the concentration gradient govern the flux(in mmol/($m^2 \cdot d$)) of CO_2 across the air-water interface as follows:

$$\text{Flux} = \mu k([CO_2]_{water} - [CO_2]_{air}). \qquad (1)$$

Where k(m/s) is the gas exchange coefficient for CO_2 at a given temperature and ionic strength. The term $[CO_2]_{water} - [CO_2]_{air}$ is the concentration difference (mmol/m^3) between the water and the air. The $[CO_2]_{water}$ equals to $pCO_2 \cdot K_H$. K_H is Henry's constant. There have been many experimental determinations of k in a variety of freshwater and marine systems. For the calculation of gas fluxes, we assumed a constant k_{600}, computed the Schmidt number for CO_2 at each temperature, and calculated k for CO_2 at each temperature(k is a piston velocity for a given gas at a given temperature; k_{600} is k for a gas with a Schmidt number of 600, e. g., CO_2 at 20℃). From K_{600} and temperature one can calculate k for any other Schmidt number and we made this temperature correction(MacIntyre, 1995).

The exchange coefficient, k, can be defined as a function of wind speed and temperature with a number of different parameterizations(Liss, 1986; Tans, 1990; Wanninkhof, 1992). Liss and Merlivat (Liss, 1986) suggested the following relationship for k as a function of wind speed.

$$K = 0.17U_{10}(600/Sc)^{2/3};$$
$$U_{10} < 3.6\text{ m/s: smooth water regime}, \qquad (2)$$
$$K = (2.85U_{10} - 9.65)(600/Sc)^{1/2};$$

$$U_{10} > 3.6 \text{ m/s: rough water regime.} \quad (3)$$

Where *Sc* is the Schmidt number, and U_{10} is the wind speed at 10 m above water surface(m/s). Wind speed data collected every 10 min were averaged to give a mean daily value for k, which combined with individual monthly pCO_2 data in the water and air, gave a monthly estimation of the flux. Reproducibilities of pH and Alk measured are 0.01 pH unit and 4 μeq/L. The resulting error on pCO_2 depends also on the water buffering capacity and thus on pH, alkalinity, and ionic strength. In our experimental conditions, this error ranging from 46—75 μatm.

The time of day that samples were taken different randomly. Time of day was not important in studies of diel variability at site 2 on 26 May and 12 Aug. in 1998. On the 2 dates that diel samples were taken(3 samples over the 24h period), the coefficient of variation(*C. V.*) ranged from 3% to 27%, and there was no pattern as to when the highest or the lowest values occurred.

2 Results

2.1 Trophic status and water quality from the monthly monitoring program

On the basis of the eutrophication classification developed by M. Aizaki(Aizaki, 1987), we evaluated relative C, N, P, and Chla data in 1998(Table 1). Of which there are very large differences among Wulihu Lake, Meiliang Bay, and the open lake, which fall into hypertrophic, eutrophic, and mesotrophic classific levels, respectively. Affected by the entering river, the riverine estuary appeared higher concentration in C, N, and P, but lower in Chla. According to pH values of Lake Taihu are all above neuter(pH 7.0), ranging pH 7.5—9.0. Wulihu Lake and the riverine estuary are higher in alkalinity than Meiliang Bay and the open lake although they have lower pH values. An obvious gradient differences between in concentrations of main nutrients, e.g. efficient phosphate, nitrite, and total organic carbon. Of which phosphorus is at present the limiting nutrient of algal growth in Taihu Lake. The polluted situations of Lake Wulihu and the riverine estuary of Zhihugang River are relative to a large of sewage and wastewater discharge from plants, farmlands, and towns and outskirts of Wuxi City. There is a rain reason (June—September) in the Taihu region almost every year, resulting in high nutrient concentrations and low oxygen contents, even approximate zero concentration at site 0 on 20 August, when the oxygen contents of Meiliang Bay and the open lake, however, are 9.59 and 7.94 mg/L, respectively. Since the water is slight basic, mean pH is near to 8.5, carbonate was very little, as a result that Alk and DIC concentrations were very similar. The higher concentrations of DIC mainly appeared in Wulihu Lake and the riverine estuary, attaining a maximum of 3.52 meq/L. There were easy to be influenced by the rivers.

Table 1 Monthly mean values for chemistry and biology data of the different areas in Taihu Lake(1998)

	Wulihu Lake	Meiliang Bay	Open lake	Riverine estuary
pH	7.90 ± 0.23	8.46 ± 0.51	8.26 ± 0.32	7.84 ± 0.29
Alk, meq/L	2.29 ± 0.58	1.61 ± 0.25	1.23 ± 0.23	1.98 ± 0.27
DO, mg/L	6.22 ± 3.71	9.22 ± 1.50	9.21 ± 1.53	6.38 ± 3.83
DIC, meq/L	2.38 ± 0.60	1.59 ± 0.33	1.30 ± 0.22	2.06 ± 0.28
NH_4^+-N, mg/L	3.0 ± 2.1	0.42 ± 0.69	0.092 ± 0.068	1.82 ± 1.42
PO_4^{3-}-P, mg/L	0.041 ± 0.029	0.011 ± 0.012	0.004 ± 0.002	0.057 ± 0.050
Chla, μg/L	40.0 ± 33.6	25.7 ± 27.3	7.8 ± 4.9	19.5 ± 10.2

2.2 Meteorology

During 1998 a relative normal weather contained light radiation, water temperature, and winds except the rainfall. The highest temperature and max radiation are all during about mid July and mid August, respectively. The range of the temperature is 3.6℃ (19 January) to 35.1℃ (12 August). The total mean temperature and standard deviation is 19.2 ± 8.8℃, which is suitable for phytoplankton to grow. The wind regime in different periods was very different. The daily mean wind speed(DMWS) in 1998 is 3.7 m. But the maximum DMWS was 8.7 m/s. During the summer and the autumn, the dominant wind was southeast to southwest and often blew a wind of daily mean less than 4 m/s; and during the winter and spring, the dominant wind was north-westerly reaching instantaneous velocities higher than 13 m/s (but the mean wind speed is about 4 to 4.5 m/s). When the wind speed excesses about 3.6 m/s, it would break surface layer of waters (Liss, 1986). Since Taihu Lake is a very shallow, but large in area, the spoondrift can be observed so long as the wind speed is more than about 4.5 m/s. The grown algae tend to gather to the lee when the wind speed is less than 4 m/s (Fan, 1998).

2.3 CO_2 partial pressure (pCO_2)

Park *et al.* (Park, 1969) reported that it have a precision of ± 5% to calculate CO_2 pressure in freshwater by measurements of pH, total CO_2, and temperature. The major feature of the annual cycles of pCO_2 (Fig. 2) is the rapid changing saturation levels between the different seasons. Most CO_2 partial pressures in the waters are higher than those in the air except Meiliang Bay and the open lake during the summer. The maximum pCO_2 value was 4053 μatm, which was as 11.3 times as the atmospheric CO_2 pressure in 1998 (~365 μatm; Houghton, 2001). The minimum value was only 3.4 μatm at site 5 on 20 August, giving a −356.6 μatm algebraic value with pCO_2 in air.

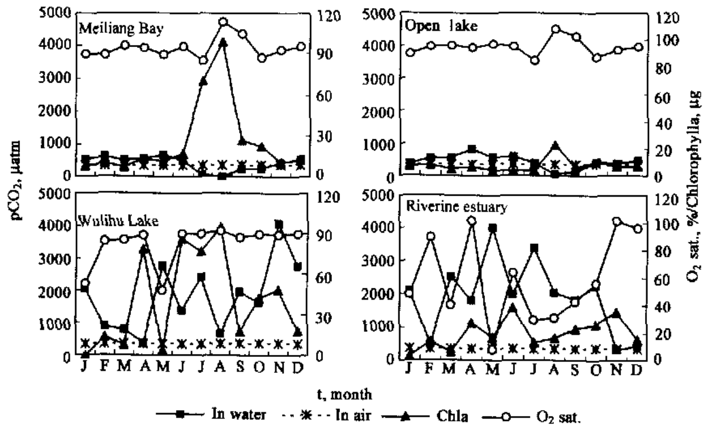

Fig. 2 Monthly variation of CO_2 partial pressures in different trophic lake areas. The dash line presents the CO_2 partial pressures change in air according to Houghton, 2001, corrected by atmospheric pressure in 1998

The four areas can be divided into two groups, high pCO_2 group for Wulihu Lake and the riverine estuary, and low pCO_2 for Meiliang Bay and the open lake. Although the former pCO_2 concentrations in February were as low as the latter, the annual mean pCO_2 of the high group are much higher than the low group (Table 2). Generally, the low group appeared higher pCO_2 values during the spring and lower values during summer. Their changes in pCO_2 principally have an inverse relationship with chlorophyll-a (Chla). This indicates the trophic production is very important factor in the carbon budget in the local waters. A calculation expressed that there was an agreeable exponential relationship between the

Table 2 Summary and average of air-water annual chlorophyll-a (μg/L), pCO_2, and CO_2 flux (mmol/(m^2·d)) in different lake areas during 1998 (mean ± 1*SD*, *n* = 12).

	Wulihu Lake	Meiliang Bay	Open lake	Riverine estuary
Chlorophyll-a	40.6 ± 33.6	25.7 ± 27.3	7.8 ± 4.9	19.5 ± 10.2
pCO_2	1807.8 ± 1025.8	416.3 ± 207.8	448.5 ± 194.0	1933.6 ± 1067.2
CO_2 flux	27.3 ± 17.4	1.99 ± 4.50	2.22 ± 4.31	34.0 ± 26.0
Minimum	0.50	−6.05	−5.16	−0.33
Maximum	48.8	9.06	9.30	80.6

pCO_2(μatm) values and Chla(μg/L) concentrations(Fig.3).

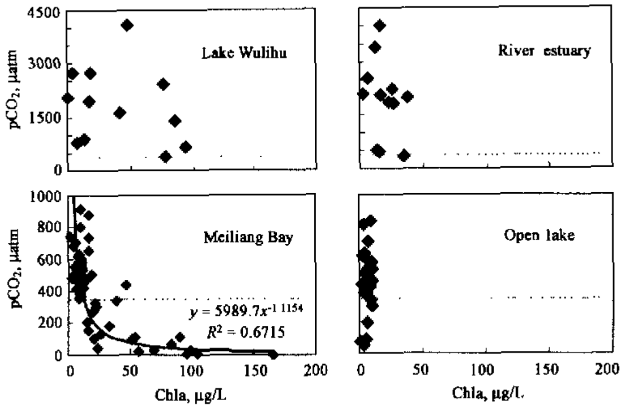

Fig.3 CO_2 partial pressures in different trophic areas of Taihu Lake as a function of chlorophyll-a concentration. The dash line presents the CO_2 partial pressures change in air

The high group, however, showed very different change except for being high pCO_2 values from May to October. The reason is that the both waters had different mechanisms producing pCO_2 values. Wulihu Lake was a high eutrophic lake, which had the highest annual mean chlorophyll-a concentration(40.6 ± 33.6 μg/L). In summer, although much CO_2 were required to assimilate in the phytoplankton photosynthetic production, its carbon quantity was sufficiently supplied with the incoming water from the Liangxihe River(Yuan, 1993). A higher alkalinity of 2.29 ± 0.58 meq/L and somewhat lower pH (7.90 ± 0.23) value there, at the same time, gave a good condition that produced more dissolved CO_2 in water by means of the carbonate components equilibrium system. But in the winter and spring, the water level in Yangtze River was low, the water is almost outlet to the north from Wulihu Lake, so almost water came from Meiliang Bay, resulting in the equal alkalinity to the latter. However, the photosynthesis had got vital in its algal body since February. So pCO_2 is in low level, even the lowest than any waters in Taihu Lake. Obviously the inflow of polluted water from the urban has more influence to Wulihu Lake than eutrophication during lower water-level periods.

The riverine estuary is in Meiliang Bay, but its water chemistry characteristics were largely impacted by the Zhihugang River discharge(Yuan, 1993). The pCO_2 value attained to 1933.6 ± 1067.2 μatm, being as about 4.6 times as that of Meiliang Bay. The main factor that influencing carbonate concentrations in the waters is large different from the bay.

2.4 CO_2 flux

Bates(Bates, 2001) revealed that using higher frequency wind speed data to estimate air-water CO_2 flux appears more accurate than high frequency $pCO_{2(water)}$-$pCO_{2(air)}$ data. The low frequent wind speed data are usually underestimated ~20% to >600%. We used daily mean wind speed data though we only have monthly pCO_2 data. Atmospheric partial pressure of CO_2 was 365 μatm in 1998 according to Houghton and Ding(Houghton, 2001). The air-water fluxes of CO_2 over the four water bodies, calculated based on Eq. (1) and corrected based on Eq. (2) and (3) using daily wind speed, are presented in Table 2 and Fig. 4. Apparently, more than a magnitude order difference was found in the CO_2 flux between the high group and the low group mentioned before. The maximum and minimum flux is 80.6 mmol/($m^2 \cdot d$)(the riverine estuary in January) and -6.05 mmol/($m^2 \cdot d$)(Meiliang Bay in August). Of which the annual mean CO_2 flux in the riverine estuary (34.0 ± 26.0 mmol/($m^2 \cdot d$)) (mean ± standard deviation) is as 16.2 times as that in Meiliang Bay (1.99 ± 4.50 mmol/($m^2 \cdot d$)) though the both are in the same bay. But during the summer, it appeared two great sinks of carbon in Meiliang Bay and the open lake. The former is -1.45 to -6.05 mmol/($m^2 \cdot d$) in July through October and the latter is -5.16 and -4.74 mmol/($m^2 \cdot d$) in August and September, respectively.

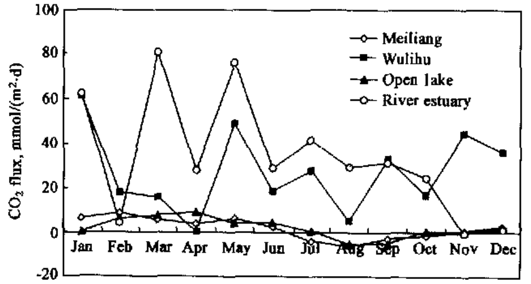

Fig.4 Monthly variation of atmospheric fluxes of CO_2 in different trophic lake areas in 1998

All DIC are very near to their alkalinity values because the carbonate concentrations were very low in the long-term environment of higher pH values. DIC values calculated from alkalinities, pH is combined for fluxes of CO_2 in Fig. 5. A striking feature found is good relationship between DIC values and the fluxes ($r = 0.772 > 0.360$, $n = 48$). In the low DIC (about 0.9—2.1 meq/L), the fluxes have great occurrence of negative values (evasion). No negative values were found about more than 2.3 meq/L of DIC, when we can obtain, given in mean 8.3 of pH, 0.0282 meq/L of CO_2 concentration in water. It may be enough, i. e, for the photosynthesis of Taihu Lake to keep more than 0.0282 meq/L of CO_2 concentration.

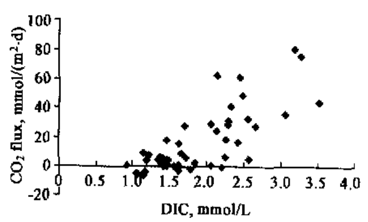

Fig.5 Distribution of atmospheric fluxes of CO_2 vs. dissolved inorganic carbon in the Taihu Lake in 1998

3 Discussion

3.1 pCO_2 difference in different trophic lake areas

We found very large differences between CO_2 partial pressure and chlorophyll-a in the four areas of Taihu Lake. In the eutrophic Meiliang Bay, during July to September, bloom development continued with strong decrease of surface water pCO_2, most of which were under 360 μatm (Fig. 3) and indicating undersaturation of carbon dioxide. Algal bloom with chlorophyll-a maximum of 166.3 μg/L corresponded to pCO_2 as low as 3.2 μatm. An annual basis, a good correlation was found between pCO_2 and Chla in Meliang Bay ($r = 0.6715$, $n = 60$, $P = 0.01$). When the chlorophyll-a concentrations are above 50 μg/L, which is correspond to the biomass of phytoplankton of 8.8 ± 3.2 mg/L in Taihu Lake according to Fan *et al.* (Fan, 1998), it is obvious that algal enhancement was in deep undersaturation circumstance, which would resulting in heterotrophic growth.

In the hypertrophic Wulihu Lake, although there is a quicker growth during the summer, but no obvious decrease in pCO_2 and all pCO_2 values are above the atmospheric CO_2 contents through the year (Fig. 2; Fig.3), expressing supersaturation of dissolved CO_2 in water. Here pH values could remain low, while inorganic carbon supplied quite sufficiency by means of the input of the river. In spite of some marked algal bloom during the summer, the algae grew in the autotrophic environment. Very similar result appeared in the riverine estuary (Fig. 2; Fig. 3). Its behavior of carbonate system is very near to hypertrophic Wulihu Lake although it locates in eutrophic Meiliang Bay. In the open lake, typical mesotrophic area, chlorophyll-a concentrations were very low and almost unchangeable responded to pCO_2 from 54.3 to 845 μatm. But a brief interval of undersaturation (August-September 1998) observed for the area may have been caused by a slight phytoplankton bloom. These changes were caused by locally different intensities of photosynthetic uptake of CO_2 and supply situation

Algae require an abundant and readily available source of carbon for high-sustained growth. The supply of carbon is regulated by availability. Abundant physiological evidence indicates that free CO_2 is most readily utilized by nearly all algae. When free CO_2 is in very low supply and HCO_3^- is abundant; a few species of algae require HCO_3^- (Felföldy, 1960). In Meiliang Bay, a bloom-form algal growth required a great rate of CO_2 supply. The uptake rate is too fast for carbonate system equilibrium to provide enough available carbon. In this situation some algae would have to utilize carbon from abundant HCO_3^-. An obviously decrease of HCO_3^- in Meiliang Bay around August responded to the increase of the chlorophyll-a concentrations.

3.2 CO_2 flux difference in different trophic lake areas

Inorganic carbon, largely as dissolved carbon dioxide and bicarbonate, is primary source of carbon for photosynthesis and the generation of organic substances. These organic compounds are generated by cynobacteria, algae, and macrophyte both within the lakes or rivers externally within the drainage basin and variously imported to the water bodies. There were 62254 t/a and 81700 t/a of total organic carbon (TOC) entering the lake from its rivers during 1987—1988 and 1994—1995, respectively (Huang, 2001). Zhihugang River and Liangxihe River are the most important incoming rivers in the north of Taihu Lake. Of which Zhihugang was about 52% occurrence to discharge its polluted water into the lake (Yuan, 1993). So the loadings of Liangxihe River plus Zhihugang River accounted for 24% —29% of the total loadings (Yuan, 1993). Although much of the organic carbon is resistant to biological mineralization (Tranvik, 1988), it can largely decrease through various processes including settling of suspended organic matter, photodegradation, diffusion and so on. Actually, a sharp downtrend was found from the riverine estuary to main lake body. As two main sources of carbon, Liangxihe River and Zhihugang River add water with high contents of inorganic and organic to the littoral zone. Part of the imported organic carbon is mineralized, increasing DIC and pCO_2. On the other hand, river water introduces high concentrations of nutrients, which stimulate algal blooms and photosynthetic uptake of CO_2 (Bakker, 1996).

The air-water flux of CO_2 is insufficient to achieve equilibrium of CO_2 in the littoral waters relative to the atmosphere. In the shallow Taihu Lake, effects on pCO_2 in surface water of biological production, mineralization, seasonal temperature changes, mixing in of river water, possible calcification and dissolution of calcareous material, and disturbation wind-induced obviously exceed the stabilizing effect of air-water exchange.

4 Conclusions

The greater differences of CO_2 partial pressures can exist between different trophic or polluted areas in a lake. The pCO_2 values of the hypertrophic area would be as twice as those of eutrophic and mesotrophic waters during May to December. The riverine estuary, lies in the eutrophic, have a similar behavior to the hypertrophic in water chemistry of carbonate system and water-air exchange of CO_2. In the eutrophic area, there was no linear relation between the chlorophyll-a concentration and pCO_2, even during a typical algal bloom occurred. But a good exponential relationship was found between pCO_2 and chlorophyll-a. Undersaturated CO_2 values were ascribed to uptake of CO_2 by algal blooms in the eutrophic areas. In addition, one order of magnitude difference could be produced among the different lake areas in respect to fluxes of CO_2. These results support the concept that, concerning CO_2 equilibrium, lake ecosystems may be considered as unique aggregation, which can contain similar and different components so long as its size enough to large. Though it has positive fluxes of CO_2 from the surface to atmosphere during the most of time, Lake Taihu, participating in external drainage via rivers, is a huge and permanent sink of carbon. Of which its external river contributions to pCO_2 enhancement may be very important for estimating the distribution and quantities of carbonate compositions. Extensive study of the inorganic and organic carbon flows over all seasons from rivers, sediments, and aquatic organisms, would be necessary to quantify the carbon fluxes from different lake areas and may yield a better understanding of the mechanisms behind it.

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