Evaluating the Metabolic Characteristics of Lake Water with Continuously Measured pH and DO

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A method for the macro-evaluation of the metabolic characteristics of lake water using continuously measured pH and DO data was examined. The value obtained by subtracting the air-water gas exchange from the observed changes in DO (dissolved oxygen) and DIC (dissolved inorganic carbon) is considered to result from biological activity. The change due to biological activity at night is assumed to be due to respiration. Subtracting the value for respiration from the daytime change due to biological activity gives a range in DO from 1.1 to 30.5 mM h^{-1} and a range in DIC from -14.4 to -0.5 mM h^{-1}. These values reflect the productivity of the water and the different concentrations of organic substances.

KEYWORDS: continuously measured data, free water method, metabolic characteristics

Introduction

Information on primary production and respiration are very important for evaluating the carbon cycle and trophic levels of lake water. Such biochemical characteristics are often studied in bottle experiments, but the effects of the bottle wall and measurement interval are unsolved problems (Welch, 1968). A method for estimating photosynthesis and respiration by continuously monitoring the pH and DO (dissolved oxygen) in water using sensors has been proposed. This method is called the Free Water Method (Weisburd and Laws, 1990). This method has the advantage that measures can be made over short time intervals to evaluate the biological activity of an entire body of water. In a series of studies carried out in an outdoor experimental pond (Fukushima et al., 1995a, 1995b), a variety of information on the carbon cycle and metabolic characteristics of the experimental pond was obtained from continuously monitoring the pH and DO. This paper examines the use of pH and DO measurements made at one-hour intervals to continuously monitor water quality at the center of Lake Kasumigaura. The changes in DO and DIC (dissolved inorganic carbon) due to primary production and respiration were evaluated, and the relationships between indices such as respiration and primary production and the metabolic characteristics of the water were examined.

Monitoring Data

The data used for this analysis include water temperature, wind velocity, pH, and DO measured automatically every hour around the clock at the center of Lake Kasumigaura. The Kasumigaura Management Office of the Ministry of Construction compiled the data. Surface layer water was sampled with a suction pump at the automatic monitoring station and the water quality was measured with various sensors. Monthly alkalinity, chlorophyll-a, and COD concentration data listed in the Water Quality Chronological Table were also considered in the analysis. The data used in this paper were collected between January 1 and December 31, 1992.

We used the same methods as Fukushima et al. (1995a) to calculate DIC from pH, alkalinity, and water temperature. Since the variation in alkalinity is believed to be small except when the weather changes sharply, the alkalinity values obtained by interpolating the monthly measurements listed in the Water Quality Chronological Table were used to calculate the DIC values.

Figure 1 shows the variation in the daily DO and DIC (average of 24 hourly measurements) over the year. There is often an inverse relationship between DO and DIC and decrement in DO. Throughout

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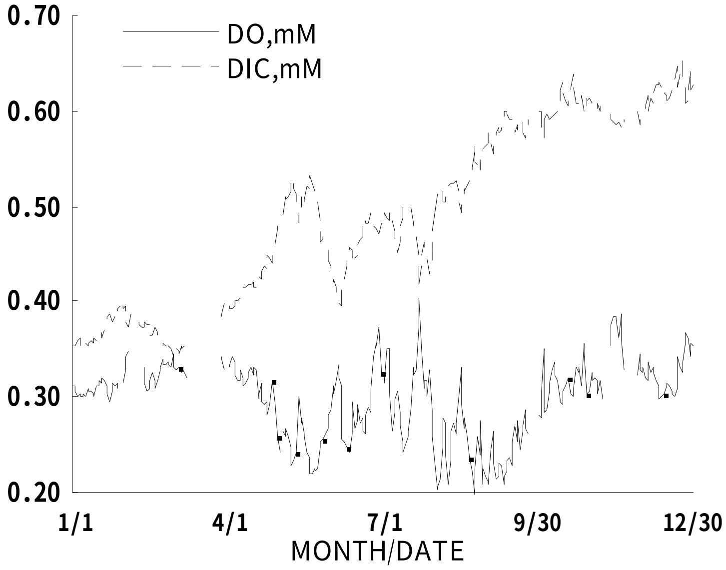

Figure 1 Daily variations in DO and DIC concentrations (means in 24 hours) at the center of Lake Kasumigaura

the year, the hourly data showed that the DO was high in the day and low at night, while the DIC behaved in the opposite fashion.

Air-water exchange flux of DO and DIC

The air-water gas exchange flux is obtained by multiplying the air-water gas exchange coefficient by the difference between the concentration in water and the equilibrium air concentration (saturated concentration in water). A method has been proposed for estimating the air-water gas exchange coefficient using an empirical equation and the wind velocity (Banks and Herrera, 1977; Hartman and Hammond, 1985; Wanninkhof et al., 1991). However, it has been pointed out that the exchange velocity cannot be determined using only physical mixing in the case of chemical species such as carbonate that dissociate in water (Smith, 1985). In this paper, we use an equation derived from the results of applying the box method using open and closed boxes in the outdoor experimental pond (Fukushima et al., 1995a) to estimate the hourly air-water gas exchange coefficient, and calculate the air-water gas exchange flux of DO and DIC.

Table 1 shows the maximum, minimum, and average (using the absolute values) hourly observed changes in DO and DIC (mM h^{-1}) and the calculated air-water gas exchange fluxes of DO and DIC (mM h^{-1}, a flux from air to water is positive). The averages of the absolute values of the air-water gas exchange are 20% (DO) and 21% (DIC) of the average of the absolute values of the observed change. The air-water gas exchange coefficient used for calculating the exchange is proportional to the wind velocity to the power of 1.5. Therefore, the air-water gas exchange varies with the measured wind velocity. The in- and outflow of water due to the transfer of water mass should be taken into consideration when the wind velocity is high. Except for values measured when the wind

Table 1 Statistical characteristics of the rates of change of DO and DIC at the center of Lake Kasumigaura

Variable	Number of Sample	Minimum	Maximum	Average of absolute value
DO, mM/h	7157	-0.1250	0.0844	0.0046
DOge, mM/h	7030	-0.0069	0.0304	0.0009
DIC, mM/h	7461	-0.2641	0.2642	0.0024
DICge, mM/h	7261	-0.0141	0.0023	0.0005

ge: gas exchange

velocity was higher than 1.5 m s^{-1}, the air-water gas exchanges are 10% (DO) and 14% (DIC) of the observed change.

Biological changes in DO and DIC due to respiration at night

The water in the center of Lake Kasumigaura is relatively shallow, about 4 m deep. With fast mixing, the value obtained by subtracting the air-water gas exchange from observed changes in DO and DIC measured every hour is considered to be the change due to biological activity, assuming that the changes due to in- and outflow are relatively small, except when climatic conditions are unusual.

On most days, DO increases during the daytime with photosynthesis and decreases after sunset because of respiration, while DIC behaves in the opposite manner. The total respiration over 24 hours is assumed to equal three times the change due to biological activity during the period from 8 o'clock in the evening until 4 o'clock the following morning. The value is obtained by subtracting the air-water gas exchange during each hour from the observed hourly change. Although the DO usually decreased and the DIC increased, the DO and DIC behaved in the opposite way on 2 and 11% of the monitoring days, respectively. Excluding the days with a reversed pattern, the average respiration rate for DO and DIC were -73.5± 68.8 mM d^{-1} (mean ± S.D.) and +39.4 ± 42.2 mM d^{-1}, respectively.

Change in DO and DIC due to primary production

The respiration rate at night and during the day was assumed to be nearly equal. The change due to biological activity from 8:00 pm until 4:00 am the following morning, was assumed to represent 8 hours of respiration. To calculate the primary production during the 8 hours of daytime, this value was subtracted from the daytime biological activity (from 8:00 am until 4:00 pm each day). For the days in which the nighttime respiration data was normal, the hourly variation in the DO was 1.1 to 30.5 ± 5.8 mM h^{-1} (average 8.8, normal on 186 days) and for DIC it was -14.4 to -0.5 ± 2.9 mM h^{-1} (average -4.5, normal on 191 days). The data when the nighttime respiration data was abnormal (DO positive or DIC negative) were ignored in this calculation.

The estimated rates of change in DO and DIC due to primary production were averaged for every month, and compared with the monthly chlorophyll-a values (average of values measured at four reference sites). The result is shown in Figure 2. The correlation between the chlorophyll-a value and the rates of change of DO and DIC due to daytime primary production was significant, and the correlation coefficients are 0.47 for DO and -0.74 for DIC. A similar tendency was also found for

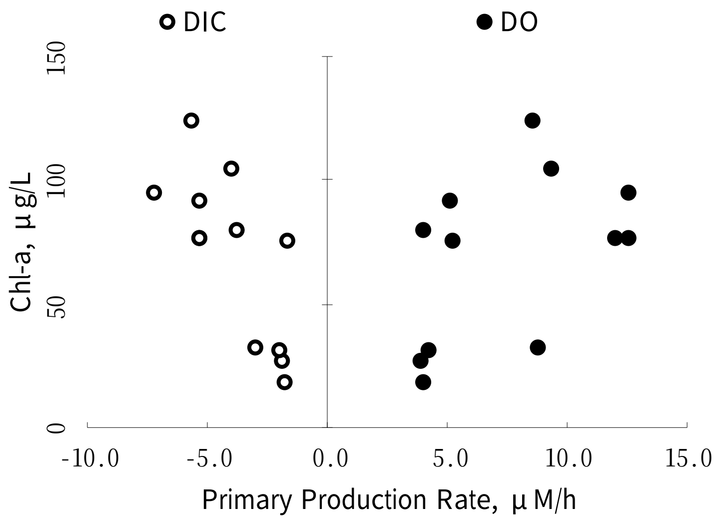

Figure 2 Primary production rate versus chlorophyll-a concentration in Lake Kasumigaura

COD, with correlation coefficients of 0.58 for DO and -0.80 for DIC. Although there are still some problems with the adequacy of chlorophyll-a and COD as water quality indices, the concentration of organic substances related to primary production in water can be evaluated from continuous monitoring data.

Conclusion

A method for macro-monitoring the carbon cycle in lakes using pH and DO data obtained by continuous monitoring was evaluated. The following conclusions were drawn:

1) The difference between the air-water gas exchange and the observed changes in DO and DIC is thought to be due to biological activity. The effect of wind velocity is reflected in the ratio of air-water gas exchange to the observed change.

2) On many days DO increases continuously during the daytime due to photosynthesis and decreases continuously after sunset due to respiration, while DIC behaves in the opposite manner. The difference in the level of production in the water and the concentration of organic substances can be accurately estimated from the change in DO and DIC due to biological activity.

3) The daytime change due to primary production is estimated by subtracting the nighttime respiration from the daytime change due to biological activity. There is a relationship between the change in DO due to primary production and COD and chlorophyll-a. This suggests that the concentration of organic substances in water associated with primary production can be estimated from continuous monitoring data.

This paper presents a method for the macro-evaluation of the carbon cycle and metabolic characteristics of an actual lake based on changes in DO and DIC calculated from continuous monitoring data. To refine this method, phenomena such as primary production must be studied in more detail while considering the effects of climate and the condition of the sensors.

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