Carbon Dioxide Exchange between Pond Water and the Atmosphere

Work Plan 7, Thailand Study 8

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Introduction

Rates of exchange of dissolved oxygen and carbon dioxide between pond waters and the atmosphere are often significant components of ponds' budgets for these materials. Because these gases are produced and taken up by pond microbes and cultured animals in respiration and photosynthesis, accurate estimates of these processes must take account of atmospheric exchange. Bottle-incubation methods typically neglected these processes because separate estimates of concentrations in the free pond water would be required and were not made. Free-water assessment of photosynthesis and respiration is based on sequential assessment of pond concentrations through time; exchange is estimated from these data, using in addition wind speeds and temperature-dependent saturation values for the gases (Banks and Herrera 1977, Weisburd and Laws 1990, Boyd and Teichert-Coddington 1992).

Oxygen exchange is routinely estimated in free water studies (Hall and Moll 1975, Green et al. 1989, Szyper et al. 1992), but far less attention has been given to carbon dioxide. If automated methods could progress to the point of short-interval estimates of daytime respiration as well as net concentration changes, for both oxygen and carbon, estimates of gross primary production and total diel community respiration could be made in terms of both elements. It would then be possible to calculate at least the photosynthetic quotient (moles oxygen evolved:moles carbon taken up) for pond phytoplankton communities, which in turn would facilitate study of carbon budgets and other pond processes.

The reported estimates of carbon dioxide exchange rates have been made under conditions of less severe density stratification and lower rates of primary production than is typical of CRSP experiments or of fed production ponds. There are indications that carbon dioxide exchange rates are too large to neglect, though they are somewhat smaller compared with photosynthesis and respiration than those observed for oxygen (Szyper and Ebeling 1993). Good estimates of these rates in typical CRSP ponds would provide baseline data and an opportunity for refinement of estimation methods, both pertinent to the Thailand project's approach to enhanced understanding of carbon cycles.

The objectives of this work were to quantify the rates of exchange of carbon dioxide between pond water and the atmosphere in fertile earthen ponds, and to elucidate major factors which determine these rates.

Materials and Methods

This study could not be completed at the site which was originally projected (AIT) because the monitoring system could not be made to perform all functions required during the project period, and the wind speed records from the AIT weather station could not be rationalized to the required time intervals. The objectives were attained, however, by analysis of data from the University of Hawaii pond research facility in the U.S. These are the PI's original data and have not been presented elsewhere. Summary totals for some of the quantities were presented and discussed in Szyper and Ebeling (1993), where the monitoring system is also described in detail. The system records temperature and pH in water samples pumped from the pond to a receiver of plastic pipe on the bank, which contains a thermocouple and pH electrode. Total carbon dioxide, which includes aqueous (dissolved molecular, or "free") carbon dioxide, carbonic acid, bicarbonate ion, and carbonate ion, is calculated from pH, temperature, and total alkalinity (the latter analyzed manually). Primary production and

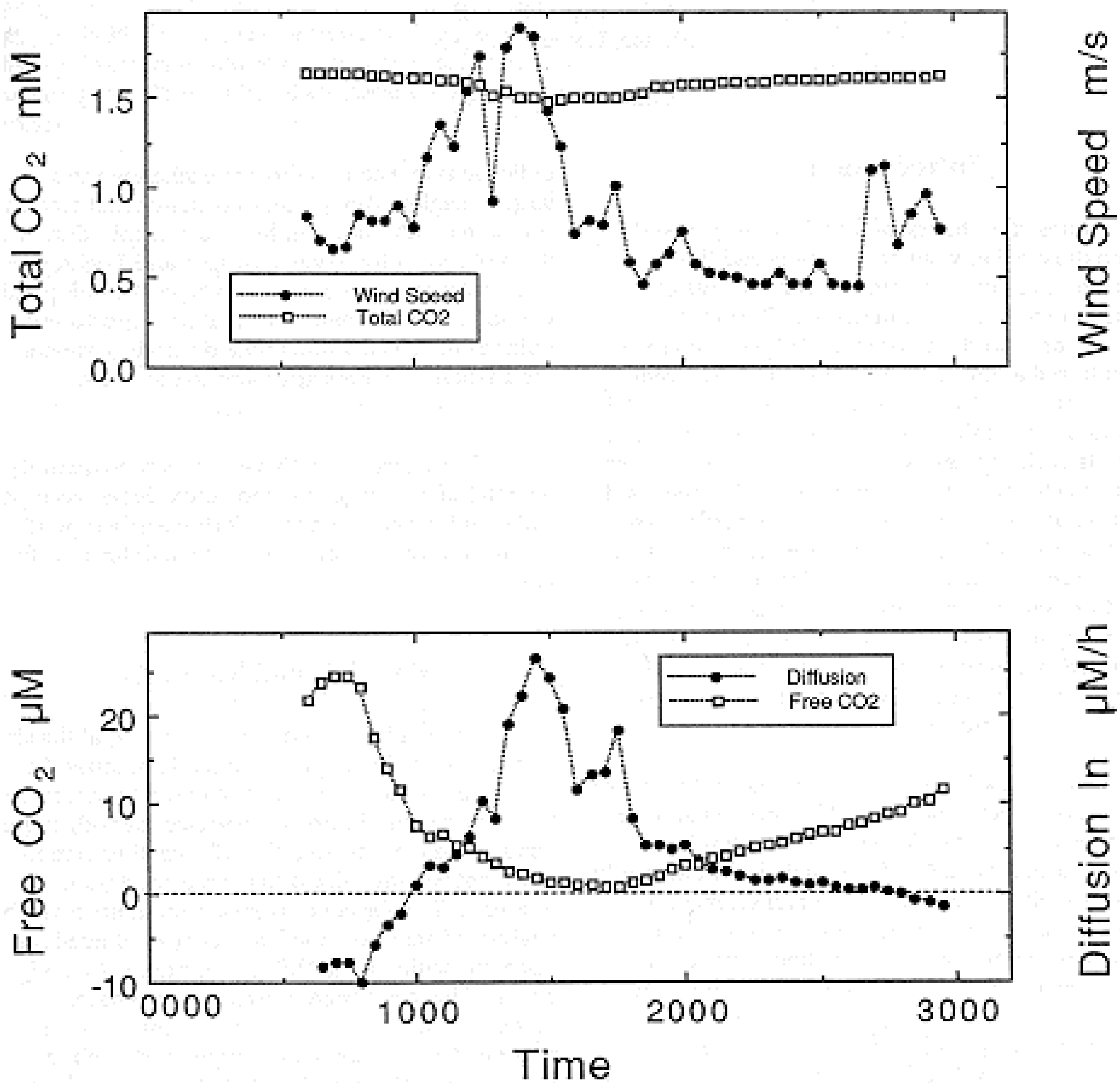

Figure 1. Typical sunny day, heavy-bloom condition diel cycles of Total CO_2, Free CO_2, and rates of CO_2 diffusion into or out of the atmosphere, observed (along with wind speed) in a fertile brackish water earthen culture pond.

community respiration are calculated by the free water method from changes in total carbon dioxide. Atmospheric exchange is calculated from wind speed, the aqueous carbon dioxide concentration (derived from the system equilibrium), and temperature-dependent saturation values (Weisburd and Laws 1990).

Results and Discussion

Figure 1 shows typical diel cycles in a brackish water earthen pond of 2000 m^2 area, 0.7 m depth, salinity of about 15 ppt, with a bloom of small coccoid cyanobacteria at chlorophyll a concentration of about 400 mg per liter. As expected, particularly in a brackish pond, total CO_2 concentrations varied little during the day, but did show a perceptible dip during midday reflecting photosynthetic uptake. Wind speeds at 0.5 m above water surface ranged from about 0.6 to 1.8 m / s, with the windiest periods concentrated into daylight hours, in this case beginning at 1000 hours. The "Free CO_2" fraction of total CO_2, amounting to about 1% of the total, (note the different vertical scales) varied in parallel with total CO_2, but accounted for only about 25% of the diel variation in total CO_2. Although only free CO_2, of all the total CO_2 components, can diffuse as a gas, the system responds to addition or removal of free CO_2 by conversion of the other forms to restore equilibrium.

Diffusion of CO_2 into or out of the water (here indexed with the rate of diffusion *into* the water taken as positive) is expected to depend primarily on wind speed and concentration of free CO_2, but will be affected by temperature and other factors. Before 1000 hours, free CO_2 was diffusing out of the water, with the diffusion rate accounting for much of the decline in concentration, but photosynthetic uptake may have contributed to the decline. After 1000 hours and until late afternoon, CO_2 diffused *into* the water due to low concentrations and increased wind speed, but the concentration continued to decline to near zero, now certainly reflecting photosynthetic uptake. The actual CO_2 species taken in by plant cells varies under different conditions and is beyond the scope of this report. "Photosynthetic uptake" here refers to any form of DIC, and it is presumed that rapid equilibrium adjustments in the distribution of CO_2 species occurs. On this date, daytime net primary production (carbon fixation) was 0.89 g C m^2; diffusion into the water column during daylight hours was 0.24 g C m^2, consistent with Szyper and Ebeling's (1993) report that diffusion typically amounted to about 30% of production during the two week study period which included this date. It should be noted, however, that diffusion was relatively much more important on days of low production.

A multiple regression analysis was made without consideration of the temperature cycle, presuming that the primary effect of increased daytime water temperatures would be to cause diffusion *out of* the water, whereas in fact diffusion was predominantly *in* during daytime hours. The analysis showed that the concentration of free CO_2 and wind speed together accounted for 81 % of the variation in the diffusion rates during this diel cycle; each of these factors was significant at a << 0.01. The net rates of change in CO_2 concentration during each 30 minute sampling interval (d DIC / dt) represent net photosynthetic uptake during daylight hours (gross uptake plus release by community respiration), and community respiration at night. This factor contributed no significant effect to diffusion rates and did not add to the percentage of the diel variation in diffusion rates which was explained by the other two factors. Model prediction of diffusion rates thus requires only observed concentrations and wind speed, though the above discussion shows that photosynthetic demand can be the primary determinant of concentrations under some conditions.

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