Tropical Ecology **41**(1): 57-60, 2000 ISSN 0564-3295

Measurement of exchange of CO_2 in mangrove forest of Sundarbans using micrometeorological method

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Abstract: Attempt has been made for the individual measurement of CO_2 fluxes in the Sundarban forest and in the water ways near Jambu Island by using micrometeorological method during 12-13 February 1998. The gas fluxes were measured directly over a short enough time period at variable flux controlling conditions. This environment has been found to be sink for CO_2 during study period. A negative linear correlation was obtained between wind speed and CO_2 flux from atmosphere to the forest (F_{af}). The atmosphere to surface water flux (F_{aw}) was found to be due to undersaturated condition of water with respect to solubility of CO_2. Measured values for the fluxes of CO_2 from the atmosphere to the forest and water areas were found to be at a rate of 24 x 10^9 and 16 x 10^6 kg C year^{-1}, respectively.

Resumen: Se realizó un intento para medir los flujos de CO_2 individuales en el bosque Sundarban y en un flujo de agua cerca de la isla Jambu el 12 y 13 de Febrero de 1998, usando métodos micrometerológicos. El flujo de gases fue medido en un período corto de tiempo a flujo variable controlando las condiciones. Se encontró que este ambiente estuvo disminuido en CO_2 para el período de estudio. Se obtuvo una correlación lineal negativa entre la velocidad del viento y el flujo de CO_2 desde la atmósfera al bosque (F_{af}). La atmósfera de la superficie del flujo de agua (F_{aw}) se encontró en una condición que se supone está no saturada de agua con respecto a la solubilidad del CO_2. Los valores medidos para los flujos de CO_2 desde la atmósfera al bosque y áreas de agua, se encontraron a una tasa de 24 x 10^9 y 16 x 10^6 kg C año^{-1}, respectivamente.

Resumo: No período de 12-13 de Fevereiro de 1998 foi feita uma tentative de medição individual dos fluxos de CO_2 na floresta de Sundarban e nos cursos de água próximos da ilha de Jambu, utilizando um método micrometorológico. Os fluxos de gás foram medidos directamente durante um período suficientemente curto sob condições controladas de fluxo variável. Encontrou-se que este ambiente, durante o período do estudo, excercia um efeito de retenção do CO_2. Obteve-se uma correlação linear negativa entre a velocidade do vento e o fluxo de CO_2 da atmosfera para a floresta (F_{af}). O fluxo da atmosfera para a superfície da água (F_{aw}) era devido às condições de substuração da água em relação à solubilidade do CO_2. Os valores medidos quanto às taxas dos fluxos do CO_2 da atmosfera para a floresta e para a superfície da água situaram-se em 24.10^9 e 16.10^6 kg C. year^{-1}, respectivamente.

Key words : Carbon dioxide flux; mangrove forest, Sundarban.

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Introduction

Our understanding of the global carbon budget based on knowledge of anthropogenic and natural sources and sinks of carbon, and the role of terrestrial biosphere in global CO_2 fluxes is incomplete. Only half of the anthropogenic CO_2 remains in the atmosphere and we do not know with confidence whether the missing half of the emitted CO_2 is being sequestered in the deep oceans, in soils or in plants biomass or what factors are modulating the annual increment of atmospheric CO_2 (Wafsy *et al.* 1993). A growing disequilibrium between society's production of CO_2 and nature's fixation of it by photosynthesis reported by Grantham (1989). Increasing atmospheric CO_2 has effects on the metabolism and structure of terrestrial ecosystems with subsequent associated feed-backs to the climate system (Walker *et al.* 1999). The net primary productivity in the mangrove ecosystems is one of the highest of all types of ecosystem and that they are disappearing tropical and subtropical ecosystem has been recognized by many workers (Hellier 1988). Several lines of evidence suggest that these terrestrial carbon sink is a transient phenomenon, currently close to its maximum value, and will decline or even change sign in future (Schimel 1995). The air-sea exchange of biogenic CO_2 gas is studied in the North-eastern Arabian sea by Sarma *et al.* 1996. Carbon dioxide is estimated to be released to the atmosphere at a rate of 74-79 x 10^{15} kg C $year^{-1}$ from this region.

This requires CO_2 flux measurement in widely varying ecosystems and climates and can lead to an independent global data base which allows to quantify the fractions of anthropogenic CO_2 which are taken up by different ecosystems. The air-sea exchange of CO_2 was first measured using Eddy correlation by Jones & Smith (1977). Comparative study of carbon dioxide system in vargin and reclaimed mangrove waters of Sundarbans during freshet was carried out by Ghosh *et al.* (1987). The characteristic species of diatoms e.g., *Coscinodiscus excentricus, Coscinodiscus radiatus, Rhizosolenia alata, Biddulphia sinensis, Dityllum brightwelli*, and *Pleurosigma elongatum*, in bloom proportion during January-February were observed by De *et al.* (1991).

Objective of this study was to analyse the fluxes of CO_2 in the Sundarban mangrove forest as well as in the water ways of using micrometeorological parameters (viz., wind gradient, temperature gradient and CO_2 concentration gradient) and partial pressure of CO_2 in the sea water. Observations were made during spring bloom of phytoplankton in the water ways.

Methods

Study site

The Indian Sundarbans Mangrove forest located between 21°32 and 22°40 N latitudes and between 88°05' and 89° E longitudes bounded by Dampier-Hodges Line comprises of more than 60% of total Indian Mangroves and is the largest delta on globe in estuarine phase of the river Ganges. So far no study has been taken up to quantify the sequestering of CO_2 in this unique world's heritage site. Total area is 4266.6 km^2 out of which the water area is 1781 km^2. Sand char without any forest is 153 km^2 and actual forest area is about 2333 km^2. This region predominantly affected by river runoff as well as by tidal mixing is one of the productive areas of the Bay of Bengal coast and it can act both as sink and source of biogenic gases. In the lower littoral zone, a patch growth of wild rice population, *Porterasia coarctata* occurs along with the occasional presence of shrub, *Acanthus ilicifolius*. Behind this rice population (towards mid littoral zone) occurrence of *Avicennia marina* and *Avicennia alba* are observed. *Bruguiera gymnorrhiza, Rhizophora mucronata* and *Sonneratia caseolaris* are all dwarf and are mature constituents of this mixed mangrove community. Both *Excoecaria agallocha* and *Avicennia officinalis* are generally found on slightly elevated land than the previously described species. All the herb, shrub and trees, except *Excoecaria agallocha* are contagiously distributed, the latter shows random distribution.

The gradient technique (Baldocechi *et al.* 1988; Macfadyen 1970) has been used to measure turbulent fluxes of CO_2. Atmospheric CO_2 at 1 m and 10 m heights were measured by drawing air (1.7 lm^{-1}) through a scrubber containing 10 ml 1 N NaOH and connected to a portable vacuum pump (APS 2, Lawrence & Mayo) with a flow meter. After 15 m run, 5 ml of 2 N $BaCl_2$ solution was added and the content was titrated with 1 N HCl using phenolphthalein as an indicator. Fluctuations in CO_2 gas concentration were correlated with vertical wind fluctuations. Above a very thin laminar boundary layer (for forest 500 mm; (Hsu 1974C) there exists

Table 1. Rate of CO_2 exchange and some physical parameters of the study site.

	Atmosphere		Water
	10 m	1 m	
Wind speed (ms^{-1})	4.3 3.6	3.6 3.4	
Temperature (^oC)	24.6 1.6	24.3 1.4	23.6 2.2
Drag coefficient (C_D)	0.00025 – 0.0013		
Salinity (ppt)			25.0 1.5
Air to forest flux, F_{af} (g $m^{-2}h^{-1}$)	5.23 – 11.047		
Air to surface water flux, F_{aw} (g $m^{-2}h^{-1}$)			3.76 x 10^{-3}
CO_2 (mg m^{-3})	709 30	609 67	510 (high tide)

a layer several tens of meters thick in which mixing is effected almost entirely by wind turbulance and the flux (F_{af}) in g $m^{-2}h^{-1}$ was calculated by using the relation F_{af} = C/r_D, where C is the difference in concentrations of CO_2 (in mg m^{-3}) at 1 m (C_1) and 10 m (C_{10}) height and 1/r_D (1, 10 m) the conductance of the boundary layer between 1 m and 10 m, is equal to the product of the difference of wind velocity (u_{10} - u_1) and drag coefficient C_D. To measure wind speed, anemometer was used. The flux (F_{aw}) in g m^{-2} h^{-1} between air and water was calculated by using the relation F_{aw} = k P_{CO_2} where, P_{CO_2} is the difference in partial pressure of CO_2 between air and water, k (the gas transfer velocity) is computed according to Wanninkhof (1992) using measured wind speeds. P_{CO_2} in water sample was calculated from carbonate alkalinity measured by Gran titration method (Ghosh & Jana 1994; Wetzel *et al.* 1991).

Flux measurements were made over 2 h interval between 8 AM and 5 PM on a 10 m tower erected with bamboo pole, 50 m from the shore line at Jambu Island, Sundarbans covered with mangrove forest (plant heights 10 m) on 12-13th February, 1998.

Results and discussion

The micrometeorological techniques for measuring CO_2 fluxes was adopted under different field conditions (Table 1). The values of drag coefficient obtained at variable wind speed can be deemed specific for this particular surface and is due to the action of pressure forces on individual surface elements (leaves, stems etc.). Similar variations of drag coefficient was observed by Smith & Benke (1975) with 1.1 x 10^{-3} at 7 ms^{-1} wind speed. Lapse and inversion conditions were observed during morning and afternoon hours, respectively. Data were taken for flux calculation when neutral conditions was observed. The stability of the surface layer of the atmosphere at any height from the ground is described by flux Richardson number, R_f which is identically equal to zero in neutral conditions. A negative correlation was observed between wind speed and CO_2 flux from atmosphere to the forest ecosystem (Fig. 1). Following regression equations were obtained for wind speed at 10 m and 1 m (u_{10} and u_1) heights.

F_{af} = 11.047 - 0.528 u_{10} (r = -0.99, P <0.01).

F_{af} = 10.766 - 0.5508 u_1 (r = -0.99, P <0.01).

The inward CO_2 fluxes were also observed from atmosphere to the surface water during high tide, which was found to be undersaturated with

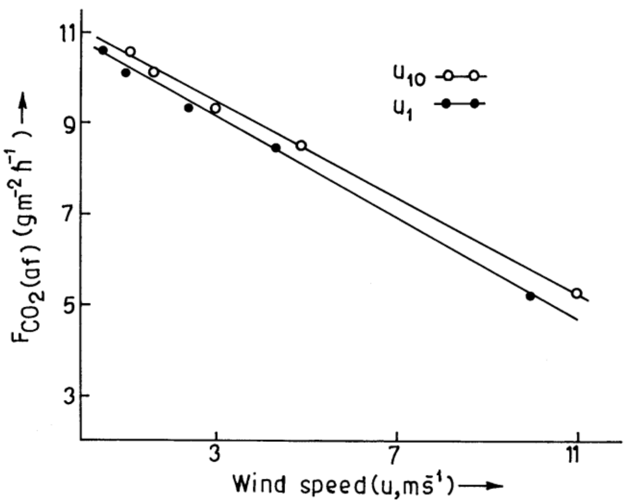

Fig. 1. Variations of flux of carbon dioxide from atmosphere to the mangrove forest with wind speed at 10 m and 1 m height.

respect to the solubility of CO_2. Atmosphere to forest flux was found many times higher than that of atmosphere to surface tidal water. Annual flux of CO_2 from the atmosphere to forest and atmosphere to water were obtained from the product of respective flux rate and total area. CO_2 is estimated to be exchanged from the atmosphere by the forest and aquatic ecosystem of the Sundarban mangrove at a rate of 24 x 10^9 and 16 x 10^6 kg C year^{-1}, respectively. Forest area covered by mangrove comprises 55% of the total area of the Sundarban and higher rate of production in the forest than that of water area could be the cause of much higher CO_2 flux rate to the forest than that of water (Odum 1971).

Acknowledgements

We are thankful to Professor A. Choudhury, Secretary, Susamadevi Choudhurani Marine Biological Research Institute, Sagar Island for his constant encouragement. We also thank Sri Kiran Lal Das for his generous help in the field.

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