

*Original Research*

# Measurements of Carbon Dioxide Fluxes by Chamber Method at the Rzecin Wetland Ecosystem, Poland

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## Abstract

The assessment of net ecosystem exchange (NEE) and respiration of ecosystem (Reco) of terrestrial ecosystems is necessary to improve our knowledge about the carbon cycle. The aims of this paper were to present reliable measurements of CO<sub>2</sub> fluxes of a temperate bog ecosystem located in Poland using a closed dynamic chamber system and to obtain a daily dynamic course of CO<sub>2</sub> fluxes over the 2007 vegetation season. Measurements of CO<sub>2</sub> fluxes were carried out at Rzecin peatland ecosystem located in northwestern Poland using the set of two chambers (dark and transparent). Reco during the experiment period ranged from 2.65 to 14.76  $\mu\text{molCO}_2\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ . The daily run of NEE was inversely related to PPFD and the values of NEE varied from 0.06 to -11.82  $\mu\text{molCO}_2\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ . We found differences between NEE and Reco in the wetland ecosystem with respect to term of measurements. The PPFD, air and soil temperatures explain most temporal variability of CO<sub>2</sub> fluxes at Rzecin. But vegetation structure, its phenology and water-level depth seem also to play important roles. The chamber technique is a useful tool for determining carbon dioxide exchange between wetland surface and the atmosphere.

**Keywords:** chamber method, CO<sub>2</sub> fluxes, net ecosystem exchange, ecosystem respiration, wetland

## Introduction

Wetlands play an important role in terrestrial carbon sequestration processes and they are considered to be one of the biggest carbon pools on the Earth's surface. It is estimated that approximately 455 Pg of carbon is stored in northern hemisphere wetlands [1]. High-latitude wetland ecosystem carbon dynamics is considered to be potentially very sensitive to globally observed climate changes.

These changes are supposed to influence dramatically the spatial and temporal distribution of air temperature and precipitation in the atmosphere. More recent results in wetland ecosystems show vulnerability (varying by geographical region) and major changes will likely occur in vegetation species composition, seasonality and production [2].

Wetland areas in Poland cover 4,345,400 ha, i.e. 14% of the country area. It is estimated that 15% of the total wetland area (both natural and transformed) is covered by forests and shrub communities. The remaining area is

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mainly grasslands and croplands. More than 80% of Polish wetlands, including hydrogenic forest sites, have been drained in order to intensify forest and agricultural production. About 9% of peatlands remain in natural or close to natural status [3]. Therefore, information on the carbon sequestration ability of Polish wetland ecosystems is needed in order to improve our knowledge about their carbon budget. Such studies become important in terms of international carbon emissions policies.

The yearly sequestered carbon amount depends on the rate of plant production and their debris decomposition in a peatland ecosystem.

There are two groups of processes related to CO<sub>2</sub> exchange between the atmosphere and peatland: the absorption that is realized by vegetation through photosynthesis process, and emissions that result from plant (autotrophic) and soil (heterotrophic) respiration [4].

Peatlands have been considered a long-term net sink of carbon to upland systems, but their future ability to store carbon seems not to be obvious. The decreasing of the water level caused by warmer and drier weather leads to an aerobic conditions in the substrate. The microbial substrate decomposition increase determined by aerobic conditions can modify peatland carbon balance to a long-term net source of CO<sub>2</sub> [5-7].

Assimilation of CO<sub>2</sub> can be modified by non-stationary solar radiation flux and by changes in the groundwater table that affect the water content of mosses [8].

The soil water table depth, because of its effect on O<sub>2</sub> supply to soil microflora, is the major control of CO<sub>2</sub> emission from thick organic layers [9].

Total ecosystem respiration is highly dependent on changes in both air and soil temperature and soil moisture.

There are considerably high spatial variabilities of carbon exchange dynamics between both whole peatland ecosystems and particular plant communities.

The adjacent plant communities may act as a CO<sub>2</sub> sink and source simultaneously [10], therefore wetland ecosystem CO<sub>2</sub> exchange dynamics depend strongly on both spatial and temporal distribution of plant communities [11].

Moreover, an increased availability of nutrients, mainly N, may alter the carbon balance of peatlands. It may also influence plant community composition, e.g. in nutrient-poor peatlands (bogs) the important peat forming *Sphagnum* mosses suffer from competitive disadvantages if the N deposition gets too high [12].

The estimation of CO<sub>2</sub> exchange can be realized by using different measurement approaches, thus different techniques are recently used in field conditions such as eddy covariance [13, 14], aircraft measurements [15, 16] and chambers [17, 18]. However, all above-mentioned methods are different in terms of spatial and temporal scales of measurement. Very small spatial scale of measurements can be carried out with the chamber technique. Each plant community can be studied separately using data obtained with chamber measurements.

Although some studies of carbon dioxide in Polish ecosystems have been published [19, 20], studies in wet-

land ecosystems related to carbon dioxide fluxes are still missing. The aims of this study were:

- 1) to present reliable measurements of CO<sub>2</sub> fluxes of a temperate bog ecosystem located in Poland using a closed dynamic chamber system,
- 2) to obtain a daily dynamic course of CO<sub>2</sub> fluxes over growing period,
- 3) to quantify the CO<sub>2</sub> exchange of this ecosystem.

## Materials and Methods

### Site Description

The study was carried out at Rzecin peatland site, Poland (52°45' N latitude, 16°18' E longitude, 54 m a.s.l.). The wetland is owned by Poznań University of Life Sciences. The Rzecin measuring station has been developed and managed by the Agrometeorology Department. It is the first wetland station in Poland where the measurements of greenhouse gas exchange (CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O) are carried out permanently.

There is a broad range of equipment installed at Rzecin station e.g. an eddy covariance (EC) system for measurements of CO<sub>2</sub>, water and energy fluxes [21], solar radiation, air and soil temperature probes, etc.

The measurement capabilities of the chamber method depend mainly on applied gas analyzer type, e.g. CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O. This method limitation is mainly related to scale of studies.

The studied peatland area is approximately 140 ha. The vegetation is dominated by the following plant species: *Sphagnum* sp., *Dicranum* sp., *Carex* sp., *Phragmites communis*, *Typha langifolia*, *Vaccinium oxycoccus*, *Drosera rotundifolia*, *Potentilla palustris*, *Ranunculus acris*, and *Menyanthes trifoliata* [22].

The substrate can be described as a Limnic Hemic Floatic Ombric Rheic Histosol (Epidystric), according to FAO 2006 classification.

The annual mean air temperature and precipitation for the whole period of measurements were 8.5°C and 526 mm, respectively. The 50 cm-thick floating peat carpet is located in the middle of Rzecin wetland.

### CO<sub>2</sub> Fluxes Measurements

Four sites (S1 - S4) at the Rzecin peatland were selected for measurements of CO<sub>2</sub> fluxes at different vegetation type conditions. Each site consists of three plots that are repetitions. The first site (S1) is dominated by *Caricetum elatae*, the second (S2) by *Calamagrostietum neglectae*, the third (S3) by *Menyantho-Sphagnetum teretis* and the fourth (S4) by *Sphagno apiculati-Caricetum rostratae* [22]. At each plot an aluminum square collar, (75 x 75 x 20 cm) was inserted about 17 cm into the substrate. The collars were installed for the following reasons:

- gas leakage prevention,
- stability,
- spatial establishment of the measuring plot.

## Chamber Design

CO<sub>2</sub> flux measurements were carried out using a closed dynamic chamber system. The single set consists of two chambers (dark and transparent), based on the model proposed by Drösler [23]. Each chamber has a quadratic prism shape (base 77 cm x 77 cm and height 50 cm) and a volume of 0.3 m<sup>3</sup>. The dark chamber was made of white PVC (3 mm thick) in order to reduce sun radiation influence and measure ecosystem respiration (Reco). The transparent chamber was made of Plexiglas (3 mm thick) that reduces Photosynthetically Active Radiation (PPFD) up to 5% during measurements of Net Ecosystem Exchange (NEE). The infrared gas analyzer (MYCO<sub>2</sub>, Edinburgh Instruments, UK) was installed inside each chamber. This gas analyzer measures CO<sub>2</sub> concentration with 2% accuracy of 2,000 ppm range. Two thermometers (T-107, Campbell Scientific, USA) were installed in each chamber in order to measure the air temperature inside (T<sub>air</sub>) and outside chamber during measurements. The temperature sensors were placed on the wall 35 cm over the chamber edge and shaded.

Each chamber was equipped with two fans (Sunon, MagLev, Taiwan) about 1 m·s<sup>-1</sup> flow speed each. The tightness of chambers during the measurement was assured by a rubber gasket installed around of the chamber's lower edge. Additionally, two elastic belts (outside of the chamber) were applied to attaching the chamber to frame. A simple cooling system was applied to avoid problems with air temperature increase inside the chamber. It consisted of ordinary cooling packs placed inside the chamber to the special frames that exchange heat with the air flowed by the fans [23].

Soil temperature at vertical profile 2, 5 and 10 cm depth (T-109 Campbell Scientific) and global radiation flux density (CM11 Kipp&Zonnen) measurements were recorded and processed using a data-logger (CR1000, Campbell Scientific, USA) at a 5-second time interval. The permanent measurements of air temperature at 2 m, soil temperature profile at different depths (2, 4, 6, 10, 20, 30 and 50 cm) and global radiation are carried out at EC tower. Precipitation was measured automatically using a rain gauge (RG2-M, Onset, USA). The obtained data can be the basis for long-term CO<sub>2</sub> studies.

Measurement campaigns were carried out from June to September 2007, at 3-week intervals and measurements were conducted only under cloudless conditions. The single campaign was realized from sunrise till late evening. Each single measurement made with a dark and transparent chamber took 2-3 or 1.5-2 minutes, respectively.

If temperature inside the chamber does not change more than 1.5°C, and PPFD does not change more than 50 μmol·m<sup>-2</sup>·s<sup>-1</sup> during individual measurement, then measurement is considered to have been made in steady state conditions [23]. The measurements were not conducted at S1 and S2 sites during September due to technical problems.

## Data Analysis

The collected time series were validated in terms of temporal linearity of CO<sub>2</sub> concentration. The correlation coefficient (r<sup>2</sup>) was calculated for each series and if r<sup>2</sup> > 0.95 then CO<sub>2</sub> flux rate (F<sub>CO<sub>2</sub></sub>) was calculated using the following equation [24]:

$$F_{CO_2} = k_{CO_2} \cdot (273 \cdot T_{air}^{-1}) \cdot (V \cdot A^{-1}) \cdot (dc \cdot dt^{-1}) \quad (1)$$

...where:

F<sub>CO<sub>2</sub></sub> – CO<sub>2</sub> flux density [mg CO<sub>2</sub>-C m<sup>-2</sup> h<sup>-1</sup>];

k<sub>CO<sub>2</sub></sub> – gas-constant at 273.15 K = 0.536 [μg C μl<sup>-1</sup>];

T<sub>air</sub> – air temperature in chamber [K];

V – chamber volume [l];

A – collar area [m<sup>2</sup>];

dc·dt<sup>-1</sup> – CO<sub>2</sub> concentration change in chamber [CO<sub>2</sub>; ml l<sup>-1</sup> h<sup>-1</sup>].

Gross Primary Production (GPP) is defined as the total amount of carbon fixed in process of photosynthesis by plant in an ecosystem, while Net Ecosystem Exchange (NEE) refers to GPP reduced by carbon losses by Ecosystem Respiration (Reco). Reco is defined as the sum of plants (autotrophic) and soil microbe (heterotrophic) respiration.

The data obtained at EC tower were used for NEE and Reco calculations for the period between each measurement campaign.

Reco was calculated based on regressions between respiration rates and air temperature using Lloyd & Taylor [25] equation (2), E<sub>o</sub> and R<sub>ref</sub> of this equation were individually fitted to the corresponding dataset, whereas T<sub>ref</sub> (283.15 K) and T<sub>0</sub> (227.13 K) were set as constant parameters [25]

$$Reco = R_{ref} e^{E_o (1/(T_{ref} - T_0) - 1/(T_{soil} - T_0))} \quad (2)$$

...where:

Reco – ecosystem respiration [CO<sub>2</sub>-C mg·m<sup>-2</sup>·h<sup>-1</sup>];

R<sub>ref</sub> – respiration at the reference temperature [CO<sub>2</sub>-C mg·m<sup>-2</sup>·h<sup>-1</sup>];

E<sub>o</sub> – activation energy [K];

T<sub>ref</sub> – reference temperature = 283.15 [K];

T<sub>0</sub> – temperature threshold of biological processes start = 227.13 [K];

T<sub>soil</sub> – soil temperature at the depth of best fit with the dataset [K].

The NEE was calculated using the following formula [26, 27]:

$$NEE = ((GP_{max} \cdot \alpha \cdot PPFD) / ((\alpha \cdot PPFD) + GP_{max})) - Reco \quad (3)$$

...where:

PPFD – Photosynthetic Photon Flux Density [μmol · m<sup>-2</sup> · s<sup>-1</sup>];

GP<sub>max</sub> – maximum rate of carbon fixation at infinite PPFD [CO<sub>2</sub>-C mg·m<sup>-2</sup>·h<sup>-1</sup>];

α – initial slope of the curve; light use efficiency [CO<sub>2</sub>-C mg·m<sup>-2</sup>·h<sup>-1</sup>/μmol m<sup>-2</sup> s<sup>-1</sup>].

The data computation and statistical analysis was realized with Microsoft Excel, numerical computing software Matlab (The MathWorks, USA) and the Table Curve 2D program (Curve Fitting Software, SYSTAT).

## Results and Discussion

### Environmental Conditions

The daily mean of air and soil temperatures at Rzecin during the 2007 growing season showed typical seasonal fluctuation. The daily mean air temperature (Fig. 1) peaked on July 15 (26.4°C), but the daily mean soil temperature (at 5 cm depth) peaked on July 19 (18.4°C). The 2007 growing season was characterized by moderated rainfall events; the highest rainfall event (49 mm d<sup>-1</sup>) was measured June 2 (Fig. 1). The daily mean PPFD varied from 35 to 926  $\mu\text{mol}/\text{m}^2\text{s}$  during this period.

Daily courses of air and soil temperature at different depth during our measurement campaigns showed a significant differentiation over the whole day. These differences are less significant for soil temperature profile. Maximum differences of soil temperature between 2 and 10 cm depths were observed in summer days after the midday (up to 3°C). The overall range of air and soil temperature at 2, 5 and 10 cm depth during our measurement campaigns were 6-28°C for air, 10-19°C, 11-18°C and 12-17°C for soil at 2, 5 and 10 cm depth, respectively. The highest growing season air and soil temperatures were measured in the middle of July and the lowest one was measured in September.

The Reco and temperatures were analyzed in terms of dependency. The best correlation was found for Reco and air temperature (Tair). Reco and Tair showed a significant relationship in all four sites (mean correlation coefficient was  $r^2 = 0.89$ ). The highest correlation was found at S2 site (up to  $r^2 = 0.989$ ) and the lowest at S1 site ( $r^2 = 0.535$ ).

Temperature is the one of the most important factor controlling CO<sub>2</sub> fluxes [28]. Most ecosystem respiration studies show significant correlation with soil temperature [25, 29]. But in our results ecosystem respiration showed correlation with air temperature, and a similar relationship

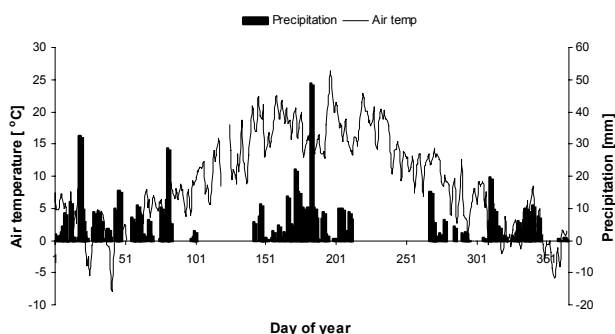


Fig. 1. Daily mean air temperatures (at 2 m) and total precipitations runs at Rzecin during the 2007 growing season .

was found by Drösler [23]. Additionally, water depth is another factor controlling CO<sub>2</sub> flux densities in wetland.

The PPFD ranged from 0 to 1855  $\mu\text{mol}/\text{m}^2\text{s}$  during NEE measurements. The maximum values of PPFD were observed at midday hours (11:00 to 13:00), which corresponded to the most active CO<sub>2</sub> uptake. Variation of the influence of PPFD on NEE during the experimental period could be explained by plant stage of development, period of the year and time of measurement. Moreover, Hirota [30] pointed out that daily variation in PPFD strongly affected the diurnal course of NEE and GPP. On the other hand, the influence of sun radiation on soil surface temperature of the measured sites was different due to plant cover. Soil surface in sites 3 and 4 were more exposed to sun radiation due to their vegetation composition (mainly covered by *Sphagnum*) while soil surface from sites 1 and 2 were shaded by the leaves of bigger plants.

### CO<sub>2</sub> Fluxes

Increases in CO<sub>2</sub> concentration were observed during Reco measurement (dark chamber, Fig. 2), while a decreasing trend of CO<sub>2</sub> concentration during measurement of NEE (transparent chamber). There was even 100 ppm depletion measured at the highest PPFD conditions (Fig. 3).

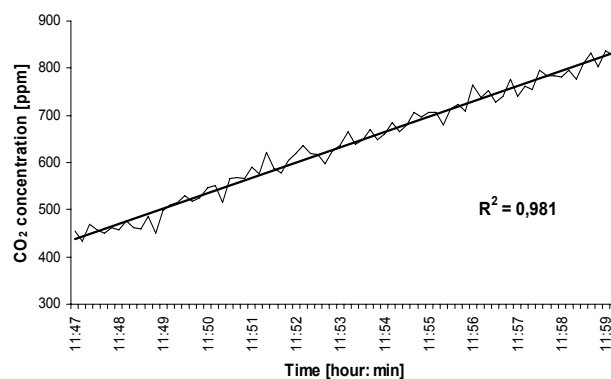


Fig. 2. CO<sub>2</sub> concentration run in dark chamber at site S4, at 14.06.2007. The increase of CO<sub>2</sub> concentration indicates the respiration activity of this plot.

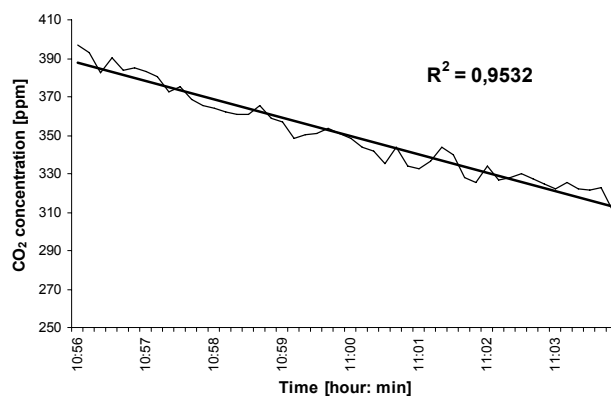


Fig. 3. CO<sub>2</sub> concentration run in transparent chamber at site S4, at 14.06.2007. The decrease of CO<sub>2</sub> concentration indicates that assimilation prevails over respiration at this plot.

The coefficient of linear correlations between the  $\text{CO}_2$  concentration and time was from 0.65 to 0.96, for each measurement in both chambers.

However, some fluctuations of  $\text{CO}_2$  concentrations were observed during single measurements, and it influenced the obtained linear correlation coefficient values. Davidson et al. [31] pointed out that frequently a traces noise appears shortly after placing the chamber over the soil as a result of small pressure differentials and other disturbances while moving and fixing the chamber in place. In our conditions, small disturbances happened throughout the single measurement and it was caused by the used gas analyzer. However, this influence was not statistically significant for the calculation of  $\text{CO}_2$  fluxes.

### Daily Courses of Reco and NEE

Reco values during all measuring campaigns ranged from 4.41 to 14.86  $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$  for S1 site, from 3.92 to 11.1  $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$  for S2 site, from 3.00 to 10.67  $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$  for S3 site and from 2.65 to 14.76  $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$  for S4 site. The daily maximum respiration rates during the summer months were generally observed in the afternoon (14:00-16:00) while the air temperature reached its maximum values (18-28°C). The daily minimum respiration rates in summer months were measured over the early morning time (5:00-7:00) when air temperature ranged between 6 and 12°C. Regarding seasonal changes of Reco, the daily maximum and minimum during the first month of autumn season (September) was observed in different times of the day compared with summer months. The daily maximum respiration was measured in the early part of the afternoon (15:00-16:00), while the minimum in the morning time (7:00-8:00) during September. Both the maximum and minimum of Reco during this month were related to air temperature during the day. The daily course of Reco is similar to air temperature inside the chamber (Tair) (Fig. 4). A strong Tair dependence of Reco at all four measured sites was found, the mean coefficient of correlation ( $r^2$ ) by sites were (0.71) S1, (0.98) S2, (0.93) S3 and (0.96)

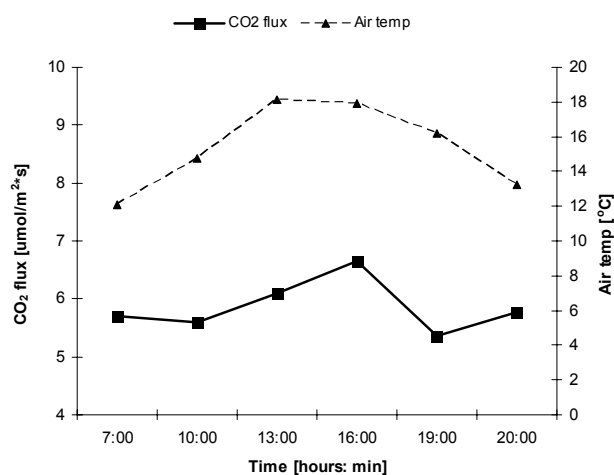


Fig. 4. The Reco and Tair (inside of the chamber) runs at S2 site on 30.07.2007.

S4, respectively. Tair is the most important Reco-controlling factor.

Reco during the measuring campaigns seemed to be related to the aboveground biomass stage of development. The highest rates of Reco were observed during summer period (July-August) that could be explained by the highest air temperature and when the aboveground biomass reached their maximum stage development. Site S1, dominated by *Caricetum elatae*, and site S4, dominated by *Sphagno apiculati-Caricetum rostratae*, showed the highest Reco. Contrary to our results, Heijmans et al. [32] reported low Reco in a position dominated by Sphagnum compared to other plant species, and explained it as a consequence of cooler soil temperature. The higher Reco at *Sphagnum* site (S4) obtained with our measurements seem to be related to substrate organic matter decomposition.

Moreover, beside temperature and aboveground biomass as influencing factors, water depth may both directly and indirectly affect Reco dynamics in a wetland. Water depth directly modifies the amount of aerated biomass. A temporal decrease in water depth would increase Reco mainly because of an increase of aerobic respiration belowground biomass [33]. For example, [34] in an experiment in peat substrate we found that lowering the water table by 10 mm increased  $\text{CO}_2$  fluxes by an average of 7.1  $\text{mg CO}_2 \text{ m}^{-2} \text{ h}^{-1}$ . On the other hand, [35] using eddy correlation instrumentation and the Lloyd and Taylor [25] model investigated night-time soil respiration in deep peat substrate, have shown no change of soil respiration with water location. Their site was rarely waterlogged and the oxygen availability in the peat soil was fairly constant. Although in our condition the water depth differed over the season and it was supposed to cause increased  $\text{CO}_2$  losses.

Daily run of NEE was inversed to daily PPFD course and the values were from 0.06 to -11.82  $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ . NEE was statistically significantly correlated to PPFD. The highest NEE was obtained usually during noon (11:00-13:00) (Fig. 5). We observed a large variation of NEE at noon, but little variation during the early morning time of the day. NEE rates during the experimental period ranged from 7.82 to -11.82  $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$  at site S1, from 9.06 to -11.85  $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$  at site S2, from 0.06 to -8.73  $\mu\text{mol}$

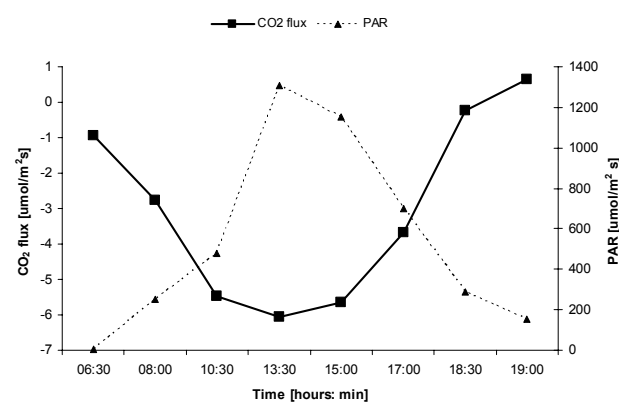


Fig. 5. NEE ( $\text{CO}_2$  flux) and PPFD runs in transparent chamber at site S3, on 6.09.2007.

Table 1. The values of  $R_{ref}$  – respiration at the reference temperature,  $E_0$  – activation energy,  $GP_{max}$  – maximum rate of carbon fixation at infinite PPFD, and  $\alpha$  – light use efficiency obtained at each site over the experiment period (June-September 2007).

Month	Parameter	S1	S2	S3	S4
June	$R_{ref}$	6.6	5.1	3.5	3.1
	$E_0$	163.3	216.0	210.4	319.9
	$GP_{max}$	-17.3	-23.0	-11.5	-24.8
	$\alpha$	-0.26	-0.04	-1.01	-0.08
July	$R_{ref}$	3.9	1.4	2.3	3.6
	$E_0$	321.7	423.9	405.1	231.3
	$GP_{max}$	-16.1	-32.4	-14.9	-16.0
	$\alpha$	-0.08	-0.61	-0.09	-0.07
	$R_{ref}$	5.8	3.3	2.3	3.0
	$E_0$	218.8	303.6	305.5	290.8
	$GP_{max}$	-19.9	-18.1	-17.3	-26.4
	$\alpha$	-0.14	-0.17	-0.08	-0.11
August	$R_{ref}$	6.7	3.8	2.4	2.1
	$E_0$	250.7	347.9	259.3	413.4
	$GP_{max}$	-22.3	19.3	-12.9	-20.2
	$\alpha$	-0.19	-0.18	-0.12	-0.08
September	$R_{ref}$	–	–	2.6	1.0
	$E_0$	–	–	203.3	561.9
	$GP_{max}$	–	–	-7.7	-12.8
	$\alpha$	–	–	-0.16	-0.05

$CO_2$   $m^{-2} s^{-1}$  at site S3, and from 4.99 to  $-11.36 \mu mol CO_2 m^{-2} s^{-1}$  at site S4. The maximum summer and autumn NEE was observed close to noon (11:00-13:00) while the minimum NEE were observed in the early morning (5:00-7:00). Both extremes were determined mainly by PPFD values and influenced air temperature.

The maximum values of NEE and Reco during July and August were measured while both the highest PPFD and  $T_{air}$  were observed. The diurnal patterns of NEE at all measuring sites are similar, but they differ in terms of magnitude. The highest NEE were observed at sites S1 and S2 dominated by *Caricetum elatae* and *Calamagrostietum neglectae*, respectively, and the lowest at site S3 dominated by *Menyantho-Sphagnetum teretis*. We consider that differences in NEE among sites as not only related to vegetation composition but also to  $T_{air}$  and water depth.

In the beginning of the experiment period (June-July), a positive NEE was observed at S1 and S2 sites in the early morning, as a result of a low quantity of active photosynthetically biomass compared to quantity of non-active photosynthetically dead biomass. It resulted in higher Reco than the assimilation rate, even under  $700 \mu mol \cdot m^{-2} \cdot s^{-1}$  PPFD values. Thus, a wetland ecosystem can be either a net source or a net sink of  $CO_2$  (eg. [30]). Both Reco and NEE values measured during the experimental period were consistent with other previous studies [36-39].

#### Modeled $CO_2$ Fluxes – Reco and NEE

The Reco and  $T_{air}$  relationship was parameterized for each site using Lloyd and Taylor function (Fig. 6A). The parameters of rectangular hyperbolic function (eq. 3) were found using the Monte-Carlo method (Fig. 6B) in order to model NEE. Both Reco and NEE was modeled on the basis of obtained coefficients (Table 1) for the whole experimental period.

All Reco and  $T_{air}$ , as well as NEE and PPFD correlation coefficients, were statistically significant. The modeled and

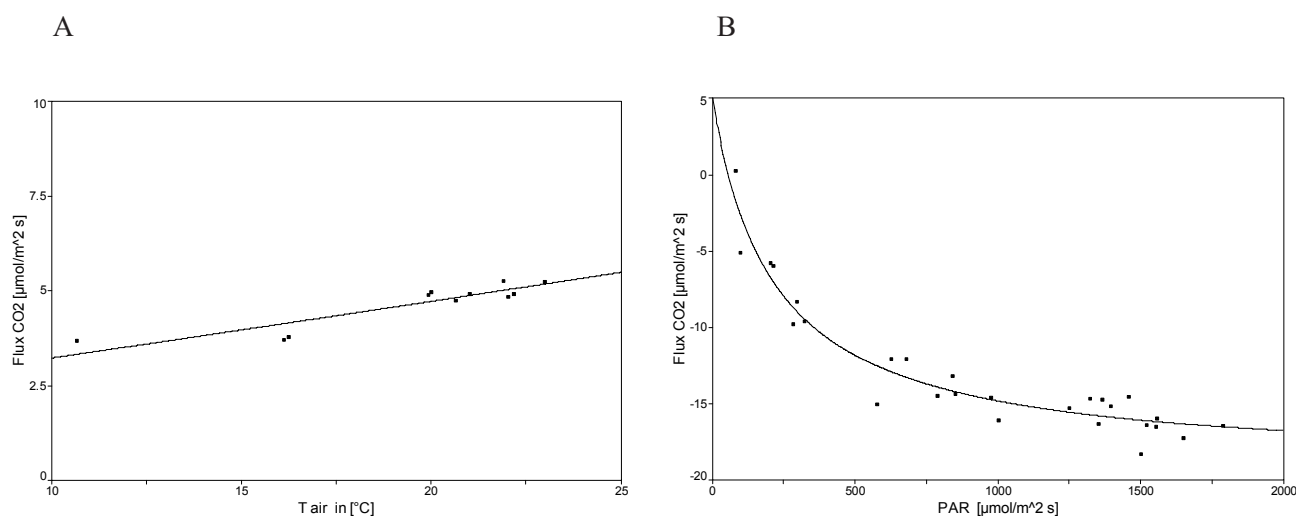


Fig. 6. Reco versus  $T_{air}$  at site S3 (A) in 06.09.2007 and GPP versus PPFD at site S4 in 9.07.2007 (B).

Table 2. Monthly total values of Reco and NEE [ $\text{g CO}_2\text{-C m}^{-2}\text{ month}^{-1}$ ].

Site	S1		S2		S3		S4	
	Reco [ $\text{g/m}^2\text{month}$ ]	NEE [ $\text{g/m}^2\text{month}$ ]	Reco [ $\text{g/m}^2\text{month}$ ]	NEE [ $\text{g/m}^2\text{month}$ ]	Reco [ $\text{g/m}^2\text{month}$ ]	NEE [ $\text{g/m}^2\text{month}$ ]	Reco [ $\text{g/m}^2\text{month}$ ]	NEE [ $\text{g/m}^2\text{month}$ ]
June	286	8	240	-70	176	-57	202	-76
July	271	40	166	-256	163	-51	83	-69
August	383	69	276	-46	138	-41	174	-57
September	-	-	-	-	90	-55	80	-21

measured Reco values were similar, but differed from each other slightly (Fig. 7). These differences could be caused by soil water content changes over the whole period, since modeled values were obtained using only Reco versus Tair dependency. Davidson et al. [33] pointed out that in wetland, oxygen rather than organic solutes may be the limiting substrate for aerobic respiration. Summer drought may dry out the wetland surface enough to limit significantly the diffusion of soluble substrates, but it can favor diffusion of oxygen into the organic layer, thus increasing aerobic respiration.

Each Reco site and NEE values were modeled for each month (Table 2). The highest Reco was estimated at site S1 ( $382.9 \text{ g-m}^{-2}\text{ month}^{-1}$ ) and the lowest at S3 ( $80.4 \text{ g-m}^{-2}\text{ month}^{-1}$ ). The Reco reached the maximum at S1 and S2 in August, but at S3 and S4 in June. At all sites the lowest values were reached in September.

The modeled NEE for the experimental period presented different dynamics at all four sites. The highest NEE was estimated at S2 ( $-258.58 \text{ g-m}^{-2}\text{ month}^{-1}$ ) and the lowest at S1 ( $68.85 \text{ g-m}^{-2}\text{ month}^{-1}$ ).

The highest monthly net loss of  $\text{CO}_2$  (Reco) at S1 (dominated by *Caricetum elatae*) (Table 1) for all measuring period might be explained by the large amount of dead biomass. The highest monthly net  $\text{CO}_2$  uptake (NEE) was observed at S2 (dominated by *Calamagrostietum neglectae*) site in July. The monthly values of NEE at S3 and S4 are similar. Positive values of NEE at S1 indicates this site

as dominated by  $\text{CO}_2$  losses (Table 2). The explanation of this phenomenon can be a small ratio of photosynthetically active to dead biomass as it mentioned above. The spatial variability of Leaf Area Index (LAI) can be another possible explanation of differences between sites. The LAI at S1 and S2 sites are higher than at S3 and S4 (data not shown).

Reco and NEE, both presented similar trends – temporal and spatial magnitude of variability of  $\text{CO}_2$  fluxes at studied wetland. There are both biotic (e.g. vegetation composition, plant stage of development) and non biotic (PPFD, Tair, water table depth) factors that influence wetland ecosystems to be either a sink or a source of  $\text{CO}_2$ . Similar results have been observed at other wetland ecosystems [39-42]. Alm [6] reported Reco values from 194 to  $288 \text{ g CO}_2\text{-C m}^{-2}$  and from -41 to  $117 \text{ g CO}_2\text{-C m}^{-2}$  for NEE at wetland in Finland during the period of May to September, while Heikkinen et al. [43] from 37 to  $129 \text{ g CO}_2\text{-C m}^{-2}$  and from 25 to  $49 \text{ g CO}_2\text{-C m}^{-2}$  at a wetland in Russia during July to September. It is difficult, however, to compare results obtained at different wetland ecosystems due to the management, experiment realization, geographical location of the site, methods used for estimation of  $\text{CO}_2$  or vegetation composition of the site. The results we obtained, indicate the main factors influencing  $\text{CO}_2$  exchange dynamics. Nevertheless, it is important to mention here that the modeled Reco and NEE were determined on the basis of short-time surveys, so that the obtained values should be taken carefully and as an estimation.

## Conclusion

The temporal variability of both NEE and Reco were found at different sites of the Rzecin wetland ecosystem. Environmental factors such as PPFD and Tair explain most temporal variability of  $\text{CO}_2$  fluxes. However, vegetation structure, its phenology and water depth also seem to play important roles in the spatial distribution of  $\text{CO}_2$  fluxes. The air temperature was the key factor for daily and seasonal ecosystem respiration rates. The chamber technique is a useful tool for determining carbon exchange dynamic at wetland since it indicates the flux differences among the measuring sites. This techniques is simple to operate at relatively low cost and low power consumption.

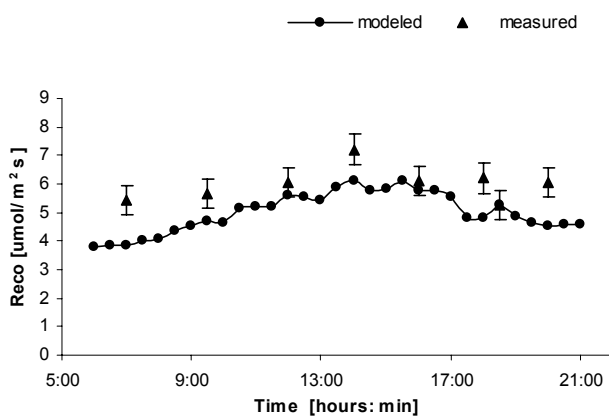


Fig. 7. Modeled and measured Reco value runs at site S2 on 30.07.2007. Error bars indicate SD.

This study shows the capability of the chamber method in terms of temporal and spatial variability of fluxes (GPP, NEE and Reco) research of wetland ecosystems. More sophisticated field surveys need to be realized in order to estimate carbon dioxide exchange estimation of Rzecin wetland.

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