CO_2 sink strengths of the New Jersey Meadowlands

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Abstract

Carbon dioxide uptake strength, particularly of intertidal wetlands in urban areas are largely unknown. Therefore, CO_2 fluxes were measured in an urban wetland with the eddy covariance technique since March of 2009. Fluxes of CO_2 saturated at 24 μmol m^{-2} s^{-1} under high light conditions. Daily mean NEE showed this ecosystem to be a CO_2 source in the wintertime reverting to a sink in summer again. Concurrent photosynthesis measurements of *Phragmites australis*, a C3-plant, and *Spartina spp*, a C4- plant, showed a lack of saturation at current external CO_2 concentration suggesting a growth advantage in urban areas were CO_2 level are higher as compared to rural areas. Both species displayed similar aboveground net primary productivity and leaf area index, despite the attempt of the managing company to eradicate *Phragmites.*

Introduction

Potential carbon dioxide (CO_2) sink strengths especially of urban areas are still unclear (Pataki et al. 2006, Grimm et al. 2008) and how it will be affected by global change (Bridgham et al. 2006). Particularly, if carbon(C) offsets nationally and internationally will be traded through the additionality of C sequestration that is achieved (Hansen 2009), proper C accounting will be crucial. In this context, it is conceivable that through management of wetlands that are known to be productive (Mitsch and Gosselink 2007) an increase in C sequestration would lead to offset credits rendered (Hansen 2009). However, C sequestration potential and sink strengths of urban tidal salt marshes and management thereof are still a significant knowledge gap (Zedler and Kercher 2005). Especially in urban areas, not only climatic and edaphic factors determine C uptake strengths but also previous land use, air pollution and the biophysical environment.

Current estimates of C uptake strengths of wetlands have an uncertainty of more than 100% associated with it (Bridgham et al. 2006), thus predictions for conditions under altered climatic conditions are even more difficult. Therefore, it is crucial to determine current C sink strengths, dynamics and factors influencing it, to be able to predict future C sink potential (Zedler and Kercher 2005, Bridgham et al. 2006, Mitsch and Gosselink 2007). On a worldwide perspective, wetlands are occupying only 7-8% of terrestrial land (Mitsch and Gosselink 2007), however, half of the world's population is living in coastal areas, and thus the ecosystem services they provide are crucial; an important one also being flood control. Even more so, two-thirds of all cities larger than 5 million people are in low elevation coastal zones (Martine 2007). A recent study suggesting that belowground accretion of biomass and ensuing sediment elevation of coastal wetlands could potentially offset some sea level rise (Langley et al. 2009), is adding to the importance of investigating structure and function of these ecosystems. Especially in urban areas, not only climatic and edaphic factors determine C uptake strengths but also previous land use, air pollution and the biophysical environment. At the very least, land use change, air pollution and the biophysical environment may determine whether the wetlands will expand, contract or remain stable (Keith et al. 2010).

Urban areas experience already on average elevated temperatures and CO_2, compared to non-urban or rural areas (Nemitz et al. 2002, Shen et al. 2008, McCarthy et al. 2010), thus an urban wetland will already experience conditions that are predicted to prevail in a decade around the world (McCarthy et al. 2010). Elevated temperatures affect biological processes and chemical processes. An increase in temperature has been shown to increase ecosystem respiration (R_{eco}) and thus decimated net ecosystem exchange (NEE) in a cattail marsh (Bonneville et al. 2008). This demonstrates the importance to investigate biophysical controls; particularly urban ecosystems offer a look into the future as temperature and CO_2 are already elevated.

Water level in tidal wetlands control gas-exchange of the vegetation; whereby the competitive advantage of *Phragmites australis* versus *Spartina alterniflora* is determined by water level changes as *Spartina* is favored under higher water elevation (Wang et al. 2006, Guo et al. 2009). Albeit productivity under high water levels is increased for *Spartina*, the tidal nature of the wetlands also enables lateral transport of C and thus cause effective C loss to the ecosystem (Guo et al. 2009). The actual C loss has thus far not been determined and may constitute 19-63% of net primary productivity (NPP) of the wetlands (Guo et al. 2009).

In recent history, the eddy covariance technique has been employed to estimate net ecosystem exchange (NEE) in wetlands, primarily peatlands (Frolking et al. 1998, Lafleur et al. 2003) and more recently also in mineral marshes (Bonneville et al. 2008) and intertidal estuaries (Guo et al. 2009, Zemmelink et al. 2009). In a cattail marsh, it was shown to be a significant C sink with a NEE of 264 gC m^{-2} yr^{-1} (Bonneville et al. 2008). In the current study, NEE of an urban tidal salt marsh is investigated and its respective biophysical controls.

Materials and Methods

Study Site

The New Jersey Meadowlands (NJM) are protected under the umbrella of the New Jersey Meadowlands Commission, and represent the most important intact wetland area in the Hudson-Raritan estuary ecosystem complex. The meadowlands are located within an urban environment, encompassing 14 municipalities in an area of 34

km^2, of which 42% are wetlands. The study site is the Marsh Resource Meadowlands Mitigation Bank, located in Carlstadt, Bergen county, New Jersey (40.8 N 74.04 W) bordered at the northeast and southeast by the Hackensack river, to the east by Metro Media tract, to the northwest by the New Jersey turnpike and to the southwest by facilities of a private company. The site is 83 ha in size, was mitigated in 1999 with *Spartina spp* planted, however *Phragmites australis* has encroached again and comprise approximately 15% of the area surveyed. The Mitigation Bank wetlands are tidal salt marshes, thus soil moisture is not limiting. The eddy flux tower is located at the center of the site where a power outlet was available. After a thunderstorm in August of 2009, the site was without power for approximately three weeks thus no data was collected throughout that time.

Soil and plant measurements

To further evaluate NEE and canopy net assimilation (A_{nC}), biomass of *Spartina spp* and *Phragmites australis* were harvested at the end of the season. As this is a mitigated site, continuous harvest was not possible thus before senescence was reached, two 0.5 m^2 plots of each species were harvested to determine aboveground biomass and leaf area. For leaf area determination, subsamples of the leaves were taken, scanned with a commercial scanner to determine leaf area and dry weight recorded. Specific leaf mass (SLM) was then used to estimate total leaf area of total leaf mass collected. Collected aboveground plant material was separated into stems, leaves and florescence and dried in a drying oven at 60ºC for 48 h. Plant material were further analyzed for nutrient and heavy metal content at the testing lab at the University of Massachusetts, Amherst (see Table 1). Soil samples of the upper 10 cm were taken at the end of August, homogenized and sent to the soil-testing lab at UMass, Amherst for determination of micro- and macronutrients (see Table 1). Subsamples of the plant and soil material were dried, ground in a ball bearing mill, weighed into tin capsules for analysis of C and N concentration and ^{13}C and ^{15}N in a mass spectrometer analyzer at the Duke EnVironmental stable Isotope Laboratory (DEVIL) in Durham, NC, USA (see Table 2).

Meteorological measurements

Meteorological measurements include net radiation (R_n, NRLite, Kipp & Zonen, Delft, NL), soil heat flux (G, Hukseflux, self-calibrating, Delft, NL), soil temperature (T_S, TVAC, Campbell Scientific Inc, Logan, UT), air temperature (T_A) and air humidity (RH, HMP45C, Vaisala, Helsinki, Finland) monitored continuously. The supplemental measurement serve to evaluate and interpret observed patterns in CO_2 and H_2O fluxes as a complete energy balance with sensible, latent and soil heat fluxes will be performed. Under conditions of atmospheric stability or instrument failure, the energy budget or multiple regression analysis with environmental drivers serves to fill data gaps (Falge et al. 2001).

Eddy flux measurements

The eddy covariance technique has been developed and successfully implemented for net ecosystem exchange (*NEE*) measurements under various conditions over a diverse array of vegetation types for several decades (Baldocchi et al. 1988, Falge et al. 2001, Baldocchi 2003, Reichstein et al. 2005). The flux of any scalar that is measured through the eddy covariance technique is defined as

$$F_S = \overline{w's'} \qquad (4)$$

where F_S is the flux of scalar S (in this case CO_2) w' the vertical wind velocity fluctuation about the mean, S' is the scalar concentration fluctuation about the mean (i.e. CO_2 concentration) and over bar denotes time average, usually 30 minutes. By convention $F_S < 0$ is downward flux to the vegetation, i.e. uptake of – in this case CO_2 - and for $F_S > 0$ upward flux (Baldocchi et al. 1988). An eddy flux tower was established at the Mitigation Bank in the New Jersey Meadowlands to measure CO_2 fluxes by continuously measuring 3D wind and virtual temperature with a sonic anemometer (CSAT, Campbell Scientific Inc, Logan, UT) and CO_2 and H_2O concentrations with an open path LiCor infrared gas analyzer (LI 7500, LICOR, Lincoln, NE) at a rate of 20 Hz and averaged over 30 minute periods. The raw, high frequency data was first subjected to despiking, time lagging between wind and concentration measurements and air density corrections according to Webb et al (1980) for open path analyzers (Detto and Katul 2007). The flow field was then rotated in x and y direction according to Wilczak et al (2001) before averaging. The time averaged data was despiked again according to

Papale et al (2006) and the friction velocity (u*) cutoff determined for each temperature class according to Reichstein et al (2005). A further analysis excluded values that are derived from the nearby turnpike.

Results

Soil and plant analysis

Soil material and plant material were collected at the end of the growing season to assess accumulated nutrients and heavy metal in plant tissue (see Table 1). Soil bulk density was 0.65 g cm^{-3} that can be attributed to its high soil organic matter content of 15.6%. The average pH of this soil is 6.6 that was also reflected by high Mg, Ca and K content (Table 1). Nutrient and metal content in plant tissue differed some between species whereby *Phragmites* seems to be accumulating more heavy metals such as Al and Mn in roots compared to *S. spp*. However, both species contained a lot of Fe in their root system albeit little Fe was found in the soil (Table 1). A difference in leaf N content was observed between the two species (Table 2) whereby *Phragmites* had higher leaf N than *Spartina*. Particularly, the species differed in their $\delta^{13}C$ as *Phragmites* is clearly a C3 plant and *Spartina* a C4 plant (see Table 2, Schäfer 2009). The soil $\delta^{13}C$ is a bulk measure, thus assuming all C in the soil to be derived from plant material, the soil C contains 62% of C3 plant material (*Phragmites*) and 38% C4-C (*Spartina*). The overall leaf area and aboveground biomass of both species are similar (Fig 1) with an average leaf area index (LAI) of 4.6 m^2 m^{-2} and aboveground biomass (NPP_{AG}) of 547 gC m^{-2}.

The $\delta^{15}N$ values of bulk soil and both plant species are fairly high and representative of urban/industrial areas where fossil fuel combustion occurs (Table 2, (Garcia et al. 2009). In this context, it would be interesting to measure atmospheric $\delta^{15}N$ to determine N deposition rate and incorporation into plant tissue.

Meteorological measurements

In Fig 2 shown are mean monthly G, R_n (both in W m^{-2}), T_S and T_A in ºC, wind speed (u in m s^{-1}) and CO_2 concentration (in ppm) at the site from April through June 2010. It is noticeable that the site experiences already on average elevated CO_2 concentration above the mean of 385 ppm by approximately 9%. Therefore, the physical environment in urban areas are already experiencing CO_2 levels expected in about a decade throughout the world. This year 2010 experienced higher T_A than last year (Fig 2) which may have impact on overall respiration and photosynthesis.

Eddy covariance measurement

Shown in Fig 3 is the CO_2 flux (F_{CO2} in μmol m^{-2} s^{-1}) in relation to R_n (in W m^{-2}) During times of high R_n, this ecosystem displayed an half hourly maximum of 24 μmol m^{-2} s^{-1} of CO_2 NEE flux (see Fig 3). As NEE is beginning to saturate at current maximum R_n an enhancement of NEE may thus not be possible.

The u* cutoff point varied with season and T_A between 0.012 m s^{-1} and 0.267 m s^{-1} , which is in the range of the ubiquitous 0.2 m s^{-1} cutoff previously used (Falge et al. 2001). Filtering according to Papale et al (2006) excluded additional 12% of the data in 2009 and 29% in 2010. Approximately 7% of the data was discarded due to instrument warnings in 2009 and 5% in 2010. Due to the turnpike, 18% of the data was rejected in 2009 and 20% in 2010. Due to overlapping filters the overall data loss in 2009 was 30% and in 2010 52%.

In Fig 4 shown is the mean daily CO_2 flux of the ecosystem at the Mitigation Bank of the remaining data. Clearly, in the wintertime this ecosystem is a C source, whereby in the summer it reverts into a sink again. Overall NEE of the entire year is yet to be determined as gap-filling methodology will crucially influence overall assessment of this ecosystem. Depending on gap-filling methodology used, annual sums of NEE can vary up to 100% (Falge et al. 2001), particularly in a tidal ecosystem (Guo et al. 2009).

Discussion

Carbon dynamics of urban wetlands are largely unknown, as well as their biophysical and hydrochemical controls (Zedler and Kercher 2005, Kathilankal et al. 2008, Erwin 2009). Understanding these controls will help predicting future changes as urban wetlands are exposed to increased temperature of air and water and experienced changes in species composition (Zedler and Kercher 2005). For example, Kathilankal et al (2008) showed a pronounced reduction of NEE for *Spartina alterniflora* under submerged water conditions, as did Guo et al (2009) for a *Phragmites australis* and *Spartina alterniflora* marsh; however, Wang et al (2006) found a competitive advantage for *Spartina alterniflora* under elevated water conditions as the productivity was enhanced compared to *Phragmites australis*. In addition, Wang et al (2006) found salinity to be advantagous to growth of *Spartina alterniflora*. Thus, the overall effect of marsh productivity or NEE is depended on water level, salinity and species composition.

In another analysis, it was shown that *Spartina alterniflora* dramatically increased in productivity when grown under higher temperatures, potentially keeping up in vertical elevation with predicted sea-level rise (Kirwan et al. 2009). A similar prediction was made by Langley et al (2009) that sea level rise may be offset through sediment elevation in a tidal marsh model ecosystem. Thus, it is important to evaluate temperature and tidal effects on productivity and NEE as well. As Fig 1 shows in this investigation, productivity seems to be comparable between the two species, despite repeated attempts by the manging company to eradicate *Phragmites* through herbicides at this site. However, the ecosystem is already saturating in NEE under current conditions, thus maximum CO_2 uptake is achieved (Fig 3).

As this research continues, it will include methane (CH_4) measurements; with which a complete greenhouse gas balance will be achieved. The concern for CH_4 emission from wetlands is preventing measures to restore those valuable ecosystems as they are not only absorbing CO_2 but also prevent floods, absorb nutrients, thus filtering water and buffer heavy storms surges. Long-term measurements provide information on ecosystem functioning over a wide range of environmental conditions that will then in turn help to examine potential future changes such as elevation in temperature and sea level. This research will enhance our current understanding of carbon dynamics in urban wetlands.

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Table 1: Soil and plant characteristics at the Mitigation Bank, NJ. All values are in ppm.

		Nitrate (NO^{3-})	P	K	Ca	Mg	Na	Al*	B	Mn	Zn	Cu	Fe	S	Pb*	Pb*	Cd	Ni	Cr
Soil sample 08/09		36	15	377	1738	1159		16	3.4	162	22	0.6	11.4	**550**	1	38	0.2	1.8	0.7
Soil sample 10/09		50	20	665	2027	1615		NT	3.9	23.4	12.2	0.6	3.7	NT	1	39	0.1	2	1.7
P. australis	Leaves		3	7	12	7	5	36	6	129	8	5	59			1	0	0	0
	Stems		2	7	2	1	16	12	1	16	1	3	20			0	0	0	0
	Rhizome		10	44	1	6	5	38	1	87	20	3	65			0	0	0	1
	Roots		10	36	14	13	30	**1017**	14	**1139**	23	19	1332			5	0	2	17
S. spp	Leaves		8	81	55	38	90	51	5	549	17	5	100			0	0	0	1
	Stems		3	65	8	17	241	14	2	125	16	4	28			0	0	0	0
	Rhizome		11	57	3	6	53	135	3	38	93	12	117			0	0	0	1
	Roots		21	66	10	22	34	324	10	715	49	12	1328			13	0	1	8

*estimated total aluminum / lead extractable

Bold indicates particularly high values for a given tissue or soil.

Table 2: Carbon (C) and nitrogen (N) properties of bulk soil and leaves of *P australis* and *S spp*

	Soil	*P australis*	S spp	Air	Fossil Fuels
C %	131	45.5	41.8	0.038	55-70[2]
N %	1.0	2.7	1.9	78	0.014-1.35[2]
^{13}C ‰	-22.4	-27.1	-14.7	-10.7*	-25.7- - 31.7[3]
^{15}N ‰	16.2	20.3	23.5	0±3[1]	4.9-17.5[4]

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[1] http://wwwrcamnl.wr.usgs.gov/isoig/period/n_iig.html

[2] Hannan et al (2003)

[3] Bush et al (2007)

[4] Ogawa and Yoshida (2005), coal combustion to N_2O

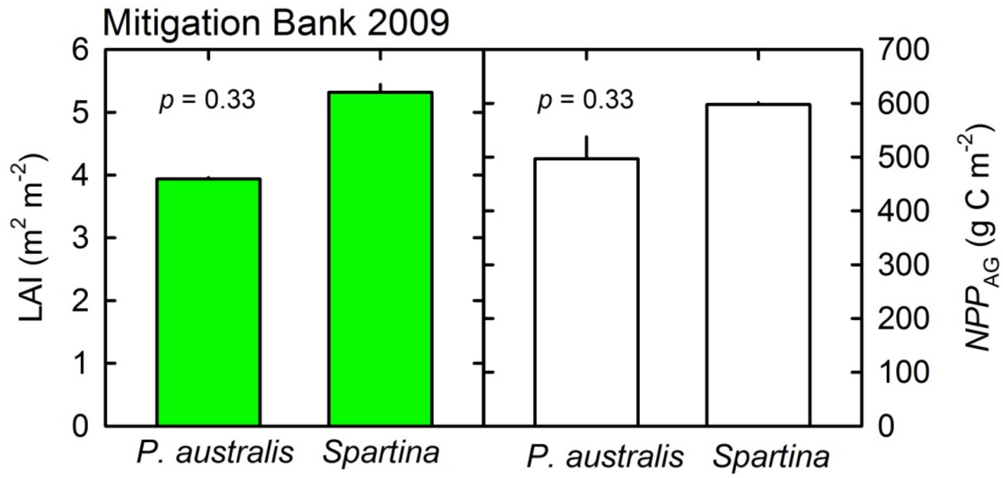

Figure 1: left graph: Leaf area index (LAI) in m^2 m^{-2} and right graph: aboveground biomass (NPP_{AG}) in gC m^{-2} for *Phragmites australis* and *Spartina spp*. at the Meadowlands Mitigation Bank.

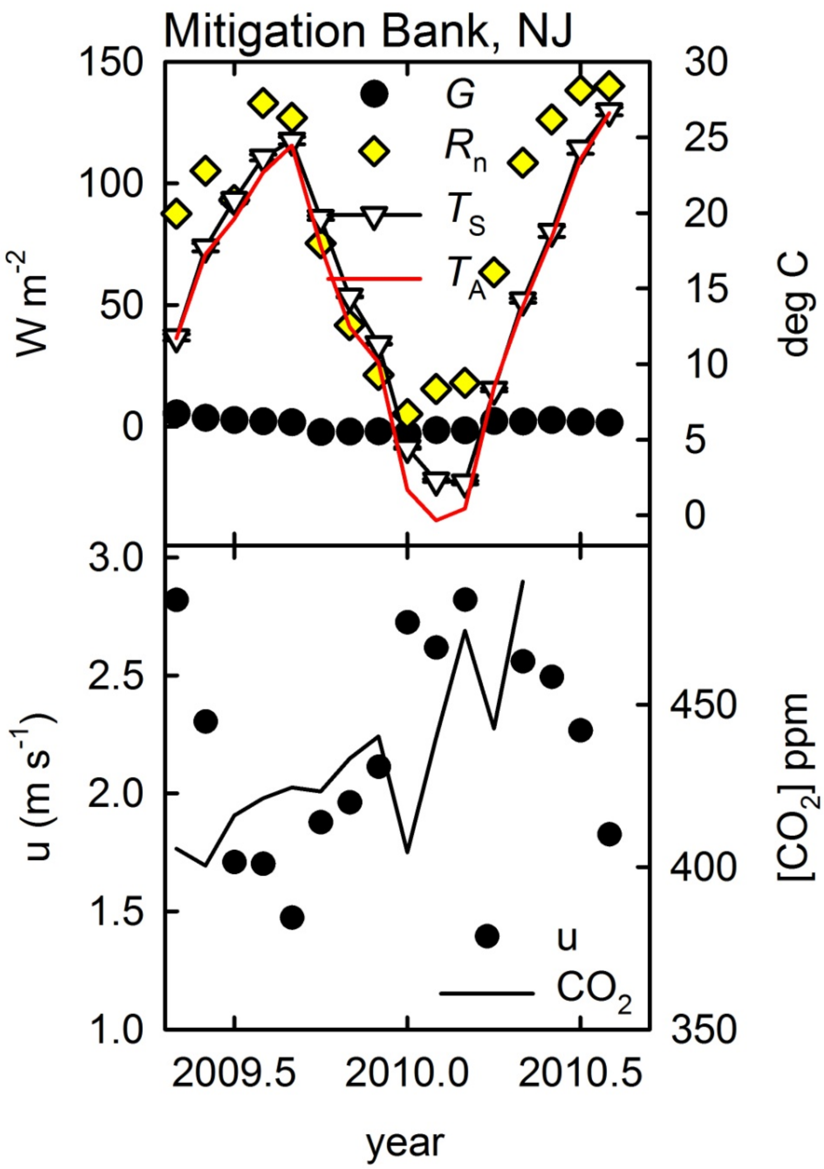

Figure 2: Monthly mean meteorological parameters at the Mitigation Bank site. Top panel: Soil heat flux (*G*, black dots), net radiation (R_n, yellow diamonds), soil (T_S, open triangles) and air temperature (T_A, red line) in ºC. Bottom panel: wind speed (*u*, black dots) and CO_2 concentration ([CO_2] in ppm, solid line)

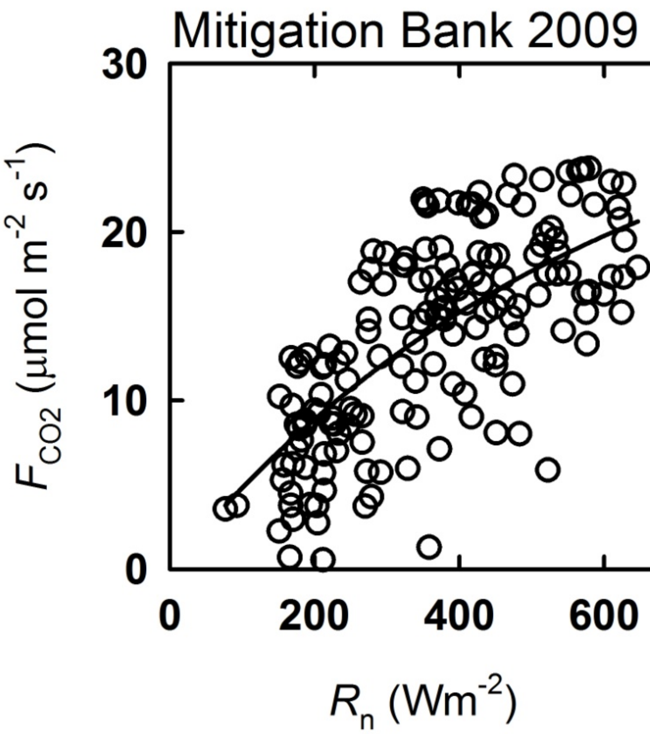

Figure 3: Net ecosystem exchange (F_{CO2}) in relation to net radiation (R_n) in 2009

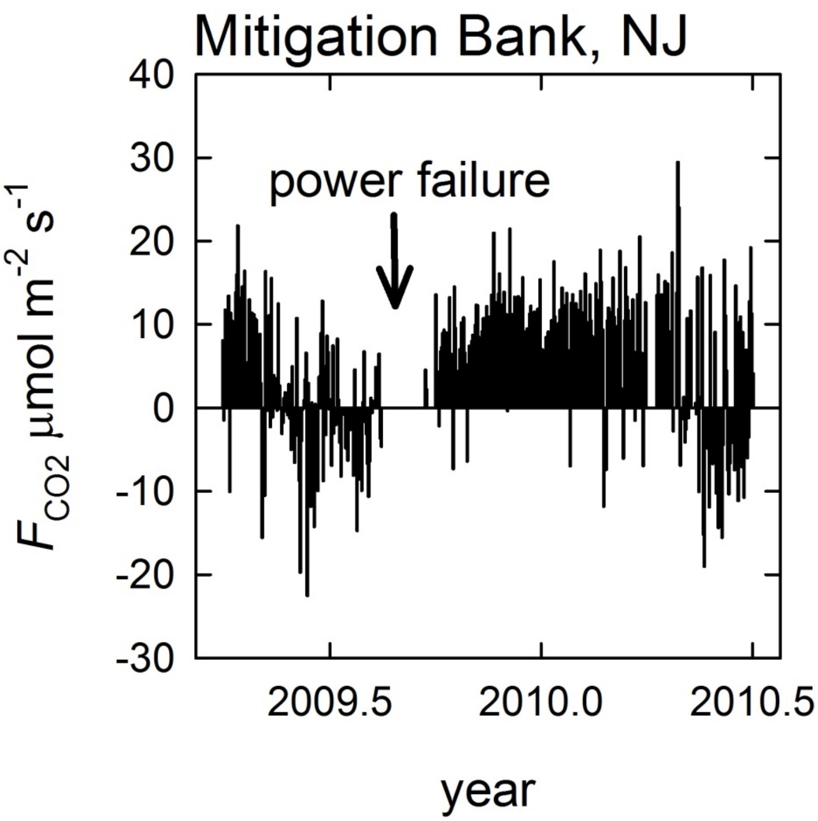

Figure 4: Mean daily CO_2 flux (F_{CO2}) at the Mitigation Bank site