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Tropical reservoirs are bigger carbon sinks than soils

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Introduction

Worldwide reservoirs total 260 000 km^2 surface area according to recent studies (DOWNING et al. 2006). The sediments of these water bodies are carbon sinks (MULHOLLAND & ELWOOD 1982, RITCHIE 1989, DEAN & GORHAM 1998, KORTELAINEN et al. 2004)

Fossilization is comparatively small in tropical soils (less than 0.5% of primary production); thus, almost all carbon (C) used in photosynthesis returns to the atmosphere as carbon dioxide (CO_2). When a reservoir is created, a fraction of that CO_2 is substituted by methane (CH_4). Methane is produced in anaerobic sediments of tropical reservoirs (ABE et al. 2005); however, anoxia hinders organic matter degradation (BASTVIKEN et al. 2004). With time, further mineralization is hampered by the physical inaccessibility of organic matter to bacteria, a process that promotes permanent carbon sedimentation (ROTHMAN & FORNEY 2007). This study presents carbon burial rates measured using silica (SiO_2) as a tracer, in 7 Brazilian reservoirs surveyed from 2003 to 2006.

Key words: Brazilian reservoirs, carbon sinks, methane emission, sedimentation rates

Study sites

Ebbulitive and diffusive fluxes at 7 tropical reservoirs (Table 1) and their respective rivers downstream were measured for 3 years. Permanent (refractory) and fresh C sedimentation rates were measured only in the reservoirs. Each of these was surveyed once in the beginning of the wet season (BW), once during the end of the wet season (EW), and once in the dry season (D).

Table 1 – Significant features of the studied reservoirs

Brazilian Reservoir	Serra da Mesa	Manso	Corumbá	Itumbiara	Furnas	Peixoto	Estreito
Watershed area (km^2)	51 233	4237	10 860	95 000	16 562	7269	1441
River	Tocantins	Cuiabá	Corumbá	Paranaíba	Grande	Grande	Grande
Impoundment year	1997	2000	1987	1980	1963	1957	1969
Latitude longitude	13°50′S 48°19′W	14°52′S 55°46′W	17°46′S 48°33′W	18°17′S 48°54′W	20°39′S 46°18′W	20°21′S 46°59′W	20°09′S 47°15′W

Materials and methods

Ebbulitive gas fluxes from the reservoirs were measured with funnels and diffusive fluxes measured with chambers. Gas samples were analyzed within 7 hours after sampling with a thermal conductivity detector and flame ionization detector equipped gas chromatograph located in a portable laboratory. Sediment samples were extracted with a UWITEC corer (Mondsee, Austria).

Permanent C sedimentation rates were obtained by the SiO_2 tracer method (SIKAR et al. 2005). This method was checked against ^{210}Pb dating for permanent C sedimentation rates. The SiO_2 tracer method takes 1.5 days to analyze at least 20 samples, while the ^{210}Pb method would require weeks. The ^{210}Pb dating technique was expected to yield higher results because of sampling location strategy. While SiO_2 traps can be deployed at any reservoir site, core sampling is usually done near sites were settling preferentially occurs. In fact, sedimentation rates as obtained by the ^{210}Pb technique were slightly higher than the rates given by the SiO_2 tracer method (Table 2).

Table 2 – Results of sedimentation rates of permanent C using 2 methods. The ratio ($^{210}Pb/SiO_2$) average is 2.

Reservoir	"^{210}Pb" ($g\ m^{-2}\ d^{-1}$)	"SiO_2 tracer" ($g\ m^{-2}\ d^{-1}$)	RATIO ^{210}Pb / SiO_2 tracer
Furnas	0.207±0.082	0.128±0.080	1.62
Peixoto	0.438±0.082	0.120±0.090	3.65
Itumbiara	0.101±0.012	0.070±0.026	1.44

Downstream CH_4 above-background emissions were calculated by multiplying water discharge flow at the dam by the difference in surface water CH_4 concentrations upstream and downstream. The following exemplifies the use of CH_4 concentration [CH_4] in water measured during the Serra da Mesa reservoir surveys:

- Upstream (assumed as background) average [CH_4] measured during EW and D season surveys: 0.5445 ± 0.1300 µM
- Downstream average [CH_4] measured during BW season survey: 199.70 ± 78.59 µM
- Above-background [CH_4] in discharged water during BW season: 199.15 µM
- Discharge water flow: 756.000 L s^{-1}

If all above-background CH_4 in downstream water was emitted, then the upper-limit emission rate estimate is:

$$199.15\times10^{-6}\times\frac{16g}{L}\times\frac{10^{-3}\ kg}{g}\times756{,}000\frac{L}{s}\times3{,}600\frac{s}{h}\times24\frac{h}{d}=208{,}131\ kg\ \ CH_4\,d^{-1}$$

$= 156{,}098$ kg C_{CH4} d^{-1}

The above-background downstream river emission rate estimate is negative when [CH_4] upstream > [CH_4] downstream.

Results and discussion

Permanent C sedimentation was a fraction (11 ± 7%) of the rates of fresh C settling daily. To quantify C sinking status, a "sink index" was calculated per reservoir after each of the 21 field surveys. The sink index is the ratio between total daily permanent C sedimentation and the sum of total daily C_{CH4} emission at each reservoir and above-background downstream emission (sink index column in Table 3). A reservoir is effectively a sink if the index is >1. A negative value would mean that the reservoir C_{CH4} emission is less than the absolute value of the negative above-background downstream emission. The index was negative for only the Corumbá D season survey.

A reservoir is not a sink if the index is <1, which happened only in the Serra da Mesa BW season field campaign. Sink index average is 9.3 (range from -0.33 to 48.40; n = 21). Our study shows that older reservoirs tend to be stronger C sinks.

Table 3 – Total sedimentation rates of permanent carbon (S) compared to C_{CH4} emission rates downstream (D) and by reservoir (R)

Reservoir-Month/ Year (survey)	Season*	Re-servoir area (km^2)	Volume (km^3)	Reservoir emission ($tC_{CH4}\ d^{-1}$) R	Above-background downstream emission ($tC_{CH4} d^{-1}$) D	Sedimentation of permanent carbon ($t\ C\ d^{-1}$) S	S/(R+D) SINK INDEX
Serra da Mesa-11/03 (1)	BW	691	17.9	79.2±91.8 (38)	156.1	35.5±40.2 (12)	**0.15**
Serra da Mesa-3/04 (2)	EW	959	26.0	6.1±8.2 (52)	13.3	50.2±56.9 (23)	2.59
Serra da Mesa-7/04 (3)	D	1045	28.8	59.5±164.9 (33)	1.9	79.6±64.5 (34)	1.30
Manso - 11/03 (1)	BW	327	5.7	20.5±13.3 (29)	6.3	40.6±32.5 (7)	1.51
Manso - 3/04 (2)	EW	379	7.1	27.6±27.1 (26)	14.3	43.5±34.8 (14)	1.04
Manso - 7/04 (3)	D	356	6.5	22.8±44.4 (39)	2.1	43.5±23.7 (24)	1.75
Corumbá-11/04 (1)	BW	49	1.1	0.8±0.7 (34)	-0.08	5.42±0.50 (21)	7.53
Corumbá - 3/05 (2)	EW	60	1.4	1.2±2.5 (45)	-0.08	3.57±0.93 (8)	3.19
Corumbá - 8/05 (3)	D	44	1.0	6.3±9.8 (18)	-22.7	5.34±2.00 ((14)	**-0.33**
Itumbiara-11/04 (1)	BW	627	12.8	16.5±11.8 (43)	-0.74	78.6±2.2 (12)	4.99
Itumbiara - 3/05 (2)	EW	788	16.9	11.3±17.80 (50)	-0.47	35.7±32.9 (14)	3.30
Itumbiara - 8/05 (3)	D	726	15.3	14.5±21.9 (34)	-0.22	35.6±77.6 (43)	2.49
Furnas-11/05 (1)	BW	1260	18.8	25.5±31.8 (48)	0.096**	211±155 (35)	8.24
Furnas-3/06 (2)	EW	1416	22.4	12.8±11.3 (51)	0.317**	272±73 (27)	20.74
Furnas-8/06 (3)	D	1275	19.2	9.7±12.6 (69)	0.164**	49±49 (30)	4.97
Peixoto-11/05 (1)	BW	242	3.6	3.03±3.39 (33)	-0.040	23.9±2.4 (28)	7.99
Peixoto-4/06 (2)	EW	257	3.9	1.65±2.36 (26)	-0.288	57.1±12.7 (27)	41.92
Peixoto-8/06 (3)	D	255	3.9	1.62±1.64 (24)	-0.120	10.7±18.5 (25)	7.13
Estreito-11/05 (1)	BW	45	1.3	0.21±0.19 (26)	0.059	1.9±0.45((12)	7.06
Estreito-3/06 (2)	EW	45	1.3	0.21±0.17 (25)	0.009	10.6±0.38 (13)	48.40
Estreito-8/06 (3)	D	45	1.4	0.21± 0.06 (22)	0.038	4.8±1.5 (13)	19.35

* BW – beginning of wet season ; EW – end of wet season ; D – dry season

** assuming $[CH_4]$ in water from upstream river is zero ($[CH_4]$ in water from upstream river was not measured)

High standard deviations confirm the fact that tropical reservoir gas emissions are highly variable in space and time. Other studies have shown that emissions continuously monitored at fixed sites also vary significantly in time (LIMA et al. 2005).

Permanent C sedimentation aereal rate average for the 21 surveys was 40.40 ± 28.11 (range from 13.87 to 120.45; n = 21) g C m^{-2} yr^{-1}. For comparison's sake, an estimate of C storing rate in soil is:

- Dry tropical forest soil density (measured by us): 1.13 g cm^{-3}
- Soil formation rate estimate (from data in GOUVEIA et al. 1999): 0.20 mm yr^{-1}
- Tropical forest and pasture soil C content (6 samples measured by us): 6.68 ± 4.35%C

$$1.13\frac{g}{cm^3}\times 0.20\frac{mm}{yr}\times 0.1\frac{cm}{mm}\times\frac{10^4\,cm^2}{m^2}(6.68\pm 4.35)\,\%\,C\times\frac{1}{100\%}=(15.1\pm 9.83)\;g\,C\,m^{-2}\;yr^{-1}$$

Sink to storage ratio is (40.40/(15.1)) = 2.68.

Therefore, we conclude that these 7 tropical reservoirs removed 2.68 times more C than the soils alone would have stored; thus, they represent large carbon sinks.

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