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Emergy Value of Mass Flows in a Tropical Ecosystem, as Native Forest and as Sugar-cane Plantation at Watersheds in Sao Paulo State, Brazil

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ABSTRACT

The production of ethanol from sugar-cane has been noticed as an ecological alternative for petroleum and also as solution for global warming. Brazil attains the status of a key country because it could supply the ethanol needed for external and internal demands. Nevertheless the increasing of sugarcane land establishes a high pressure on natural resources. The conversion of a natural ecosystem into agriculture land can result in losses of ecosystem services. Using emergy methodology, there were estimated the Emdollar values of mass flows in natural and human-managed systems for three material cycles. Hydrologic cycle: a watershed covered by native forest had a water percolation estimated as Em$ 3929 $ha^{-1}year^{-1}$, while a sugar-cane field in the same region, this service was valued as Em$ 1479 $ha^{-1}year^{-1}$. Carbon cycle: semi-decidual forest in Piracicaba basin shows a carbon fixation service valued from Em$ 113 $ha^{-1}year^{-1}$, while sugar-cane areas in Serrana and Pradopolis show a carbon fixing value of Em$ 589 $ha^{-1}year^{-1}$, however, this value doesn't consider the loss of this service after harvesting; moreover, with the cane-burning for cropping, the CO_2 and CH_4 emissions are up to Em$ 172 $ha^{-1}year^{-1}$ and Em$ 56 $ha^{-1}year^{-1}$, respectively. Nitrogen cycle: the biological fixing in tropical forest ranged from Em$ 23 to 7126 ha^{-1} $year^{-1}$; for sugar-cane systems the value varied from Em$ 0 to 1226 $ha^{-1}year^{-1}$, for sugar-cane without nitrogen fixation and for RB72 454 genotype, respectively. The fertilizer used for sugar-cane volatilize ammonia and leach nitrate around Em$ 4082 $ha^{-1}year^{-1}$.

INTRODUCTION

Human beings benefit from processes and structures within ecosystems that produce a range of goods and services called "ecosystems services", including fresh water, food, fiber, oxygen production, aesthetic values and others. Nevertheless, humans have modified ecosystems more in the last 50 years than in any comparable period of human history (MEA. Agriculture, in particular, results in simplification of the ecosystem to increase the economic value of one ecosystem service (such as food production) whereas this kind of extensive modification can reduce the ecosystem capacity to provide a broad range of another services (POST, 2007).

In Brazil , sugar cane is a crop in expansion of production and land area use, standing out in Sao Paulo State, with 60% of total sugarcane production. The fabrication of ethanol from sugar cane as an ecological alternative for petroleum and also as a solution to global warming will increase internal and external consumption of ethanol; as consequence, new agricultural land areas will be needed to attend these demands, threatening all the natural ecosystems around (Agrianual, 2008).

Sao Paulo State's major ecosystem was Atlantic Forest, that covered 82% of its territory before the Discovery of Brazil, in 1500. However, this ecosystem was devastated through the centuries, firstly to extract essences from *Pau Brasil*, on the early 16th century; the following destruction was due cane and coffee cycles on the 19th and 20th centuries. After 500 years of exploration and urban expansion, Atlantic Forest occupies only 3% of the State's territory

(CNRBMA/SOS, 1997). Currently, Atlantic Forest and another ecosystems (such as *Cerrado, a kind of savanna*) are threatened by this recent sugar cane expansion.

The aim of this paper is to compare the capacity of ecosystem services provision in two different systems: native forest (principally Atlantic forest) and sugar-cane crop. Using emergy methodology, there were estimated the em-dollar values of mass flows in natural and human altered systems for three different material cycles: hydrologic cycle, carbon cycle and nitrogen cycles. Moreover, this paper presents new proposals of evaluation of ecosystem services and processes, such as water percolation, carbon fixation and losses of nitrogen due nitrate leaching.

Emergy accounting allows a special understanding of ecosystem services (ES) in which one single ecosystem service can be dismembered in a range of biogeochemical processes. This paper describes how Watanabe (2008) used the theoretical foundation from Odum et al. 2000, Buenfil (2001) and Brown & Ulgiati (2004) to calculate the monetary value of global processes related water, carbon and nitrogen biogeochemical cycles. The ecosystem processes assessed are extremely important because they are directly correlated with phenomena such as global warming, water availability and the overload of fertilizer in the modern agriculture.

METHODS

Ecosystem Services Calculation

This paper considered water, carbon and nitrogen mass flows as co-products of the same Geobiosphere Empower (15.83 E+24 sej.yr^{-1}). Tables 1, 2 and 3 shows the emergy per mass values of global processes calculated by Watanabe (2008) using fundaments of Odum et al. (2000), Buenfil (2001) and Brow & Ulgiati (2004). Using brazilian Emdollar, monetary values for global processes were calculated for each material cycle in terms of Em$ per gram.

The next step was to use the global emergy per mass values for local scale assessment – native forests and sugarcane cropland – to find changes in ecosystem services provision due to the transformation of natural areas in intensive agriculture field. To avoid double accounting, the values (given in Em$ or Em$.ha^{-1}.yr^{-1}) of different co-products of each material cycle were not summed but only the most significant mass flow (bold marked line in tables 4,5,6,7,8 and 9) was considered.

Selected Study Areas

The selected areas in Sao Paulo State are showed in the Figure 1. All of them had previous studies regarding water, carbon and nitrogen mass flows in terrestrial systems. The sugarcane areas were *Corumbataí* watershed (water flows; Garcia et al., 2006), experimental farms at *Serrana* and *Pradopolis* (carbon and nitrogen flows; Campos, 2003), *Piracicaba* river basin (nitrogen deposition; Lara et al., 2001), and Piracicaba city (nitrogen flows; Bergamasco, 2003). The native forest areas were *Corumbatai* watershed (water flows; Garcia et al. 2006), experimental catchments at Cunha (nitrogen flows; Ranzini et al. 2007), a watershed at Piracicaba river basin (carbon flow; Silveira et al., 2000), and an experimental watershed at *Santa Rita do Passa Quatro* (carbon flow; Silva et al., 2007).

RESULTS

Hydrologic Cycle Case Study: Corumbatai Watershed

The mass flows of hydrologic processes at *Corumbatai* watershed were obtained by simulation (Garcia et al., 2006) using SWAT (Soil and Water Assessment Tool). Using the values of emergy per mass for global processes, it was possible to estimate the em-dollar value of the hydrologic flows considering sugarcane crop or native forest. The most significant flow was the groundwater flow, that occurs in the saturated soil zone. Table 4 shows the results obtained to a simulation for a system with 100% of sugar-cane land-use and Table 5 for a 100% of forest land-use.

Table 1. Distribution and emergy values of global water flows (Buenfil, 2001; Watanabe, 2008).

Note	Process	Annual flow rate (10^{18}g/yr) *	Global Empower base (sej.yr^{-1})**	Emergy per mass (sej/g)	Brazil em-dollar*** (sej/US$)	Em-dollar per volume for Brazil (Em$/m^3)
1	Global evaporation	483	15.83E+24	3.28E+04	3.33E+12	0.01
2	Ocean evaporation	418	15.83E+24	3.79E+04	3.33E+12	0.01
3	Land evapotranspiration	65	15.83E+24	2.44E+05	3.33E+12	0.07
4	Global precipitation	483	15.83E+24	3.28E+04	3.33E+12	0.01
5	Ocean precipitation	378	15.83E+24	4.19E+04	3.33E+12	0.01
6	Temperate rain	256	15.83E+24	6.19E+04	3.33E+12	0.02
7	Tropical rain	227	15.83E+24	6.98E+04	3.33E+12	0.02
8	Precipitation to land	105	15.83E+24	1.51E+05	3.33E+12	0.05
9	Temperate rain on land	79	15.83E+24	2.00E+05	3.33E+12	0.06
10	Tropical rain on land	60	15.83E+24	2.64E+05	3.33E+12	0.08
11	Total runoff to oceans	40	15.83E+24	3.96E+05	3.33E+12	0.12
12	Surface & subsurface water flow	33	15.83E+24	4.80E+05	3.33E+12	0.14
13	Groundwater flow to oceans	3.8	15.83E+24	4.17E+06	3.33E+12	1.25
14	Global groundwater recharge	3.2	15.83E+24	4.95E+06	3.33E+12	1.49
15	Ice melt	2	15.83E+24	7.92E+06	3.33E+12	2.38

* Conversion: 1E3 km^3 water = 1 E18 grams of water.
** It was assumed that all global water flows are co-products of the global empower base (15.83 E+24 sej yr^{-1}).
*** Brazilian Emdollar (Coelho et al., 2003).
[1,2,3,4,5,6,7,8,9,10,12,14,15] Values of Buenfil (2001).
[11] Total water runoff from land to oceans 40 km^3.ano^{-1}, including groundwater discharge (Odum & Barret, 2007).
[13] Estimative from Watanabe (2008): Groundwater flow from land to rivers/oceans = (40 – 33 – 3,2) E3 km^3.yr^{-1} = 3.8 E3 km^{3}yr^{-1}.
[14] Flow to stored water (Buenfil, 2001).

Carbon Cycle Case Study

The mass flows of carbon processes at native forest were collected from three places due the absence of carbon flows. It was considered the mean carbon flux at net primary production (NPP) for Piracicaba river basin (Silveira et al., 2000) but the carbon fixation flow follows Malhi et al. (1999) estimative to temperate global forests. Organic dissolved carbon (O.D.C) mean flow at Santa Rita do Passa Quatro complement the calculations. The ranges of emergy-based values for these processes are present in the Table 6.

Campos (2003) has estimated mean carbon dioxide and methane emissions from soils and biomass burning for cropping. Carbon fixation estimative considered the carbon content in a sugarcane productivity of 101 tons (Mg) per hectare in a Sugarcane cropland at Serrana and Pradopolis (Manfrinato e Rocha, 2002; apud Gomes 2005). Losses of dissolved organic carbon followed Silva et al. (2007). Table 7 shows the results of ecosystem services obtained for such sugarcane cropland areas.

Nitrogen Cycle Case Study

The mass flows of nitrogen processes at native forest were collected from Ranzini et al. (2007) simulation data for Cunha catchment. However, the lack of values regarding biological nitrogen fixation (BNF) for this locality implied on using the wide range of BNF values observed in natural ecosystems (Silvester, 1983). Values showed in Table 8 regards the nitrogen input of

Table 2. Emergy per mass values of global carbon flows (Watanabe, 2008).

Note	Process	Unit	Annual mass flows ($un.yr^{-1}$)	Global empower base ($sej.yr^{-1}$)*	Emergy per mass (sej/un.)	Brazil Emdollar (sej/US$)**	Em-dollars values for Brazil*** (Em$/t C)
	Oceans						
1	Carbon fixation (CO_2)	g C	99.6E+15	15.83E+24	1.59E+08	3.33E+12	47.75
2	Carbon emission (CO_2)	g C	99.8E+15	15.83E+24	1.59E+08	3.33E+12	47.63
3	Carbon emission (CO)	g C	0.10E+15	15.83E+24	1.59E+11	3.33E+12	47,748.95
4	Inorganic carbon sedimentation	g C	0.15E+15	15.83E+24	1.06E+11	3.33E+12	31,705.31
5	Organic carbon sedimentation	g C	0.04E+15	15.83E+24	4.00E+11	3.33E+12	120,095.85
	Land						
6	Carbon fixation (CO_2)	g C	125E+15	15.83E+24	1.27E+08	3.33E+12	38.14
7	Carbon emission (CO_2)	g C	120E+15	15.83E+24	1.32E+08	3.33E+12	39.67
8	Methane emission (CH_4)	g C	0.99E+15	15.83E+24	1.59E+10	3.33E+12	4,774.90
9	Runoff of O.D.C. and I.D.C.	g C	0.80E+15	15.83E+24	1.98E+10	3.33E+12	5,944.74
	Atmosphere						
10	Methane oxidation (CH_4)	g C	0.99E+15	15.83E+24	1.59E+10	3.33E+12	4,774.90
11	Carbon monoxide oxidation (CO)	g C	1.68E+15	15.83E+24	9.43E+09	3.33E+12	2,830.83

* It was assumed that all carbon flows are co-products of the global empower base (15.83 E+24 $sej.yr^{-1}$).

**Brazilian em-dollar 3.33 E12sej/ US$ (Coelho et al., 2003).

*** Mass Conversion: 1E6 g C = 1 t C.

[1.2.3.4.5.6.7.8.10.11] Carbon mass flows from Jackson & Jackson (1996).

[9] IPCC (2001). Loss of carbon to streams. O.D.C. = organic dissolved carbon; I.D.C= inorganic dissolved carbon.

Table 3. Emergy per mass values of global nitrogen flows (Watanabe, 2008).

Note	Process	Unit	Annual mass flows ($un.yr^{-1}$)	Global empower base ($sej.yr^{-1}$)*	Emergy per mass (sej/un.)	Brazil Emdollar ** (sej/US$)	Em-dollars values for Brazil*** (Em$/kgN)
	Oceans						
1	Biologic nitrogen fixation (BNF)	gN	40.6E+12	1.58E+25	3.90E+11	3.33 E+12	117.14
2	N atmospheric deposition	gN	60.2E+12	1.58E+25	2.63E+11	3.33 E+12	79.00
3	Denitrification (N_2O, N_2)	gN	130E+12	1.58E+25	1.22E+11	3.33 E+12	36.53
4	Sedimentation	gN	20.0E+12	1.58E+25	7.92E+11	3.33 E+12	237.79
	Land						
5	Biologic nitrogen fixation (BNF)	gN	200E+12	1.58E+25	7.91E+10	3.33 E+12	23.76
6	N atmospheric deposition	gN	160E+12	1.58E+25	9.92E+10	3.33 E+12	29.80
7	Denitrification (N_2O, N_2)	gN	140E+12	1.58E+25	1.13E+11	3.33 E+12	33.97
8	Ammonia volatilization (NH_3)	gN	190E+12	1.58E+25	8.32E+10	3.33 E+12	24.98
9	O.D.N and I.D.N losses	gN	29.4E+12	1.58E+25	5.39E+11	3.33 E+12	161.76
	Atmosphere						
10	Fixation (lightening, combustion)	gN	29.4E+12	1.58E+25	5.39E+11	3.33 E+12	161.76

Table 3. Continued (notes).

* It was assumed that all carbon flows are co-products of the global empower base (15.83 E+24 sej.yr^{-1}).
** Brazilian em-dollar; 3.33 E12sej/ US$ (Coelho et al., 2003).
*** Mass conversion: 1E3 g N = 1 kg N.
[1.2.3.5.6.7.8.9.10] Fluxos de massa baseados em Jackson & Jackson (1996).
[4] Botkin & Keller (2005).
[9] Loss of nitrogen to streams and leaching.O.D.N.=organic dissolved nitrogen; I.D.C=inorganic dissolved nitrogen (Jackson & Jackson, 1996).

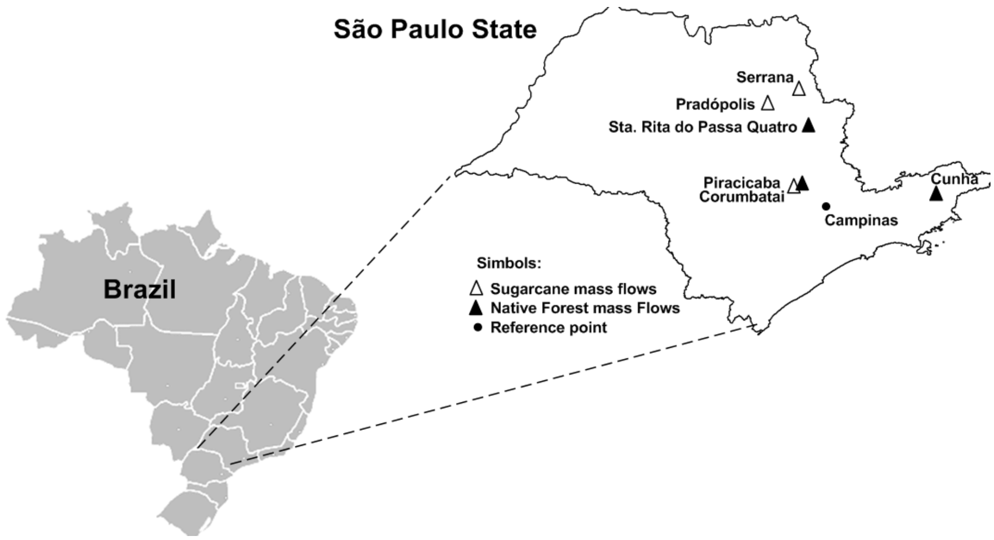

Figure 1. *Study areas at Sao Paulo State, Brazil (Watanabe, 2008).*

atmospheric deposition from Sao Paulo urban zone, which pollution affects ecosystems around, including Cunha catchment since its distance from Sao Paulo is about 150 km (Ranzini et al., 2007).

Table 9 regards nitrogen processes at sugar-cane cropland. Biologic fixation in sugarcane was estimated as 0 to 31% contribution of the total nitrogen within its biomass (Bergamasco, 2003), although this value could be higher depending on the sugarcane variety. Denitrification from decomposition and biomass burning estimative was observed at Pradopolis and Serrana (Campos, 2003). Ammonium volatilization and nitrate leaching was simulated (Bergamasco, 2003) at Piracicaba to the following conditions: with fertilizer (100 kgN ha-1 yr-1) and without it. In summary, Ecosystem services estimative for water, carbon and nitrogen ecosystem services at two different systems at Sao Paulo State are grouped in Figure 3.

Table 4. Emergy values for hydrologic processes at Corumbataí watershed (simulation considering 100% of sugarcane cover), Watanabe (2008).

Note	Hydrologic process	Unit	Output flows (un.ha^{-1}yr^{-1})	Emergy per mass of water (sej/unit)	Solar emergy (sej. ha^{-1}yr^{-1})	Em-dollar flow* (Em$. ha^{-1}yr^{-1})
1	Evapotranspiration	g	7.82E+09	2.44E+05	1.91E+15	572.31
2	Surface flow	g	6.86E+09	4.80E+05	3.29E+15	988.48
3	Subsurface flow	g	2.57E+08	4.80E+05	1.23E+14	37.04
4	**Groundwater flow**	**g**	**1.18E+09**	**4.17E+06**	**4.93E+15**	**1479.30**

[1] Flow estimated by mass balance.
[2,3,4] Simulated flows by Garcia et al. (2006).
* Brazilian em-dollar; 3.33 E12sej/ US$ (Coelho et al., 2003).
Em-dollar flow = Emergy flow /em-dollar = (sej.ha^{-1}.yr^{-1}).(Em$.sej^{-1}) = Em$.ha^{-1}.yr^{-1}

Table 5. Emergy values for hydrologic processes at Corumbataí watershed (simulation considering 100% of native forest). Watanabe (2008).

Note	Hydrologic process	Unit	Output Flows ($un.ha^{-1}yr^{-1}$)	Emergy per mass of water (sej/unit)	Solar emergy ($sej. ha^{-1}yr^{-1}$)	Em-dollar flow* ($Em\$. ha^{-1}yr^{-1}$)
1	Evapotranspiration	g	7.69E+09	2.44E+05	1.87E+15	562.35
2	Surface flow	g	4.97E+09	4.80E+05	2.39E+15	716.25
3	Subsurface flow	g	3.24E+08	4.80E+05	1.55E+14	46.69
4	**Groundwater flow**	**g**	**3.14E+09**	**4.17E+06**	**1.31E+16**	**3929.79**

[1] Flow estimated by mass balance.
[2,3,4] Simulated water flows by Garcia et al. (2006).
* Brazilian em-dollar; 3.33 E12sej/ US$ (Coelho et al., 2003).
Em-dollar flow = Emergy flow /em-dollar = $(sej.ha^{-1}.yr^{-1}).(Em\$.sej^{-1}) = Em\$.ha^{-1}.yr^{-1}$

Table 6. Emergy-based values for carbon flows in a subtropical forest at Piracicaba river basin, from Watanabe (2008).

Note	Carbon process	Unit	Output flows ($un. ha^{-1}yr^{-1}$)	Emergy per mass of carbon (sej/unit)	Solar emergy ($sej. ha^{-1}yr^{-1}$)	Em-dollar flow* ($Em\$. ha^{-1}yr^{-1}$)
1	Carbon fixation	Mg C	17.25	1.27 E+14	2.19 E+15	657.98
2	Carbon respiration	Mg C	14.28	1.32 E+14	1.89 E+15	-(566.61)
3	**Net prim. production**	**Mg C**	**2.97**	**1.27 E+14**	**3.77 E+14**	**113.29**
4	Methane emission	kg C	–	1.59 E+13	–	–
5	Runoff O.D.C.	kg C	6.00	1.98 E+13	11.88 E+13	-(35.67)

[1, 2, 3, 4, 5] Calculations are presented at Appendix A.

Table 7. Emergy based values for carbon flows in a sugarcane cropland at Serrana and Pradopolis, from Watanabe (2008).

Note	Carbon process	Unit	Output flows ($un. ha^{-1}yr^{-1}$)	Emergy per mass of carbon (sej/unit)	Solar emergy ($sej. ha^{-1}yr^{-1}$)	Em-dollar flow* ($Em\$. ha^{-1}yr^{-1}$)
1	**Carbon fixation (NPP)**	**Mg C**	**15.50**	**1.27 E+14**	**1.96 E+15**	**589.44**
2	Burn./decomp. (CO_2)	Mg C	4.70	1.32 E+14	5.75 E+14	-(172.73)
3	Soil emission (CO_2)	Mg C	11.30	1.32 E+14	1.49 E+15	-(446.90)
4	Burn./decomp. (CH_4)	kg C	11.70	1.59 E+13	1.87 E+14	-(56.05)
5	Runoff O.D.C.	kg C	9.40	1.98 E+13	18.6 E+13	-(55.89)

[1, 2, 3, 4, 5] Calculations are presented at Appendix B.

Table 8. Emergy-based values for nitrogen flows at Cunha catchment, from Watanabe (2008).

Note	Nitrogen process	Range of mass flows ($kg N. ha^{-1}yr^{-1}$)	Emergy per mass (sej/kg N)	Range of Solar Emergy ($E 15 sej. ha^{-1}yr^{-1}$)	Range of Em-dollar flow* ($Em\$. ha^{-1}yr^{-1}$)
1	Biological fixation	1-300	7.91 E+13	0.08 – 23.70	23 – 7126
2	Atmosph. deposition	9 - 51	9.92 E+13	0.89 – 5.04	268 – 1513
3	Denitrification	10 - 27	1.13 E+14	1.12 – 3.13	-(337 – 941)
4	NH_3 volatilization	-	8.32 E+13	-	-
5	**Leaching/ runoff**	**2 -7.6**	**5.39 E+14**	**1.08 – 4.09**	**-(323 – 1229)**

[1, 2, 3, 4, 5] Calculations are presented at Appendix C.

Table 9. Emergy-based values for nitrogen flows in sugarcane cropland, from Watanabe (2008).

Note	Nitrogen process	Range of mass flows (kg N. $ha^{-1}yr^{-1}$)	Emergy per mass (sej/kg N)	Range of Solar Emergy (E 15 sej. $ha^{-1}yr^{-1}$)	Range of Em-dollar flow* (Em\$. $ha^{-1}yr^{-1}$)
1	Biological fixation	0 - 53	7.91 E+13	0 – 4.2	0 – 1261
2	Atmosph. deposition	9 - 60	9.92 E+13	0.9 – 6	268 – 1788
3	Denitrification	1 - 24	1.13 E+14	0.01 – 0.7	-(3 – 810)
4	NH_3 volatilization	0 - 82	8.32 E+13	0 – 6.9	-(0 – 2059)
5	**Leaching/ runoff**	**0.5 – 25**	**5.39 E+14**	**0.3 – 13.6**	**-(77 – 4082)**

[1, 2, 3, 4, 5] Calculations are presented at Appendix D.

DISCUSSION

Since all water flows comes from the same global emergy input, it is important – to avoid double accounting – to consider only the most important water service, that is the groundwater flow (bold marked, see tables 4 and 5). It corresponds to 3929 Em$ $ha^{-1}yr^{-1}$ for native forest and to 1479 Em$ ha^{-1} yr^{-1} for sugarcane cropland. It means that sugarcane reduces particularly (near to 2450 Em$ ha^{-1} yr^{-1}) water percolation capacity since this vegetal cover allows more water runoff if compared to natural areas.

Carbon fixed in the net primary production (NPP) is the main flow and it corresponds to the higher value that enters in the system. Results showed that for sugarcane with high productivity the service of carbon fixation in the NPP is equivalent to 589 Em$ $ha^{-1}yr^{-1}$ (see table 7). However, this performance is attained due to an excess of fertilizer inputs in the field. Furthermore, carbon dioxide from sugarcane burning and underground soil emissions sums 619 Em$ $ha^{-1}yr^{-1}$, that could be a negative value that surpass the benefit of carbon fixation. On the other hand, young native forests assessed at Piracicaba river basin have carbon fixation (in NPP) near to 113 Em$ $ha^{-1}yr^{-1;}$ although lower service value, there is a positive balance of carbon in the system.

Although biological nitrogen fixation has the higher monetary value in forests, it refers to a wide range calculated for global forests (1 to 300 kg N ha^{-1} yr^{-1}); the maximum value could not be applied due to it uncertainty. Considering the next important nitrogen service, the nitrate leaching and runoff, this output flow is higher in sugarcane cropland (maximum of 4082 Em$ ha^{-1} yr^{-1}) than in native forest (maximum of 1229 Em$ ha^{-1} yr^{-1}). Due to the artificial inputs as fertilizer for sugarcane (until 100 kg of N per hectare per year) there is higher loss of nitrogen carried by water that could reflect the negative costs of water pollution with nitrate and the eutrophication of water bodies due excess of nitrogen load in agriculture.

CONCLUSIONS

Results obtained showed that:

(1) Emergy per mass of nitrogen flows are higher than water ones because nitrogen within global processes are less abundant (in terms of grams per year) than the magnitude of water within global hydrological cycle. As a consequence, values of ecosystem services (Emdollar per gram) increases with scarcity of a given chemical element (such as N, C) or molecule (such as water).

(2) Intensive agriculture of sugarcane increases biomass productivity (reflected on high carbon fixation) but carbon doesn’t stay in the system and is lost through cropping, cane-burning, and soil emissions from organic matter decomposition; moreover, there are superior losses of nitrogen (due to leaching and volatilization of nitrogen fertilizer) and water (due to the decrease of water percolation) if compared with native forest.

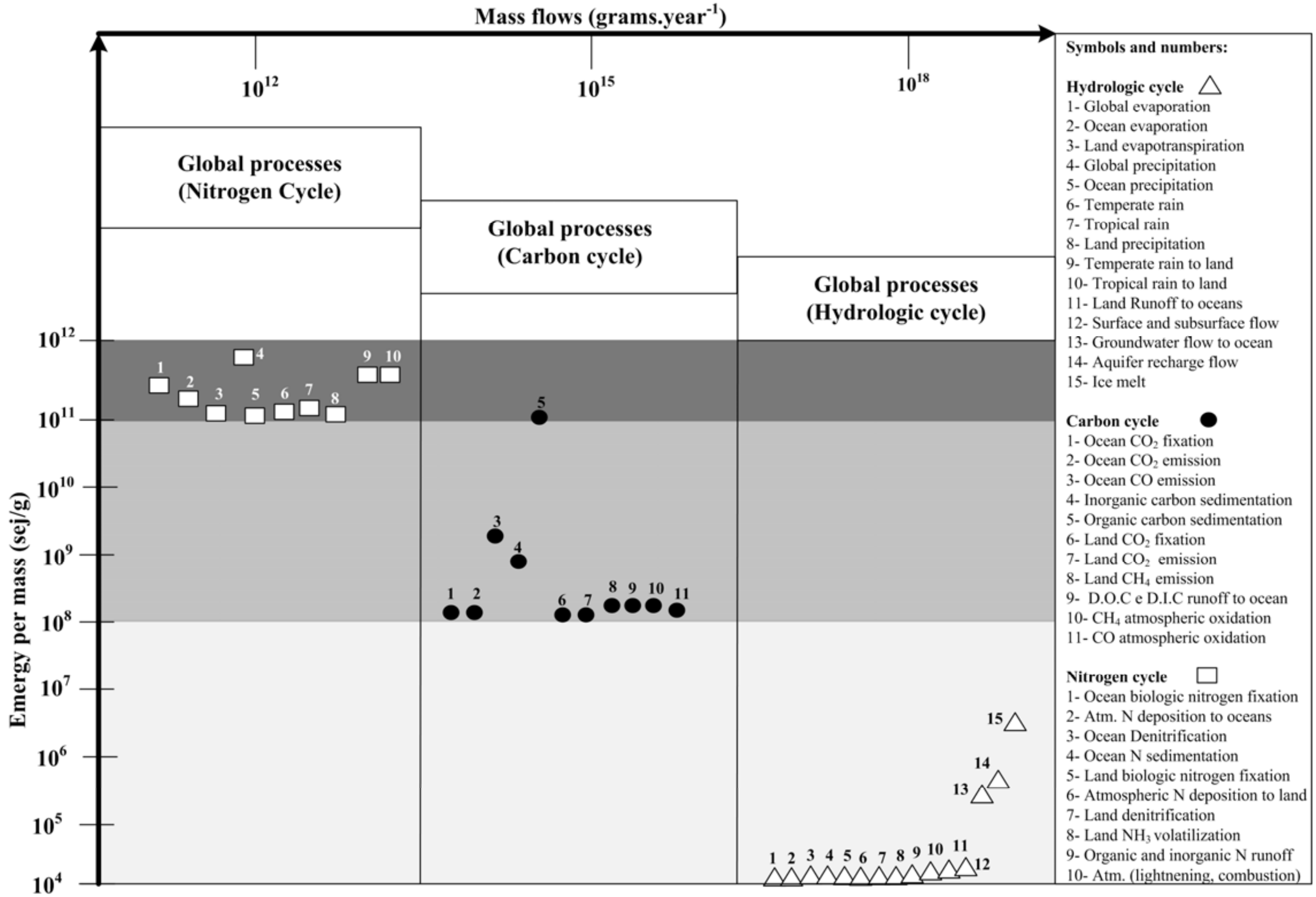

Figure 2. *Global emergy per mass values and flows of water, carbon and nitrogen cycles (Watanabe, 2008)*

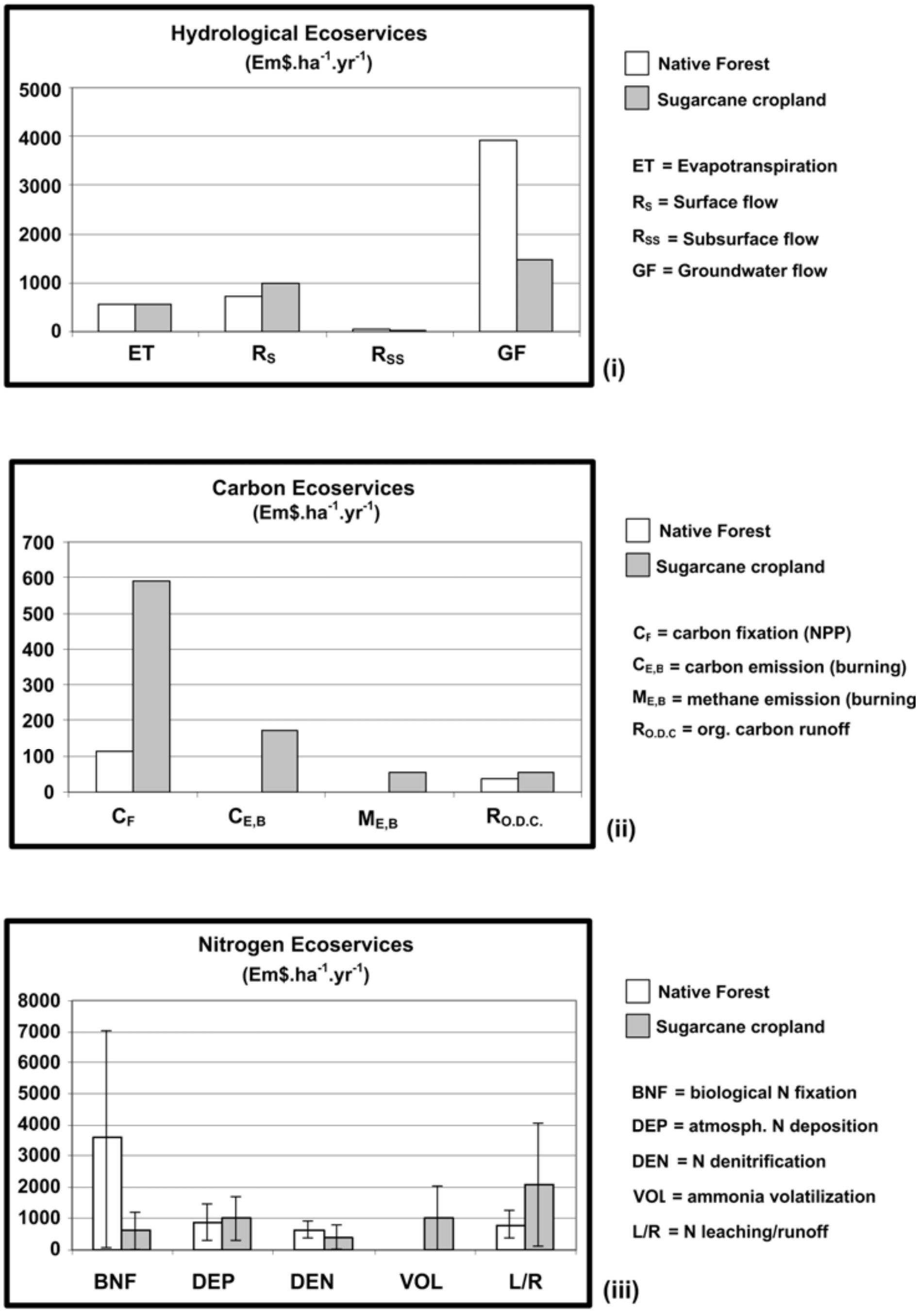

Figure 3. *Emergy-based values for (i) hydrological ecoservices, (ii) carbon ecoservices and (iii) nitrogen ecoservices at native forest and sugarcane crop.*

(3) For practical aims, such as public policies involving payment for ecosystem services losses, the most significant ES alteration related to the forest conversion to sugarcane field assessed in this paper was the higher loss of nitrogen observed in nitrate leaching/runoff flow, which value reaches Em$ 4082 $ha^{-1}yr^{-1}$. This high magnitude of monetary value suggests that fertilizer inputs applied in intensive sugarcane systems can be dangerous due to the innumerous consequences of possible groundwater pollution.

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APPENDICES

APPENDIX A. CALCULATIONS OF CARBON MASS FLOWS AT NATIVE FORESTS.

1) Photosynthesis general value of 1725 g $C.m^{-2}.yr^{-1}$ from Malhi et al. (1999) for temperate forests, equivalent to 17.25 Mg $C.ha^{-1}.yr^{-1}$.

2) Total ecosystem respiration (autotrophic and heterotrophic) estimated by difference between photosynthesis carbon flow (Malhi et al. 1999) and the net primary production (NPP = 2.97 Mg C $ha^{-1}yr^{-1}$) observed in a subtropical forest located at Piracicaba river basin. Total respiration = Photosynthesis – NPP = 17.25 – 2.97 = 14.28 Mg C ha^{-1} yr^{-1}.

3) Net primary production in a subtropical forest at Piracicaba river basin. Silveira et al. (2000) simulation estimate 6.6 tons of biomass per hectare annually; Weber et al.(2006) estimates 45% carbon content in this forest biomass;

Carbon in NPP = 6.6 (biomass) * 0.45(ton carbon / ton biomass) = 2.97 Mg C $ha^{-}1.yr^{-1}$;

4) Methane natural emission by native forests was not found.

5) Organic dissolved carbon (O.D.C.) loss observed at a “Cerradao” vegetal formation situated at a Santa Rita do Passa Quatro watershed has been quantified as 4.9 to 7.0 kg C ha^{-1} yr^{-1} (Silva et al., 2007).

APPENDIX B. CALCULATIONS OF CARBON MASS FLOWS AT SUGARCANE CROPLAND

1) Campos (2003) has quantified sugarcane productivity as 101 $Mg.ha^{-1}.yr^{-1}$ of biomass. Manfrinato e Rocha (2002; apud Gomes, 2005) estimates 34% of sugarcane biomass is dry-matter, and 45% of dry-matter is carbon.

Carbon fixation = 101E+06 (g sugarcane ha^{-1} yr^{-1}) * 0.34 (dry matter / sugarcane biomass) * 0.45 (g C/ g sugarcane) = 1.55 E+07 g C ha^{-1} yr^{-1}. This value doesn’t include the carbon within underground biomass (as roots).

2) Campos (2003) quantified an emission of 15.96 E+06 g $CO_2.ha^{-1}.yr^{-1}$, that includes organic matter decomposition (foliage) and biomass burning emissions relative to a sugarcane productivity of 101 $Mg.ha^{-1}.ano^{-1}$. Conversion to carbon mass:

Carvalho (2006): CO_2 Emission = 15.96 E+06 (g CO_2) * (12/44) * (g C/g CO_2) = 4.35 E+06 g C ha^{-1} yr^{-1}.

3) Campos (2003) estimates that exists an additional flow of CO_2 from soil during the year of 11,265 kg $C.ha^{-1}.yr^{-1}$, maybe originating from underground biomass, as roots.

4) Methane flow calculated as 1.36 E+05 g C-CO_2 equivalent $.ha^{-1}yr^{-1}$, obtained from biomass burning for cropping. Carvalho (2006) converts equivalents of CO_2 to CH_4 emissions as follows:

CH_4 emission = 1,36 E+05 g CO_2 eq / [23 (global warming potential) * (16/12) * (gC/gCH_4) * (12/44) * ($gC/gC0_2$) = 15650 g CH_4 ha^{-1} yr^{-1}.

Converting methane mass to carbon mass (g C) = 15650 (g CH_4) * (12/16) * (gC/gCH_4) = 1.17 E+04 g C ha^{-1} yr^{-1}, emitted as methane.

5) Mean flow of organic dissolved carbon (O.D.C.) observed in sugarcane-covered watersheds near to 9.4 E+03 g C ha^{-1} yr^{-1} (Silva et al., 2007).

APPENDIX C. CALCULATIONS OF NITROGEN MASS FLOWS AT NATIVE FOREST.

1) Forest biological nitrogen fixation (BNF) ranges from 1 to 300 kg $N.ha^{-1}.yr^{-1}$, depending on the system ability of nodulation (Silvester, 1983).

2) Nitrogen deposition flows at Atlantic Forest in Cunha watershed can vary from 9.0 kg $N.ha^{-1}.yr^{-1}$ (Ranzini et al. 2007) to 50.8 $kgN.ha^{-1}.ano^{-1}$ (Forti et al. 2005; apud Ranzini et al. 2007), principally at regions near dense urban zones.

3) Nitrate denitrification simulated by Ranzini et al. (2007) at Atlantic Forest in Cunha-SP watershed shows that it varies from de 9.92 a 27.7 kgN ha^{-1} yr^{-1}.

4) There is no data describing ammonia volatilization flows at natural forests.

5) Inorganic dissolved carbon (NID) losses at Atlantic Forest in Cunha watershed has a flow ranging from 2.0 to 4.0 kg N ha^{-1} yr^{-1} (Silva et al., 2007); measures at Cunha-SP shows that inorganic forest outputs (NO_3^- and NH_4^+) from leaching reach 7.6 kg N. ha^{-1} yr^{-1} (Ranzini et al., 2007).

APPENDIX D. CALCULATIONS OF NITROGEN MASS FLOWS AT SUGARCANE CROPLAND.

1) Coelho et al. (2003)[b] estimates that nitrogen biological fixation (NBF) contribution on sugarcane is 31% (for RB72 454 cane genotype) of 172 kg total nitrogen (Bergamasco, 2003) content in one hectare of sugarcane, equivalent to 53 kg $N.ha^{-1}.yr^{-1}$. This value was obtained with nitrogen fertilizer (urea) input of 100 kg N ha^{-1} yr^{-1}.

2) Total nitrogen atmospheric deposition at Piracicaba river basin varies from 4.3 to 6.0 g $N.m^{-2}.yr^{-1}$ (Lara et al., (2001)) equivalent to 43 to 60 kg N ha^{-1} yr^{-1}. The minimum value of 9.0 kg $N.ha^{-1}.yr^{-1}$ was estimated by Ranzini et al. (2007).

3) Bergamasco (2003) has simulated a denitrification flow of 0.09 kg N ha^{-1} yr^{-1} in a sugarcane cropland without foliage burning, and without nitrogen fertilization.

Campos (2003) has measured a N_2O flow of 4,777 E+03 g as C-CO_2 equivalent $ha^{-1}yr^{-1}$, originating from foliage burning and another flows during the year. Nitrogen fertilization of 75 kg N ha^{-1} yr^{-1} (as ammonium nitrate).

Carvalho (2006) conversion to obtain N_2O mass flow: N_2O emission= 4,777 E+03 g CO_2 eq / [296 (global warming potential) * (44/28) * (g N_2O/g N) * (12/44) * (g C/g CO_2)] = 37,506.31 g N_2O ha^{-1} yr^{-1}. Conversion to nitrogen mass (g N) = 37,506.31 (g N_2O) x (28/44) x (g N/g N_2O) = 23,867 g N $ha^{-1}yr^{-1}$, emitted as nitrous oxide.

4) Flows simulated for sugarcane cropland system without biomass burning management showed a range for ammonia volatilization from 0 to 82.4 kg N ha^{-1} yr^{-1}, due nitrogen fertilization of 0 and 100 kg N ha^{-1} yr^{-1} (as urea), respectively (Bergamasco, 2003).

5) Nitrate leaching rate has been simulated and ranged from 0.48 to 25.2 kg $N.ha^{-1}$ yr^{-1}, due urea annual fertilization of 0 to 100 kg N per hectare , respectively (Bergamasco, 2003).