BIOMASS AND CARBON IN NON-WOODY VEGETATION, DEAD WOOD AND LITTER IN IGUAÇU NATIONAL PARK

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Abstract

This study was carried out in 2004 in Iguacu National Park (INP), Paraná-Brazil. The vegetation is composed of Araucaria Forest (AF) (13.1%) and Seasonal Semi-deciduous Forest (FES) (86.9%). Two types of materials were analyzed: litter (L) and woody material (W) (alive (A) and dead (D)), and classified by diameter: W1(0–0.70 cm), W2(0.71–2.5 cm), W3(2.51–7.50 cm), and W4(≥7.5 cm). The results for the FES was 21.7 t/ha, with 42.4% in diameter class WD4 (8.98 t/ha) and 38.6% was litter (8.17 t/ha). The FOM was 12.87 t/ha, with 78.9% litter. The carbon stocks of the materials varied between 36.2% and 42.1% (for litter and WD4), both in the FES. There were no significant differences between the carbon stocks of the forest types. Rather differences existed between the pools (5% ANOVA and Tukey test). In the FES the carbon stock was 8.29 t/ha, which is equivalent to 30.41 tCO_{2e}/ha, and in the FOM the stock was 4.94t/ha or 18.12 tCO_{2e}/ha. For the vegetation types the carbon stock in INP was 8.35 tC/ha and 30.62 tCO_{2e}/ha for the FES and FOM, respectively. The carbon pools analyzed in this study contribute significantly to the total carbon stock of a forest ecosystem and should always be taken into consideration when developing estimates for a forest.
Keywords: Araucaria; Seasonal Semideciduous Forest; Araucaria Forest; climate change; carbon fraction.

Resumo

Biomassa e carbono na vegetação não arbórea, madeira morta e serapilheira no Parque Nacional do Iguaçu. O trabalho ocorreu em 2004 no Parque Nacional do Iguaçu (PNI), Paraná. O PNI tem Floresta Ombrófila Mista (FOM) (13,1%) e Floresta Estacional Semidecidual (FES) (86,9%). Foram analisados L – serapilheira e W – materiais lenhosos (vivos – A e mortos – D), classificados pelos diâmetros: W1 (0 a 0,70 cm), W2 (0,71 a 2,5 cm), W3 (2,51 a 7,50 cm) e W4 (≥7,51 cm). Os resultados da FES mostram 21,7 $t.ha^{-1}$, sendo 42,4% do WD4 (8,98 $t.ha^{-1}$) e 38,6% da serapilheira (8,17 $t.ha^{-1}$). Na FOM, foram 12,87 $t.ha^{-1}$ (78,9%) da serapilheira. Os teores de carbono dos materiais variaram de 36,2 a 42,1% (para serapilheira e WD4), ambos na FES. Não houve diferenças significativas nos teores de carbono, havendo diferença nos compartimentos (5% ANOVA) e teste de Tukey. Na FES, o estoque de carbono foi 8,29 $t.ha^{-1}$, correspondendo a 30,41 $tCO_{2e}.ha^{-1}$, e na FOM de 4,94 $tC.ha^{-1}$ e 18,12 $tCO_{2e}.ha^{-1}$. Para as fitofisionomias, o estoque de C no INP foi de 8,35 $tC.ha^{-1}$ e 30,62 $tCO_{2e}.ha^{-1}$. Os reservatórios de C analisados no estudo apresentam participação importante no estoque total de C do ecossistema florestal, devendo sempre serem considerados quando do desenvolvimento de estimativas para a floresta.
Palavras-chave: Araucária; Floresta Estacional Semidecidual; Floresta Ombrófila Mista; mudanças climáticas; teor de carbono.

INTRODUCTION

The heavy use of fossil fuels and their harmful effects on the Earth are one of the principal problems of contemporary society. In addition to emissions from industrial and urban pollution, the process contributes negatively to the already devastating human pressure on forests, and leads to increased concentration of greenhouse gases (GHGs) from burning. This in turn leads to decreased carbon assimilation by reducing photosynthetically active biomass. According to Houghton (1998), between 1850 and the present, deforestation has contributed approximately one third of the increased concentrations of CO_2 in the atmosphere. According to the IPCC (2007) to prevent disastrous changes in global climate, the planet's average temperature should not increase by more than 2 ºC. The problem is that to achieve this goal, carbon dioxide emissions must be reduced by between 50% and 85% by 2050 based on the 1990 emissions.

The conservation of forests is an important way to mitigate the problems caused by elevated CO_2 emissions, the main driver of an augmented greenhouse effect. Although the Kyoto Protocol treats reforestation activities, forest conservation as a natural regenerative process at present is not considered in the regulatory market for carbon credits. Corte (2005) cites that LULUCF (Land Use and Land Use Change and Forestry) activities imply reforestation in order to fix atmospheric carbon in the form of CO_2. Thus, forest plantation owners may benefit from this process by developing projects, whether in voluntary markets or mandatory market of the Kyoto Protocol.

Although Brazil has important role to play in climate change, particularly with respect to the role of forests, many knowledge gaps about the carbon cycle in natural ecosystems persist. Leon (2000) writes that the primary function of forests is to fix the carbon dioxide using absorbed water in the soil. The process produces carbohydrates, which ultimately restores to the earth part of the fixed carbon, which becomes a component part of the earth's crust, and maintaining the balance of gases, water and nutrients, process known as photosynthesis.

Forest ecosystems have evolved as an important means of reducing carbon dioxide in the atmosphere. Besides storing carbon in their tissues, these ecosystems return part of the sequestered carbon as litter, and this is the result of the periodic shedding of leaves, twigs, fruits and sometimes, entire trees. In order to describe cycling patterns it is essential to study the dynamics of production and decomposition of litter with implications for biomass and carbon transfer to the environment (GOLLEY, 1983), as it is the primary pathway by which nutrients and organic matter return to the soil (PAGANO; DURIGAN, 2000). Likewise, including non-woody vegetation in these studies also improves the overall picture of forest ecosystems' contribution to climate change.

Given this context, this study aimed to quantify the carbon and biomass stocks in non-arboreal vegetation, dead wood and litter, to unit area, in the Iguaçu National Park, located in the West of Paraná State, one of the most important protected areas of the country, and represent one very few remnants of Atlantic Forest belonging to Seasonal Semideciduous and Araucaria Forest types. Additionally, differences in carbon content of the compartments and forest formations were evaluated.

METHODS

Study area location and physical environment

This study was conducted in the Iguaçu National Park (INP), the largest of the protected areas in the State of Paraná, Brazil. INP extends through counties of Céu Azul (49.56%), Foz do Iguaçu (7.48%), Matelândia (19.87%), São Miguel do Iguaçu (11.73%) and Serranópolis do Iguaçu (16.92%), in the West of the state. It is located between parallels 25º 05' and 25º 40' South latitude and the meridians 54º 30' and 54º 40' West longitude, bordered to the North by the old wagon-road between Cascavel and Foz do Iguaçu and the BR-277 highway, to the East by the Rio Gonçalves Dias, to the West by the Rio São João, and to South by the Rio Iguaçu. The park has a perimeter of approximately 420 km and an area of 185.265,50 ha (MELO, 2005).

According to Köppen classification system, the region's climate is of Cfa type, or mesothermal humid subtropical with hot summers and mild temperatures between 15 °C and 25 °C. The rains are typical of a transitional climate with high rainfall between 1,100 mm and 2,000 mm annually. The average intensity of the winds in the area is around 11 km/h (MELO, 2005).

Vegetation in the study area

PNI's vegetation is composed of two distinct forest formations or vegetation types: Mixed Ombrophylous Forest (MOF), also known as "Araucaria Forest," comprising 13.1% of the PNI and Seasonal Semideciduous Forest (SSF), comprising 86.9% of the park's area.

FOM is one of the most important forest formations in southern Brazil, distributed widely into parts of Brazil's neighboring countries: northern Argentina and southeastern Paraguay. The most striking species of this formation is *Araucaria angustifolia*, also known as the Paraná pine, whose abundance and large stature distinguish it from other trees. The Paraná pine is associated with several other species of different families such as Lauraceae, Myrtaceae, Aquifoliaceae, Anacardiaceae, Flacourtiaceae, Euphorbiaceae and Sapindaceae (PIZATTO, 1999; DURIGAN, 1999; BARTH FILHO, 2002). The Brazilian Geographic Institute (IBGE 1992) further refines the Araucaria Forest into sub-categories: Mixed Alluvial Araucaria Forest, Mixed Sub-Montane Araucaria Forest, Mixed Montane Araucaria Forest and Mixed High Montane Forest.

The FES is characterized by communities where 20-50% of individuals occupying the upper canopy lose their leaves during the cold and dry season. This occurs discontinuously in virtually every states in the northeast, southeast and south of the country and partly in the central-west, reaching the Uruguay River basin in Paraguay and in Argentina. The FES has four established formations based on the relative altitude and latitude of their occurrence. The most important formations in Brazil are: Alluvial, Lowland, Sub-montane and Montane (IBGE, 1992). According to Lorenzi (1992). FES's most representative species are: *Cupania vernalis*, *Helietta longifoliata*, *Nectandra megapotamica*, *Luehea divaricata*, *Trichilia clausseni*, *Enterolobium contortisiliquum* and *Parapiptadenia rigida.*

Data collection

The 135 plots were placed randomly to collect litter and dead wood (woody material (ML)) throughout the PNI, 29 in the FOM and 106 in the FES, proportionally to the area of each forest types. Plots were defined by a 1m x 1m square metal frame. Materials were collected between the months of July and August 2004.

All live vegetation up to 1.80 m above the soil was removed from within the frame. The remaining live vegetation (i.e., above 1.80 m above the soil, which includes plants with diameter at breast height – DAP ≥ 2.5 cm) was dealt with in another study. All material was classified by diameter, identified as W1 (0 to 0.70 cm), W2 (0.71 to 2.5 cm), W3 (2.51 to 7.50 cm) and W4 (≥ 7.51 cm) as well as litter (L) containing the leaf litter or fine litter, as shown in table 1. The material was further sub-classified as either alive or dead.

Table 1. Types of materials collected of compartment.
Tabela 1. Tipos de materiais coletados dos compartimentos.

Litter	Woody 1 (0 to 0.7 cm)		Woody 2 (0.71 to 2.5 cm)		Woody 3 (2.51 to 7.6 cm)		Woody 4 (>7.6cm)	
L	Live	Dead	Live	Dead	Live	Dead	Live	Dead
	WA1	WD1	WA2	WD2	-	WD3	-	WD4

WA1: Live Woody Material; WD1: Dead Woody Material; WA2: Live Woody Material 2; WD2: Dead Woody Material 2; WD3: Dead Woody Material 3; WD4: Dead Woody Material 4. *Note*: Live Woody Material categories 3 and 4 were not observed.

Live material was collected and the thickness of the organic layer (dead material) was measured. The dead woody material was separated from the litter and sorted by diameter. The green weight of living and dead materials was recorded.

Laboratory and statistical analysis

Materials (litter, woody material alive and dead) were dried and weighed again. They were then passed through a mill with six blades and a metal sieve till a powdery consistency was achieved. The mill was cleaned with a jet of compressed air to avoid contamination between samples. The ground samples were then placed in plastic containers and labeled for determining carbon content.

The carbon content in the samples was determined using a LECO brand analyzer model C-144, which has software for digital recording of samples. In this method, solid material samples are completely combusted at a temperature of 1000 °C. Before proceeding to the analyses, certain checks were conducted, such as the temperature of the analyzer and other calibration checks.

The data collected in the field and analyzed in the laboratory were analyzed by computer programs licensed to the UFPR.

Descriptive statistical data of carbon content per compartment and vegetation types was performed. The average carbon concentrations of pools was submitted to ANOVA and Tukey (α = 0.05) using SPSS software (Statistical Package for Social Sciences Version 13.0 for Windows, SPSS).

Additionally, an estimate was made of carbon stocks and CO2e per vegetation type and compartments, per unit area.

RESULTS AND DISCUSSION

Dry biomass stock of compartments

Table 2 presents the results for dry biomass weight per pool and by vegetation type in the Iguaçu National Park. One notices that Seasonal Semideciduous Forest had 21.17 t/ha of dry biomass, or almost 65% more than the Araucaria Forest (12.87 t/ha). The results for the FES indicate that 42.4% of dry matter corresponds to the MLM4 pool, followed by the litter pool, with 38.6% (8.17 t/ha). These results are similar those of Pinto *et al.* (2008) in study in Seasonal Semideciduous Forest in Viçosa - MG, who found values between 6.31 and 8.82 t/ha dry material. In a study by Santos *et al.* (2007), for a remnant of FES in Maringá, the authors found an average 8.85 t/ha litter, 62.60% of which corresponded to the leaves, 6.46% to the twigs and branches and 30.94% to other materials. In the study by Martins and Rodrigues (1999), total litter production was 5.968 t/ha, predominantly made up of leaves, with 75.87% of the total dry weight (4.528 t/ha/year). The results of this study indicate a lesser proportion of live woody material in FES as compared to the studies previously cited, representing 3.5% and 4.5% for WA1 and WA2, respectively.

In the case of dry biomass for the FOM, the average value per hectare was lower, i.e., 12.87 t/ha, which represents 78.9% of the litter. Britez *et al.* (2005) studied the litter deposition in an Araucaria Forest in São Mateus do Sul, Paraná, reporting a total yield of 6.53 t/ha. Wisniewski *et al.* (1997) conducted two years of study in an Araucaria Forest in Ponta Grossa, Paraná, and found that the average annual production of litter was greater in winter, with 2.4769 t/ha and lower in summer, 0.8136 t/ha. In that study 57% of the total deposited material was leaves, 30% were branches and 13% was miscellaneous materials.

Table 2. Dry biomass stock by pool and vegetation type.
Tabela 2. Pesos secos de biomassa por compartimento e por fitofisionomias.

Vegetation type	Pool	Dry weight (t/ha)	Composition of biomass (%)
Seasonal Semideciduous Forest	L	8.17	38.6%
	WD 1	0.40	1.9%
	WD 2	0.76	3.6%
	WD 3	1.15	5.4%
	WD 4	8.98	42.4%
	WA 1	0.75	3.5%
	WA 2	0.96	4.5%
Total		21.17	100.0%
Araucaria Forest	L	10.15	78.9%
	WD 1	0.60	4.7%
	WD 2	0.93	7.2%
	WD 3	0.65	5.1%
	WD 4	-	0.0%
	WA 1	0.35	2.7%
	WA 2	0.18	1.4%
Total		12.87	100.0%

Figueiredo Filho *et al.* (2003) observed in their studies in Araucaria Forest in São João do Triunfo, Paraná, total biomass values of between 7.481 t/ha and 7.99 t/ha for years 1 (spring/1998) and 2 (winter/2000) respectively of the study, with an average of 7.7368 t/ha. The same authors found foliage biomass composition of 55.1% and 58.9%, branches of 30.6% and 22.5%, and 14.3% and 18.6% of miscellaneous materials, respectively, for years 1 and 2 respectively.

Caldeira *et al.* (2007) found an average accumulation of litter of 7.99 t/ha in an area of Araucaria Forest in southern Paraná. In the same region Watzlawick *et al.* (2002) reported values of dry litter biomass were 7.90 t/ha, 8.59 t/ha and 7.60 t/ha for the initial, intermediate and advanced stages of regeneration, respectively.

Considering the values reported in the work of Watzlawick *et al.* (2002) for the average biomass of vegetation above ground components of trees in the FOM, ranging from 68.37 t/ha, 168.84 t/ha and 397.79 t/ha for the initial, intermediate and advanced stages, respectively, the biomass values found in the FOM for this work may represent between 3.2% and 18.6% of total biomass and carbon stock in this vegetation type, depending on stage of regeneration considered. As FOM in the study area of the PNI is predominantly comprised of medium stage vegetation, it can be said that such a forest type corresponds to roughly 12.2% of the biomass and the carbon stocks. In turn, FES forest type would represent 87.8% of the biomass and carbon stocks of the park da biomass, taking into account an average biomass stock ranging from 69.18 t.ha-1 to 152.35 t.ha-1 (BOINA, 2008).

Carbon content

The average carbon concentrations varied between vegetation types and from pool to pool, as shown in the descriptive statistics (Table 3). For the FES vegetation type, the highest carbon content was observed in the WD4 pool, at 42.11%, and was associated with the lowest coefficient of variation, indicating greater homogeneity in values. The next highest was the WD1 pool, at 39.92%, followed by WD2 and WD3, with values of 39.34% and 39.12% respectively. The lowest carbon content in this vegetation type was observed in the litter pool, at 36.22%. Besides these averages, it is important to note the maximum and minimum values, as well as the coefficient of variation and standard deviation of each pool.

Table 3. Descriptive statistics the carbon for pools and vegetation types.
Tabela 3. Estatísticas descritivas dos teores de carbono por compartimento e por fitofisionomias.

Vegetation type	Pool	Average carbon	Standard	CV%	Maximum	Minimum	N
Seasonal Semideciduous Forest	L	36.22	4.10	11.32	41.04	24.88	30
	WD 1	39.92	1.81	4.52	43.71	36.12	32
	WD 2	39.34	1.60	4.08	43.46	36.32	25
	WD 3	39.12	2.14	5.47	41.99	34.98	9
	WD 4	42.11	1.49	3.55	43.17	41.05	2
	WA 1	37.33	1.69	4.54	39.69	31.80	34
	WA 2	37.51	3.28	8.74	42.01	28.60	13
Araucaria Forest	L	38.21	2.21	5.80	40.78	33.57	12
	WD 1	39.96	2.05	5.13	42.55	37.54	10
	WD 2	39.71	1.06	2.68	41.91	38.30	11
	WD 3	39.70	0.07	0.18	39.75	39.65	2
	WD 4	-	-	-	-	-	-
	WA 1	37.63	2.06	5.48	41.12	32.92	12
	WA 2	38.08	1.55	4.08	40.40	36.18	5
Both	L	37.60	3.74	10.18	41.04	24.88	39
	WD 1	39.93	1.93	4.84	43.71	35.63	42
	WD 2	39.45	1.455	3.687	43.46	36.32	36
	WD 3	39.23	1.93	4.92	41.99	34.98	11
	WD 4	42.11	1.49	3.55	43.16	41.05	2
	WA 1	37.41	1.78	4.75	41.12	31.80	46
	WA 2	38.20	2.87	7.61	42.01	28.60	17

For the FOM vegetation, type the highest value of the carbon content was observed in the WD1 pool at 39.96%, followed by the WD2 pool at 39.71% and the WD3 at 39.70%. The lowest value was observed in the WA1 pool, with an average of 37.63% carbon, whose maximum and minimum values were 41.12% and 32.92%, respectively. Litter resulted in an average carbon content of 38.21%, varying between 40.78% and 33.57%. Watzlawick *et al.* (2002) found carbon concentrations of 37.85%, 38.42% and 38.16% for the initial, intermediate, and advanced stages of regeneration for the litter produced in an FOM type landscape in southern Paraná.

Carbon concentrations found in other biomes were similar. Piccolo et al. (1994) found 39.4% in a *terra firme* forest in central Rondônia. Grace *et al.* (1995) showed that the highest concentrations of carbon were observed in the branches, which corresponded to the woody material, and which would suggest that the carbon assimilated by the forest is being incorporated into the woody fraction, returning to the soil as the branches fall to the ground. In a study by Cabianchi (2010), the average concentration of carbon in the litter observed over a two-year study was 44.8%, ranging from 45.0% to 44.5% for years 1 and 2, respectively.

Taken together, the two vegetation types in this study have a combined litter carbon concentration of 42.11% for the WD 4 pool, 39.93% for the WD 1, 39.45% for the WD 2, and 39.23% for the WD 3. The lowest carbon concentration observed was in the WA 1 and litter, with 37.41% and 37.60%, respectively.

To verify statistical differences between the levels of carbon, ANOVA and Tukey tests were performed, and revealed no statistically significant differences between the two vegetation types. However, average carbon concentrations differed between pools ($p = 0.0012$), as shown in table 4. Results of the Tukey test suggested four distinct groups.

The first was formed by the WA1, L, WA2 and WD3 pools, whose carbon concentrations varied between 37.41% and 39.23%. The second group was formed by the L, WA2, WD3, and WD2 pools, with average values ranging from 37.60% to 39.45%. The third group consisted of the WA2, WD3, WD2, WD1 pools, with carbon concentrations ranging from 38.20% to 39.93%. The fourth group refers to the WD4 pool and had average carbon concentration of 42.11%.

Table 4. Average carbon concentrations of pools.
Tabela 4. Médias dos teores de carbono entre os compartimentos avaliados.

Pool	Average	Tukey Test (p=0,05)			
WA 1	37.41	a			
L	37.60	a	b		
WA 2	38.20	a	b	c	
WD 3	39.23	a	b	c	
WD 2	39.45		b	c	
WD 1	39.93			c	
WD 4	42.11				d

Carbon stocks

For the FES vegetation type, considering all compartments assessed by this study, we estimate a carbon stock of about 8.29 tC/ha, corresponding to 30.41 tCO_{2eq}/ha. Based on this result, there is a greater accumulation of carbon in the MLM4 pool with 3.78 tC/ha (or 13.85 tCO_{2eq}/ha), followed by litter compartment with 2.96 t/ha (10.85 tCO_{2eq}/ha). Carbon is represented in the other pools to a lesser extent: less than 0.5 tC/ha or <1.8 tCO_{2eq}/ha (Table 5).

A lower carbon stock was observed in the FOM vegetation type compared to the other vegetation type, i.e., 4.94 tC/ha (or 18.12 tCO2eq/ha). In this vegetation type, the largest carbon stock (78.58%) resided in the litter pool, with 3.88 tC/ha (or 14.24 tCO_{2eq}/ha). Carbon was represented in other pools to a lesser degree. The values found in this study were similar to those reported by Watzlawick *et al.* (2002), who found values for litter of 2.99 t/ha, 3.30 t/ha, and 2.90 t/ha for the initial, intermediate and advanced stages of regeneration in the FOM. Caldeira *et al.* (2008) report organic carbon concentrations in litter in three successional stages of Atlantic Forest in Blumenau, Santa Catarina, with average values of 1.26 tC/ha, 1.55 tC/ha and 1.51 tC/ha.

When considering both vegetation types, considering the values as a function of their composition in the same area of PNI, it appears that the WD4 pool had the highest carbon stock with 3.78 tC/ha (or 13.85 tCO_{2eq}/ha), followed by the litter pool, with 3.08 t/ha (or 11.29 tCO_{2eq}/ha). Under these conditions the total carbon accumulation was 8.35 tC/ha and 30.62 tCO_{2eq}/ha.

Table 5. Carbon stocks and CO_{2e} by pool and by vegetation type.
Tabela 5. Estoques de carbono e CO_{2e} por fitofisionomia e compartimentos.

Vegetation type	**Pool**	**Carbon stock**	**CO_{2eq}**
Seasonal Semideciduous Forest	L	2.96	10.85
	WD 1	0.16	0.59
	WD 2	0.30	1.10
	WD 3	0.45	1.67
	WD 4	3.78	13.85
	WA 1	0.28	1.01
	WA 2	0.36	1.34
Total		8.29	30.41
Araucaria Forest	L	3.88	14.24
	WD 1	0.24	0.86
	WD 2	0.37	1.36
	WD 3	0.26	0.95
	WD 4	-	-
	WA 1	0.13	0.48
	WA 2	0.07	0.24
Total		4.94	18.12
Both	L	3.08	11.29
	WD 1	0.17	0.63
	WD 2	0.31	1.13
	WD 3	0.43	1.58
	WD 4	3.78	13.85
	WA 1	0.26	0.94
	WA 2	0.32	1.20
Total		8.35	30.62

Considering all compartments assessed by this study, we estimate a carbon stock of about 1,454,547 tC, corresponding to 5,335,648 tCO_{2eq} in Iguacu National Park.

CONCLUSIONS

- Non-woody vegetation, dead wood and litter accumulate to a lesser extent in Araucaria Forest than in Seasonal Semideciduous Forest, mainly due to seasonality and the impact of the leaf fall from deciduous species. Therefore, it is very important that landscapes be stratified before estimates are made in order to reduce uncertainties in estimates of biomass and carbon stocks in forest ecosystems.
- The carbon concentrations found in the various vegetation types were not significantly different from each other. Therefore, average values may be used within pools, but not between, since differences were detected between pools as revealed in the four groups in the Tukey test.
- It can be concluded that the non-arboreal vegetation, dead wood and litter comprise significant proportion of the vegetation types occurring in the PNI. Therefore, these should be taken into account when estimating biomass and carbon stocks in forest ecosystems.
- The results of this study can be used for forest carbon projects and compensating GHG emissions. Consequently, they can be helpful in action to mitigate climate change.

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