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Litterfall and organic matter decomposition in a seasonal forest of the eastern Chaco (Argentina)

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Abstract: Amazonia and the Gran Chaco are the largest phytogeographic units of the Neotropical Region. The Forest Wedge of the Santa Fe province of Argentina is the southernmost part of the Eastern Chaco, and there are three main types of forest, 1) the mixed dense forests, 2) the *Schinopsis balansae* “quebrachal” and 3) the *Prosopis nigra* var. *ragonesei* forests, distributed along an environmental gradient correlated with topographic elevation. In this paper litterfall and organic matter decomposition of four species were studied in two different microsites in a *Schinopsis balansae* forest during three years. Litter fall varied along the year following seasonal environmental variation but litterfall variations between years were not significant. Litterfall was not uniform over the whole surface, under close canopy monthly average litterfall amounts 32.67 g/m^2, in open gaps 4.47 g/m^2 and 15.07 g/m^2 under medium density canopy. Organic matter decomposition, like in other forests, was a negative exponential function of time, and the decomposition rate is independent from the microsites where it falls, 0.15 and 0.12 in sunny and shadow microsites respectively for *Maytenus vitis-idaea*, 0.10 and 0.11 in sunny and shadow microsites respectively for *Achatocarpus praecox*, 0.04 and 0.03 for *Acacia praecox*, 0.04 and 0.06 for *Schinopsis balansae* in sunny and shadow microsites respectively. Shurbs litter was decomposed faster than the tree litter, and the shurbs litter nutrientes level was also higher. Therefore the rate of organic matter decomposition is more correlated with leaf characteristics than with environmental variables.

Key words: Chaco, forest communities, litter fall, litter decomposition, organic matter circulation, *Schinopsis balansae* forests.

Organic matter circulation has been studied in tropical rainforests, boreal deciduous forests, and other forests but very little is known about carbon cycle in chaquenian forests. Litterfall and decomposition as well as seasonal changes of bioelements in four species of chaquenian forests have been recently studied (Palma *et al.* 1998, 2000) but the problem has never been analysed on *Schinopsis balansae* Engl. forests (quebrachal) of the Cuña Boscosa of Santa Fe, Argentina. The “quebrachal” is the most widespread type of forest in the southernmost portion of the Eastern Chaco. It is a xerophitic forest where *Schinopsis balansae* is abundant together with *Acacia praecox* Gris., *Aspidosperma quebracho blanco* Schlecht., *Prosospis* sp. (*P. alba* Gris., *P. nigra* (Gris) Hieron. and their hybrids) *Myrcianthes cisplatensis* (Camb.) Berg. and many other tree species and shrubs (Lewis & Pire 1981). They have been heavily fell for tanin industry in the past, followed by grazing cattle and timber extraction for fuel and charcoal production.

Litterfall is the most important way of energy and organic matter transfer from the forest canopy to decomposer organisms of the soil surface (Lousier & Parkinson 1976, Hirabuki 1991). If litterfall is analysed, it is possible to asses its variation, storage, composition and decomposition (Hart 1995), organic matter production rate, and to quantify nutrient availability and its recycling capacity, which is different among species (Montagnini *et al.* 1993) Nutrient liberation from organic matter is determined by the environment and the physico-chemical properties of the litter that falls (Facelli & Pickett 1991).

The most important factors that affect litter decomposition are on one hand temperature, humidity and aeration which affect soil biota activity (Santa Regina *et al.* 1989, Martin *et al.* 1994), and on the other hand, litter composition and quality (Velazco 1992-1993, Montagnini *et al.* 1993, Gallardo & Merino 1993, Couteaux *et al.* 1995). Litter quality is related to leaf characteristics such as lignine/nitrogen ratio (Facelli & Pickett 1991, Cornelissen 1996). Nutrient content of litter is determined by mineral content of foliar tissues and time and mode of deposition (Lousier & Parkinson 1976). Organic matter deposition and decomposition rate may not be constant along the year and over the surface, so they can contribute to the creation of different microhabitats and therefore they may have an effect on the floristic composition, productivity and diversity of the community (Carson & Peterson 1990, Molofsky & Augspurger 1992, Facelli & Facelli 1993). The same type canopy disturb can have different effects on different communities of similar architecture, but with different amount of litter on the ground (Carson & Peterson 1990). These together with other factors contribute that mature forests became a mosaic of several different units (Hirabuki 1991).

The object of this paper is to analyse litterfall, its amount and temporal and spatial distribution, and litter decomposition on different microsites on a *S. balansae* forests of the Cuña Boscosa (Forest Wedge) of Santa Fe (Argentina). The hypotheses are that: 1) litterfall varies along the year and between years and it is not uniform over the whole surface. 2) the organic matter decomposition rate (k) is different on different soil microsites. 3) the organic matter decomposition rate depends on the chemical composition and leaf characteristics.

MATERIALS AND METHODOS

The region and the study site: Amazonia and the Gran Chaco are the most important phytogeographyc units of South America. The Cuña Boscosa (Forest Wedge) of Santa Fe is the southernmost portion of the Eastern Chaco and runs from 28ºS to 30ºS paralell, between the River Paraná and the Submeridional Lowlands, covering more than 1,000,000 hectares (Lewis y Pire 1981). Climate is humid warm with Summer rainfalls and a relatively long Winter drought, average annual rainfall ranges from 800 to 1100 mm. (Burgos 1970). Soils are a complex mosaic of different types which often have a halo-hydromorphic character (Espino 1981). There are three fundamental kinds of forest distributed along soil gradients correlated with topographic elevation (Ragonese y Covas 1940, Lewis 1991). At the highest part of the gradient are the mixed dense forests (Lewis *et al.* 1994), then the quebrachal of *S. balansae* (Lewis *et al.* 1997) and at the lowest part the *Prosopis nigra* var *ragonesei* Burk. Forests. The study area was on a relatively well recovered stand of *S.balansae,* "quebrachal" placed in the Provincial Ministry of Agriculture estate, 20 km west of Vera, in Santa Fe Province, Argentina.

Data collection: on a transect 22 funnels were layed 1 m above the ground every 10 m, 11 funnels were under closed canopy, 6 on open gaps and 5 under medium density canopy. Each was made of glass fiber 0,70 m x 0,70 m. Every month from January 1995 up to December 1997, fallen litter from the trees was collected from every funnel. Leaves from the litter were oven dried for 48 h at 70°C and then weighted.

Decomposition rate of organic matter, (k), of four species, 2 trees (*S. balansae, Acacia* *praecox*), and 2 shrubs (*M. vitis idaea* and *Achatocarpus praecox*) was analysed. These species were chosen for their relative importance in terms of cover and abundance in the quebrachal. Leaves were collected from at least three individuals of each species, in late Autumn previous to their fall, oven dried, and then 10 g were put in 20 x 20 cm sacs of 1 mm mesh, and left on the ground in two different microsites; 1) in open gaps exposed to the sun and 2) in the shadow of closed canopy forest. Every month during a whole year, three sacs of each species and microsites were taken, oven dried and weighted.

As litter decomposition is a negative exponential function of time, the rate (k) of decomposition can be expressed with Olson (1963) equation for organic matter decomposition with no production:

$$k= - [\ln(W/Wo)]/t$$

where W: is the dry weight, Wo: initial dry weight and t: time.

Leaves were collected from three individuals of each of the four species and analysed to determine nutrient content and C/N ratio, in Autumn 1996 and again on Spring 1997 in order to find out if differences were intrinsic to the species or were due to translocation. Organic matter was determined by weight loss after ignition in a furnace. Mineral nutrients were determined by dissolving the ashes in hydrochloric acid, Potassium by flame photometry, and Calcium and Magnesium with the Varsene titration procedure. Nitrogen was determined by Kjeldahl method (Jackson 1958). Two replicas of all analysis were done.

Data analysis: litterfall data were analysed by Kruskal-Wallis test. Organic matter left over after a year of decomposition of the four species and on the two microsites were analysed using one and two way ANOVA test. Mean values of organic matter decomposition (k) of each species and microsites were compared using Friedman rank test. Differences in nutrient content among the leaves of the four species were analysed by Kruskal-Wallis test.

RESULTS

Litterfall varied along the year and between years (Fig. 1). Although, leaves from the canopy fall to the ground the whole year around, litterfall is more important during Winter than during Summer. Most leaves fall from April to September, with a maximum from June to August; August in 1995, July in 1996 and June in 1997. Litterfall annual average was 20.89 g/m^2 in 1995, 21.26 g/m^2 in 1996 and 22.44 g/m^2 in 1997, however differences between years are not significant. Nevertheless the litterfall is not constant over the whole surface, funnels in an open canopy collect far less leaves and debris than those under a close canopy. As an average, litterfall from the tree layer is 32.67 g/m^2 under a close canopy, 4.47 g/m^2 in large canopy gaps and 15.07 g/m^2 under a medium density canopy and these differences between microsites are significant ($p<.05$) (Table 1).

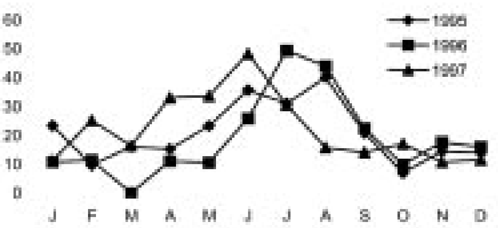

Fig. 1. Monthly average litterfall. Y axis g/m^{-2}; X axis months.

TABLE 1

Monthly average litterfall in g/m^2

Year	Open gaps	Medium density canopy	Close canopy
1995	5.88	15.1	31.32
Sd	4.44	11.49	12.03
1996	3.84	14.57	32.11
Sd	3.26	7.39	24.96
1997	3.7	15.55	34.58
Sd	2.38	13	9.41

Sd=standard deviation

In all cases Olson (1963) model fit well decomposition data, r^2 was high in all species and in both microsites except for *S. balansae* in open gaps and *Acacia praecox* under dense canopy, however deviations from the model were not significant. Decomposition rates are significantlty different between species when analysed with one way ANOVA ($p<0.05$, and r^2 = 0.98). When analysed with two way ANOVA 93.67% of total variation correspond to species which is significant, and 10.06% to microsites, which is not significant.

Decomposition rates of *S. balansae* and *Acacia praecox* are significantly different ($p<.05$) from those of *M. vitis-idaea* and *Achatocarpus praecox* on the sun microsite while under shadow microsite are significantly different between *S. balansae* and *M vitis-idaea*, between *Acacia praecox* and *M. vitis-idaea* and between *Acacia praecox* and *Achatocarpus praecox* (Table 2). The decomposition rate in both microsites of *S. balansae* and *Acacia praecox* trees is similar between them, as well as it is between *M. vitis-idaea* and *Achatocarpus praecox* shrubs. But there are significant differences of organic matter decomposition rates between the tree species and shrubs; organic matter decomposition in shrubs is faster than in trees (Fig. 2 and 3).

TABLE 2

Leaf decomposition parameters of each forest species

Single exponential model (Olson, 1963)

		K				r-2		n
Species	Time (yr)	sun		shadow		sun	shadow	
Schinopsis balansae	1	0.04	a	0.06	b	0.59	0.86	4
Acacia praecox	1	0.04	a	0.03	a	0.87	0.52	4
Achatocarpus praecox	1	0.10	b	0.11	c	0.84	0.80	4
Maytenus vitis-idaea	1	0.15	b	0.12	c	0.87	0.92	4

Decomposition values were always fitted to the negative exponential model, therefore according to the decomposition rates found, the “half life” for accumulation or decay (0.693/k) of tree litter more than doubled “half life” shrub litter, and the time required to reach 99% of accumulation or decay (5/k) is shown in Table 3 (Olson 1963).

Although there may be significant differences in the amount of organic matter and nutrient content of leaves of the four species (Table 4), the most significant differences ($p=.05$) were in the ammount of ashes and, Potassium, Calcium and Magnesium. *Achatocarpus praecox* and *M. vitis idaea* had a higher Calcium and Magnesium content than the big trees and *Achatocarpus praecox* had a higher Potassium content than any other species (Fig. 4 a, b, c).

DISCUSSION

Litterfall from the canopy occurs throughout a long time during the year, however it is not very important until May and comes almost to and end in September. Most trees, such as *S. balansae, Acacia praecox* and *Prosopis* sp are deciduous, but a few tree species like *A. quebracho blanco* and *M. cisplatensis* and some shrubs like *M. vitis-idaea* keep part of their foliage the whole year. Strong frosts accelerate the whole process but they affect in a different way each individual

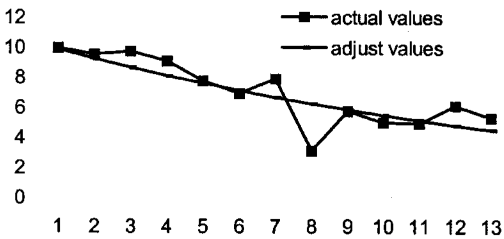

Fig. 2a.

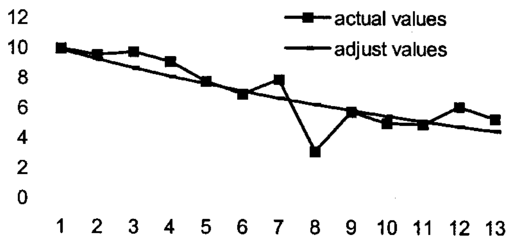

Fig. 2b.

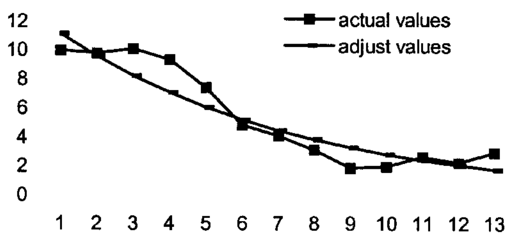

Fig. 2c.

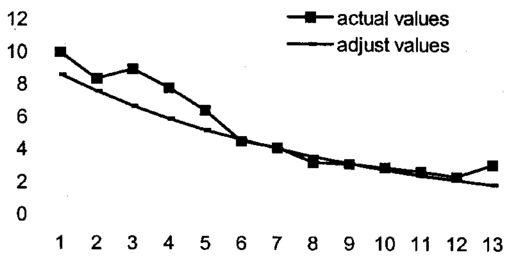

Fig. 2d.

Fig. 2. Litter decomposition rate in shadow microsites from June 1996 during a year. Y axis k, X axis months. a) *Schinopsis balansae*, b) *Acacia praecox*, c) *Achatocarpus praecox*, d) *Maytenus vitis-idaea*.

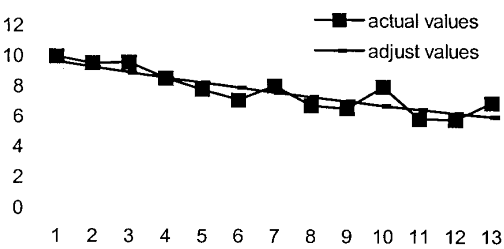

Fig. 3a.

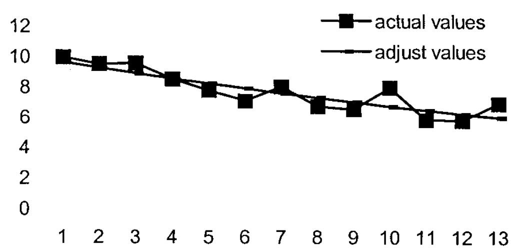

Fig. 3b.

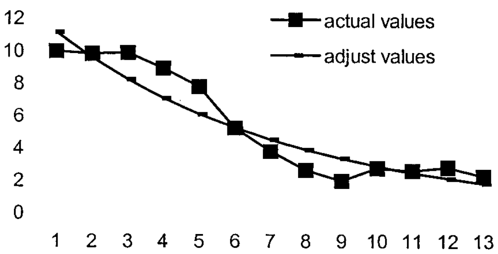

Fig. 3c.

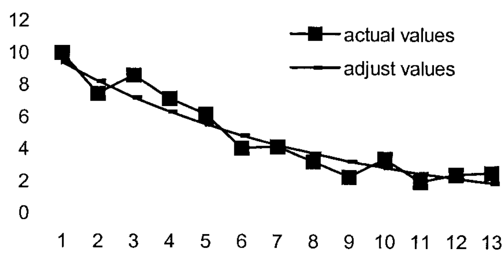

Fig. 3d.

Fig. 3. Litter decomposition rate in sunny microsites from June 1996 during a year. Y axis k, X axis months. a) *Schinopsis balansae*, b) *Acacia praecox*, c) *Achatocarpus praecox*, d) *Maytenus vitis-idaea*.

TABLE 3

Parameters for exponential accumulation of organic matter with steady litterfall rate

	Half-life		5/k	
	Microsites			
Species	Sun	Shadow	Sun	Shadow
Schinopis balansae	17.32	11.55	125	83
Acacia praecox	17.32	23.10	125	166
Achatocarpus praecox	6.93	6.30	50	45
Maytenus-vitis-idaea	4.62	5.77	33	41

TABLE 4

Significative diferences in nutrient content between species

	Om	C/N	C	A	P	K	Ca	Mg
Sb; Ap	-	*	-	-	*	-	*	-
Sb; Mv	*	-	*	*	*	-	*	*
Sb; Tn	*	-	*	*	*	*	-	*
Ap; Mv	*	*	*	*	-	*	*	*
Ap; Tn	*	-	*	*	-	*	*	*
Mv; Tn	-	*	-	-	-	*	-	-

Sb=*Schinopsis balansae*, Ap=*Acacia praecox*, Mv=*Maytenus vitis-idaea*, Tn=Achatocarpus praecox, Om=organic matter, C/N=ratio carbon/nitrogen, C=Carbon, A=Ashes, P=phosphorus, K=potassium, Ca=calcium, Mg=magnessium, * p=0.001, - =ns

according to its position in the forest. Those trees protected by other ones, on more humid ground or at the edge of internal ponds, keep part of their leaves for a longer period during Winter, even until the Spring sprout. Nevertheless, leaves fall continuously, especially after strong frosts and winds. During Summer some leaves fall if there is water shortage, strong winds or if they are old remaining leaves from a former season.

The amount of litter fall in the quebrachal, even under close canopy microsites (32 g/m^2), is within the range considered very low by Olson (1963) for montane forests of California, what means that they are relatively unproductive forests. We assume that the herbaceous layer contribution to soil organic matter is important in the big canopy gaps and may be important in other microsites too, but we have no data and the problem needs further research.

Litterfall below 100-300 g/m^2, increases yield and diversity in herbaceous communities, probably because it preserves moisture, while in woody communities less amount of tree leaves litter may intercept more light and may work as formidable barrier for germination (Carson & Peterson 1990).

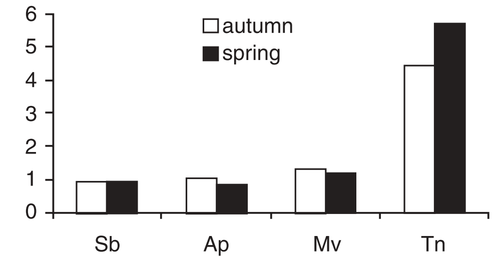

Fig. 4a.

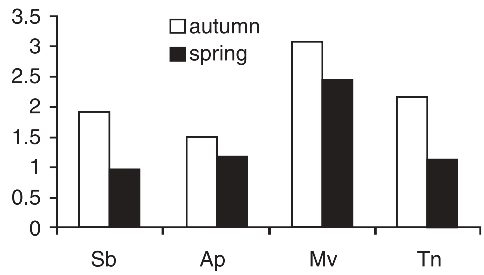

Fig. 4b.

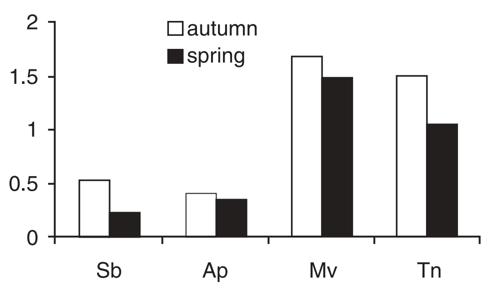

Fig. 4c.

Fig. 4. Rate (%) in ashes per species and season. a) K, b) Ca, c) Mg.

However, in tropical forests of Costa Rica there were more abundance of individuals in forest plantations where was found more accumulation of litter (Horn & Montagnini 1999, Carnevale & Montagnini in press).

Our results strongly support the hypothesis that litterfall varies along the year and that it is not homogeneous over the whole surface because the forest canopy is not uniform and there are big gaps without any trees at all. However, leaves are carried to gaps with no trees by the wind from the tall surrounding trees, and they are trapped by the grass mesh. Variation along the year follow seasonal variations, droughts and frosts, but between years differences were not significant in the analysed years.

Our results do not support the hypothesis that organic matter decomposition rate (k) is different on different soil microsites. As these forests are deciduous, during Winter there is little light interception by the forest and it is also the dry season, so there is a possibility that soil surface temperature and moisture are relatively homogeneous. In the same way, on Summer as the air is almost still inside the forest, temperature is high in the understory as well as under the grass canopy. Therefore, at this scale, environmental conditions for organic matter decomposition may be similar in both microsites.

Decomposition rates range from large negative values (*e.g.*, k < -1.0) in the tropics to very small negative values (*e.g.*, k = -0.001) at high elevations, high latitudes, and other areas of impeded decomposition (Olson 1963, Schelesinger 1977, 1981). Our results (k = -0.03 a k = -0.15) are within the range of values observed by other authors fot other species (k = -0.04 a k = -0.28) of the Chaco (Palma *et al.* 1998).

Litter decomposition rate of shrubs is higher than that of trees, that means a more rapid nutrient reposition to the system of shurbs rather than of trees. These differences in decomposition rate between trees and shurbs may be related to the higher nutrient level of *M. vitis-idaea* and *Achatocarpus praecox*, as in many other litter sources, higher levels of Ca, Mg, and K make litter more palatable, favouring microorganisms activity, therefore litter decomposition (Nicolai 1998, Berg 1998). Our data agree with other authors conclusions that litter decomposition rate is more related to leaves chemical composition than to environmental conditions (Day 1983, Facelli 1991, Alvarez Sánchez & Becerra Enríquez 1996, Scott & Binkley, 1997), and the results support the hypothesis that litter decomposition rate depends on leaves chemical composition.

The different "half life" and decomposition rates between trees and shrubs discussed above show that nutrient releasing time may be very different according to specific composition of litter, and this can compensate temporary nutrient losses such as litter sweeped from surface by heavy rains during Autumn or Spring.

Nevertheless, there are other factors that affect litter decomposition such as the composition of organic matter, celulose, hemicelulose, lignin, phenols, Si content (Keyser *et al.* 1978, Horner *et al.* 1987, Berg 1998), structural characteristics of the leaves, which are in need of further research. Also there should be analysed with more detail environmental conditions, moisture, flood length, temperature, etc. inside the "quebrachal" in order to have a better understanding of this complex process in this type of forest.

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RESUMEN

Amazonia y el Gran Chaco son las unidades fitogeográficas más importantes de la región Neotropical. La Cuña Boscosa de Santa Fe es el extremo austral del Chaco Oriental. Está cubierta por tres tipos fundamentales de bosques, 1) los bosques densos mixtos, 2) los "quebrachales" de *Schinopsis balansae* y 3) los bosques de *Prosopis nigra* var. *ragonesei*, los que están ordenados siguiendo un gradiente correlacionado con la topografía. En este trabajo se analiza la circulación de materia orgánica, la caída de la hojarasca durante tres años y la descomposición de la hojarasca de cuatro especies en dos micrositios diferentes del mismo bosque, durante un año. La caída de hojarasca es diferente a lo largo del año, siguiendo variaciones ambientales estacionales, y las diferencias interanuales no son significativas. La caída de hojarasca no es uniforme sobre la superficie, en las abras se registró un promedio de 4.47 g/m^2, bajo canopeo cerrado 32.67 g/m^2 y bajo canopeo semi cerrado 15.07 g/m^2. La descomposición de materia orgánica es independiente del micrositio donde se deposita. La hojarasca de los arbustos se descompone mas rápido que la de los árboles. La tasa de descomposición es de 0.15 al sol y 0.12 a la sombra para *M. vitis-idaea* y de 0.10 al sol y 0.11 a la sombra para *Achatocarpus praecox*, en los árboles disminuye a 0.04 y 0.03 para *Acacia praecox* y 0.04 y 0.06 para *S. balansae* en micrositio soleado y umbrío respectivamente. El contenido de nutrientes también es mayor en los arbustos. Por lo tanto y aparentemente, la tasa de descomposición de la materia orgánica está más correlacionada con las características de las hojas que con las variables ambientales.

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