Comparison of two different types of throughfall collectors

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Vergleich zweier Sammlersysteme für den Kronendurchlass

Introduction

The redistribution of rainfall by the canopy determines the amount of rain water that reaches the soil surface and typically results in marked spatial and temporal variability in throughfall (Levia & Frost, 2006; Keim et al., 2005). This spatial variability in throughfall has important effects on soil moisture (Coenders-Gerrits et al., 2013) and soil chemistry (Kohlpaintner et al., 2009; Raat et al., 2002), as well as subsurface stormflow generation (Hopp & McDonnell, 2011; Bouten et al., 1992). However, capturing this variability and understanding its controlling factors is not straightforward, in part because of the possible bias introduced by the use of different throughfall collectors or by adopting different experimental designs and sampling strategies (Zimmermann et al., 2010; Holwerda et al., 2006). Unlike rainfall, there are no standardized instruments or sampling designs to measure and monitor throughfall amount and variability in forested environments. Previous studies have shown that roving gauges are more likely to capture dripping points and thus give a better estimate of the average throughfall amount (Ritter & Regalado, 2014; Holwerda et al., 2006) but the roving of the gauges makes it more difficult to study the link between throughfall and soil moisture or soil chemistry.

In this study, we installed two types of throughfall collectors in a plot in a pre-Alpine broad-leaved forested hillslope in Italy and monitored throughfall 21 times to assess: *i*) the difference in throughfall amount obtained by the two types of collectors; *ii*) the difference in throughfall spatial variability based on the two types of measurements; and *iii*) if the two types of collectors identify a similar number of

Zusammenfassung

Der Kronendurchlass wurde in einer 500 m^2 Fläche an einem mit Buche und Kastanie bewaldeten Hangstandort im Italienischen Alpenvorland anhand zweier Sammelsysteme gemessen. Dies erfolgte mittels Kübel und Regenmesser. Die Ergebnisse zeigten unabhängig von Unterschieden in der Auffangfläche gleichwertige Größen des Kronendurchlasses. Allerdings zeigten sich Unterschiede aufgrund der räumlichen Verteilung hinsichtlich der Häufung (Clusterung) und der Ausreisserwerte. Diese Unterschiede sollten bei der Festlegung zukünftiger Messanordnungen berücksichtigt und vorab an alternativen Standorten getestet werden.

Schlagwörter: Kronendurchlass, Sammelsysteme, räumliche Variabilität, Punkt Skale.

Summary

Throughfall was measured in a 500 m^2 plot on a forested hillslope dominated by beech and chestnut trees in the Italian pre-Alps using two types of throughfall collectors: buckets and rain gauges. The collectors differed in size, number and spatial arrangement. The results show that despite the order of magnitude difference in the area covered by the collectors, the amount of throughfall measured by buckets and rain gauges statistically similar. However, there were differences in the spatial variability of throughfall and locations of local clusters and outliers. These differences should be considered in future throughfall studies that focus on the spatial variability in throughfall and its influence on soil moisture and soil chemistry and should be tested for other areas as well.

Key words: Throughfall, collector, spatial variability, dripping points, plot scale.

spatial clusters and outliers in throughfall. We hypothesized that the larger collectors, which represented a larger fraction of the plot, give a better estimate of mean throughfall but also integrate over a larger area, which results in a smaller spatial variability in throughfall.

Study area and methodology

Throughfall was measured from April 2013 to March 2014 in a 500 m^2 experimental plot (Fig. 1) on a hillslope of the forested Ressi catchment in the Italian pre-Alps. A detailed description of the catchment can be found in PENNA et al. (2015). The main tree species in the plot are beech and chestnut. The stem density in the plot is 3100 trees/ha; the basal area is 57.1 m^2/ha. The diameter at breast height varied between 1 and 61 cm (median: 4 cm). Two different types of throughfall collectors were used: buckets (BK; collecting area per bucket: 556 cm^2; capacity: 162 mm) and rain gauges (RG; collecting area per gauge: 47 cm^2; capacity: 90 mm). Fifty buckets were randomly distributed in the plot, while 40 rain gauges were installed on a regular grid (2.5 m by 3 m spacing). The buckets covered 0.56 % of the plot area, whereas the rain gauges covered 0.04 % of the area. Positions of the throughfall collectors were determined using a laser distance meter. A bucket and a rain gauge were installed in a nearby open area as well (approximately 150 m from the experimental plot) to collect gross rainfall.

The difference in throughfall amount and spatial variability in throughfall obtained by the two types of collectors was analyzed for 21 events. The rainfall characteristics for the events (Table 1) were determined from the inverse distance-weighted mean rainfall measured at three weather stations operated by the Regional Agency for Environmental Protection and Prevention of Veneto (ARPAV): Passo Xomo (1056 m a.s.l.), Contrà Doppio (725 m a.s.l.), and Castana (430 m a.s.l.), at 2.3, 3.9, and 4.8 km from the study area, respectively (PENNA et al., 2015).

We expressed throughfall as the fraction of rainfall that fell through the canopy and reached the ground (i.e., the ratio between throughfall measured at each collector (mm) and gross rainfall measured in the open area (mm), multiplied by 100). The bootstrap method (EFRON, 1979) was used to resample throughfall measured by the two types of collectors 10,000 times to compare the differences in the throughfall means for each measurement day. To investigate the optimum sample size for both throughfall collectors, we computed the number of collectors required to measure throughfall for each measurement day υ (HOLWERDA et al., 2006; KIMMINS, 1973):

$$m_v = \frac{z_c^2 \times CV_v^2}{c^2} \qquad (1)$$

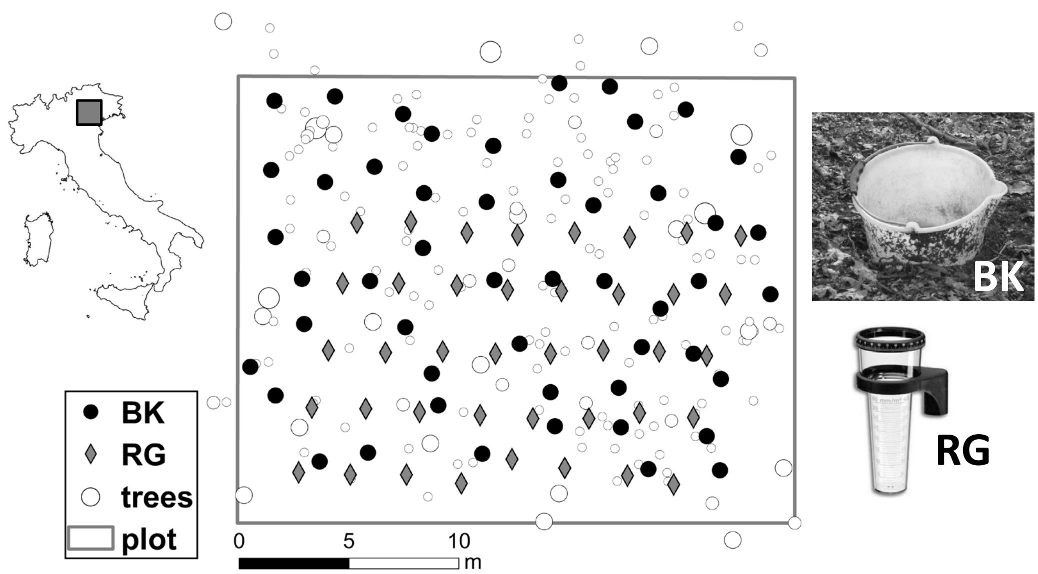

Figure 1: Location of the throughfall plot in Italy and the spatial distribution of the trees and the two types of throughfall collectors in the plot (BK: buckets; RG: rain gauges)

Abbildung 1: Lage der Kronendurchlass-Sammler in Italien und Verteilung der Bäume und Kollektoren am Standort (BK: Kübel, RG: Regenmesser) where m_υ is the required number of collectors, z_c is the critical value of 95 % confidence level (2.0; KIMMINS, 1973), c is the pre-set error of the mean (10 % in this study) and CV_υ is the coefficient of variation of throughfall measured on day υ.

The analysis of local spatial clusters and outliers in measured throughfall was carried out by computing the Local Moran's index I (ANSELIN, 1995) for each measurement day for both types of collectors:

$$I_i = \frac{r_i \sum_{j=1}^{n} w_{ij} r_j}{\sum_{j=1}^{n} r_j^2 / n} \qquad (2)$$

where $r_i = t_i - \overline{t}$, the deviation of the throughfall (t_i) measured at collector i from the mean throughfall, $\overline{t}$; w_{ij} is the spatial weight between collectors i and j and n is the total number of collectors. For the calculation of the Local Moran's I, the inverse distance weights were used to characterize the spatial relations between the throughfall collectors.

Table 1: Characteristics of rainfall events for the 21 throughfall measurements

Tabelle 1: Charakteristik der Niederschlagsereignisse während der 21 Messtermine

	Mean	Min.	Max.
Gross rainfall (mm)	28.6	4.0	82.6
Mean rainfall intensity (mm/hr)	1.3	0.3	4.0
Max. rainfall intensity (mm/hr)	6.8	1.0	29.8
Duration (hr)	23	8	44
Plot-averaged throughfall based on BK data (%)	80.1	69.7	93.5
Plot-averaged throughfall based on RG data (%)	82.2	68.4	100.2

3 Results and discussion

There was a significant difference (α = 0.05) between the average throughfall measured by the two types of collectors for only two measurements in fall, when beech and chestnut usually shed their leaves (31/10/2013 and 11/11/2013; Fig. 2). A negative difference in mean throughfall (i.e. a larger mean throughfall for the rain gauges than for the buckets) was detected for 15 of the 21 sampling times, likely due to the different number of dripping points detected by the buckets and rain gauges. Indeed, the difference between the 90th percentile of throughfall measured by buckets and rain gauges ranged between 0.6 % and –26.3 % (mean: –10.9 %). The difference between the throughfall means appeared to be independent from the gross rainfall amount. The non-significant difference in mean throughfall indicates that the arrangement of the collectors (sample size, collecting area and spatial distribution) was sufficient and did not affect mean throughfall measured in the study plot. The assessment of the minimum sample size for each measurement day showed that the number of collectors required to measure throughfall within 10 % of the mean with a 95 % confidence interval ranged between 9 and 36 for the buckets and between 12 and 185 for the rain gauges. These optimum sample sizes indicated that the number of required buckets was smaller than the number of samplers deployed in the field (n = 50) but that more rain gauges were needed to determine throughfall during small rainfall events. As expected, the optimum sample sizes (y) decreased with increasing gross

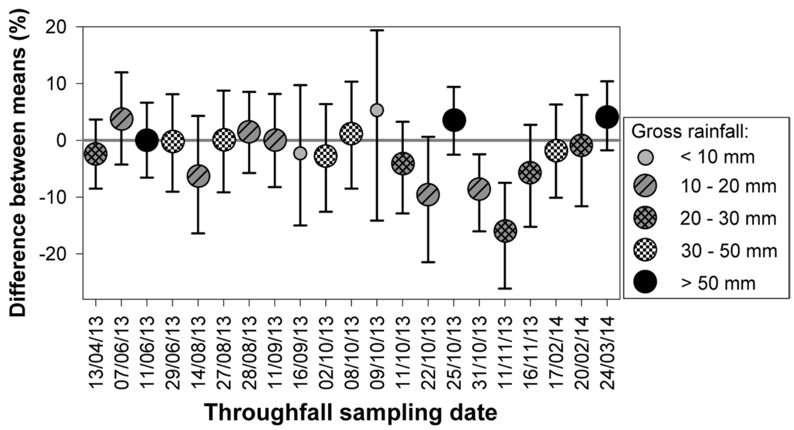

Figure 2: Difference between mean throughfall measured by the buckets and rain gauges for the 21 measurements. Means and 95 % confidence intervals were computed after application of the bootstrapping re-sampling method. The differences between the two means are significant when the confidence intervals do not intersect zero (solid line). A positive difference between the means indicates that the buckets collected more throughfall than the rain gauges

Abbildung 2: Unterschied zwischen dem mittleren Kronendurchlass aus gemessenen Kübel und Regenmessdaten an 21 Standorten. Mittelwerte und 95 %-Konfidenzintervalle anhand einer Bootstrapping Probenauswahl. Unterschiede zum Mittelwert sind signifikant sofern der Konfidenzbereich den Mittelwert (rote Linie) nicht schneidet. Ein positiver Wert der Differenz deutet auf einen höheren Messwert bei der Kübelmessung hin rainfall (*x*) following an exponential decay relation ($y = 23.98 * e^{-0.015*x}$, $R^2 = 0.28$, n = 21 for buckets; $y = 233.11 * e^{-0.106*x}$, $R^2 = 0.52$, n = 21 for rain gauges) because the spatial variability of throughfall decreased with increasing gross rainfall. There was also a significant negative correlation between gross rainfall and the 95 % confidence interval (Spearman's $\rho = -0.51$, $p < 0.05$, n = 21).

The observed spatial variability in throughfall was larger for the rain gauges than the buckets (Fig. 3). This difference in the observed spatial variability was probably related to the difference in the area of the two collectors: buckets have a larger collecting area than rain gauges, thus they integrate more small scale variability and consequently the variability between individual measurement locations is smaller. The difference between the standard errors of throughfall measured by the buckets and rain gauges as a fraction of precipitation (%) tended to decrease with increasing rainfall (Fig. 3d), suggesting less variability in throughfall and a reduced difference in spatial variability of throughfall measured by the two types of collectors for large events.

More significant local spatial clusters and outliers were identified in throughfall measured with the buckets than for rain gauges (Fig. 4a and b). The average number of measurements sites that were considered outliers was 2.3 % (buckets) and 1.5 % (rain gauges) for high throughfall sites surrounded by low throughfall (HL) and 1.4 % (buckets) and 1.3 % (rain gauges) for low throughfall sites surrounded by high throughfall (LH). The average number of high throughfall clusters (HH) was 2.1 % (for buckets) and 0.7 % (for rain gauges); the average number of low throughfall clusters (LL) was 0.7 % (for buckets) and 0.6 % (for rain gauges). We hypothesize that the difference in the number

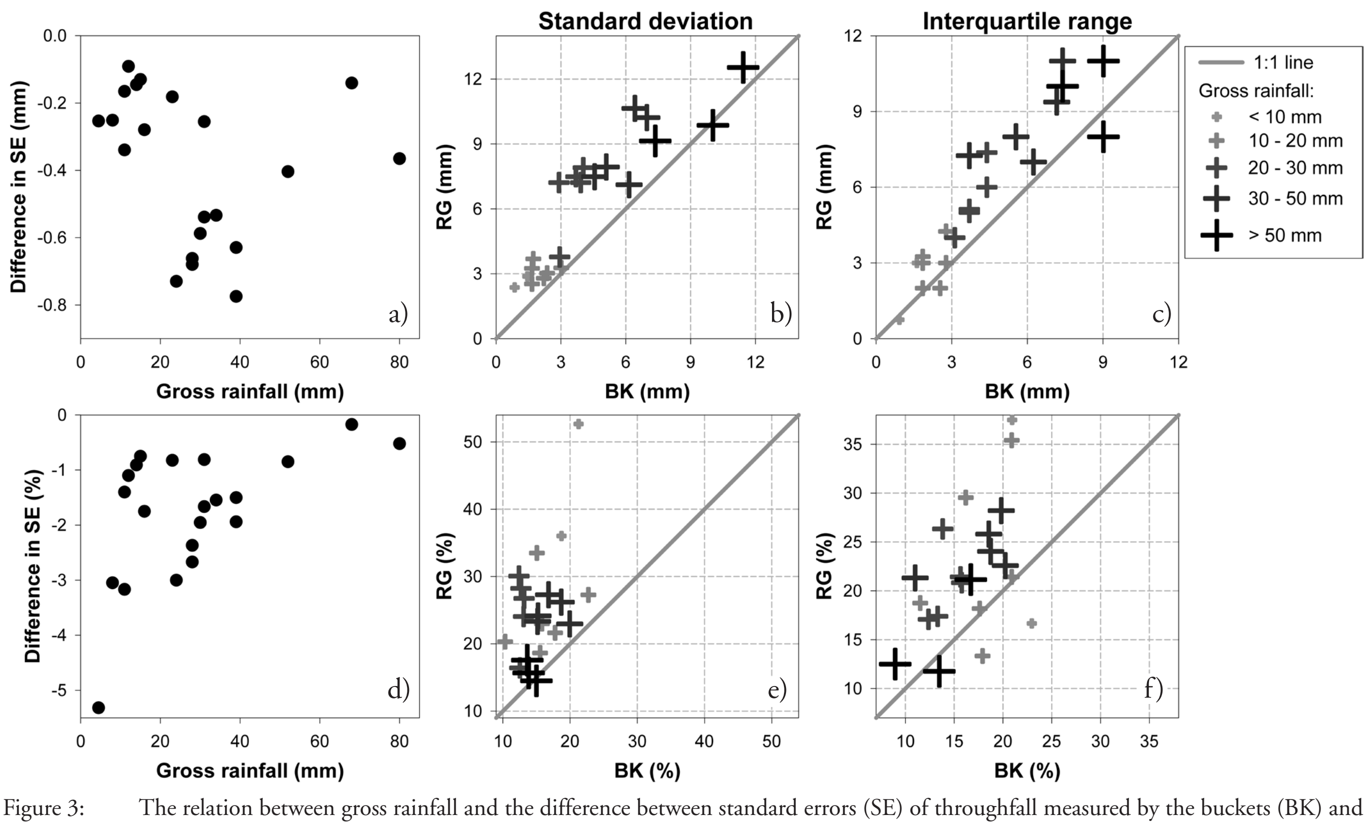

Figure 3: The relation between gross rainfall and the difference between standard errors (SE) of throughfall measured by the buckets (BK) and rain gauges (RG) (*a* and *d*) and the relation between the standard deviation (*b* and *e*) and interquartile range (*c* and *f*) of throughfall measured by the buckets (BK) and the rain gauges (RG). The measured throughfall is expressed as amount (mm) (*a–c*) and as a fraction of precipitation (%) (*d–f*). A negative difference indicates larger standard errors for rain gauges than for buckets. Symbols represent different event size classes; the pink solid line represents the 1:1 line (*b, c, e* and *f*)

Abbildung 3: Zusammenhang zwischen Gesamtniederschlag und dem Standardfehler des Kronendurchlasses mittels a) Kübel (BK) und d) Regensammler (RG). Zusammenhang zwischen Standardabweichung mittels b) Kübel (BK) und e) Regensammler (RG). Zusammenhang zwischen dem Interquartilswert mittels c) Kübel (BK) und f) Regensammler (RG). Die Werte des Kronendurchlasse sind als Absolutwerte (in mm) (a–c) und als Prozentwerte des Gesamtniederschlags (d–f) angegeben. Eine negative Differenz zeigt größere Standardfehler des Regensammlers gegenüber der Kübelmessung. Symbolgrößen charakterisieren verschiedene Ereignisklassen, die rote Linie zeigt die 1:1 Linie (*b, c, e* und *f*) of significant local outliers and clusters was due to the spatial arrangement of buckets and rain gauges in the plot. However, further analyses are needed to assess if the sample size and spatial arrangement have an effect on the identification of significant locations of large or small throughfall amounts. Local outliers, and especially dripping points (HL), were more frequent than local clusters, suggesting the importance of dripping points in shaping the spatial variability of throughfall. The overall low number of significant local clusters and outliers indicates the presence of a near random pattern in measured throughfall.

Dripping points (HL) displayed the highest persistence (i.e. temporal stability up to 38 % of the sampling times for the highest-frequency locations) (Fig. 4c), confirming the important role of dripping points in the spatial distribution of throughfall. When comparing the spatial distribution of the significant local spatial clusters and outliers, it appears that the clusters identified for bucket measurements were not far from the ones identified for the rain gauges when HL or LH were considered. However, locations where the canopy intercepted more rainfall (LL) for the buckets were far from similar locations for the rain gauges. In addition, sites that were significant high clusters for more than 10 % of the measurements for the buckets were not identified as high throughfall clusters by the rain gauge measurements. This suggests that the size of the collectors and the number of measurements influenced both the observed spatial variability and the spatial patterns of throughfall.

4 Conclusions

The results from this experimental study on the representativeness of different collectors for monitoring throughfall

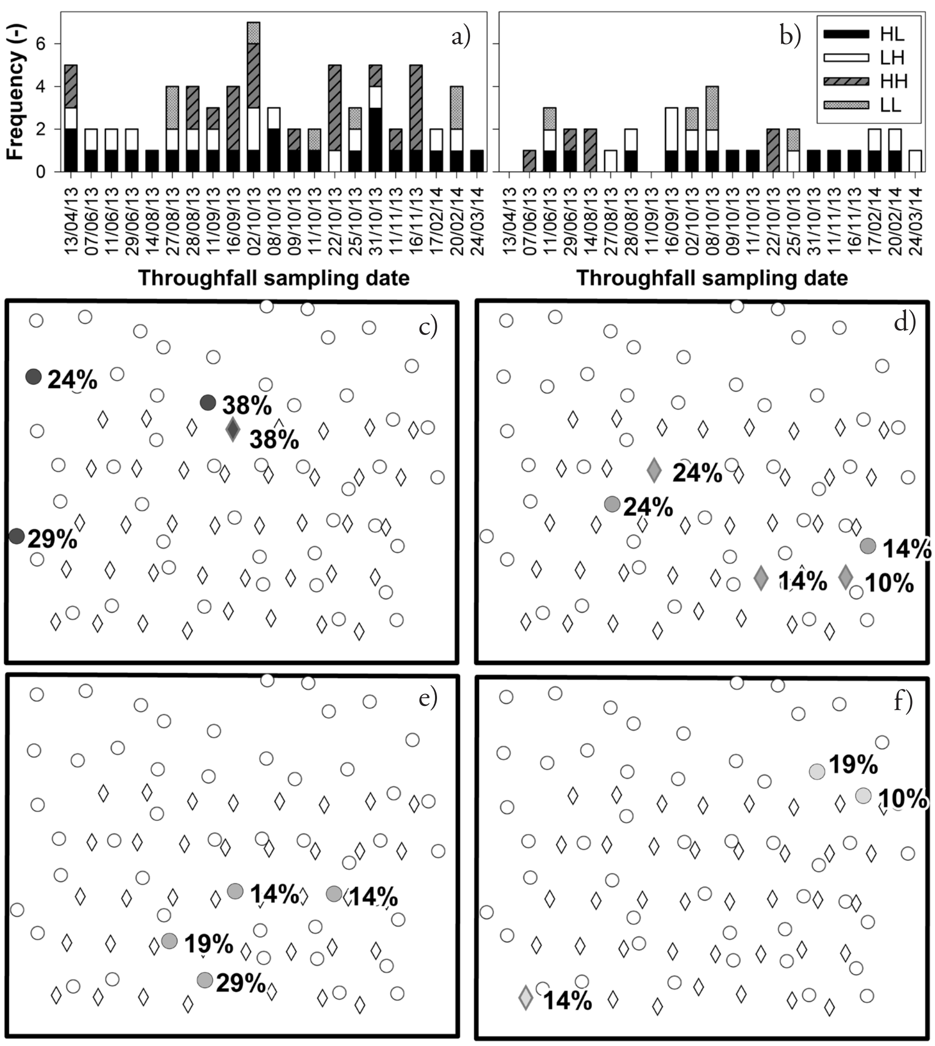

Figure 4: Frequency of significant local outliers and clusters of throughfall for each sampling date in buckets (*a*) and rain gauges (*b*) and location of the gauges that were significant local outliers or clusters for more than 10 % of the measurement dates: high throughfall surrounded by low throughfall (HL) (*c*); low throughfall surrounded by high throughfall (LH) *d*); clusters of high throughfall (HH) (*e*); low throughfall (LL) (*f*). The locations of the buckets are shown with circles, the locations of the rain gauges with diamonds

Abbildung 4: Häufigkeit signifikanter Ausreißer des Kronendurchlasses für einzelne Probentermine für Kübel- (a) und Regenmessungen (b). Lage von Ausreisser an mehr als 10 % der Termine: c) hoher Kronendurchlass umringt von geringem KD (HL); d) niedriger Kronendurchlass umringt von hohem KD (LH); e) Clusterbildung von hohem KD (HH) und f) Clusterbildung von geringem KD (LL): Lage der Kübel als Kreissymbole, Lage der Regensammler als Rautensymbole amount and spatial variability showed that buckets and rain gauges measured similar throughfall amounts during rainfall events, except during the fall. However, our findings indicate that different collectors and their spatial arrangement can lead to differences in the observed spatial variability of throughfall and the presence of local clusters and outliers. These differences should be considered when planning throughfall monitoring strategies to determine the effects of throughfall on soil moisture and soil water chemistry but need to be confirmed at other study sites as well.

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