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A preliminary study on the occurrence and significance of phytophagous arthropods and natural enemies on *Sapindus saponaria* saplings

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Abstract

Sapindus saponaria trees exhibit potential for global application in the restoration of degraded ecosystems. However, the susceptibility of *S. saponaria* saplings to detrimental effects caused by various phytophagous insects and mites necessitates a comprehensive evaluation. In this investigation, 48 *S. saponaria* saplings were scrutinized with a focus on phytophagous arthropods and their natural enemies. The assessment involved the determination of the Importance Index-Production Unknown (*% I.I.-P.U.*) to rank the arthropods based on their impact. Notably, phytophagous arthropods such as *Liriomyza* sp., *Bemisia* sp., Phaneropterinae, *Tetranychus* sp., *Tropidacris collaris*, and *Stereoma anchoralis* exhibited the highest *% I.I.-P.U.* on the *S. saponaria* saplings, highlighting their potential threat to future commercial crops given their association with crop pests. Conversely, natural enemies, including *Cycloneda sanguinea* and *Pseudomyrmex termitarius*, demonstrated the highest *% I.I.-P.U.* on these saplings. This underscores the significance of these natural predators in mitigating the impact of herbivorous arthropods on *S. saponaria* saplings. The presence of *C. sanguinea* and *P. termitarius* suggests their potential value in enhancing the resilience of *S. saponaria* saplings by effectively reducing the population of herbivorous arthropods.

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Introduction

Sapindus saponaria (Sapindaceae) is widely distributed throughout the Americas[1], attaining heights of up to eight meters[2]. In Brazil, it is ubiquitously present across all regions[3]. Renowned for its ecological significance, this species is extensively employed for the reclamation of degraded ecosystems globally[4−6]. Additionally, the fruits of *S. saponaria* find utility in Brazilian folk medicine, primarily for their saponin content, while its seeds and wood are utilized in the creation of jewelry and baskets, respectively[2,7]. Despite the economic importance of this plant, the knowledge about its associated arthropods remains largely deficient. A recent discovery in China identified a novel species, *Leptopulvinaria sapinda* (Hemiptera: Coccidae), as an assailant of *S. saponaria*[8]. However, comprehensive insights into the arthropod fauna associated with this plant are still lacking. Notably, insects and mites pose potential threats to *S. saponaria* saplings, and the mitigating influence of spiders on defoliation caused by beetles is recognized. The intricate interactions between the plant and its arthropod inhabitants warrant further investigation to elucidate the ecological dynamics and potential implications for the sustainability of *S. saponaria* populations.

The aim of this investigation was to assess the population dynamics of phytophagous insects, mites, and natural enemies associated with 48 *S. saponaria* saplings over a two-year period. The quantification and comparison of these arthropod species were conducted utilizing the Importance Index-Production Unknown (*% I.I.-P.U.*), a metric derived as a percentage from the Importance Index (*I.I.*)[9,10]. This methodology enabled the classification and ranking of the arthropods based on their relative importance to the studied *S. saponaria* saplings, providing a quantitative basis for evaluating their ecological significance within the examined timeframe.

Materials and methods

This research was undertaken at the 'Instituto de Ciências Agrárias da Universidade Federal de Minas Gerais (ICA/UFMG)', Brazil, spanning the period from April 2015 to March 2017. For comprehensive information regarding climate classification, latitude, longitude, altitude, and soil characteristics, please refer to the supplementary details provided in Alvares et al.[11] & Silva et al.[12].

Comprehensive information pertaining to seedling production, the substrate employed, field planting procedures, fertilization practices, irrigation protocols, and other relevant details can be found in Silva et al.[12]. The quantification of defoliation percentage caused by insects, the assignment of damage scores resulting from sap-sucking insects and mites, and the evaluation of arthropod populations are elaborated upon in the study by Demolin-Leite[10].

Each replication are the total individuals collected on 12 leaves (three heights and four sides of the sapling) for 24 months. The distribution type (aggregated, random, or regular) for the lost source (*LS*) or solution source (*SS*) was defined by the Chi-square test using the R-package 'IlProductionUnknown'[13] (Supplemental Table S1 & S2). The data were subjected to simple regression analysis, and the parameters were all significant ($p < 0.05$) using the R-package 'IIProductionUnknown'[13] (Supplemental Table S3). Simple equations were selected by observing the criteria: (1) data distribution in the figures (linear or quadratic response), (2) the parameters used in these regressions were the most significant ($p < 0.05$), (3) $p < 0.05$ and F of the Analysis of Variance of these regressions, and iv) the coefficient of determination of these equations (R^2). Only *L.S.* and *SS* with $p < 0.05$ were shown in Supplemental Table S1−S3. The data above were used in the Percentage of Importance Index-Production Unknown (*% I.I.-P.U.*).

Percentage of Importance Index-Production Unknown (*% I.I.-P.U.*)[10] is:

$\% \, I.I.\text{-}P.U. = [(ks_1 \times c_1 \times ds_1)/\Sigma(ks_1 \times c_1 \times ds_1) + (ks_2 \times c_2 \times ds_2) + (ks_n \times c_n \times ds_n)] \times 100$[9],

where, **i)** the *key source* (*ks*) is: *ks* = damage (non-percentage) (*Da.*)/total *n* of the *LS* on the samples or *ks* = reduction of the total *n.* of *LS* (*RLS*)/total n. of the *SS* on the samples[10]. Where *Da.* or *RLS* = $R^2 \times (1 - P)$, when it is of the first degree, or $(R^2 \times (1 - P)) \times (\beta_2/\beta_1)$, when it is of the second degree, where $\mathbf{R^2}$ = determination coefficient and $\boldsymbol{P}$ = significance of ANOVA, β_1 = regression coefficient, and β_2 = regression coefficient (variable^2), of the simple regression equation of the loss source (*LS*) or solution source (*SS*)[10].

When it is not possible to separate the *Da.* between two or more *LS*, there should be a division of the *Da.* among the *LS* as a proportion of their respective 'total *n*'. *Da.* = 0 when *Da.* was non-significant for damage or non-detected by *LS in* the system[10]. When an *SS* operates in more than one *LS*, that caused damage, its *ks* are summed. *RLS* = 0 when *Da.* by *LS* or *RLS* was non-significant for damage by *LS* or reduced *LS* by *SS* in the system[10].

ii) *c* (*constancy*) = Σ of occurrence of *L.S.* or *S.S.* on samples, where absence = 0 or presence = 1[9].

iii) *ds* (*distribution source*) = 1 − ***P*** of the chi-square test of *LS* or *SS* on the samples[9]. Counts (non-frequency) of *L.S.* or *S.S.* are used to perform the chi-square test.

These data, above, are obtained, by R-package 'IIProductionUnknown'[13].

Percentage of *RLS* per *SS* (% *RLSSS*) = (*R.L.S.S.S.*/total *n* of the *LS* – abundance or damage) × 100, where *RLSSS* = *RLS* × total *n* of the *SS*, with the *R.L.S.* not being summed in this case[10]. These data, above, are obtained, by R-package 'IIProductionUnknown'[13].

Results

The phytophagous arthropods exhibiting the highest *% I.I.-P.U.* on the leaves of *S. saponaria* saplings encompassed *Liriomyza* sp. (mines) (Diptera: Agromyzidae) at 53.49%, *Bemisia* sp. (Hemiptera: Aleyrodidae) at 13.29% (with a maximum damage score of IV), Phaneropterinae (Orthoptera: Tettigoniidae) at 11.21%, *Tetranychus* sp. (Acari: Tetranychidae) at 8.95% (with a maximum damage score of III), *Tropidacris collaris* (Orthoptera: Romaleidae) at 4.61%, and *Stereoma anchoralis* (Coleoptera: Chrysomelidae) at 1.33% (Table 1).

The natural enemies with the highest *% I.I.-P.U.* on the leaves of *S. saponaria* saplings were identified as *Cycloneda sanguinea* (Coleoptera: Coccinellidae) at 98.94% and *Pseudomyrmex termitarius* (Hymenoptera: Formicidae) at 1.06%. Notably, the presence of *P. termitarius* (0.13%) and *C. sanguinea* (0.02%) led to a reduction in the numbers of *Liriomyza* sp. mines and *Bemisia* sp., respectively, on these saplings. Furthermore, the damage inflicted by *Bemisia* sp. on leaves exhibited a reduction per the number of *P. termitarius* (2.92%). Conversely, the number of *Brachymyrmex* sp. (Hymenoptera: Formicidae) resulted in an increase in the number (1.18%) and damage (61.95%) of *Bemisia* sp. on *S. saponaria* saplings. The cumulative balances for the reduction in abundance and damage (%) were negative, measuring at −1.03% and −59.03%, respectively, on *S. saponaria* saplings (Tables 2 & 3).

Discussion

The phytophagous arthropods, *Liriomyza* sp., *Bemisia* sp., Phaneropterinae, *Tetranychus* sp., *T. collaris*, and *S. anchoralis*, demonstrated the highest *% I.I.-P.U.* on *S. saponaria* saplings. *Liriomyza* sp. mines, known to diminish the photosynthetic area in various plants such as *Solanum lycopersicon* (Solanaceae), *Phaseolus vulgaris* (Fabaceae), and *Terminalia argentea* (Combretaceae)[14−18]. Certain species of Aleyrodidae, exemplified by *Bemisia tabaci*, are recognized pests inflicting damage on crops including *P. vulgaris*, *Glycine max*, *Acacia auriculiformis*, *A. mangium*, and *Platycyamus regnellii* (Fabaceae); *Capsicum annuum* and *S. lycopersicon* (Solanaceae); *Cucumis melo* (Cucurbitaceae); and *T. argentea*[10,19−25]. Aleyrodidae, in addition to causing fumagine, are implicated in virus transmission and the introduction of insect toxins[10,19−25]. Certain species of Tettigoniidae have been documented as causing damage to the fruits of *Musa* spp. (Musaceae) and the leaves of grasses, *A. mangim*, *A. auriculiformis*, and *T. argentea*[10,12,18,26,27]. Tetranychidae mites, recognized for puncturing the epidermis of leaves, are implicated in *G. max*, *Caryocar brasiliense* (Caryocaraceae), *S. lycopersicum*, and *P. vulgaris*[28−33]. *T. collaris* is known to attack *S. saponaria*, *Casuarina glauca* (Casuarinaceae), *A. auriculiformis*, *A. mangium*, *L. leucocephala*, and *T. argentea* (Combretaceae)[12,18,27,34,35]. Lastly, *S. anchoralis* has been reported to inflict damage on *A. mangium* and *A. auriculiformis*[10,12,27].

Cycloneda sanguinea and *P. termitarius* exhibited the highest *% I.I.-P.U.*, thereby diminishing both the numerical abundance and damage caused by *Bemisia* sp., as well as the population of *Liriomyza* sp. on *S. saponaria* saplings. *Cycloneda sanguinea*, recognized as a significant predator of sap-sucking insects, has demonstrated efficacy in mitigating pest populations on *T. argentea* saplings in degraded areas and various crops such as *Gossypium hirsutum* (Malvaceae), *Foeniculum vulgare* (Apiaceae), and *Abelmoschus esculentus* (Malvaceae), both in field conditions and laboratory bioassays[23,36−38]. Tending ants, exemplified by *P. termitarius*, have been observed to reduce beetle and caterpillar attacks on leaves and fruits[39−42]. Additionally, *Cephalocoema* sp. (Orthoptera: Proscopiidae), along with ants, serves as a bioindicator[10,43]. The potential influence of these predators, particularly those at the apex of the trophic pyramid such as *C. sanguinea*, in controlling the abundance of herbivores like *Bemisia* sp. through top-down effects suggests a mechanism that could contribute to the survival of *S. saponaria*. However, the nuanced relationships between predators and herbivory in commercial crops of *S. saponaria* warrant further investigation. Contrary to expectations, a negative effect of *P. termitarius* on *Bemisia* sp. damage was observed on *S. saponaria* saplings, defying the anticipated mutualistic relationship

Table 1. Total number (*n*), damage (*Da.*), key-source (*ks*), constancy (*c*), distribution source (*ds*), number of importance indice (*n. II*), sum of *n. I.I.-P.U.* (Σ *n. II*), and percentage of *II* by loss source (*LS*) on 48 *Sapindus saponaria* (Sapindaceae) saplings.

Loss source								
LS	*n*	*Da.*	*ks*	*c*	*ds*	*n. II.*	Σ *n. II.*	% *II.*
Liriomyza sp. (mines)	478	0.8600	0.0018	27	1.00	0.0486	0.091	53.49
Bemisia sp.	2333	0.8800	0.0004	32	1.00	0.0121	0.091	13.29
Phaneropterinae	51	0.0206	0.0004	27	0.93	0.0102	0.091	11.21
Tetranychus sp.	709	0.9600	0.0014	6	1.00	0.0081	0.091	8.95
T. collaris	17	0.0069	0.0004	14	0.74	0.0042	0.091	4.61
S. anchoralis	5	0.0020	0.0004	3	1.00	0.0012	0.091	1.33
Charidotis sp.	4	0.0016	0.0004	2	1.00	0.0008	0.091	0.89
Alagoasa sp.	5	0.0020	0.0004	5	0.36	0.0007	0.091	0.80
Cerotoma sp.	4	0.0016	0.0004	4	0.40	0.0006	0.091	0.71
Curculionidae	3	0.0012	0.0004	3	0.44	0.0005	0.091	0.59
Lordops sp.	3	0.0012	0.0004	3	0.44	0.0005	0.091	0.59
Walterianela sp.	2	0.0008	0.0004	1	1.00	0.0004	0.091	0.44
Lepidoptera	2	0.0008	0.0004	2	0.49	0.0004	0.091	0.43
D. speciosa	2	0.0008	0.0004	2	0.49	0.0004	0.091	0.43
Lamprosoma sp.	2	0.0008	0.0004	2	0.49	0.0004	0.091	0.43
Eumolpus sp.	2	0.0008	0.0004	2	0.49	0.0004	0.091	0.43
Epitragus sp.	2	0.0008	0.0004	2	0.49	0.0004	0.091	0.43
Parasyphraea sp.	1	0.0004	0.0004	1	0.53	0.0002	0.091	0.23
Wanderbiltiana sp.	1	0.0004	0.0004	1	0.53	0.0002	0.091	0.23
Gryllidae	1	0.0004	0.0004	1	0.53	0.0002	0.091	0.23
Cephalocoema sp.	1	0.0004	0.0004	1	0.53	0.0002	0.091	0.23
A. reticulatum	11	0.0000	0.0000	2	1.00	0.0000	0.091	0.00
Anastrepha sp.	4	0.0000	0.0000	4	0.40	0.0000	0.091	0.00
B. hebe	10	0.0000	0.0000	7	0.99	0.0000	0.091	0.00
Euxesta sp.	3	0.0000	0.0000	3	0.44	0.0000	0.091	0.00
Fulgoridae	19	0.0000	0.0000	5	1.00	0.0000	0.091	0.00
Nasutitermes sp.	280	0.0000	0.0000	5	1.00	0.0000	0.091	0.00
P. torridus	1	0.0000	0.0000	1	0.53	0.0000	0.091	0.00
Pentatomidae	6	0.0000	0.0000	6	0.32	0.0000	0.091	0.00
Phenacoccus sp.	30	0.0000	0.0000	2	1.00	0.0000	0.091	0.00
Q. gigas	2	0.0000	0.0000	2	0.49	0.0000	0.091	0.00
T. spinipes	5	0.0000	0.0000	1	1.00	0.0000	0.091	0.00

I.I.-P.U. = *ks* × *c* × *ds*. *ks* = *Da.*/total *n* of the *L.S.*. *Da.* = $R^2 \times (1 - P)$ when it is of the first degree, or $(R^2 \times (1 - P)) \times (\beta_2/\beta_1)$ when it is of the second degree, where R^2 = determination coefficient and P = significance of ANOVA, β_1 = regression coefficient, and β_2 = regression coefficient (variable^2), of the simple regression equation, or non-percentage of damage per *L.S.* $c = \Sigma$ of occurrence of *L.S.* on each sample, 0 = absence or 1 = presence. $ds = 1 - P$ of chi-square test of the *L.S.* *Da.* = 0 when *Da.* non-significant for damage or non-detected by *L.S.*

between tending ants and sap-sucking insects (Hemiptera)[44,45]. While Demolin-Leite[10] did not identify correlations between this tending ant and Aleyrodidae or *Aethalion reticulatum* (Hemiptera: Aethalionidae) on *A. auriculiformis* saplings, an increase in the number (≈ 1%) and leaf damage (≈ 62%) caused by *Bemisia* sp. was noted in relation to the population of *Brachymyrmex* sp. on *S. saponaria* saplings, underscoring the complexity of interactions within this ecological system. Further studies are warranted to elucidate the underlying mechanisms governing these relationships. These outcomes can be attributed to the collaborative interactions between tending ants and sap-sucking insects, leading to an exacerbation of the damage inflicted upon these plants. Analogous findings were observed in the context of *A. auriculiformis* saplings, where the presence of tending ants, specifically *Brachymyrmex* sp. (e.g., *A. reticulatum*), and *Cephalotes* sp. (e.g., Aleyrodidae), resulted in a substantial increase (≈ 95%) in the populations of *A. reticulatum* and Aleyrodidae, accompanied by a corresponding rise (≈ 30%) in Aleyrodidae-induced damage to this plant[10]. The detrimental impact of these interactions was reflected in a negative final balance on *A. auriculiformis* saplings, with a subsequent rise of approximately 57% in herbivorous insect populations within these saplings[10], mirroring the observed trends in *S. saponaria* saplings. Particularly at elevated population densities, sap-sucking insects may establish associations with tending ants[44,45], wherein these ants collectively and aggressively defend their resources, including phytophagous hemipterans[44]. The lack of a positive effect of tending ants on the biological control of sap-sucking insects may be attributed to mutualistic relationships with these phytophagous insects[46,47]. In agricultural systems, this dynamic can potentially exacerbate pest-related challenges[48]. Although *Brachymyrmex* sp. initially does not pose a significant issue for *S. saponaria* saplings, the potential for this tending ant species to proliferate and increase sap-sucking insect populations (e.g., *Bemisia* sp.) exists, particularly under specific conditions such as monoculture, climate, soil variations, and favorable fertilization. This scenario may pose challenges for *S. saponaria* saplings, especially in the context of prospective commercial crops with monoculture practices.

Liriomyza sp., *Bemisia* sp., Phaneropterinae, *Tetranychus* sp., *T. collaris*, and *S. anchoralis*, exhibiting the highest % *I.I.-P.U.* on *S. saponaria*, pose a potential threat, indicating their capacity to induce losses in crops of this plant. In contrast, *C. sanguinea* and

Table 2. Total number (*n*), reduction of *LS* (*RLS*), key-source (*ks*), constancy (*c*), distribution source (*ds*), number of importance indice (*n. II*), sum of *n. I.I.-P.U.* (Σ *n. II*), and percentage of *II* by solution source (*SS*) on 48 *Sapindus saponaria* (Sapindaceae) saplings.

Solution source								
SS	*n*	*RLS.*	*ks*	*c*	*ds*	*n. II.*	Σ *n. II.*	*% II.*
C. sanguinea	3	0.1231	0.0410	2	0.99	0.08	0.08	98.94
P. termitarius	121	0.0053	0.0000	20	1.00	0.00	0.08	1.06
A. rogersi	4	0.0000	0.0000	4	0.40	0.00	0.08	0.00
A. uncifera	3	0.0000	0.0000	3	0.44	0.00	0.08	0.00
Araneidae	31	0.0000	0.0000	18	1.00	0.00	0.08	0.00
Brachymyrmex sp.	184	0.0000	0.0000	21	1.00	0.00	0.08	0.00
Camponotus sp.	130	0.0000	0.0000	26	1.00	0.00	0.08	0.00
Chrysoperla sp.	3	0.0000	0.0000	2	0.99	0.00	0.08	0.00
Dolichopodidae	9	0.0000	0.0000	6	1.00	0.00	0.08	0.00
Ectatoma sp.	20	0.0000	0.0000	12	1.00	0.00	0.08	0.00
Leucauge sp.	13	0.0000	0.0000	4	1.00	0.00	0.08	0.00
M. religiosa	11	0.0000	0.0000	9	0.75	0.00	0.08	0.00
O. salticus	1	0.0000	0.0000	1	0.53	0.00	0.08	0.00
Oxyopidae	14	0.0000	0.0000	12	0.50	0.00	0.08	0.00
Pheidole sp.	272	0.0000	0.0000	23	1.00	0.00	0.08	0.00
Polybia sp.	6	0.0000	0.0000	4	1.00	0.00	0.08	0.00
Quemedice sp.	3	0.0000	0.0000	3	0.44	0.00	0.08	0.00
Salticidae	13	0.0000	0.0000	9	1.00	0.00	0.08	0.00
Syrphus sp.	2	0.0000	0.0000	2	0.49	0.00	0.08	0.00
T. angustula	2	0.0000	0.0000	1	1.00	0.00	0.08	0.00
Teudis sp.	3	0.0000	0.0000	3	0.44	0.00	0.08	0.00
Tmarus sp.	2	0.0000	0.0000	2	0.49	0.00	0.08	0.00
Uspachus sp.	4	0.0000	0.0000	4	0.40	0.00	0.08	0.00

I.I.-P.U. = *ks* × *c* × *ds*. *ks* = *R.L.S.*/total *n.* of the *SS.*. *R.L.S.* = $R^2 \times (1 - P)$ when it is of the first degree, or $(R^2 \times (1 - P)) \times (\beta_2/\beta_1)$ when it is of the second degree, where R^2 = determination coefficient and *P* = significance of ANOVA, β_1 = regression coefficient, and β_2 = regression coefficient (variable^2), of the simple regression equation. *c* = Σ of occurrence of *S.S.* on each sample, 0 = absence or 1 = presence. *ds* = 1 − *P* of chi-square test of the *SS*. When a *SS* operates in more than one *LS*, that caused damage, its *ks* are summed. *ES.* = 0 when *Da.* by *LS* or *ES* non-significant for damage by *LS* or reduced *LS* by *SS*.

Table 3. Percentage of reduction in abundance and/or damage (*%R.*) of loss source (*LS*) per solution source (*SS*), sum (Σ), and total of Σ of *RLS* (T.Σ) on 48 *Sapindus saponaria* (Sapindaceae) saplings.

	LS.	
% RLSSS - abundance		
SS.	*Liriomyza* sp. (mines)	*Bemisia* sp.
C. sanguinea	/	0.02
Brachymyrmex sp.	/	−1.18
P. termitarius	0.13	/
Σ	**0.13**	**−1.16**
***T.Σ**	**−1.03**	/
% RLSSS - damage		
SS.	*Bemisia* sp.	
Brachymyrmex sp.	−61.95	
P. termitarius	2.92	
Σ	**−59.03**	

/ = *L.S.* was not reduced per *S.S.* *% R.L.S.S.S.* = (*R.L.S.S.S.*/total *n* of the *L.S.* – abundance or damage) × 100, where *R.L.S.S.S.* = *R.L.S.* × total n of the *S.S.* *R.L.S.* = $R^2 \times (1 - P)$ when it is of the first degree, or $(R^2 \times (1 - P)) \times (\beta_2/\beta_1)$ when it is of the second degree, where $\mathbf{R^2}$ = determination coefficient and ***P*** = significance of ANOVA, β_1 = regression coefficient, and β_2 = regression coefficient (variable^2), of the simple regression equation.

P. termitarius, characterized by the most substantial *% I.I.-P.U.*, exhibit potential as agents capable of mitigating herbivorous insects on *S. saponaria*. Furthermore, an anticipated increase in the abundance of ladybeetles, particularly those with major ecological significance, could be expected in future commercial crops of *S. saponaria*. It is imperative to accord special attention to the association between *Brachymyrmex* sp. and *Bemisia* sp. in prospective *S. saponaria* commercial crops, as this tending ant species has demonstrated an ability to augment the population of the sap-sucking insect. The *% I.I.-P.U.* emerges as an effective tool for delineating sources of loss and potential solutions in this plant species within systems characterized by production unknown, such as degraded areas. This innovative index holds promise as a valuable tool in the realm of agricultural technology, particularly for monitoring and managing degraded areas.

Author contributions

The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

Data availability

All data generated or analyzed during this study are included in this published article. The data that support the findings of this study are available on request from the corresponding author.

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Conflict of interest

The author declares that there is no conflict of interest.

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