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Influence of climatic factors on the abundance and spread of the Papaya mealybug, *Paracoccus marginatus* (Hemiptera: Pseudococcidae) in southwestern Nigeria.

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Abstract

This study assessed how weather variables shape the population dynamics and infestation intensity of the papaya mealybug, *Paracoccus marginatus* Williams & Granara de Willink (Hemiptera: Pseudococcidae), on papaya across three agro-ecological zones in southwestern Nigeria—Akure (Rainforest), Ogbomoso (Guinea savannah), and Ibadan (Derived savannah)—from January to December 2016. Monthly field assessments showed no significant differences ($p > 0.05$) in infestation intensity or mealybug counts between leaves and fruits across the zones. August, the wettest month (266.43 mm rainfall), had the lowest insect percentage (7.5%), whereas March recorded the highest percentage population (57.94%) on both leaves and fruits; infestation levels followed the same pattern. Relative humidity was negatively associated with both infestation ($r = -0.392$, $N = 36$, $P = 0.018$) and population ($r = -0.426$, $N = 36$, $P = 0.010$). Although some months differed significantly ($p < 0.05$) in infestation and population, overall variation was linked to intra-annual weather (rainfall, relative humidity, and temperature) rather than to the agro-ecological zone. These results indicate that seasonal climatic conditions, particularly high rainfall and relative humidity, suppress *P. marginatus* abundance and damage, independent of site-level ecological differences.

Keywords: *Carica papaya,* Abiotic factors, papaya mealybug, *Paracoccus marginatus*

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INTRODUCTION

Carica papaya L. (Caricaceae)—widely known as papaya or pawpaw—ranks third among tropical fruits by global production, following bananas and citrus, and serves as a major export commodity for many developing nations, sustaining the livelihoods of thousands (Rivera et al., 2010). Although numerous insect pests feed on papaya, most do not cause economically significant damage in West Africa; a notable exception is the papaya mealybug, *Paracoccus marginatus* (Williams and Granara de Willink), an invasive pest that is progressively expanding its range on the continent (David *et al*., 2011).

P. marginatus is a small, sap-feeding pseudococcid with a broad host range, infesting many economically important tropical fruit trees and ornamentals, and is native to Central America (Miller *et al.,* 1999). It can inflict severe injury on papaya and other tropical crops, as well as on ornamentals such as *Annona* and *Hibiscus* spp. (Miller *et al.*, 2001). Following its arrival in Ghana in late 2009, papaya production area contracted dramatically—from roughly 2,500 ha to about 380 ha—underscoring its destructive potential (IITA, 2011). After the Ghana outbreak, the pest was reported in Nigeria. Beyond papaya, alternate hosts include crops like cassava and maize, along with several weed species (Miller and Miller, 2002). Patterns of insect abundance and distribution emerge from the interplay of biotic and abiotic drivers, with temperature and humidity among the most influential physical factors; additional abiotic elements—such as water, light, radiation, atmospheric conditions, and soil—also contribute (Ricklefs, 2005).

Papaya is nutritionally valuable, supplying vitamin C and folate, while its peel, pulp, and seeds contain diverse phytochemicals, carotenoids, and polyphenols. Infestations of *P. marginatus* produce honeydew that coats leaves and fruits, causing sooty fouling. Heavy pressure on thin-skinned papaya cultivars renders fruit unmarketable, leading to substantial economic losses. Given the pest's ongoing spread across African countries, there is an urgent need to clarify the factors governing its expansion and impact, as it presents a serious threat to papaya production in tropical regions, including Nigeria.

Accordingly, this study examines how key climatic variables—temperature, relative humidity, and rainfall—shape the population density, infestation intensity, and associated damage caused by *P. marginatus* in southwestern Nigeria. While the effects of temperature on insect survival, development, and reproduction have been extensively studied over decades, information remains limited on how interacting biotic and abiotic factors constrain the distribution and abundance of P. marginatus. The research sites are situated across representative agro-ecological zones in the region: Akure (rainforest), Ibadan (derived savannah), and Ogbomoso (guinea savannah). The rainforest experiences an extended wet season with annual precipitation typically exceeding 2,000 mm. The derived savannah is a transition belt between tropical rainforest and guinea savannah, with a mean annual rainfall of 1,314 mm and an average temperature of 26.5 °C (Ahmed et al., 2011). The guinea savannah—the most expansive ecological zone in southwestern Nigeria—has a unimodal rainfall pattern, an average annual temperature of 27.3 °C, and a mean rainfall of 1,051.7 mm, and is marked by comparatively low precipitation and a prolonged dry season (Sowunmi *et al.*, 2010). This work, therefore, provides baseline evidence on the biotic and abiotic determinants of *P. marginatus* occurrence in southwestern Nigeria.

MATERIALS AND METHODS

Study area

The study was carried out in papaya-mealybug–endemic sites spanning three agro-ecological zones of southwestern Nigeria: Akure (rainforest; 7.2571° N, 5.2058° E), Ogbomoso (Guinea savannah; 8.1227° N, 4.2436° E), and Ibadan (derived savannah; 7.3767° N, 3.9398° E). Within each zone, three independent orchards were selected to serve as replicates, yielding a total of nine orchards (three per zone) for the investigation.

The influence of agroecological zones on the papaya mealybug population and damage levels.

For each sampled plant, ten leaves and ten fruits were examined, and the number of *P. marginatus* (adults plus juveniles) was assigned to one of five categories: 0 for 0 individuals, 1 for 1–9 individuals, 2 for 10–99 individuals, 3 for 100–1,000 individuals, and 4 for more than 1,000 individuals. At each location, five papaya plants were also evaluated for injury symptoms, and damage was scored on a 0–4 scale as follows: 0 indicated no infestation; 1 indicated that less than 25% of leaves/fruits appeared healthy with curled tips or side shoots; 2 indicated that less than 25% of leaves/fruits were covered with papaya mealybug (PM); 3 indicated 25–50% coverage; and 4 indicated more than 50% coverage.

Collection of weather parameters

Meteorological data for the study period—air temperature, relative humidity, and rainfall for each ecological zone—were obtained from the Nigeria Meteorological (NiMET) station in Lagos.

Statistical Analysis

Population and infestation/damage levels of *P. marginatus* on both the fruits and the leaves were computed as the Infestation index according to Puntener (1981) using the formula:

$$Infestation\,index \equiv \sum \frac{ab}{NR} \times 100$$

Where: N = Total number of investigated plants

R = Highest category value

a = Number of plant parts in each category

b = Value of category

The resulting data were analyzed by analysis of variance (ANOVA) at the 95% confidence level. When effects were significant, means were separated using Tukey's test.

RESULTS

Influence of Agroecologies on the population of *P. marginatus* on papaya leaves and fruits.

The highest mean population of P. marginatus on papaya leaves occurred in Ogbomoso (26.89; Table 1), but this did not differ significantly from Ibadan (26.45) or Akure (24.54) ($p > 0.05$). A comparable pattern was observed on fruits: Ogbomoso had the highest mean (26.90), yet it was not significantly different from Ibadan (25.48) or Akure (24.74) ($p > 0.05$; Table 1).

Table 1: Population of *P. marginatus* on leaves and fruits of pawpaw at different agro-ecologies.

	Mean Population Level in %	
Agro-ecology	Leaf population	Fruit population
Guinea Savannah Ogbomoso	26.89±4.17 [a]	26.90±4.37 [a]
Derived Savannah Ibadan	26.45±3.52 [a]	25.48±3.68 [a]
Rainforest Akure	24.54±3.40 [a]	24.74±3.91 [a]

Means denoted by the same letter within a column are not significantly different (Tukey's post hoc test, $p < 0.05$).

Agro-ecological influence on the damage level of *P. marginatus* on leaves and fruits of Pawpaw.

Table 2 summarizes leaf and fruit damage by *P. marginatus* across the agro-ecological zones. Leaf infestation was highest in Ogbomoso (29.72), but did not differ significantly from Ibadan (29.24) or Akure (28.29) ($p > 0.05$). A similar pattern held for fruits: Ogbomoso recorded the highest value (27.30), yet this was not significantly different from Ibadan (25.05) or Akure (25.03) ($p > 0.05$).

Table 2: Percentage damage level of *P. marginatus* on leaves and fruits of pawpaw at different agro-ecologies

Mean Infestation Level in % (Damage Severity)		
Agro-ecology	Leaf	Fruit
Guinea savannah (Ogbomoso)	29.72±6.02 [a]	27.30±6.03 [a]
Derived savannah (Ibadan)	29.24±5.90 [a]	25.05±5.65 [a]
Rainy forest (Akure)	28.29±6.19 [a]	25.03±5.84 [a]

Means sharing the same letter within a column do not differ significantly (Tukey's test, $p > 0.05$).

Monthly variation in population of *P. marginatus* on leaves and fruits of *Carica papaya*

The leaf-dwelling population of *P. marginatus* peaked in March (57.94) and was significantly higher than in all other months ($p < 0.05$; Fig. 1). The minimum leaf population occurred in August (7.50), which did not differ significantly from July or September ($p > 0.05$). On fruits, the pattern was similar: the highest population was also in March (58.94), significantly exceeding all other periods ($p < 0.05$), while the lowest value in August (7.50) was not significantly different from those recorded in July and September ($p > 0.05$).

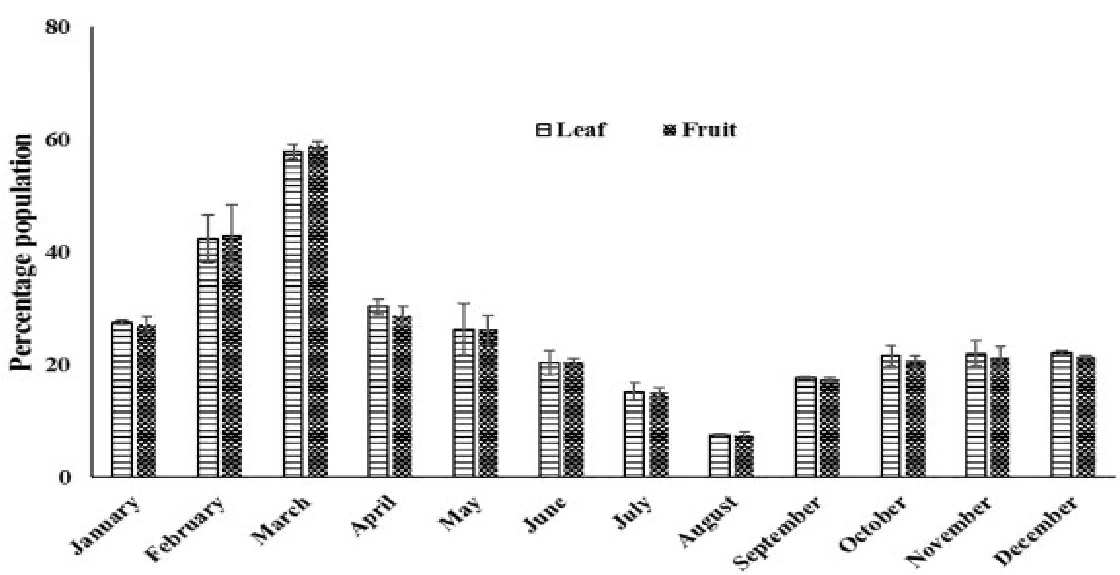

Figure 1: Monthly dynamics in the population of *P. marginatus* on papaya leaves and fruits

Monthly variations of *P. marginatus* damage levels on papaya leaves and fruits

Damage on papaya leaves was greatest in March (79.47; Fig. 2). This value did not differ significantly from February (60.33) ($p > 0.05$), but was significantly higher than in all other months ($p < 0.05$). The lowest leaf infestation occurred in August (6.08), which was significantly lower than the levels recorded in the remaining months ($p < 0.05$).

On fruits, damage peaked in March (74.78), but this value was not significantly different from those observed in other months ($p > 0.05$) (Fig. 2). The minimum fruit infestation was recorded in August (5.25); it did not differ from July (11.17) ($p > 0.05$), but was significantly lower than the values for the other months ($p < 0.05$).

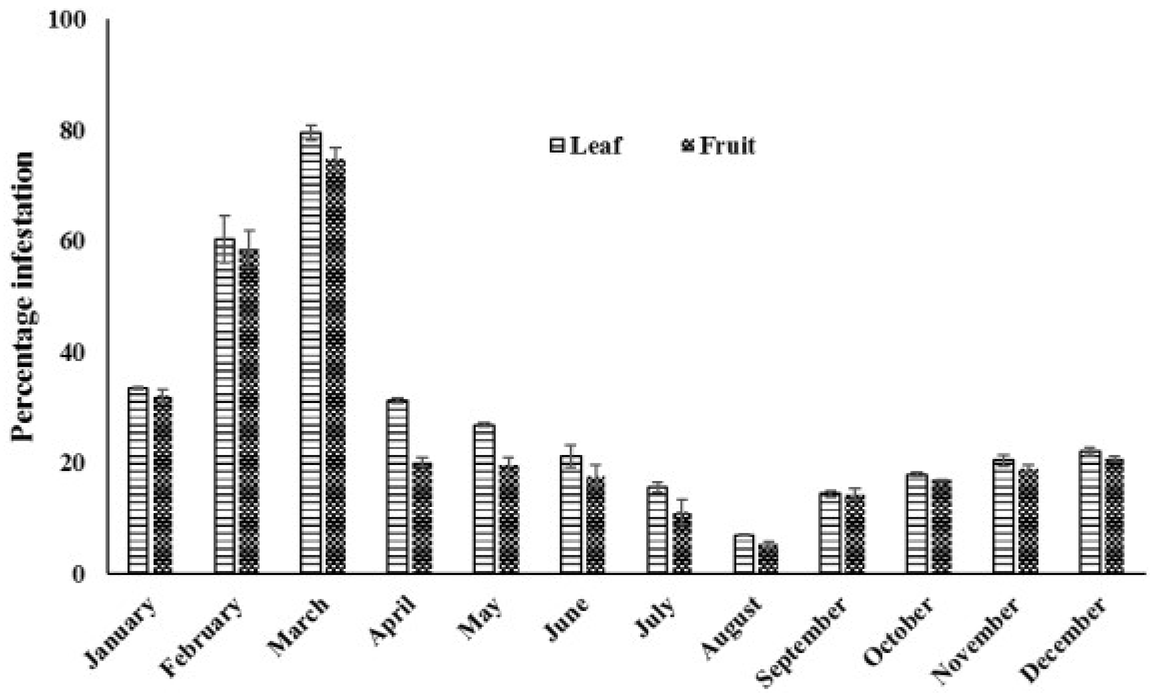

Figure 2: Monthly dynamics of damage caused by the papaya mealybug, *P. marginatus*, on papaya leaves and fruits.

Effects of rainfall on the population dynamics of *P. marginatus in* three ecological zones.

During January–June, total rainfall was 422.13 mm, and the mean population of *P. marginatus* was 205.9. From July–December, rainfall increased to 784.9 mm while the mean population declined to 106.5 (Fig. 3). August, the wettest month (266.4 mm), had the lowest mean population (7.5), consistent with the notion that heavy rains can wash away eggs and immature stages. By contrast, February recorded the lowest monthly rainfall (3.67 mm) and the second-highest mean population (42.30), whereas March, with only 16.33 mm of rain, exhibited the peak mean population (57.94) (Fig. 3). Overall, *P. marginatus* abundance was higher during low-rainfall periods and suppressed during high-rainfall periods, as reflected in a strong negative Pearson correlation between population and rainfall ($r = -0.614$, $N = 36$, $P = 0.000$).

Effects of temperature and relative humidity on the infestation level of *P. marginatus* in different ecological zones

In Ogbomoso, mean monthly relative humidity rose steadily from 57.1% in January to 90% in December (Fig. 4). Infestation peaked in March (80.08) when average air temperature was 23.14 °C and relative humidity 77.29%, and reached its minimum in August (6.42)—the month with both the highest rainfall and RH (90%). In Akure, the lowest infestation (6.00) also occurred in August, coinciding with the highest RH (89.8%) and an average temperature of 25.5 °C; infestation declined from May through August as RH increased, whereas the maximum infestation (79.75) was recorded in March at 27.37 °C (Fig. 5). In Ibadan, RH increased from 54.1% to 66.55% and then to 76.65% between January and June, while damage rose from 35.08 to 38.08 and then 78.58 over the same interval; from April to August, infestation declined progressively from 31.67 to 5.83 as humidity climbed from 78.97% to 87% (Fig. 6).

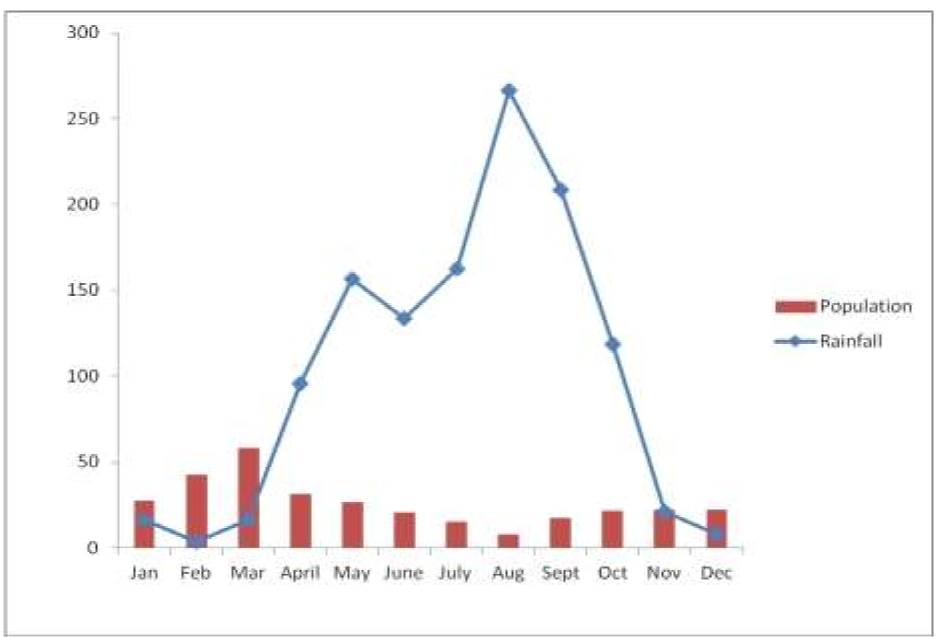

Figure 3: Relationship between monthly rainfall and *P. marginatus* population (January–December 2016) across all agro-ecological zones.

Figure 4: Monthly air temperature and relative humidity versus damage levels on papaya leaves and fruits in Ogbomoso.

Figure 5: Monthly air temperature and relative humidity in the rainforest site (Akure) versus damage levels on papaya leaves and fruits.

Figure 6: Monthly air temperature and relative humidity in the derived savannah (Ibadan) versus damage levels on papaya leaves and fruits.

Pearson correlations indicated a significant positive association between temperature and *P. marginatus* population (r = 0.702, N = 36, P = 0.000) and a significant negative association with relative humidity (r = −0.426, N = 36, P = 0.010). All correlations were significant at $P < 0.05$.

DISCUSSION

The abundance and injury caused by insects like *P. marginatus* are shaped by the surrounding agro-ecosystem (Babasaheb et al., 2012). Population dynamics reflect the interplay between abiotic drivers—temperature, relative humidity, rainfall, soil conditions, pollutants—and biotic factors including host crops, weeds, insect pests, pathogens, and nematodes (Babasaheb et al., 2012). Within this framework, the comparatively severe infestations documented in Ogbomoso (Guinea savannah) likely reflect zone-specific environmental conditions that favored mealybug buildup. Consistent with prior observations, mealybugs exhibit greatest activity under warm, dry weather; reduced rainfall during such periods promotes heavy oviposition by females, accelerating population growth (Jithu et al., 2016).

Observations across sites indicated that *P. marginatus* populations—and the associated damage on both leaves and fruits—peaked in Ogbomoso. The heightened pressure in this Guinea savannah locale likely reflects multiple, interacting drivers. While defoliators occur widely in agricultural systems, the notably greater mealybug buildup in Ogbomoso is plausibly linked to its thermal and moisture regime. In line with earlier work on sap-sucking insects, including *P. marginatus*, abiotic conditions can strongly shape population dynamics; Rahmathula et al. (2015) reported highly significant positive associations between temperature, relative humidity, and mealybug activity. Additional facilitative mechanisms may also be involved.

Mealybug–ant mutualisms, which can deter parasitoids and enhance dispersal, were more conspicuous in Ogbomoso (Tanwar et al., 2010). Morphological protection may further contribute: individuals there bore a pronounced waxy layer and wax fibers over the ovisac, features that can buffer adverse conditions and promote persistence. Finally, the presence of alternate hosts and surrounding weeds likely sustained populations between papaya flushes; weeds such as *Abutilon indicum*, *A. digitata*, and *Jatropha* spp. have been identified as important reservoirs supporting *P. marginatus* proliferation (David et al., 2011). August registered the highest mean rainfall (266.43 mm) and, correspondingly, the lowest mean *P. marginatus* population (7.5%). Heavy precipitation can dislodge eggs and immature stages—either directly or shortly after metamorphosis—thereby depressing field counts (Omoloye, 2008). This mechanism helps explain the August pattern. Although some reports posit a strong linkage between mealybug activity and rainfall, the intense rains during this month likely contributed to the markedly reduced papaya mealybug abundance observed.

A consistent pattern emerged across ecological zones: infestation peaked in March and was lowest in August, with infestation declining as relative humidity rose. Insect physiological systems operate efficiently only within bounded thermal ranges; for many species, enzymatic activity, tissue function, and whole-organism behavior are optimal at relatively high temperatures—often ~30–40 °C (Chapman, 1998). Temperature therefore exerts a strong influence on *P. marginatus* development. More broadly, insect abundance and distribution reflect the interplay of biotic and abiotic drivers, with temperature and humidity among the principal abiotic constraints (Alison et al., 2003), and temperature is well recognized as a key regulator of insect community ecology (Matilda et al., 2012).

Seasonally, January–April (dry season) supported higher *P. marginatus* populations and infestation than the rainy months, during which increasing relative humidity from May to August coincided with declining infestation. This pattern accords with reports that mealybugs are most active under warm, less humid conditions (Walker et al., 2003). The especially high population observed in March—slightly exceeding February—may reflect early rains stimulating new leaf and fruit flushes after the long dry period, thereby enhancing resource availability (Omoloye, 2008). Laboratory evidence further contextualizes these field trends: *P. marginatus* can develop, survive, and reproduce successfully between 18 and 30 °C, with peak fecundity at ~25 °C (≈300 eggs per female) (Amarasekare et al., 2008). The March mean temperature of ~28 °C falls within this favorable window, providing a mechanistic basis for the elevated field incidence recorded across agro-ecological zones. Any discrepancy between optimal laboratory conditions and field optima likely reflects additional environmental and ecological factors acting on populations in situ (Amarasekare et al., 2008)

CONCLUSION

Climatic factors—temperature, relative humidity, and rainfall—strongly shape the spread and development of *P. marginatus*. Across southwestern Nigeria, the temperatures recorded in all ecological zones fall within a favorable window for the pest's growth and dispersal. By contrast, periods of heavy rainfall (and the accompanying high humidity) were unfavorable for build-up relative to drier, warm conditions. Among the zones, Guinea savannah weather patterns appeared particularly conducive to mealybug proliferation. These insights into weather–

pest relationships can inform the timing and design of integrated pest management (IPM) strategies tailored to local climatic regimes.

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Author Contribution Statement

Conceptualisation; Umeh Vincent Chukwuemeka, Adedire Chris Olukayode.
Methodology; Larayetan Ayo Adebowale, Adedire Chris Olukayode.
Formal Analysis and Investigation; Larayetan Ayo Adebowale, Adedire Chris Olukayode.
Writing - Original Draft Preparation; Larayetan Ayo Adebowale.
Writing Review and Editing; Adedire Chris Olukayode, Umeh Vincent Chukwuemeka.
Funding Acquisition; Umeh Vincent Chukwuemeka, Goergen Georg.
Resources; Goergen Georg, Umeh Vincent Chukwuemeka.
Supervision; Adedire Chris Olukayode.

Conflict of Interest

I, AYO ADEBOWALE, LARAYETAN, as the corresponding author of the manuscript titled; Influence of climatic factors on the abundance and spread of the Papaya mealybug, *Paracoccus marginatus* (Hemiptera: Pseudococcidae) in southwestern Nigeria, declared that there is no known competing financial interests, or personal relationships that could have appeared to influence the work reported in this paper.

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