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Vulnerability of smallholder agriculture in Calakmul, Campeche, Mexico

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The susceptibility and capacity to recover after a time of stress was evaluated with an *ex-ante* and *ex-post* hurricane (*Isidore* of September 2002) response by farming households in Calakmul, Mexico. Interviews and plot measurements of maize and jalapeño pepper were applied for two non-continuous agricultural cycles (1999-2000; 2002-2003) in four households of subsistence oriented agriculture (HSA) and four households of commercial agriculture (HCA). Quantified inputs were family labor in tilling, weeding, harvesting, wage labor, and time to sow the plots. Output measurements were grain and pepper production and sales of cash crops. While both subsistence and commercially oriented households had similar investments and crop production before the hurricane, vulnerability after the hurricane differed between the two household strategies (HSA and HCA). HSA families' resilient strategy consisted of both an investment of more household labor *ex-post* hurricane, and an early sowing period for crop staples (maize and beans). As a result HSA families obtained higher maize crop yields and similar economic profitability pre- and post- hurricane as compared with HCA families. In contrast, HCA families delayed planting maize in order to recover their economic investment, resulting in less production for own consumption and therefore higher vulnerability.

Keywords: Commercial agriculture, Resilience, Slash and burn agriculture, Vulnerability

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Agriculture is an activity threatened by natural disturbances, such as hurricanes, and smallholders who live in regions with high incidence of such disturbances are faced with risk[1-4]. Natural disturbances can reach disaster levels when combined with a human population's vulnerability[5,6]. Vulnerability is defined as the susceptibility of a group and its situation to a natural hazard factor, which affects social, productive, economic, cultural and ecological components of a population. The group's vulnerability is determined by its capacity to anticipate, cope with, resist and recover from the impacts of natural disturbance[6,7]. Rural populations with a low human development index (HDI) have been observed to be highly vulnerable because they lack the means necessary to confront natural hazards[3]. Such is the situation of the population living in the rural areas of the tropical forest in the Yucatan Peninsula, southeastern Mexico[8] who have had a long history of coexistence with hurricanes as well as with the climatic rhythms of droughts and rains[9]. Through adaptive responses to external stimulus (disturbances)[10], such as agricultural extensification and intensification, diversification, innovation, and revitalization among others[11,12] these people have developed livelihood strategies adapted to their ecological and social environment that have allowed them to reduce their overall vulnerability to climate shocks [adaptive strategies (*ex-ante*)] and to deal with the impacts [coping strategies (*ex-post facto*)] resulting in a resilient system[4,13-15].

The subsistence agriculture practiced by rural families, based on slash and burn, or swidden methods (*milpa*) is one of the main landscape management options in the region. This agricultural system, characterized by agroecological management of diversified and multipurpose crops at different successional stages, offers food security and provides the principal source of income while managing its natural resources in a sustainable manner[16]. However, this system is under threat as it faces demographic growth and an emphasis on inclusion of a wider economic system of markets, which has been the driving force in developing a monoculture production

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strategy (commercial agriculture) and simplifying the smallholders' traditional agriculture systems. These transformations could result in a decrease in biological and crop diversity, lower nutrient returns to the soil, and lower overall productivity, threatening family food security, and leading to an increase in rural emigration. In turn, these developments could result in less family labor and loss of indigenous knowledge, giving way to exploitation of more fragile environmental niches[17]. These changes may increase vulnerability and, depending on the type of adaptive strategy developed by the smallholder families, could jeopardize the sustainability of the agricultural system when it is faced with a natural hazard[18]. The vulnerability to climate hazards and the different rural strategies families use to deal with the impacts *ex-post facto* (coping strategies) have been little evaluated from an agriculture-environmental perspective[12]. Production and investment in agriculture made before and after hurricane impact are compared between households that practice agriculture as part of a diversified subsistence strategy, and households that practice agriculture as a business, both of them established in the recently populated Mayan tropical forest of South Campeche, in Southern Mexico. Our findings suggest that subsistence farmers developed a more resilient mechanism and a coupled strategy after being hit by a hurricane as compared with commercial agriculture oriented farmers.

Methodology

Location of the study area

The study was carried out at the *municipio* (the smallest official administrative and territorial unit in Mexico) of Calakmul, Campeche, Mexico, located 350 km to the south of the state capital and housing the Calakmul Biosphere Reserve (Fig. 1). The region's karst topography is characterized by undulating uplands with elevations ranging from 100 to 350 m above mean sea level, and the main soil types are rendzinas[19]. A significant difference in total annual rainfall is observed from the south to the north, ranging from approximately 1400 to 900 mm, with high evapotranspiration and few permanent sources of surface water. Two main types of seasonal deciduous forest cover the area: upland forest (*selva mediana*) and wetland forest (*selva baja indundable*)[19]. This region has been identified as a hot spot of tropical deforestation, forest fragmentation and biodiversity loss[20]. The forests are a mosaic, comprised of old forest, which has been heavily exploited for precious woods, and secondary forest with a range of ages. The secondary forests are fallow from the slash-and-burn corn production system (*milpa*), which is the mainstay for the families. The *milpa* system depends on a dry season, from February to May, and a rainy season from June to January. It is during the rainy season that hurricanes occur and increase the probability of an impact on the inhabiting population[21] (Fig. 1).

Family adaptive strategy

The Calakmul municipality is populated by settlers from different states of Mexico, mostly Chiapas, Tabasco, and Veracruz, who began to arrive in the area in the 1970s [22]. The *municipio* has a population of about 22,480 and a population density of 1.5 inhabitants per km^2. Most are peasants who in the past 29 yrs have developed two distinctive adaptive strategies termed: Household Subsistence Agricultural Strategy (HSA) and Household Commercial Agricultural Strategy (HCA)[23]. Their main cash crop is jalapeño pepper (*Capsicum annuum* L.) and their subsistence crop is maize (*Zea mays* L.). From the land, other income generating options include citrus fruits (*Citrus* spp.), squash (*Cucurbita pepo; Cucurbita moschata* Duchesne.) and grasses, which are sold to the tourist industry of Quintana Roo[24]. The two strategies, however, differ in terms of how people organize their production, their family structure and household composition, their goals as agricultural producers[25], and the ways in which they deal with the season of food scarcity before harvest[26]. For the first strategy, HSA, agriculture is part of a mixed and

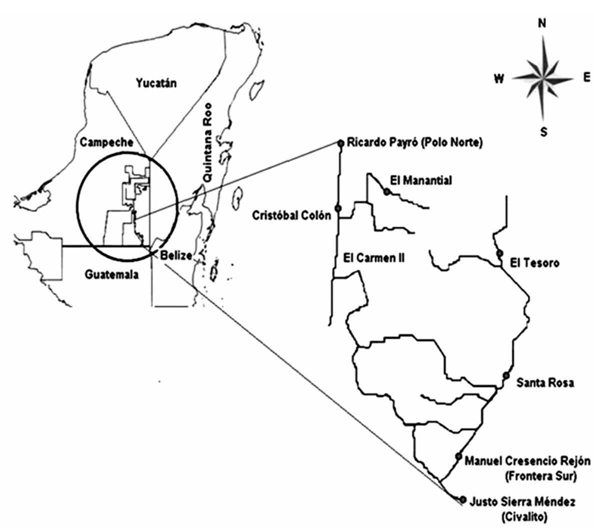

Fig. 1—Location map of study area.

diversified survival system that depends on different cultigens and fewer external inputs. From the *milpa,* they harvest maize, squash, watermelon (*Citrullus lanatus* (Thunb.) Matsum & Nakai), beans (*Phaseolus vulgaris* L. and *Phaseolus lunatus* L.), sweet potato (*Ipomea batatas* L.), cassava (*Manihot esculenta* Krantz), banana (*Musa* spp.), and "jalapeño" pepper, all of which can be harvested throughout the year. They also have widely diversified and productive homegardens that produce fruits and herbs, as well as meat from chickens (*Gallus domesticus*), turkeys (*Meleagris gallopavo*), ducks (*Anas platyrhynchus*) and pigs (*Sus scrofa*) for home consumption[27]. In the HSA, most decisions regarding agricultural production (i.e. cultivation strategies, inputs to be used, and destination of goods) are made by the head of the family, who also may control labor disaggregation within the household unit according to age and sex members. In the HSA, certain cash income is generated, which is, however, invested mainly in basic needs (i.e. food and clothing) and occasionally in agricultural inputs such as agrochemical and mechanical tools. The HSA thus has no means to generate any cash savings.

For the second strategy, HCA, agriculture is less diversified and the main goal is to further the "family business". In their agricultural fields, called *milpas*, the HCA families produces maize, squash, beans and "jalapeño" peppers. All of the produce, except maize, is sold on the market, together with the animals (chickens; turkeys; pigs; and sheep, *Ovis ovis*) produced in their homegardens, which are also less diversified and productive than those of the HSA[27]. In the HCA, the families invest in agrochemicals (fertilizers and pesticides), use tractors, and hire outside labour to help them during harvest period. They spend a smaller portion of their income on consumer goods, and they generate savings when they sell their "jalapeño" crop. These savings are used to invest in capital goods or to buy cattle. During the season of scarcity, they sell their cattle to purchase food or other necessary survival items. Cattle may also be sold during the jalapeño pepper harvest to pay pickers[23]. Their most productive and distributive decisions are made by the head of the family, who does not, however, have absolute control over family labour.

Sample selection

The study was carried out using a subsample of eight peasant families whose survival strategy belonged to one of the two types described above. These families were classified in a previous study and are part of a representative sample of 500 household units from 32 communities in southern Calakmul, Campeche[23]. For the study, eight families from three communities were selected and invited to participate. Four of the HSA and four of the HCA families that showed interest were chosen and surveyed. Questionnaires were used in interviews to obtain information on the 1999-2000 agriculture cycle, and for the 2002-2003 agriculture cycle, monthly interviews and measurements were conducted with families to assess the jalapeño cash crop, their spring-summer maize crop (*milpa grande*), and their autumn-winter maize crop (*milpa tornamil*). During the *milpa tornamil* in September 2002, hurricane *Isidore* (Category III Shaffir-Simpson scale) beat the Yucatan Peninsula, resulting in one of the strongest agricultural loss events since hurricane *Gilbert* hurricane in September 14 of 1988, with 164,110 hectares cultivated with crop staples being affected, out of two million hectares of forest and wetland[28]. Fowl, pork and beekeeping production were also severely affected with losses of 8.2 million individual fowl, 70,000 heads of pork, and 140,000 bee hives[29,30]. Such losses resulted not only in a strong economic upheaval but also in a food staple shortage for rural families across the Yucatan Peninsula. In addition, important infrastructure necessary for the well-being of both rural and non-rural families was severely affected, including hospitals, schools, potable water plants, houses and both public and privately owned buildings, together with the collapse of electricity system and strong damage to important roads; all damage together was estimated to have a monetary cost of 1000 millions of USD for reconstruction and recovery[31]. In Campeche state, this natural phenomenon brought 205 km/h winds and 227.7 mm of rain in 24 hours[32]. In Calakmul intense winds and rain, equivalent to 26% of the total annual precipitation (226.2 mm), were experienced[33]. The hurricane arrived in Calakmul when the families in the study had already begun to harvest their maize crops (*milpa grande*), but harvest of the cash crop (jalapeño pepper) was just beginning (Fig. 2).

Data collection

Crop production, area harvested, and labour invested in different daily activities by members of families belonging to both strategy groups (HSA and HCA) were documented. Structured interviews (close-ended questions) were conducted monthly with

Fig. 2—*Hurricane Isidore*, September 1, 2002[34]

all of the eight households, where all of the adult male and female members where interviewed separately. The interviews were conducted over two non-continuous agricultural cycles (1999-2000; 2002-2003). For every month, each interviewee was asked about the household's agricultural activities in which he/she had participated during the period, the relative time by weekday devoted to every activity mentioned, and the estimated land area covered in that period. The last question included transects walks in agricultural fields as means of identifying the plot's location and for future follow-up. Additionally, during the 2002-2003 agricultural cycle, crop production, labor investment and percent of damaged plants were quantified. To measure crop production, 16 randomly distributed 10 x 10 m plots were harvested: eight *milpa* plots and eight jalapeño pepper plots. A sample of the harvested materials was selected to determine their dry matter (DM) content by drying them in an oven at $60^{o}C$[35]. Additionally, the percentage of plants damaged by wind and rain was calculated immediately after the hurricane subsided. After the jalapeño pepper harvest, the land was planted with an autumn-winter maize crop (*milpa tornamil*). Family labor invested and the time spent in deciding to sow the *milpa tornamil* was quantified. A questionnaire was administered every 30 days over a 15-month period. Each questionnaire was answered by both male and female household heads. Using local measurement units and product names, household heads were asked to provide information on the type, quantity and cost of all herbicides, insecticides, fungicides, and fertilizers they applied during the 30 days preceding the interview. They were also questioned as to the types of activities they had performed in their agricultural fields and the relative time they had invested in each activity. Finally, input and output matrices were employed to compare HSA and HCA productivity and economic profitability[36,37]. The data were analyzed with a Mann-Whitney μ test using the statistical software SPSS[38]. A larger sample may have allowed us to use t-tests or one-way ANOVAs to test for differences between strategies. Unfortunately, the effort invested in data collection throughout the years made a larger sample size unmanageable. A Mann-Whitney μ test converts the raw data into ranks before comparisons are made, allowing us to ignore assumptions about homogeneity of variances and normality. This procedure masks real differences between strategies but reduces the possibility of finding significant results where none exist. For this study, the sample size was selected under the assumption that the quality of our data would allow us to find significant differences between strategies in spite of the lower resolution power of non-parametric statistics.

Results

Agricultural production and damage in crops

In the 1999-2000 agriculture cycle, before the arrival of hurricane *Isidore*, it was found that there were no significant differences ($P>0.05$) between HSA and HCA strategies in terms of harvested area and crop production of maize with the slash-and-burn production system (*milpa grande* and *milpa tornamil*), and of jalapeño pepper. Similar trends were observed between family strategies (HSA and HCA) in terms of investment in family labor in *milpa* production (Table 1). Also, before the hurricane impact similar findings ($P>0.05$) were observed for both HSA and HCA families (Table 2) in terms of harvested area, crop production and investment of family labour in *milpa grande* and jalapeño pepper production, although it was found that the wage labor invested on jalapeño pepper growing was significantly higher ($P<0.02$) on HCA plots (Table 2). After the hurricane, the impact on both agricultural strategy groups was similar in terms of the extent of damage to both maize and jalapeño plants (M-W μ = 4.0; P=0.48 for *milpa grande* and M-W μ = 5.50; P=0.47 for jalapeño pepper, respectively) (Tables 1 & 2).

Family response

Although the crops of both family strategy groups were affected, their responses to the hurricane's

Table 1—Mean crop area, crop production, and family labor input in *milpa* and jalapeño pepper of two familiar strategies in Calakmul, Campeche, Mexico

	Strategy [d]			
1999-2000 agriculture cycle	HCA (*n*=4)	HSA (*n*=4)	M-W µ	*P*-value
Milpa grande [a]				
Crop area (ha)	2.50 (1.73)	2.87 (1.31)	8.00	1.00
Grain harvested [c]	530.03 (211.70)	538.42 (383.50)	5.00	0.38
Family labor (days)	226.25 (87.83)	234.00 (18.74)	7.00	0.77
Milpa tornamil [b]				
Crop area (ha)	0.25 (0.25)	0.87 (0.42)	4.00	0.21
Grain harvested [c]	87.25 (74.50)	118.05 (39.05)	5.50	0.44
Family labor (days)	2.00 (2.00)	37.00 (36.7)	2.50	0.09
Month of sow the plot	November	November		
Jalapeño pepper				
Crop area (ha)	1.13 (0.72)	1.87 (0.55)	5.00	0.37
Fruit harvested [c]	56.80 (35.67)	256.30 (85.35)	2.00	0.08

M-Wµ: µ Mann-Whitney test; [a] *Milpa grande*: Spring-summer maize crop; [b] *Milpa tornamil*: Autumn-winter maize crop; [c] kg DM of grain or fruit /ha; [d] HCA: Household commercial agricultural strategy; HSA: Household subsistence agricultural strategy; (1.73) Standard deviation.

Table 2—Mean crop area, crop production and family labor input in *milpa* and jalapeño pepper before hurricane *Isidore* impacted the familiar strategies in Calakmul, Campeche, Mexico

	Strategy			
2002-2003 agriculture cycle				
Before hurricane	HCA (*n*=4)	HSA (*n*=4)	M-W µ	*P*-value
Milpa grande [a]				
Crop area (ha)	2.83 (1.04)	2.87 (0.75)	5.00	0.69
Grain harvested [b]	1105.7 (79.3)	1369.5 (592.1)	4.00	0.48
Family labor (days)	29.71 (24.83)	60.24 (48.66)	6.00	0.56
Jalapeño pepper				
Crop area (ha)	1.31 (0.86)	1.00 (0.71)	6.50	0.65
Fruit harvested [b]	136.8 (99.2)	344.7 (305.0)	5.00	0.38
Family labor (days)	25.92 (12.50)	50.43 (28.22)	2.00	0.08
Wage labor (days)	25.89 (14.56)	1.37 (0.44)	0.00	0.02

[a] *Milpa grande*: Spring-summer maize crop; [b] kg DM of grain or fruit /ha; (1.04) Standard deviation.

impact differed. In particular, the two household strategies (HSA, HCA) differed in their decisions to cultivate autumn-winter *milpa* (*tornamil*) (Table 3). Although HCA and HSA families cultivated similar areas of land, the HCA families delayed sowing (HCA 85 days vs HSA 47 days) (Table 3). This HCA decision could have been influenced by the families' attempts to recover their investment in the jalapeño pepper plots, thus leaving less family labor (M-W µ=0.00; P=0.02) for their *tornamil* plots (3 days), compared with the HSA labour used for their *tornamil* planting (19 days). Otherwise, HSA families perceived the damage caused by hurricane (31 % on cornfields) as a possible threat to their food security, and therefore, they emphasized their work on the *tornamil* plots, allowing them, eventually, to harvest a greater amount (M-W µ =1.00; P=0.04) of grain (616.8 kg DM/ha) than the HCA families (93.5 kg DM/ha) (Table 3). A similar trend was observed in post-hurricane family labor used in *milpa grande*: HSA increased family labor (40 days), whereas the HCA family labour decreased significantly (12 days). However, no differences (P>0.05) in investment in family labour was observed in jalapeño pepper (20 days HCA and 18 days HSA, respectively) (Table 3).

Economic balance

The economic value of jalapeño pepper production of the two family strategy groups was found to be similar (P>0.05). However, HCA families tended to obtain lower total economic returns (US$ 826.5/ha) and profitability (US$ 2:1) than HSA families (US$ 1268.5/ha, and US$ 3.9:1, respectively), due their high investment in agrochemicals and wage labor (Fig. 3). The strategy of the HCA families was to delay its *milpa tornamil* cultivation in order to devote more money and time to their jalapeño crop.

Discussion

In recent findings of the effects of climate change on rural areas of developing countries, little scientific

Table 3—Mean crop area, crop production and family labor input in *milpa* and jalapeño pepper after hurricane *Isidore* impacted the familiar strategies in Calakmul, Campeche, Mexico

2002-2003 agriculture cycle	Strategy			
After hurricane	HCA (*n*=4)	HSA (*n*=4)	M-W μ	*P*-value
Milpa tornamil [a]				
Crop area (ha)	0.84 (0.49)	1.98 (1.07)	3.00	0.14
Sowing time (days) [d]	85.5 (17.9)	47.0 (29.6)	2.00	0.06
Month of sow the plot	2nd week Dec.	1st week Nov.		
Grain harvested [c]	93.5 (74.1)	616.8 (442.5)	1.00	0.04
Family labor (days)	2.91 (1.5)	19.23 (7.91)	0.00	0.02
Milpa grande [b]				
Maize plant damage (%)	42.67 (8.02)	30.50 (17.89)	4.00	0.48
Family labor (days)	11.88 (7.11)	40.48 (28.54)	2.00	0.08
Jalapeño pepper				
Jalapeño plant damage (%)	13.32 (7.05)	29.80 (24.60)	5.50	0.47
Family labor (days)	19.66 (17.65)	17.86 (9.61)	7.00	0.77

[a] *Milpa tornamil*: Autumn-winter maize crop; [b] *Milpa grande*: Spring-summer maize crop; [c] kg DM of grain /ha; [d] Means that HCA sowed their corn plots on the second week of December while HSA sowed their corn plots on the first week of November; (0.49) Standard deviation.

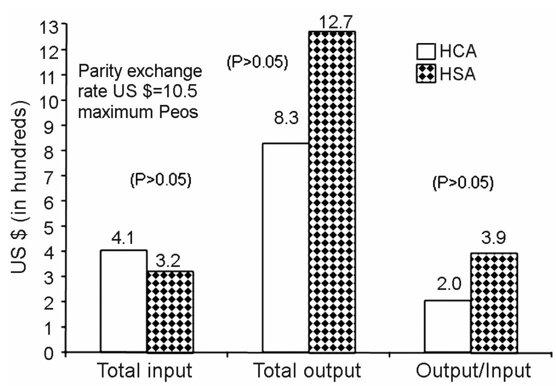

Fig. 3—Total input, output and economic profitability of Jalapeno pepper (per hectare) in two familiar strategies in Galakmul, Campeche, Mexico

attention has been given to its impact on subsistence agriculture systems or to the effect of peasant strategies on the sustainability of these systems[39-42]. It has been proposed that evaluation of the sustainability of different peasant strategies be approached through adaptability and vulnerability measurements[43]. The adaptability and vulnerability of each family strategy is influenced by climatic factors as well as the peasants' own choices[44, 45]. When peasants place emphasis on a market-oriented crop (*i.e.* jalapeño pepper), this decision increases the level of risk and reduces their capacity for resistance and adaptation, resulting in a smaller portion of the food production allotted to family subsistence[46], as was observed with HCA families in comparison with HSA families in the study. This differentiation could be related to different agricultural management strategies. The agro-ecological management of the HSA families is a strategy adapted to the tropical conditions, including major disturbances events, and allows the families to maintain constant food production, minimize risks, and cope with environmental variability[16,47,48]. Their food production systems are complex and diverse, combining different plants and animals with multipurpose objectives and social household arrangements for decision-making and managing natural resources[4].

In the study, post-hurricane HSA family decision-making gave rapid attention and emphasis on labor in maize production (*milpa tornamil*), resulting in a higher volume of production devoted to food security and, thus, decreasing the family's vulnerability to the natural disaster. The HSA group's vulnerability status was observed to be similar to agro-ecological farmers when impacted by hurricanes [49], and this post-impact management is one of the main responses frequently observed in subsistence strategies to reduce the risk to food security from natural phenomena. What began as a coping strategy could become a household adaptation strategy, and ultimately, development of greater resilience. For extreme climatic events, small farmers have developed the following resilience factors: efficient use of family labor, shifts in relative importance of crops, and indigenous knowledge that allows exploiting risky environmental niches[4,50]. Nonetheless, when agro-ecological systems are transformed to non-ecologically adapted systems, extreme climatic factors can reduce people's resilience mechanisms and increase vulnerability by jeopardizing peasant production, household food security and the system's economy[45,51-53]. This phenomenon was observed in the study, before and after the hurricane impact, with HCA families emphasizing more wage labor in jalapeño pepper production, and in so doing, reducing family labor and delaying the autumn-winter maize crop (*milpa tornamil*). This decision reflects a change in the relative perceived importance of their crops, with the goal of recovering the economic investment made in jalapeño pepper production. Despite the efforts made by these families, their economies were affected adversely simultaneously by the low prices of the cash crop on the market and their lower maize production. As a result, the trend of lower economic profitability- and lower food security and resilience- for the HCA families was observed relative to the HSA families.

Conclusion

The findings of the study confirm that agricultural subsistence strategies reduce the risk and impact of climatic hazards. Household subsistence agriculture (HSA) in Calakmul responds as an environmental coping system and better manages resilience mechanisms, emphasizing maize production and making decisions quickly to invest more family labor in maize cultivation, without reducing family labor in their cash crop. These responses made this family strategy less vulnerable to hurricane impact than the household commercial agricultural strategy (HCA), which increased wage labor in the cash crop, jalapeño pepper, decreased family labour and delayed cultivation of the maize crop, resulting in less maize harvested and food production for home-consumption, while the economic profitability, affected by their higher economic investments in chili pepper and lower market price, was the same as that of the HSA strategy, making them less resilient to this environmental catastrophe.

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