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SHORT-TERM EFFECT OF HURRICANE IRMA AND MARÍA IN THE POPULATION OF *Gesneria pauciflora* (GESNERIACEAE)

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Abstract

The Caribbean was recently struck by two hurricanes (Irma and María) considered among the most powerful since 1928 in that region. These hurricanes brought intense and continuous rainfall, which likely impacted plants inhabiting riparian areas through flash floods and landslides. We conducted a post-hurricane assessment of *Gesneria pauciflora*, an endemic riparian species of conservation concern in Puerto Rico, to determine the number of individuals of this species, their distribution and their response to the influence of these natural phenomena across its distribution range; also, the assessment was an opportunity to survey additional sites within and outside of the Maricao Forest Reserve. A total of 79 colonies were surveyed during the study period (56 known colonies and 23 new records), yet seven of the known colonies were extirpated due to landslide or flood-driven habitat modifications. The survey yielded 7,853 plants distributed across three sub-watersheds with non-reproductive plants comprising 65.2% of the plants surveyed, followed by reproductive adults (25.3%) and seedlings (9.5%). Plants were found in a variety of habitats associated with riparian environments. Results from colonies that had pre-hurricane information suggest that plant mortality could have been as high as 89% with variation likely resulting from differences in their location within the riverine system (higher mortality for colonies in the main channel of the watershed). There was approximately an 11% reduction in estimated canopy cover at the site, and percent plant mortality showed a negative association with canopy cover after the hurricanes. While the number of individuals is higher than expected for a threatened species, the patchy distribution of its populations justifies the continuation of monitoring activities for the species at larger spatio-temporal scales to examine potential delayed responses to these hurricanes.

Keywords Caribbean, disturbance, endemics, plant conservation, riverine ecosystem.

Resumen

El Caribe fue golpeado recientemente por dos huracanes (Irma y María) considerados entre los más poderosos desde 1928 en esa región. Estos huracanes trajeron lluvias intensas y continuas que probablemente impactaron en plantas que habitan áreas ribereñas a través de inundaciones repentinas y eventos de deslizamientos de terreno. En este estudio,

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realizamos una evaluación post-huracán del estado poblacional de *Gesneria pauciflora*, una especie ribereña endémica de Puerto Rico y de interés de conservación, específicamente para determinar el número de individuos de esta especie, su distribución y la influencia de estos fenómenos naturales sobre los individuos en su área de distribución. Esta evaluación representó además una oportunidad para explorar lugares adicionales dentro y fuera de la Reserva Forestal de Maricao en búsqueda de poblaciones desconocidas al momento. Evaluamos 79 colonias durante el período de estudio (56 colonias conocidas y 23 nuevos registros), mas sin embargo, siete de las colonias conocidas fueron extirpadas debido a deslizamientos de tierra o modificaciones de hábitat generadas por inundaciones. La evaluación resultó en 7,853 plantas distribuidas en tres subcuencas hidrográficas donde las plantas no-reproductivas representaron el 65.2%, seguidas de adultos reproductivos (25.3%) y plántulas (9.5%). Las plantas se encontraron en distintos microhábitats asociados a ríos. Para las colonias con información previa al huracán, los resultados sugieren que la mortalidad de plantas alcanzó hasta un máximo de 89% con variaciones entre colonias dependiendo de la ubicación dentro del sistema fluvial (mayor mortalidad para las colonias localizadas en el río principal de la cuenca hidrográfica). Hubo una reducción del 11% en la cobertura estimada del dosel y el porcentaje de mortalidad de plantas mostró una asociación negativa con la cobertura luego de los huracanes. Si bien el número de individuos aparenta ser relativamente alto para una especie considerada amenazada, la distribución geográfica restringida de sus colonias justifica el continuar los monitoreo de las mismas a mayor escala espacio-temporal, para examinar posibles respuestas tardías de sus individuos ante estos huracanes.

Palabras clave Caribe, conservación de plantas, disturbio, ecosistema riverino, endémico.

INTRODUCTION

Caribbean forests frequently experience tropical storms, which often become major natural phenomena transforming their structure, composition, and ecosystem function, and large-scale catastrophic events to infrastructure (Boose et al. 1994; Lugo 2000; Van Bloem et al. 2003, 2005, 2006). Visible hurricane effects include massive defoliation, snapped and wind-thrown trees, large accumulation of debris, landslides, debris flows, and altered stream channels, among others (Lugo 2008)noticeable over the short-term and relatively well documented in the literature. Invisible effects are less understood as they require well-focused research both in the short- and long-term time scales. Even though these natural phenomena might favor the survival and growth of some species (i.e., Boucher and Mallona 1997), it may also diminish the persistence of others either by direct mechanical damage or changes in species interactions. For example, hurricanes may promote immediate or delayed mortality in trees through complete defoliation and severe branch damage (Frangi and Lugo 1998), facilitate the establishment of pioneer and shade-intolerant species in disturbed sites within the forest (Brokaw 1985, 1987), increase herbivory rate (Hunter and Forkner 1999) and even help accelerate the spread of invasive plants (Bellingham et al. 2005; Lynch et al. 2011; Bhattarai and Cronin 2014). For species of conservation concern in the Caribbean, understanding the effects of these natural events on them is a priority in order to increase their chance of recovery, with assisted rehabilitation, in response to these events.

Puerto Rico receives hurricanes at a rate of one every 21 years historically, but between 1852 and

1998, that rate reduces to one every 11.2 years when thirteen hurricanes affected the island including Hurricane Georges, a category-3 hurricane in 1998 (Scatena and Larsen 1991; Feng et al. 2018). In September 2017, however, Puerto Rico received the impact of two higher-category hurricanes (Irma and María). On 6 September 2017, the trajectory of Hurricane Irma (category-5) crossed about 85 km East-Northeast from San Juan, with maximum-sustained-winds of 295 km/h. Even though the eye of Hurricane Irma was away from the U.S. Virgin Islands (it struck the British Virgin Islands and moved upwards into the Atlantic Ocean), tropical storm and hurricane conditions were reported for Puerto Rico (Cangialosi et al. 2018). On 20 September 2017, the eye of Hurricane María made landfall near Yabucoa, southeast coast of Puerto Rico, as a top category-4 storm with maximum-sustained-winds of 250 km/h (Pasch et al. 2018). Hurricane María crossed the island exiting it from the north coast between the municipalities of Camuy and Quebradillas at around 1800 h (Pasch et al. 2018). As Hurricane María made landfall on the island, damage to infrastructure and natural areas was evident (Hu and Smith 2018). It is estimated that Hurricane María may have killed or damaged more than 20 million trees (Feng et al. 2018) with massive wind-driven defoliation leading to the browning of forests throughout the landscape (Burnett 2017).

During hurricane events, rainfall may become extreme, increasing the number and intensity of flash floods and landslides (Scatena and Larsen 1991; Larsen and Torres Sanchez 1992). Species associated with riparian ecosystems might be especially vulnerable to the action of flashflood events and landslides, possibly experiencing extirpation following these events when extreme. If the number and intensity of hurricanes in the Caribbean increase as predicted by models (Emanuel 2005), species endemic to riparian areas and of conservation concern could face a much more complicated scenario in the near future. *Gesneria pauciflora* (Gesneriaceae) is

Figure 1. *Gesneria pauciflora*, an endemic species from Puerto Rico. Photo by O. Monsegur-Rivera.

the only one of five endemic Gesneriaceae species to Puerto Rico (Skog 1976) (Figure 1), classified as Threatened under the Endangered Species Act (U.S. Fish and Wildlife Service 1995). This riparian species was listed due to its narrow distribution restricted to serpentine soils in the western part of Puerto Rico (i.e., Maricao Forest Reserve boundaries), and the potential for population extirpation due to the threats from large-scale natural phenomena (i.e., hurricanes, landslides, flooding) and from human activities (i.e., modifications in the river hydrology due to water extraction; U.S. Fish and Wildlife Service 1995). Populations of *G. pauciflora* at the reserve inhabit riverine environments and are established on wet rocks near to the river flow. Some of

these populations have been monitored since 2013, and we expected that populations might have experienced consequences of intense and prolonged duration because of hurricanes Irma and María. One hypothesis is that colonies (i.e., patch level) with more individuals were more susceptible to plant mortality or extirpation. Likewise, flooding events may lead to differential mortality across plant stages if, for example, different plant stages were to be differentially impacted by the incoming water during flash flood events, and small individuals may be more likely to be washed than juveniles or adults.

In this study, we took advantage of ongoing studies to assess the post-hurricane condition of 11 colonies of *G. pauciflora* for which there were plant counts before the hurricane events of 2017. We took the opportunity to visit all known colonies distributed in the Maricao Forest Reserve to conduct a full count of plants for this species. Also, we surveyed other watersheds outside of the reserve to evaluate the potential of occurrence of additional populations and provide more updated information on the distribution, general habitat, and the number of plants for this species. This information expands previous knowledge from other studies and allows us to make recommendations on the best practices to conserve and restore the population of this endemic and threatened species.

METHODS

Study Site

The Maricao State Forest Reserve (4,150 ha; Figure 2) is located at the western end of Puerto Rico within the municipalities of Maricao, Sabana Grande, and San Germán (Anadon-Irizarry 2006). The protected area's topography is dominated by rugged mountains and is characterized by serpentine soils. This particular geological soil type distinguishes the Maricao Reserve as an important ecological area due to a high number of associated endemic species (Ricart Pujals and Padrón Vélez 2010). The mean temperature and rainfall at Maricao are 21.7°C and 2,326 mm, respectively (Tossas 2006). A seasonal trend in rainfall in the Maricao reserve is suggested, with a wet season from August to November and a dry season from January to April (Fogarty and Vilella 2002). Data from a period of 32 years (1985-2016; https://waterdata.usgs.gov) indicate highly variable streamflow in the Maricao River with the lowest monthly mean discharge reported in February (0.54 m^3/s) and the highest in October (3.1 m^3/s). The maximum discharge values for this river were reported in 1998, in September (8.7 m^3/s) and October (204.8 m^3/s), which were associated with Hurricane Georges. In 2017, rainfall associated to Hurricane María, between 19 to 21 September, was estimated within a range between 254 mm and 381 mm (Pasch et al. 2018), and the maximum daily mean discharge recorded for Maricao River was about 14.2 m^3/s, also in September; there is no data on the maximum discharge of the Maricao River associated to Hurricane María, however, because most of the sensors were damaged. Nonetheless, flooding and landslides associated with Hurricane María caused unprecedented damage to the infrastructure and the Maricao River watershed (current and former staff from the Maricao Fish Hatchery, Department of Natural and Environmental Resources [DNER], personal communication).

Field monitoring

Fifty-six previously known colonies of *G. pauciflora* were visited from March to April of 2018 (between five and six months after María impacted the island). At each colony, we counted the number of plants and classified individual plants in one of three categories or life-history stages using the classification scheme of Pérez et al. (2019): seedlings, non-reproductive, and reproductive. Individuals were considered

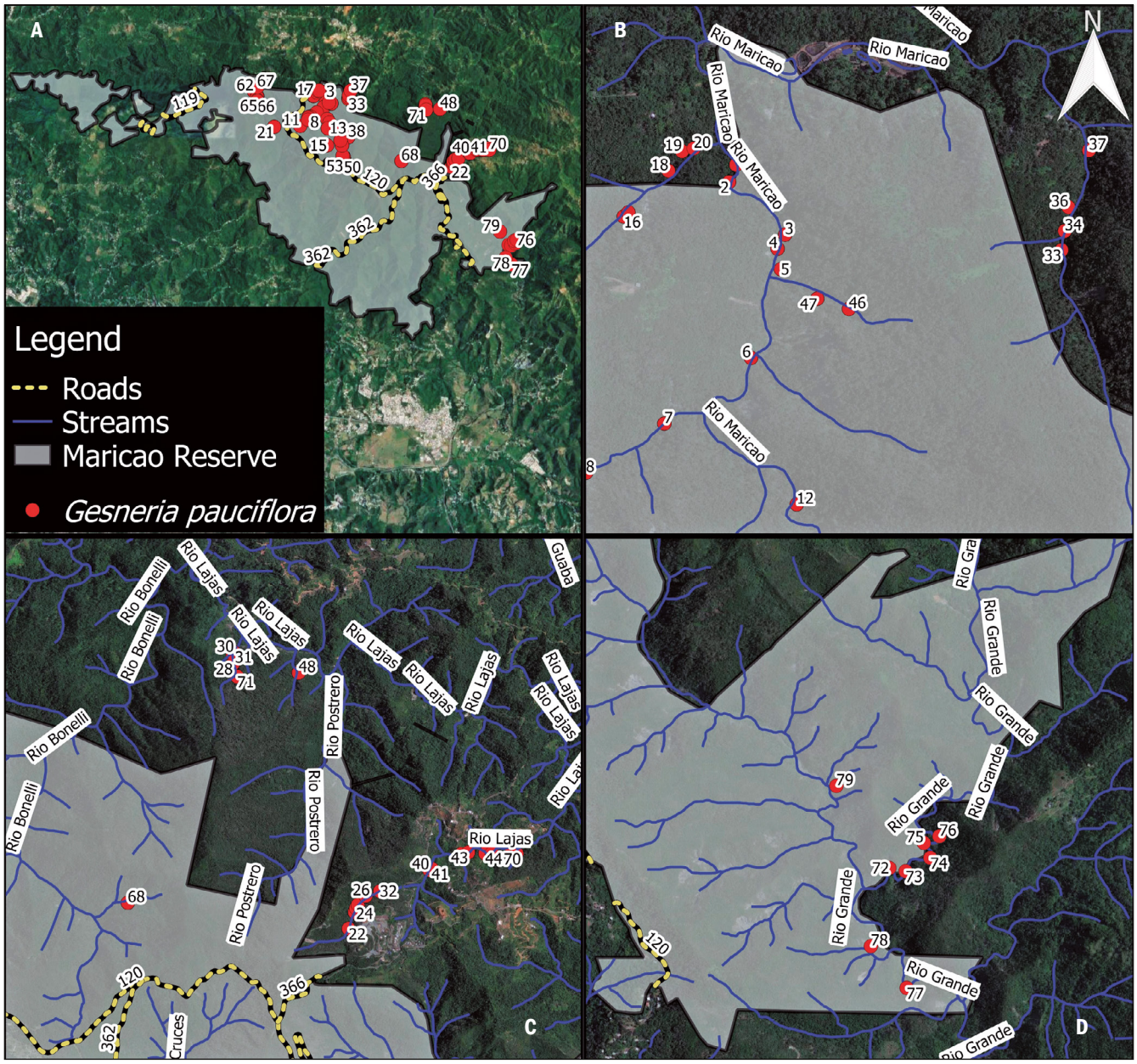

Figure 2. Distribution of the 79 colonies of *Gesneria pauciflora* distributed in the Maricao Reserve. (A) All of the colonies combined; (B–D) distribution of the 29 colonies located outside the limits of the Maricao Reserve. (B) Four colonies located at Quebrada Santa Rita and three in the Maricao River; (C) twenty colonies established along the Rio Lajas around the Salto Curet touristic place and Indiera Alta; (D) two colonies along the Rio Grande.

seedlings if they were small plantlets with a hyaline stem with two or four leaves (approximately less than 0.4 mm in high). Non-reproductive plants were those greater than 0.4 mm and smaller than 15 cm. Reproductive plants were those larger than 15 cm, but if plants smaller than 15 cm were flowering or had remnants of inflorescences, they were also categorized as reproductive individuals. For each plant, we recorded the length of the largest branch, the number of inflorescences, flowers, and fruits (when present), and the frequency of floral herbivory. To characterize the habitat of each colony after the hurricane, we collected the following information: habitat type (i.e., cascade, rock wall, step, and pool), the surface area occupied by the species, percentage of area available for reintroduction (unoccupied space within

the colony, or available space with similar microhabitat conditions), canopy cover (estimated using a densitometer), and the presence of landslides. If new colonies were found, these were georeferenced, and we collected all parameters described above.

Table 1. Population structure and habitat characterization of *Gesneria pauciflora* colonies. Life history stage: Seed = seedlings; NRP = non-reproductive plants; RP = reproductive plants. Habitat characteristics: R = rock-wall; C = cascade; S = step; P = pool; CC = canopy cover; AfR = area for restoration. * = grand mean of all sites.

Locality	Life history stage						Habitat characteristics					
	Seed		NRP		RP		Patch surface				CC (mean %)	AfR (m^2)
	Total	%	Total	%	Total	%	R	C	S	P		
Bonelli	–	–	–	–	–	–	0	1	0	0	–	–
Lajas	0	0	953	65.3	506	34.7	10	6	4	6	70.8	89.7
Maricao	447	8.7	3,419	66.3	1,288	25.0	8	16	10	10	79.7	158.3
Prieto	217	17.5	749	60.4	274	22.1	3	1	6	0	71.4	30.3
Total	664	8.5	5121	65.2	2,068	26.3	21	24	20	16	76.5*	278.3

Hurricane Impacts

We have pre-hurricane count data (number of plants per life-history stage) for a subset of 11 colonies (out of the 56 previously known colonies), located in the Rio Maricao watershed. For these 11 colonies, we used post-hurricane counts of plants to estimate percent mortality (i.e., {[number of plants in 2017 – plants in 2018]/[number of plants in 2017]} *[100]) for the whole colony and by stage. We analyzed changes in the number of plants per colony before (June 2017) and after (April 2018) these hurricanes and tested if the difference between the pre- and post-hurricane count of plants was significantly different among plant stages using a Negative Binomial General Linear Model (NBGLM) and a post hoc analysis using the "emeans" package in R (R Core Team 2018). At each colony, we also estimated changes in canopy cover after Hurricanes Irma and María by taking hemispherical photographs (using a Nikon Coolpix 8400 camera and fish-eye lens FC-E9) before (October 2016) and after the hurricanes (April 2018). The percent of canopy cover at each colony was estimated from the images with the software ImageJ (Rasband 2014) using Hemispherical 2.0 macro (Beckschäfer 2015). We conducted a paired t-test to determine if the difference in the percentage of canopy cover before and after hurricanes was significant. The relationship of the percentage of plant mortality with canopy cover and initial population size was analyzed using regression analysis. All statistical analyses were conducted using R (R Core Team 2018).

RESULTS

The overall survey resulted in 79 colonies (23 new ones), which expanded the inventory of *G. pauciflora* colonies; 29 colonies were located outside the Maricao Forest Reserve limits (Figure 2). Also, 46 colonies were in a third-order stream, 30 in a second-order, and 3 in a fourth-order stream. After the hurricanes, seven colonies were extirpated. These were mostly located in second- and third-order streams in the lower part of the basin; five of these colonies were extirpated because of landslides. For the 72 extant colonies among the three sub-watersheds, colony size varied from 4 to 476 individuals with larger colonies concentrated in the upstream within the watershed. Among all colonies, we found 7,853 individuals quantified and classified as follows: 8.5% seedlings, 65.2% non-reproductive, and 26.3% reproductive plants (Table 1). Most of the colonies had at least one individual classified as a reproductive adult (> 15 cm in length), and only 397 (5.1%) out of the 7853 individuals had reproductive structures. At the time of the survey, reproductive adults were developing 105 inflorescences (average = 1.61/plant, ± 0.22 [standard error of the mean]), and produced 375 flower buds (2.27/plant ± 0.13), 76 open flowers (1.18/plant ± 0.06), and 1914 fruits (3.59/plant ± 0.19). Overall, floral herbivory was minimal (2.9% of the plants presented damages), and the level of damage from herbivory varied between 0% and 25% per colony. Colonies of *Gesneria* were distributed across

Table 2. Number of plants (n) and reproductive individuals (Reprod.), before and after hurricanes Irma and María, and percent mortality per colony in each of two riverine localities. ext. = extirpated.

		Pre-hurricane		Post-hurricane		
Locality	Colony	n	Reprod.	n	Reprod.	Mortality (%)
Main Channel	1	16	1	5	1	68.8
	2	251	14	44	2	82.5
	3	40	3	5	0	87.5
	4	14	1	ext.	—	—
	5	573	45	63	5	89.0
	6	225	29	42	3	81.3
Tributary	7	36	5	13	1	63.9
	8	1	0	ext.	—	—
	9	21	5	5	2	76.2
	10	219	17	129	6	41.1
	11	241	8	174	4	26.1

four types of microhabitats (in decreasing percentage): cascades (29.6%), rockwalls (25%), steps (24.6%), and pools (19.8%) (Table 1). On average, the area occupied by colonies was 20.2 m^2 (± 4.4), and the average canopy cover was 76.5% (± 1.73). The average available space for reintroduction within a colony was 4.5 m^2 (± 0.9); the total area available for reintroduction among the three watersheds was approximately 278.3 m^2.

Out of eleven colonies monitored for reproduction and mortality before hurricanes Irma and María, two were extirpated: one was in the main channel and another in a tributary of the Maricao River. The two extirpated colonies had the lowest number of plants before the hurricanes (Table 2). Colonies located in the main channel exhibited an average rate of mortality of 81.2%, while colonies in the tributary had an average rate of 51.8% (Table 2). The average number of plants per colony was significantly lower six months after the hurricanes: it changed from 148.8 plants (± 52.9) to 44 plants (± 17.8) (NBGLM: $X^2 = 3.86$, $p = 0.049$) (Table 2). Changes in the number of plants were related to plant stage, but changes were larger for seedling than for juveniles when compared with adults (Figure 3).

Overall, survivorship was higher in the juvenile and adult size-categories with 48.5% and 56.7%, respectively (Table 2). The average number of reproductive individuals changed from 11.6 (± 4.25) per colony to about 2.7 (± 0.7) before and after the hurricanes, respectively

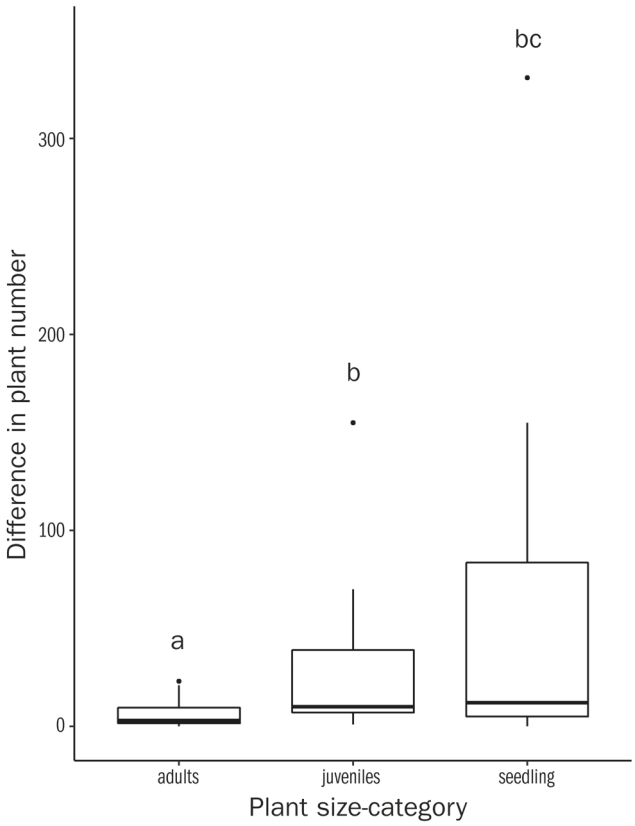

Figure 3. Difference in the number of individuals before and after the hurricane events as a function of plant stage (adults, juvenile, and seedlings). The full model (see text) was expressed as the difference = 1.92 + (1.54) juveniles + (2.25) seedlings (all significant at $p < 0.01$). Different letters in the figure indicate significant differences at $\alpha = 0.05$ among groups.

(NBGLM: $X^2 = 10.52$, $p = 0.03$). Colonies 5 and 6 (see Figure 2b) had the greatest number of reproductive plants before the hurricanes, but also scored the highest reduction (Table 2). The percent of canopy cover ranged between 79.4% and 98.7% (average = 93.8 % ± 1.6) before the hurricanes, and between 71.6% and 93.6% (average = 82.9% ± 2.3) after the hurricanes (NBGLM: $X^2 = -5.94$, $df = 10$, $p = 0.0001$). Percent mortality of plants per colony was negatively related with canopy cover after hurricanes (Estimate ± standard error of the mean = -2.6 ± 0.51, $F_{1,9} = 25.85$, $p = 0.0006$) (Figure 4a) and a positive relationship with the percent canopy cover change (Estimate ± standard error of the mean = 2.3 ± 0.94, $F_{1,9} = 6.1$, $p = 0.0350$) (Figure 4b) and these models explained 71.3% and 40.4% of the total variation in plant mortality, respectively. Initial population

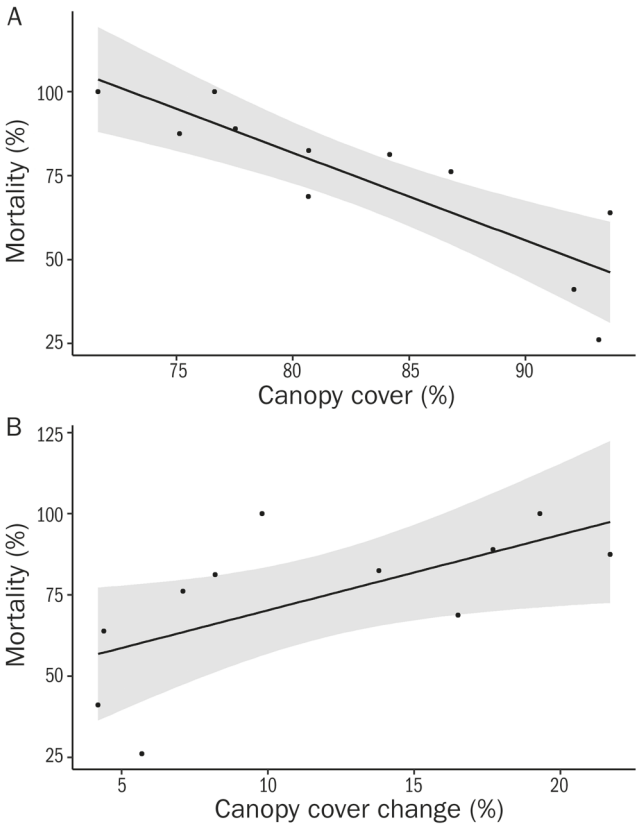

Figure 4. Relationship between percent plant mortality of *Gesneria pauciflora* among colonies as a function of (A) percent canopy cover and (B) percent canopy cover change after the 2017 hurricane events at the Maricao Forest Reserve in Maricao, Puerto Rico.

size did not explain the percent mortality of plants per colony ($F_{1,9} = 0.21$, $p = 0.6600$).

DISCUSSION

As expected, hurricanes Irma and María induced higher plant mortality rates, which is partly consistent with theory. For example, theory predicts that small populations are usually more vulnerable to environmental stochasticity (Colling and Matthies 2006). In fact, our results showed that 1) changes in canopy cover (higher mortality occurred in areas with less cover); 2) the location within the riverine system (main channel vs. a tributary); 3) and stochastic events (landslide extirpating some of the colonies) were factors that explained most of the variation in plant mortality and population persistence. Theory also predicts that populations with less than six plants are more likely to be extirpated (or extinct in the case of whole species) (Matthies et al. 2004; Öckinger and Nilsson 2010). Contrary to theory, however, our results showed that few colonies were extirpated and that the initial number of individuals in a colony was not a significant factor explaining plant mortality after these hurricanes. Most likely, environmental variation may play a greater role in plant mortality than frequently acknowledged (see next).

Colonies of *Gesneria pauciflora* appear to be associated with shaded environments (Pérez et al. 2018). Hurricane María defoliated most forests across Puerto Rico massively (Miller et al. 2019). Canopy cover and changes in it were significantly associated with percent mortality of plants among colonies, with higher mortality in colonies located in more-open forest areas or where the reduction in the percent canopy cover was highest. Also, plant mortality seemed to be highest in seedlings relative to juveniles and adults following these hurricanes. Several hypotheses may explain these results. First, evapotranspiration rates of plants increases in an opened canopy, and these increases are higher in seedlings relative to other plant stages by virtue of having a higher surface to volume ratios (Zotz et al. 2001) Also, and in the case of seedlings, they may have a less developed root system relative to juveniles and adults and thus, are less able to access groundwater, which makes them more susceptible to drought stress due to an open canopy. In addition, our observations frequently revealed plants slightly detached from the substrate and showed drying symptoms, which suggest that seedlings may be more susceptible than other stages of plant development to mechanical forces from water currents.

Overall, the rate of plant mortality ranged from 68% to 89% in the main channel, while in the tributary, it was between 26% and 76%. Colonies along the main channel were likely to be subjected to greater volumes of water and sediment that scraped the vegetation along river margins due to the flooding events

associated with hurricanes Irma and María. Prior demographic studies of *G. pauciflora* suggest that plants in different locations along the river system may exhibit life-history trade-offs that are consistent with different disturbance regimes along the river (Pérez et al. 2019). Although we did not have data to quantify and compare the discharge in the main channel and the tributary, structural damage of the forest was higher along the main channel where more landslides and greater accumulation of rocks and sediments were evident (M. Pérez, personal observation).

Plants documented in this study are distributed among 79 local patches in the forest, and only 63.2% of patches are currently protected, and at least 29 colonies are located outside areas managed for conservation. Also, even when the number of plants detected for the species could be considered high (> 7,000 individuals), and that 11 "new" colonies were added to previous surveys, only a quarter of plants sampled were flowering and capable of sexual reproduction. Even when this species is capable of some autogamy (i.e., autonomous pollination), fruit production is often pollination limited (Pérez et al. 2018). Pollen limitation on sexual reproduction may be even stronger if these natural phenomena also affected populations of pollinators like hummingbirds, which are the main visitor to individuals of *G. pauciflora* (Pérez et al. 2018).

In this study, we did not measure plant damage nor reductions in plant size, which likely occurred during the hurricane-driven flood events as plants can be broken easily. Plant damage following hurricanes, however, may lead to delayed mortality and decrease reproduction and recruitment in the long term. For example, the reproductive effort of two epiphyte orchid species did not return to pre-hurricane condition, and one of them, *Dendrophylax lindenii*, showed a decline in the population growth rate that continued eight years after Hurricane Ivan struck Cuba in 2004 (Mújica et al. 2013; Raventós et al. 2015). Similarly, over a period of nine years, values of the population growth rate of the cactus *Mammillaria gaumeri* were lower than unity and were associated with the flooding period that occurred in the Yucatán Península due to the Hurricane Isidore in 2002 (Ferrer-Cervantes et al. 2012).Therefore, although it was beyond the scope of our study, we need to continuously monitor colonies of *G. pauciflora* to assess its long-term response to the influence of these hurricanes, particularly the survival, growth, and fecundity of its individuals at a larger spatio-temporal scale.

Management Recommendations

We provide recommendations based on the quantitative and qualitative information herein discussed. After the hurricanes, there were plants slightly detached from the rock or hanging from their roots. Thus, we recommend that following a hurricane, plants under such conditions (detached from the rock) should be glued to the rock (based on preliminary experiments we recommend using Loctite® marine adhesive sealant) or relocated in microhabitats with environmental conditions similar to those of pre-hurricane conditions and mostly undisturbed. The species can generate roots from vegetative material within a period of two or three months (Pérez et al., unpublished data). Relocation of large plants (i.e., adult plants) after a hurricane seems to provide an acceptable management strategy for some epiphyte orchids after hurricane events (Tremblay 2003; Raventós et al. 2015). Therefore, relocating adult plants of *G. pauciflora* also might be a plausible strategy, at the population level, to increase their probability of survival.

The spatial location and microsite conditions where the establishment of plants is most successful should be known before relocating plants or establishing new colonies (Tremblay 2003; Tremblay and Castro 2009; Vale et al. 2013). Colonies distributed in the second- and third-order streams may be more vulnerable than the ones in the upper part of the basin (first-order streams) during extreme natural events because they showed higher mortality of plants after

these hurricanes. Fortunately, our surveys within the Maricao Forest Reserve revealed available space for reintroduction, either in sites in which colonies were extirpated, in sites were colonies were reduced in number, or in new microhabitats that share ecological features similar to pre-hurricane conditions. Therefore, these new microhabitats may represent adequate options for future relocations if deemed necessary. Also, we recommend monitoring all colonies documented here, at least once a year, to detect signs of delayed mortality before it reaches unsustainable levels. Likewise, we need to study the reproductive activity because recent population models of *G. pauciflora* suggest that populations are declining in numbers across the main watershed examined here (Pérez et al. 2019). Finally, we recommend executing efforts to educate and integrate surrounding communities and private stakeholders in conservation efforts for this species, given that recent surveys suggest that 36.7% of colonies lie outside the Maricao Forest Reserve boundaries.

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