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Notes on the Natural History of *Harrisia portoricensis* (Cactaceae): A General Update Including Specific Recommendations for Management and Conservation

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Abstract.—*Harrisia portoricensis* is a threatened columnar cactus whose distribution range is currently restricted to three small islands of the Puerto Rican Bank: Mona, Monito, and Desecheo. In this work we present a brief summary of results on natural history and population size estimates of *H. portoricensis* populations, extracted from two years of population and community-level intensive studies performed at Mona and Monito Islands. Analyses of the demographic profiles of *H. portoricensis* populations demonstrated that for Mona Island populations included plants in the adult, juvenile, and seedling stages, whereas population of this species on Monito Island only included adult plants. For both islands, we detected a high percentage of *H. portoricensis* plants showing vegetative lesions. Additionally, we found that the presence and abundance of these vegetative lesions in *H. portoricensis* were significantly associated with increases in total plant length. Our combined results suggested that active management *in situ* is necessary for the recovery of this threatened species and also highlight the need for long-term monitoring to determine the effects of changing biotic and abiotic interactions on the future of *H. portoricensis* populations.

Keywords.— Columnar cactus, conservation, *Harrisia portoricensis*, Mona Island, Monito Island, population size estimate, tropical dry forest, vegetative lesions

Cacti are a species-rich angiosperm family and represent one of the most conspicuous and ecologically important plant groups in dry, arid, and semiarid ecosystems (Fleming and Valiente-Banuet 2002, Nobel 2002). Despite its high diversity and dominance in environments with low water availability, the family contains a large number of endangered and threatened species (Walter and Gillett 1998, Ortega-Baes and Godínez-Alvarez 2006). *Harrisia portoricensis* Briton, is a columnar cactus formerly endemic to four Caribbean islands of the Puerto Rican bank. At present, this species is extinct on the island of Puerto Rico and is geographically restricted to the small islands of Mona, Monito and Desecheo (USFWS 1990). *Harrisia portoricensis* is listed as a threatened species under US Federal Regulations, a status mostly attributed to habitat loss and vegetation changes due to the presence of feral goats and pigs throughout their critical habitats (USFWS 1990). The US Fish and Wildlife Service recently conducted the mandatory five-year review of the status for *H. portoricensis* with a recommendation to maintain its "threatened species" status (USFWS 2010).

The Center for Applied Tropical Ecology and Conservation (CATEC) of the University of Puerto Rico at Rio Piedras Campus is currently gathering experimental and long-term data to evaluate the viability and risks to populations of *H. portoricensis* on Mona Island Reserve. This is a semi-arid island located in the Caribbean Sea between Puerto Rico and Hispaniola and currently comprises the largest remnant population of *H. portoricensis*. The island is a raised platform of dolomite (magnesium-rich limestone rock) that reaches up to 100 m at its highest point and covers an area of 5517 ha (Cintrón 1991, Frank et al.1998). Work conducted by CATEC has already yielded updated results on the pollination biology of the species that contrast dramatically with what was assumed for the species (Rojas-Sandoval and Melendez-Ackerman 2009). Specifically flowers of *H. portoricensis* have a partially self-compatible breeding system that is not autogamous, and thus, requires an external mechanism for the movement of pollen to set fruit. Anthesis for this species is nocturnal and flowers last only few hours and open during one night. More than 300 hours of direct observations and videotaping have shown that visits to flowers by animals are uncommon events. Observations have also concluded that within-flower pollination is facilitated by the rotation of flowers by strong windy conditions. Even when the species clearly exhibits extremely high levels of homocigocity (Santiago-Vélez 2000), controlled pollination experiments show that inbred seeds are still of lower quality relative to outbreed seeds (Rojas-Sandoval and Meléndez-Ackerman 2009; Figure 1). Preliminary analyses of phenological data obtained from 572 plants over a two year period confirm that *H. portoricensis* does produce flower all year long except on periods with dry spells (often July and January; Rojas-Sandoval 2010).

Fig. 1. Seeds of *Harrisia portoricensis* produced by controlled pollination experiments. Seed on the left is product of cross-pollination and seed in the right is product of self-pollination.

In this work we present additional results on the natural history of the incidence of vegetative lesions (and its relation to plant size) and provide updates on population size estimates for *H. portoricensis* populations on Mona and Monito Islands extracted from two years of intensive population and community-level studies performed at Mona Island Reserve. Data presented here was generated from 22 permanent plots established in 2007 by CATEC on Mona Island (n = 18 plots) and Monito Island (n = 4 plots) for long-term monitoring of phenological, reproductive, and demographic characteristics of this threatened species. Additionally, in 2008, the US Forest Service Southern Research Station (USFS-SRS) in collaboration with CATEC and the Department of Natural Resources and the Environment (DNRE) of the Commonwealth of Puerto Rico carried out the fieldwork for the nationwide Forest Inventory Analysis (USDA-FIA 2006) on Mona Island. This fieldwork provided an island-level assessment of the distribution of *H. portoricensis* and was used to re-calculate population size estimates for Mona Island. For Monito Island which was not covered under the FIA survey, we present the first estimates of population size for *H. portoricensis* but using information of four plots established there by CATEC. Given this new information, we offer new recommendations for the conservation and management of this threatened cactus species.

Following the methodology described for the Forest Inventory and Analysis (FIA), 50 sampling points were established on Mona Island in November 2008 (USDA-FIA 2006). Each sampling point consisted of a cluster of four circular subplots (7.3 m radius) located at 36.5 m horizontal at azimuths of 360°, 240°, and 120° from the center of every sampling point (USDA-FIA 2006). Two subplots per sampling point were selected for a total of 100 subplots. At each subplot, we counted the total number of *H. portoricensis* cacti present. We used this information to estimate the mean density of *H. portoricensis* on Mona Island by dividing the total number of individuals recorded in all subplots sampled by the total sampled area. We estimated the population size of *H. portoricensis*, by multiplying this density estimate by the total area of Mona Island (55 km^2). The FIA survey yielded density values for *H. portoricensis* on Mona Island equal to 0.001 plants / m^2 and a population size estimate of 59 857 (SE = 1058) *H. portoricensis* plants. Our estimates are higher than those reported by Breckon and Kolterman (20 280 plants; 1994) because the FIA survey included distribution data for the whole island instead of just the cactus forest, which was the presumed distribution for this species initially. For each individual cactus counted under the FIA survey, we also measured the length of all stems and branches to obtain a measure of total plant length as an indicator of available plant sizes. When plants were multi-branched, the length of each branch was measured from tips to the point of attachment to the main stem and added to the length of the main stem to obtain a measure of total plant length. With these measurements we produced a size profile for the population by classifying each *H. portoricensis* plant into one of three size categories: (1) *seedling*s: individual between 0 – 10 cm, (2) *juveniles*: individuals between 11 – 50 cm, and (3) *adults*: individuals greater than 50 cm. These size categories were based on seed germination and seedling growth greenhouse studies as well as field observations on reproductive timing of plants of different size categories. The demographic profile of the Mona Island population included plants in the adult (59%), juvenile (34%), and seedling stages (7%), indicating that at least some recruitment is occurring at this locality. Population size and profiles on Monito Island were estimated with four 100 × 20 m plots where all *H. portoricensis* plants growing within these plots were counted. Plant density on Monito plots was estimated at 0.0008 plants / m^2. Using this estimate and the recorded area of the island (172 800 m^2) we estimated that the population size for Monito Island was equivalent to 149 plants. Interestingly, the demographic profile of the population on this island only included adult plants which suggest that recruitment if occurring is very rare for Monito Island.

We took advantage of the above FIA survey to establish an island-wide evaluation of the incidence and intensity of vegetative lesions across Mona Island and CATEC plots on Mona Island to relate the presence of lesions to plant size, growth, and mortality. For each FIA subplot, we recorded the presence/absence and number of lesions for each individual cactus present. Lesions were diverse and included the presence of tunnels, holes, rotting or dry tissues or other visible marks on stems and branches (Figure 2). For each plant, we reported lesions as the percent of the plant showing tissue damage. Plants within CATEC's plots on Mona Island, which included 611 *H. portoricensis* plants, were also monitored for the presence and number of lesions. Given that these plants were monitored over a two year period (2007 – 2009) we were able to relate the presence/absence and number of lesions to plant size, growth, and survival. Lesions were never detected on *H. portoricensis* seedlings and the smaller plant with one lesion was classified as a juvenile (11cm tall). Using logistic regression, the presence and abundance of lesions in *H. portoricensis* were significantly associated with increases in total vegetative length ($r^2 = 0.76$, $p < 0.001$, $n = 723$). A total of 85% of adult plants (total length > 50cm) and 32% of juvenile plants (total length > 10cm) of *H. portoricensis* were affected by lesions. For these plants, the most common lesions were circular spots on the stem and cacti branches, which progressively increased in diameter and became brownish (Figure 2A-B). Field observations indicate that these damaged areas are the pre-cursors of the more extensive black areas that eventually lead to necrosis of branches and main stems that drop off entirely (Figure 2D-E). Literature on cacti-pathogen interactions indicates that many columnar cacti are often visited by insects that use the plants as hosts for oviposition. This process creates fissures that later undergo secondary invasion by bacteria and/or fungi and lead to tissue damage (Foster and Fogleman 1994). On Mona Island, we have observed the genus *Leptoglossus* (Coreidae: Coreinae: Anisocelini), copulating and ovipositing in stems and

FIG. 2. Lesions detected in stems and branches of *Harrisia portoricensis* at Mona Island Reserve. (A) Typical circular spots on the stem and branches. (B) Progressively increase in diameter of circular spots that became brownish. (C) Tunnels detected in stems. (D and E) Secondary invasion of damaged areas by bacteria and/or fungi generate large black spots. (F) Tissue damage by desiccation.

branches of *H. portoricensis*. Punctures developed by this insect eventually lead to the circular spots that we described previously. Other lesions that were considerably less frequent included the presence of tunnels (Figure 2C) and dry tissue (Figure 2F) in stems and branches. Mortality rates for adults, juveniles and seedlings were recorded at 15%, 55%, and 93% respectively. For adult plants, mortality resulted from the progression of lesions that eventually led to desiccation and necroses of the tissues. For juveniles and seedlings, mortality factors were varied and included the above lesions plus feral pig and feral goat damage. For these last size categories, we found that near 20% of the deaths were caused by feral pigs and goats that crushed plants while using the areas under shrubs to rest or feed. For seedlings and juveniles, the absence of suitable conditions for germination and establishment may also be an important limiting factor (Rojas-Sandoval 2010). Both the presence/absence of lesions and their abundance on plants were also monitored for Monito Island using the same methodology previously described for Mona Island. Here more than 95% of *H. portoricensis* plants were affected by lesions, and all plants censused had more than 50% of their vegetative body covered by lesions. As in Mona Island, the most common lesions observed were the presence of black spots and the damage of tissue by desiccation.

Even when our data suggest that plant numbers are substantial and higher than previously reported for Mona Island, they also establish that tissue death is also common. Indeed, tissue damage caused by negative interactions with other species (i.e., herbivores, microbes) may be an important threat for this species. This threat might be particularly relevant to the Monito Island population where all plants are infected. Our results also document that feral mammals in Mona Island are still impacting recruitment stages for this species even under the strict conservation regulations for the island and established controls for these animal populations. Literature suggests that the likelihood of attack by pest and diseases under natural conditions is not necessarily equally distributed across individuals and instead may be influenced by intrinsic species variables (i.e., plant size, palatability) as well as ecological variables at the population level (i.e., plant density, plant distribution) (Burdon 1987, Coley and Barone 1996). Consequently, we consider that more detailed studies determining which factors influence the probability of herbivore or pathogen attack and how these are spatially distributed may provide useful information as to how negative biotic interactions may influence population sizes of cacti. These data would be especially important in managing the small and restricted populations of threatened and endangered species.

Lastly, to maximize the chances of success of recovery for this species, we consider that active management *in situ* will be necessary for its recovery. We suggest increasing harvest quotas for feral mammal populations and planting individuals that at least lead 50 m long away from areas of high infection incidence to reduce the chances of plant mortality. Studies to characterize the pathology leading to large lesions and subsequent death are sorely needed to find ways to control this interaction and protect plants from further attack. Plant lesions are clearly a source of mortality in reproductive adults that makes this population potentially more vulnerable than before. The expansion of long-term monitoring strategies like those presented here would be helpful to determine the dynamics and interactions of biotic (i.e., plant lesions, effect of exotic species) and abiotic elements (i.e., environmental factors) on plant survival.

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