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After the fall: did coffee plants in Puerto Rico survive the 2017 hurricanes?

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ABSTRACT

Hurricanes Irma and Maria hit Puerto Rico in September 2017. According to initial estimates, 90% of coffee plants were destroyed. We surveyed damage to coffee plants in 81 plots throughout the coffee-growing area of west-central Puerto Rico; we used the change in the Landsat derived Normalized Difference Vegetation Index (ΔNDVI) to estimate damage to vegetation in coffee farms. ΔNDVI values ranged from 0 to 0.36. Almost half of all plots had ΔNDVI ≤ 0.17 and had less than 20% damaged plants, whereas twelve plots in six municipalities were severely hit and had ≥80% plants damaged. Damage varied greatly among plots and even within plots. Probability of damage was significantly higher in sites with north- and south-facing slopes than in sites with east- and west-facing slopes. Neither minimum distance from the center of Hurricane Maria, altitude, precipitation nor maximum wind speeds were related to extent of damage. Coffee berry borer (*Hypothenemus hampei*) populations decreased after the hurricanes but recovered quickly. Understanding patterns of damage and their causes may help suggest ways to protect the coffee industry from future natural disasters.

1. Introduction

Hurricane Irma (Category 5) grazed Puerto Rico on September 6, 2017. It was closely followed by a direct hit from Hurricane Maria (Category 4) on September 20th. Damage to Puerto Rican agriculture was estimated at $45 million and $780 million, respectively (Robles and Ferré-Sadurní, 2017). Many news reports focused on damage to coffee and coffee farms.

Coffee is the principal crop of the mountainous area of west-central Puerto Rico. The region is geographically and geologically diverse (Muñiz and Monroig, 1994; Fain et al., 2018). The crop has great economic, social and cultural importance in a region with many socioeconomic challenges. Harvesting had started in some areas before Irma and Maria, but most of the 2017 coffee crop was lost.

The quantification of damage to coffee (and other crops) is mostly anecdotal. Preliminary estimates from three municipalities (Jayuya, Yauco and Ponce) all stated that 90% of coffee plants were destroyed (Hoffman, 2017; Kennedy, 2017; Newton and Quiñones-García, 2017). (Here we focus exclusively on damage to plants; we do not consider loss of coffee fruits or the coffee crop.) However, no data have been published on the extent of damage, how it varied across the coffee-growing region, or what environmental variables could explain this variation.

The principal pest of coffee is the coffee berry borer (CBB), an invasive beetle that arrived in Puerto Rico in 2007 (NAPPO, 2007). In Puerto Rico CBB infestation tends to be severe relative to other countries (Mariño et al., 2017). Several coffee growers have told us that the only positive aspect of the hurricanes is that the CBB was carried off by the wind or destroyed along with the crop, but no data are available to evaluate this claim.

In this study we asked the following questions:

1) What proportion of coffee plants were knocked down or defoliated by the hurricanes? We predicted that damage would match the levels estimated in news reports, 90%.
2) Did damage vary with proximity to Hurricane Maria's track? We predicted more damage in Ciales and Orocovis, at the NE edge of the coffee country, since they were closest to the center of Maria, (Fig. 1; wind velocity is inversely proportional to distance from the eye), and less damage in Yauco and Maricao, which were further away.
3) Did damage to coffee plants vary with peak wind speed, altitude and orientation of the plot? Did it reflect changes in vegetation indices (ΔNDVI, Hu and Smith, 2018)? We predicted that higher peak wind speed would be associated with higher incidence of damage to coffee plants. Similarly, plants at higher altitudes would be exposed

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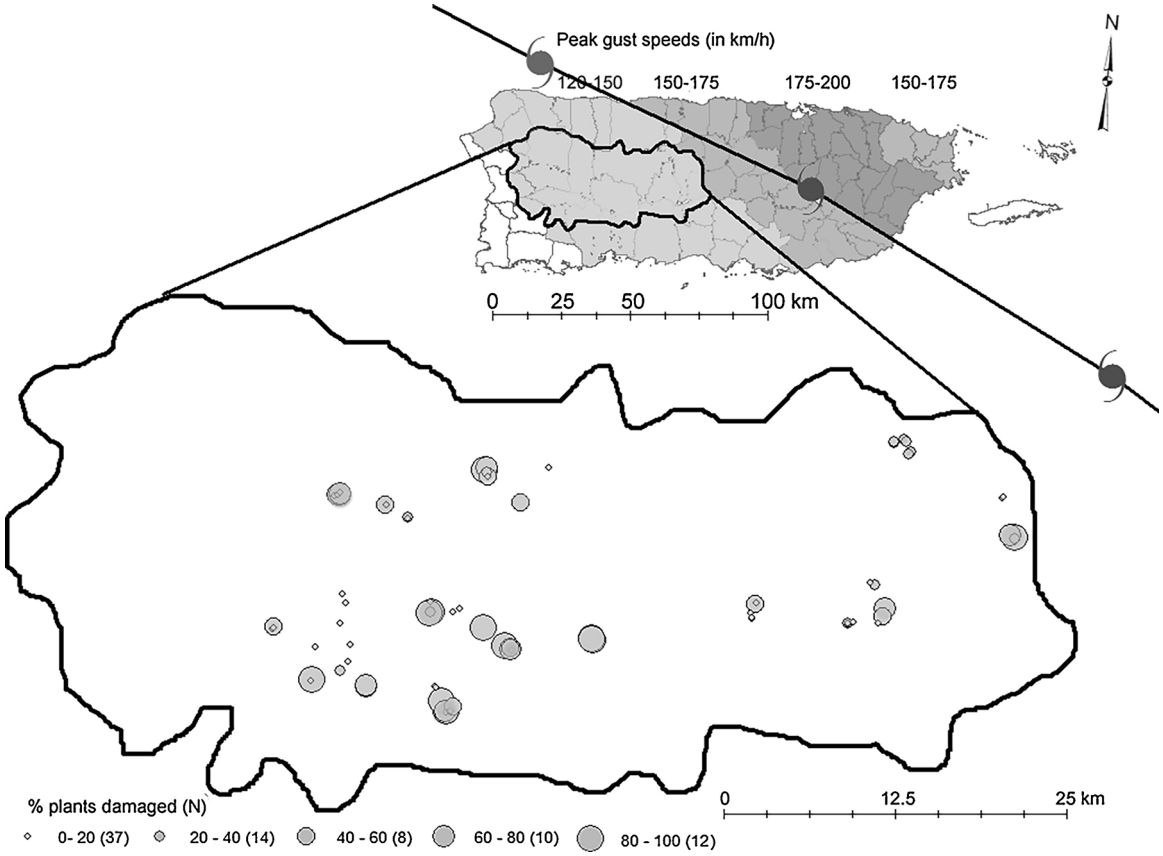

Fig. 1. Map of Puerto Rico showing the path of Hurricane María, wind speed zones, and coffee farms sampled in this study (inset).The outline represents the main coffee-growing area. Size of circles indicates levels of damage on each plot. Wind speed data from Pacific Disaster Center (2017). Hurricane Irma passed just off the northeast corner of Puerto Rico.

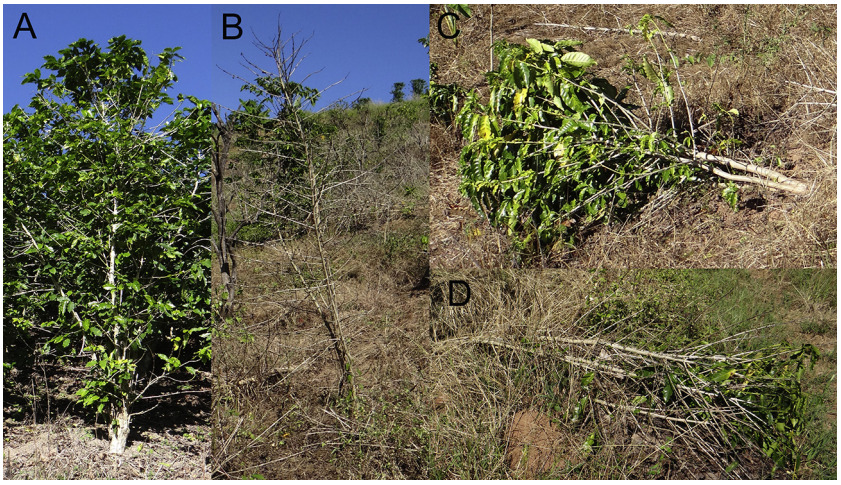

Fig. 2. Examples of **healthy** (A), **defoliated** (B), and **fallen** (C, D) coffee plants, the categories used in this study.

to higher wind speeds, and therefore sustain more damage. Also, we predicted that plants on north-facing slopes would be more exposed to strong winds and therefore receive more damage, since Maria passed to the north and the rotation of the storm was counter-clockwise.

4) Did damage to coffee plants correlate with number of CBBs found in remaining fruits? We predicted a positive relationship, because when most plants and fruits are knocked down, the CBB will concentrate in the few remaining fruits, so population per fruit should increase.

2. Methods

2.1. Sites and census

We surveyed a total of 81 plots on 45 farms in nine municipalities in the coffee-growing region of west-central Puerto Rico (Fig. 1). Plots were defined as areas with ~100 *Coffea arabica* plants. The plots were selected based on previous studies and on accessibility, because many areas were still unreachable when the survey was conducted. The order and timing of survey visits was determined by when roads to each area became accessible. When more than one plot was sampled per farm, the