TAILORED VINES AND TAYLOR'S LAW: Examining Vine Growth on Puerto Rican Coffee Farms

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Background

- Puerto Rico and the Virgin Islands have ~274 native species of vines (Acevedo-Rodriguez, 2005).
- On coffee farms, vines can use coffee plants to help with vertical growth, and, when not controlled, can cover the entire plant reducing its photosynthetic capacity. Therefore, most vines are considered weeds on Puerto Rican coffee farms.
- **Taylor's Law of Fluctuation Scaling**: power law relationship between a population's size and its variance (Taylor, 1961):

$$V = bM^{\alpha}$$

- α is the slope of the linear regression on a log-log scale of population mean and variance and tends to fall between 0 and 2 for populations of living organisms (Eisler *et al*, 2008).
- Two main forms of TL:
  1. Temporal
  2. Spatial
- **Process of Vine Growth:** starting from some random biomass and at some initial point in time, a plant will experience an exponential increase in biomass over time:

$$x(t+1) = rX(t)$$

- Exponential distribution is expected among a group of plants that started from random biomasses.
- Expected parameter of Taylor's Law for a given population:

$$mean\ (x) = \frac{1}{\lambda}$$

$$variance\ (x) = \frac{1}{\lambda^2} = \left(\frac{1}{\lambda}\right)^2 = [mean\ (x)]^2$$

- Same as the TL equation:

$$\ln[variance(x)] = \ln[mean(x)]^2 \quad \textbf{OR}$$

$$\ln[variance(x)] = 2\ln[mean(x)]$$

- x should follow TL with an α value of 2. Expected slope for TL to be 2 when using variance, or 1 with standard deviation.
- Two criteria for establishing the presence of TL in our study:
  1. **High R^2 value (indicating a good fit of the regression prediction to the data)**
  2. **Consistent slope (α) value of 1 with standard deviation**

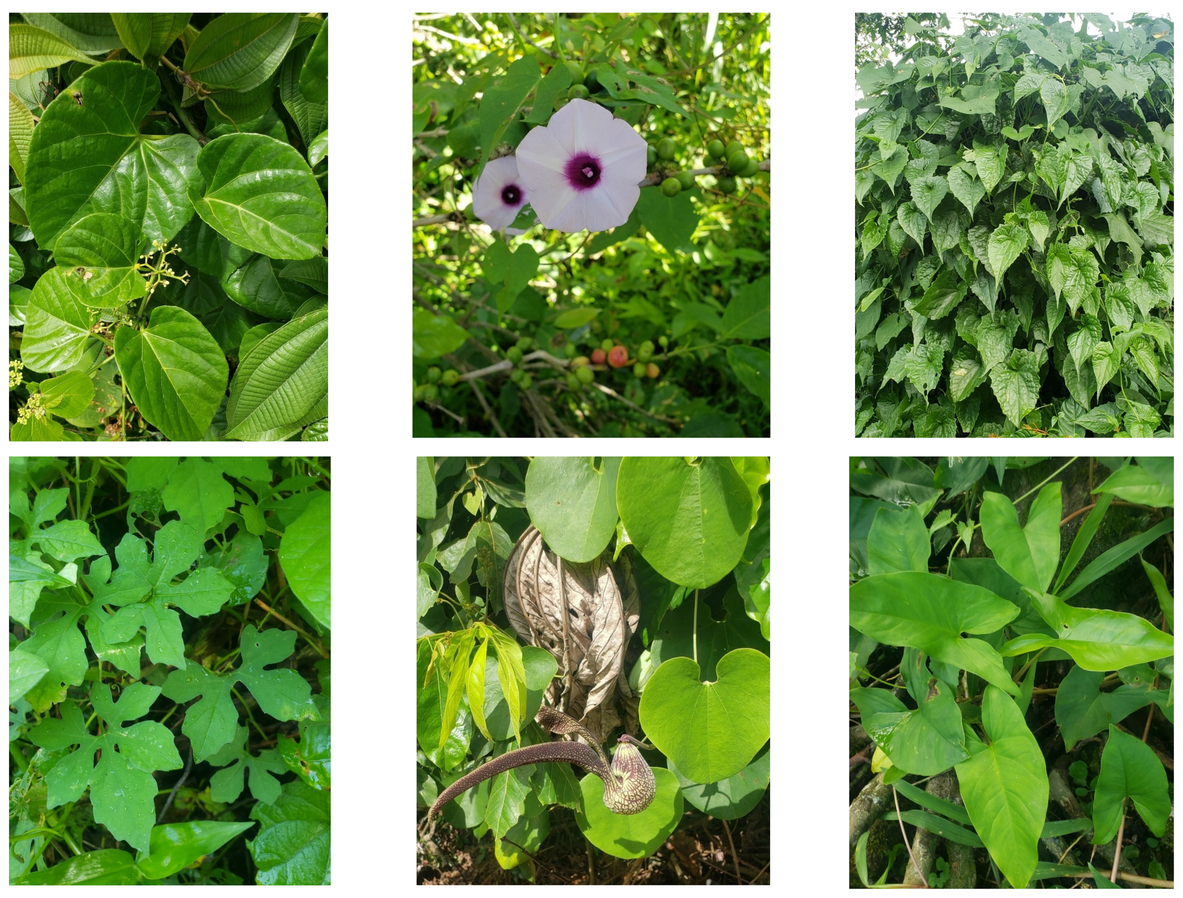


Figure 2: Vines of Puerto Rico. Top row, from left: *Cissus verticillata, Ipomoea triloba, Mikania micrantha*. Bottom row, from left: *Momordica charantia, Aristolochia ringens, Syngonium podophyllum*

Methods

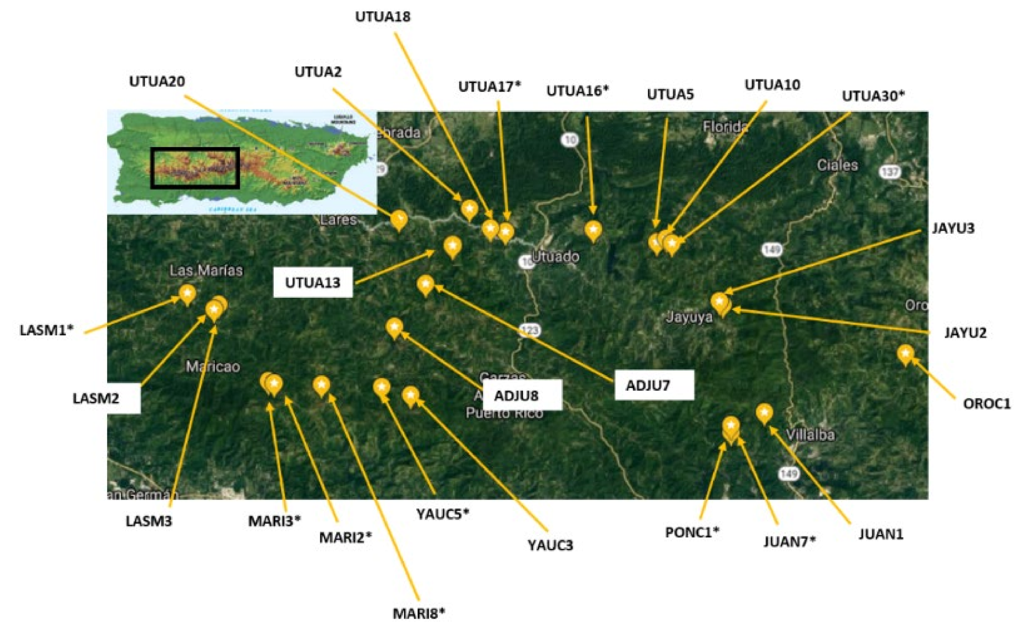


Figure 2: Map of the central coffee-production region of Puerto Rico, showing locations of coffee farms used in this study.

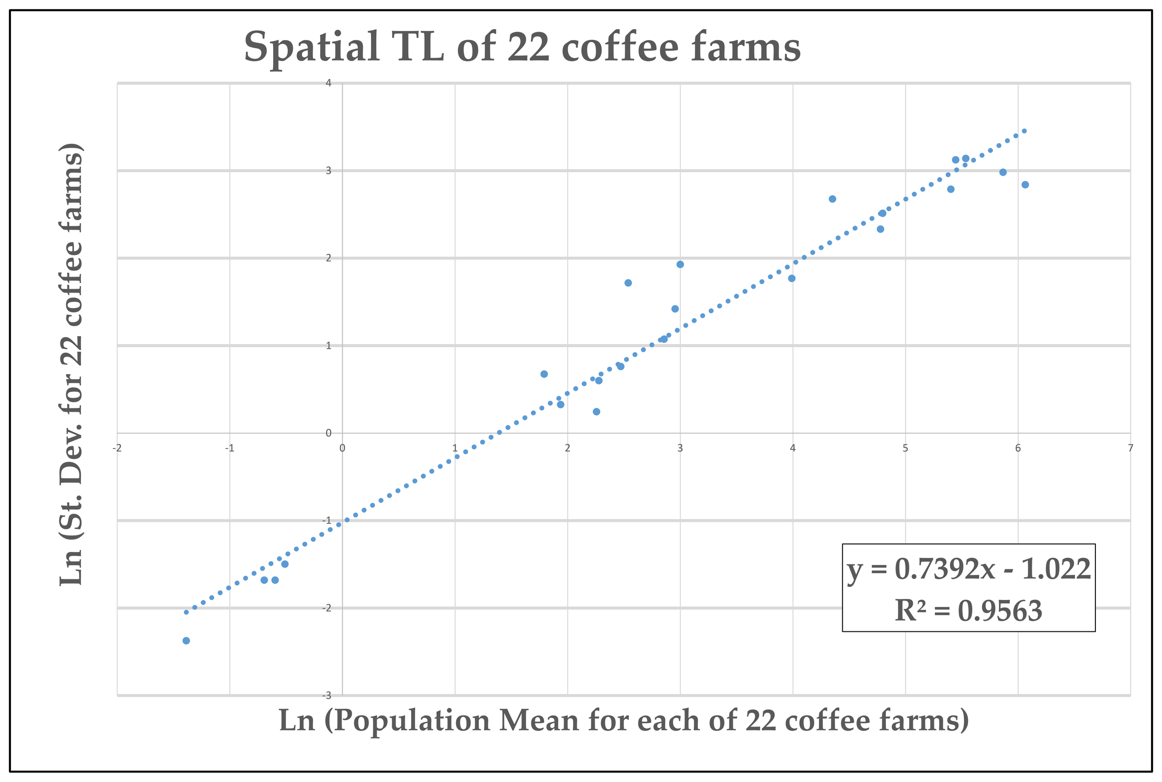
Data Collection

- Time frame of August 2018 to July 2019
- 12 monthly visits to 25 coffee farms. On each farm, a 10x10 m plot was established and 20 coffee plants were randomly selected. Vine coverage percentage (regardless of vine species) of the 20 plants was estimated

Analysis

- Done using Excel 2016, and included data for 22 of the 25 coffee farms.
- Calculations for log-log graph of population mean and variance for both the spatial and temporal forms of TL for all 22 farms:
  1. Calculated the total vine coverage (TVC) of each farm
  2. Got the mean for spatial and temporal by dividing TVC by 20 (coffee plants) and 12 (monthly visits) for spatial and temporal respectively
  3. Calculated standard deviation for all 20 plants/farm for spatial TL, and for all 12 monthly visits/farm for temporal TL

Results



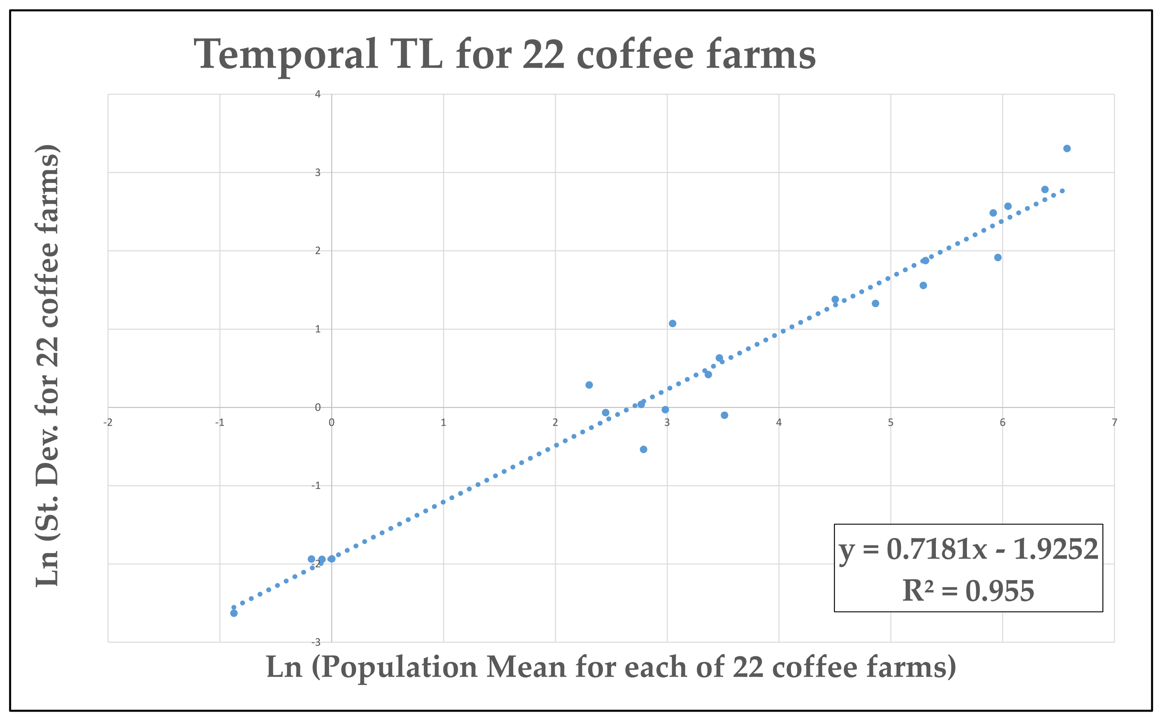


Figure 3: Initial Results of TL, pooling data from all 22 farms. The R-Square is 95% for both, but slope values are less than 1.

Discussion

- Stochasticity on population growth: r, the exponential rate of increase, varies at random, independently of both population size and time (Lewontin & Cohen, 1969).
- The Lewontin-Cohen model (LC) of stochastic growth states:
  "The exponent of TL exceeds 2 if and only if the LC model is supercritical (growing on average), equals 2 if and only if the LC model is deterministic, and is less than 2 if and only if the LC model is subcritical (declining on average)…" (Cohen *et al*, 2013)
- If LC model is at play, our α value is less than 1 as our vine population is declining on average. We did simulations of the vine growth to see if true

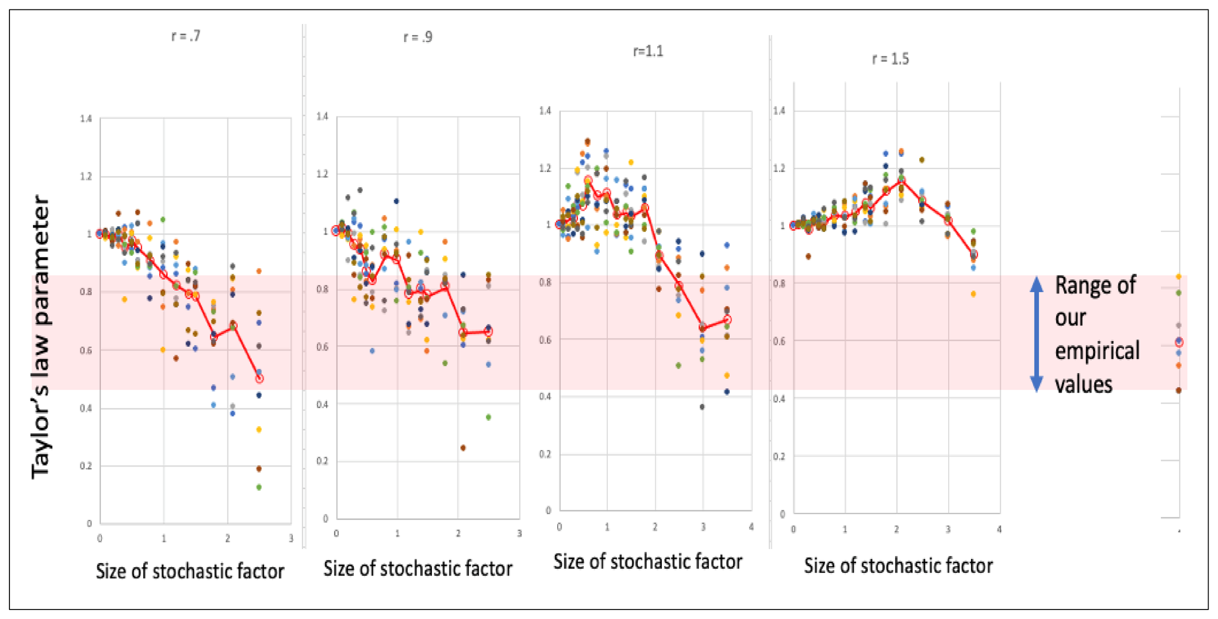


Figure 4: Simulations of TL with varying sizes of stochastic factor for four values of the exponential parameter. Red, open circles represent mean α values of simulations run at a particular stochastic factor value

- Simulations match the expectations of a system operating under the LC model of stochasticity (Cohen et al., 2016).
- Another simulation on range of α values according to sample size:

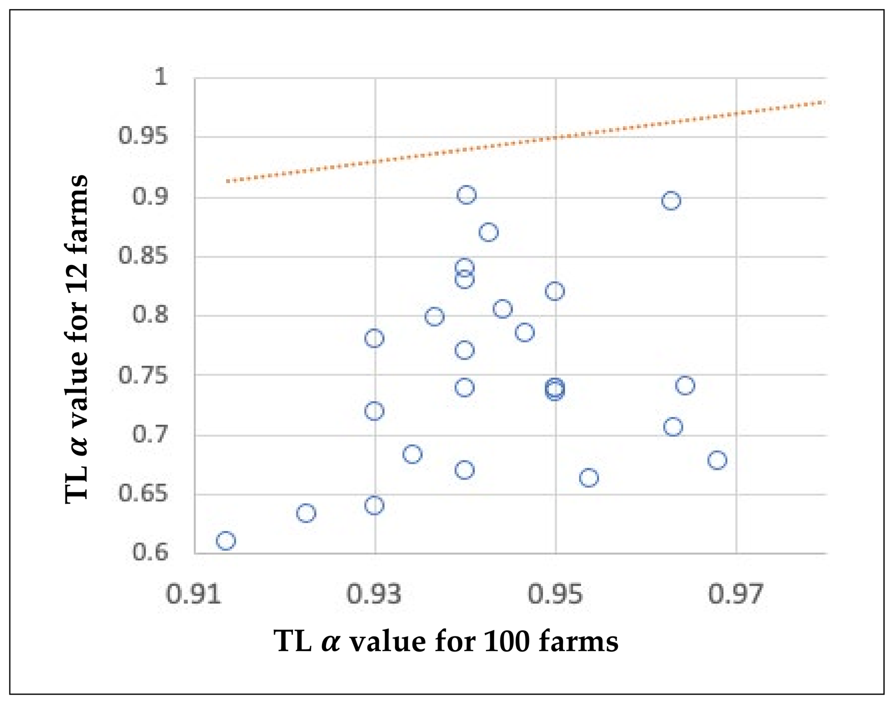


Figure 5: Comparison of α values of simulations of Taylor's Law for 12 farms (close to sample size) versus 100 farms. Stochastic factor is set to zero. Dashed red line indicates one to one relationship.

- In simulations using only 12 farms, α values range was ~0.6 to 0.9. But simulations using 100 farms had α value ranges from 0.91 to 0.97.
- Thus, even with no stochasticity, when the LC model predicts that the α value of TL should be at 1, the simulation with a smaller number of farms had α values far below 1. In comparison, the simulation with a larger sample size more closely followed the LC model.
- **Conclusion: TL is present in the vine coverage on the sampled Puerto Rican coffee farms. However, the deviations in the empirical α values can be attributed to both the Lewontin-Cohen model of stochasticity where the community of vines are declining over time and space on average, and the fact that our empirical data was from a small sample size in both space and time.**