Mathematical Framework for Modeling the Movement of Adult Spotted Lanternfly into Vineyards and Application for Optimal Control

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ABSTRACT

The spotted lanternfly (*Lycorma delicatula*, SLF) is a plant hopper that primarily feeds on hosts such as the tree of heaven and grape vines. Hosts may succumb and die from the infestation, posing a significant concern for the agricultural industry in particular vineyards are at great risk. SLF can damage and even kill vines throughout a season this coupled with the emergence of adults, the time when SLF are most mobile, coinciding with grape harvest makes the control of SLF very challenging in these landscapes. The SLF has been observed participating in a gliding-ascending cycle where the SLF "jumps" or is knocked off a host and moves randomly away for some time, eventually seeking out a new host, then finds a host and climbs up and repeats the cycle.

We construct a model based on the gliding-ascending cycle of the SLF to capture how agents would move around in a landscape of hosts. This model utilizes experimental data to help parameterize model functions describing the movement and preferences of SLF. Further, we reduce the model using assumptions based on the SLF behavior to a Markov model for how SLF hops from host to host. We model the SLF movement in three stages:

- Feeding Stage: Here is where SLFs spend most of their time on hosts feeding.
- Gliding Stage: Here SLF glide pseudo-randomly away from hosts.
- Seeking Stage: Here SLF will head towards the most attractive host they see based on their current location.

We assume that SLF glide away from a host on average a distance proportional to the height with a fixed variance and that a host's attractiveness at a given location is based on its height, species, and how far away from the host the location is. This allows us to construct a host hopping model on given an arrangement of hosts only parameterizing the preference for each host type in the model, the gliding variance, and the mean gliding distance.

Using satellite data and data from the NEON SERC database we apply our host hopping model to the Vineyards at Dodon a Maryland-based vineyard seen in Figure 1.

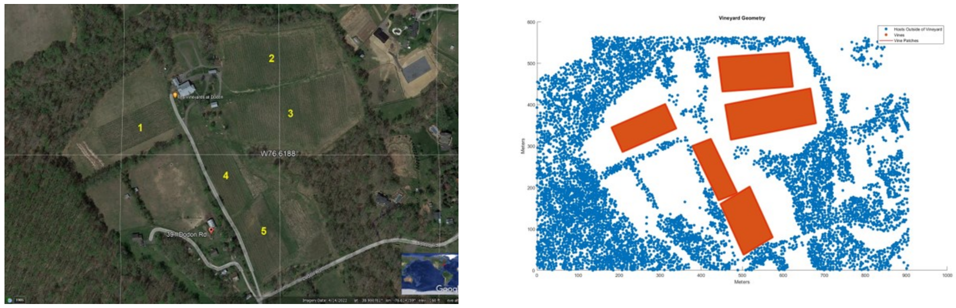

Figure 1: GPS imagery marking 5 patches of vines labeled(left). model hosts with hosts in blue being forest trees and hosts in red being vines in the vineyard(Left).

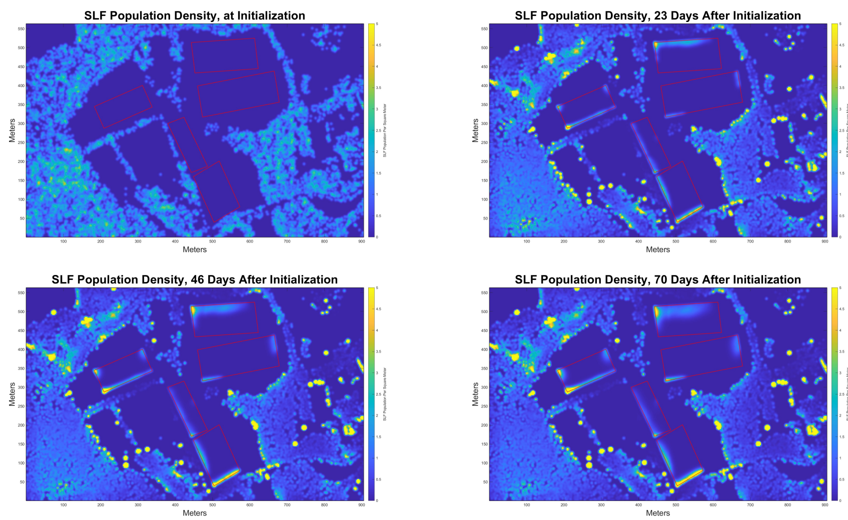

Figure 2: Simulation of SLF Host hopping model on the Vineyards at Dodon. SLF initialized population uniformly spread in the forest.

We run our host hoping model on the Vineyards at Dodon landscape digitized as seen in Figure 1 for 70 days, representing the time from adult emergence till harvest of grape. Compared to field observations we see qualitatively similar distributions of SLF with the population quickly invading and occupying the edge of the vineyard but rarely moving deeply into it.

We then look at control actions based on thresholds for a fixed initial population looking at how various thresholds affect the population over time in the vineyard in Figure 3. We see that thresholds too low miss out on control of SLF moving into the vineyard late in the season and thresholds too high miss out on preventing damage done by SLF that move into the vineyard early. All thresholds are tested for two different initial conditions and we observe which threshold maximizes the damage reduction in the vineyard when compared to no control action plotted in Figure 4 for both initial populations. We see for a given geometry the relationship between threshold and damage reduction is non-trivial for our different initial conditions this relationship looks qualitatively different. This indicates that the optimal choice of threshold for when to administer control actions may be context-dependent.

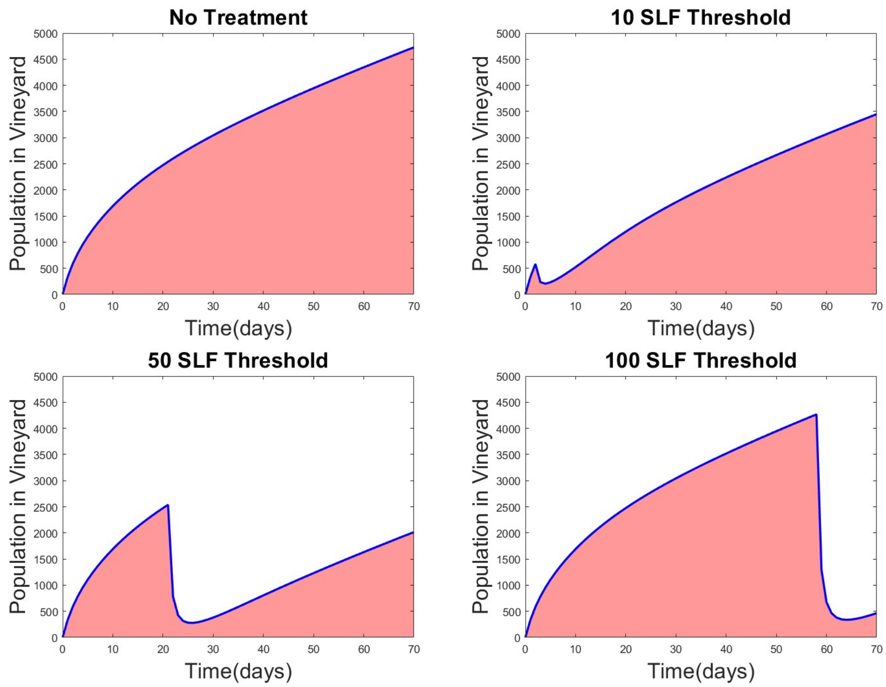

Figure 3: SLF population as a function of time for no treatment and three different treatment thresholds for an initial population evenly distributed in the forest. The area of the pink region represents the number of SLF*days spent on vines in the vineyard. For a threshold of 10 SLF there is a 38.5% reduction of SLF days, for a threshold of 50 there is a 60.8% reduction, and for a threshold of 100 there is a 23.2% reduction.

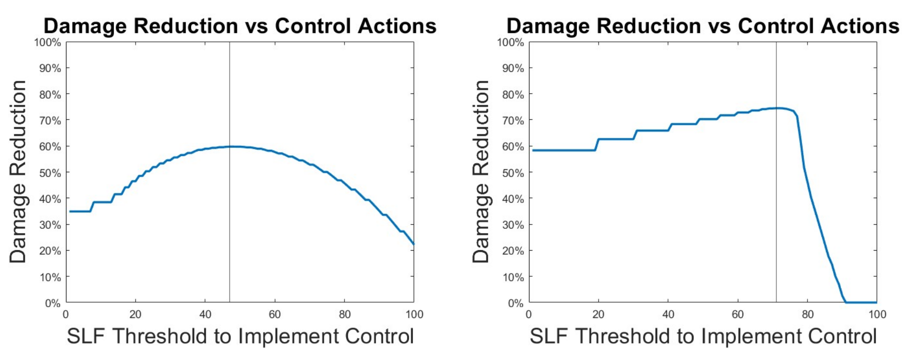

Figure 4: Percent damage reduction as a function of SLF threshold for two different initial SLF populations.