LA MODELACION MATEMÁTICA DEL CONTROL NATURAL DE PLAGAS EN LOS CÍTRICOS DE CUBA: EL CASO DE *Lepidosaphes gloverii,* HONGOS Y PARASITOIDES HIMENÓPTEROS

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Introduction

Research was conducted to study the population dynamics of a citrus scale, and its parasites in "Empresa Citricos Ceiba", Havana Province, Cuba. Glover's scale *Lepidosaphes gloverii* (*coccidae, homoptera)* (Metcalf and Flint 1962) is not a serious pest of citrus in Cuba. The question was, why not, and what needs to be done to prevent it from becoming a pest. The number of scales on leaves vary during the annual cycle of the orange trees but is kept in check by several natural enemies among which the most important are the fungi *Sphaerostilbe auranticola*, *Podonectria coccicola* and the chalcid wasp *Aspidiotiphagus* sp. The scales and their natural enemies were studied in their distributions in space and time, and their interactions in order to determine the mechanisms of population regulation in its natural environment.

Life cycle of the scale

Scale insects are a relatively immobile group. When crawlers emerge from the eggs they move about during their first day and then attach to their permanent surfaces on the branches, leaves and fruits, and develop into nymphs. The rest of their lives, spanning approximately ten weeks, is spent in the same place if they are females, while males have wings and fly locally (Metcalf and Flint 1962). Therefore it is reasonable to consider scales on different trees and even sections of trees as distinct populations. We use mathematical models to study the distribution and patterns of aggregation of the insects, migration of the crawlers to produce new foci, reproduction, and rate of infection.

Methods

Site and data collection

The field work was carried out at the "Empresa Citricos Ceiba", located 17.5 km northeast of Artemisa, Havana Province. The major pests of citrus on this farm were rust mites and two species of curculionid, with thrips, aphids, and a few other coccids and mites having minor importance.

In this paper we analyzed a set of data with 4740 observations which were made biweekly, following a flush during 1986, enabling us to study scale dynamics through many cycles of population growth.

Five trees of Valencia oranges were selected: 4 located at the corners of a field and one tree was in the middle. Branches for each tree were studied at each of four different cardinal points (N, S, E, W,) and at three different strata defining levels of height above the ground (1, 2, 3). Two leaves from a recognizable flush were chosen at random from each tree, at each cardinal point and at three strata levels, resulting in a minimum of 120 leaves examined on each date. As the season progressed and more leaves developed, then the other leaves in that flush were also identified and examined. The upper and lower surfaces of each leaf were examined as well. The scales and their parasites were counted on the leaf and classified visually as to stage of development.

Analysis

Data were analyzed using EPI Info version 6, a non-proprietary program prepared by the Center for Disease Control (Dean et al. 1990) and Lotus 1-2-3 (Lotus Development Corp. 1988).

a) Distribution of scales in space and time

Distribution of scales across leaves at the various positions along the branch was determined by calculating the mean number of scale per leaf for a particular position. Contingency tables were constructed to compare the numbers of scales on different trees, strata, cardinal points, upper and lower leaf surfaces over time; chi-square statistics were used to test statistical significance.

b) Crawler migration

The formation of new communities of scales depends on the migration of crawlers since they are the only mobile immature stage. A model to assess migration was developed:

$$(1 - p_l)\, p_c = x \quad (1)$$

p_c is the fraction of the crawlers which exit from the leaf on which they were born; x is the fraction of the crawlers found on leaves without fecund females; $1-p_c$ of the crawlers remain on their birth leaves.

p_l is the fraction of the other leaves that have females with eggs, since the fraction p_l of the other leaves have females with eggs, $p_c p_l$ of the crawlers would move to other leaves with females with eggs and $(1-p_l)\ p_c$ would reach leaves without them.

c) Reproduction

We counted the crawlers as the first stage of life. Since crawlers live for only a day, the ratio of crawlers to fecund female (with eggs) is an indicator of fecundity. This may not be a true fecundity since the crawlers experience high mortality during their one day of life. In our analysis we used the ratio of crawlers to fecund females as a measure of reproduction.

d) Taylor's regression to study aggregation

We used Taylor (Taylor *et al.*, 1978) regression to study aggregation of scales:

$$\log M = \log a + b \log V \qquad (2)$$

where **M** and **V** are the mean and variance of the numbers in different sites, estimated from data analysis. Aggregation would show up in values of $b > 1$. This method was previously used to compare aggregation in other scale populations in Israel (Nestel *et al.,* 1995).

e) Probability of infection

Let p_{i1} be the probability that a propagule of a fungus, or a foraging wasp from outside a leaf finds a host on a non-parasitized leaf. Suppose that there are n uninfected scales on the leaf. Then the probability of missing all of them is $(1-p_{i1})^n$ and the probability p_{i1} of a unit propagule finding a scale is estimated by

$$p_{i1} = 1 - y^{(1/n)} \qquad (3)$$

where **y** is the fraction of leaves with n scales, none of them infected.

Similarly we can calculate $p_{i2,}$ be the probability of a second scale becoming infected conditional on there being one infected on the same leaf:

$$\mathbf{p_{i2} = 1 - z^{(1/(n-1))}} \qquad \mathbf{(4)}$$

where **z** is the fraction of leaves with n scales that have only one infected scale. The same rationale is used for estimating the probability that a third or a fourth scale becomes infected conditional on there being one less infected scale.

Results

i) Crawler's migration and emergence of new foci
Using equation (1) we can estimate the proportion of crawlers that leave the site of birth to start up new communities. Migration varied slightly from tree to tree with a mean of 0.8 (Table 1).

Table 1. Crawler migration.

	Tree 1	Tree 2	Tree 3	Tree 4	Tree 5
X (cr w/o feggs)	.700	.650	.660	.704	.799
pl (leaves w feggs)	.146	.165	.142	.085	.069
pc (migration)	.817	.778	.769	.769	.858

ii) Reproduction
Reproduction estimated by the ratio between crawlers and fertile females show a seasonal oscillatory pattern ranging between 0.1 and 6.8.

An analysis for individual trees showed a similar seasonal pattern for scale reproduction with a mean, varying around 2.6 crawlers per female with eggs.

iii) Aggregation
The mean number of scales per leaf changes over time and so does its variance. We explore aggregation using equation (2). For all stages a plot of log **M** vs **log V**, shows **b > 1**, indicating aggregation. However the degree of aggregation is greatest for crawlers and decreases with stage, indicating that the immature stages are more aggregated and some aggregation is being lost along the developmental course.

Aggregation across dates was not affected by the presence of parasites (b=1.4; SE =.06; Rsq=.96). Crawlers will have some effect on aggregation whether the parasites are included or excluded in the analysis.

Aggregation takes on importance in relation to density-dependent regulation. The fraction of parasitized scales that share their leaves with other scales increases with population density so that mortality increases with density.

iv) Parasitation rates of scales
Our observations indicate that there are more parasites per scale as density of scale increases.

This observation might be due to the possibility that a higher density of scales could attract more parasites, or perhaps once a parasite lands on a scale its subsequent expansion will depend on the opportunity to infect adjacent scales. Using equations (3) we calculate the probability that the first parasite will settle on a scale on leaves with no infections; and similarly for the second on scales with one infection (equation (4)), and so on with more infections.

Table 2 shows that the probability of infection by the first, second and third parasites are all independent of n.

Table 2. Probability of infection by all parasites.

Number of scales (n) (Sessile stages)	P_{i1}	P_{i2}	P_{i3}
1	.235	----	----
2	.234	.407	----
3	.224	.314	.413
4	.246	.317	.385
5	.247	.327	.320
6	.241	.367	.420
7	.205	*	*
8	.262	*	*
9	.219	*	*
10	.200	*	*
Mean	.231	.346	.385

* The numbers were too small for the calculations.

The probability that a second parasite infests scales, p_{i2}, given that a first infection already exists was calculated using equation (4). Table 2 shows that although this probability is higher than the probability of infection with the first parasite it is also independent of scale density. The same can be said for p_{i3}. In summary: we observed that $p_{i3} > p_{i2} > p_{i1}$. It seems that p_i is random and once the first parasite settles it needs just an adjacent scale to propagate and not the entire foci.

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