

Factors Influencing the Abundance of Pests in Production Fields and Rates of Interception of *Dracaena marginata* Imported From Costa Rica

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ABSTRACT Importation of live nursery plants, like *Dracaena marginata* Lamoureux (Ruscaceae), can provide a significant pathway for the entry of foliar pests from overseas into the United States. We studied the abundance of foliar pests of quarantine importance found on Costa Rican-grown *D. marginata*. These include five genera of leafhoppers (Heteroptera: Cicadellidae, *Oncometopia*, *Caldwelliella*, *Diestostema*, *Gypona*, and *Empoasca*), Florida red scale (Heteroptera: Disapididae, *Chrysomphalus aonidum* (L.)), katydids (Orthoptera: Tettigoniidae), and a snail (*Succinea costarricana* von Martens (Gastropoda, Stylommatophora, Succineidae)). In our first study, we examined the rationale behind size restrictions on *Dracaena* cuttings imported into the United States from Costa Rica. When comparing plant size, no differences were found in the abundance of quarantined pests on small (15–46 cm), medium (46–81 cm), and large (81–152 cm) propagules. In a second study, we estimated monthly abundances of pests in production plots for 1 yr to determine their relationship to rates of interception at U.S. ports. In any given month, <6% of the marketable shoots standing in the field were infested with at least one quarantine pest. There was no relationship between the average monthly frequencies of pest detection in the field and in U.S. inspection ports. Pest detections increased during the 1 mo when average monthly shipments were abnormally high. Our data suggest that off-shore postprocessing efforts to remove pest-infested material from the market stream need to be adjusted to accommodate sharp increases in the volume of shipped plants.

KEY WORDS offshore preclearance program, size restriction, nursery stock, Cicadellidae, *Dracaena marginata*

Live nursery stock imported into North America has been identified as a major pathway for invasive forest pests that feed on plant sap and foliage (Liebhold et al. 2012). These pests are responsible for substantial annual losses to forest and agricultural systems (Pimentel et al. 2005, Aukema et al. 2011). *Dracaena* was identified as the genus of live plants most frequently imported in the United States between 2005 and 2009 (Liebhold et al. 2012). With >11,000 interceptions of pests in U.S. ports on plants from Costa Rica, *Dracaena* has also been labeled as a genus likely to serve as a conduit for importation of exotic pests. For this reason, the importation of *Dracaena* plants from Costa Rica to the United States has been restricted to exporters who have agreed to comply with specific production, harvesting, and processing procedures that prevent shipments of pest-infested plants (Shea 2012). In this article, we investigate underlying assumptions about how plant size and the abundance of pests in the field

influence rates of interception of pests on these plants in U.S. ports. *Dracaena marginata* Lam. (Ruscaceae) is one of six species exported from Costa Rica. We use it as a model species for the genus because it represents >40% of the *Dracaena* shipments sent to the United States annually (Panjiva 2013).

D. marginata is an ornamental foliage plant native to Asia and Africa. This species is now grown in most tropical regions of the world for export as rooted cuttings for indoor house plants. Commercially viable varieties are distinguished by their leaf color. The variety Bicolor has a green leaf with a yellow stripe and red margins, whereas Magenta and Green have red and green leaves, respectively. In Costa Rica, *Dracaena* is grown as a perennial plant and propagated for sale in different forms including bare canes, rootless tips, branches, and rooted plants (Acuña et al. 1991). These plants are grown in full sun as perennial plants at sites with altitudes from a few meters to 1,200 m above sea level for up to 15 yr before replanting. The plants are pruned to induce the continuous production of shoot tips on stems of various sizes. The growing point is then cut off to stimulate the production of new leafy shoots that will be ready for harvesting in

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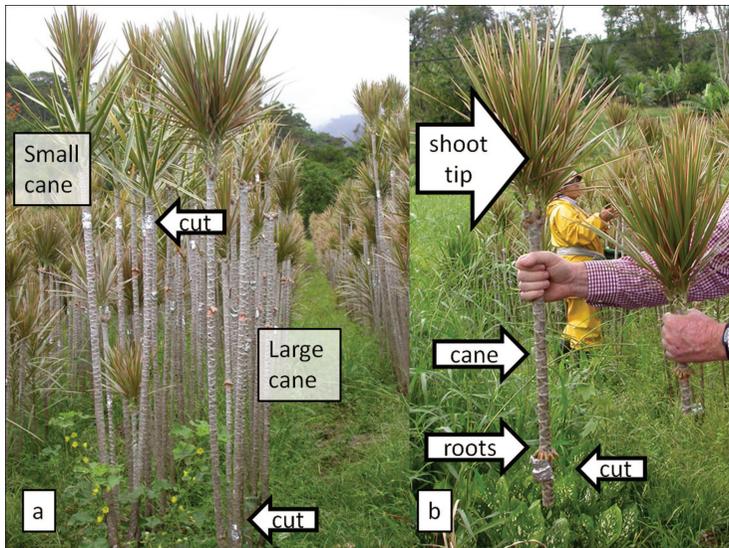


Fig. 1. (a) Large and small cane cuttings of different lengths are produced in Costa Rica by making foil-covered cuts in stems at specific distances below the growing points of *D. marginata* variety 'Bicolor' to promote growth of aerial roots. (b) Cuttings of different heights are harvested just below aerial roots. (Online figure in color.)

≈16 wk. During this time, cuts are made into each stem to facilitate the production of aerial roots at specific distances below the growing point to produce cuttings with canes of specific sizes (Fig. 1). Marketable shoots with roots are cut from the plant at the time of harvest.

Like other live nursery crops, the majority of pests detected on exported shoots of *Dracaena* in U.S. ports are leaf feeders (Liebhold et al. 2012). More than 70% of the interceptions on *Dracaena* shipments arriving to the United States from Costa Rica are because of the detections of katydids (Orthoptera: Tettigoniidae), armored scales (Hemiptera: Diaspididae), leafhoppers (Hemiptera: Cicadellidae), and the snail *Succinea costaricana* von Martens (Gastropoda, Stylommatophora, Succineidae) on or in leaf tissue (Colpetzer et al. 2011).

In our previous work, we found the abundance of foliar pests on field-grown Costa Rican *D. marginata* to be strongly influenced by production practices of growers and the time of year when samples were taken (Prado et al. 2008). In tropical countries, where plants grow continuously, the abundance of foliar pests can be influenced by more than the direct effects of pesticide applications. Factors that influence production of new leaves such as plant vigor and seasonal patterns of rainfall can also contribute to the abundance of foliar-feeding arthropods (Novotny and Basset 1998, Whitfield et al. 2012). Thus, plant vigor, as indicated by the length of the *Dracaena* cane from which marketable tips are propagated, and the time of year when plants are harvested could affect the quality of foliage and the abundance of leaf-feeding pests. For this reason, the first objective of this article was to determine whether the abundance of foliar pests was influenced by the size of the parent plants. The second objective was to determine whether there were temporal patterns in the abundance of pests that could be explained

by seasonal patterns of rainfall. The final objective was to determine whether there was a relationship between monthly estimates of pest-infested *Dracaena* in production fields and rates of their interception at the U.S. Port of Miami over the course of 1 yr.

Materials and Methods

Description of the Study Area. The study was conducted in two of the primary zones in Costa Rica where *D. marginata* is grown for the export market to the United States: San Carlos, in the Northern portion of the country, and Guápiles–Guácimo, in the Atlantic zone. These zones differ in climatic, landscape, and crop management characteristics (IMN 2010). The Northern zone has a mean altitude of 170 m with a mean temperature and precipitation of 25°C and 3,849 mm, respectively. The Atlantic zone has a mean altitude of 262 m, a mean annual temperature of 25°C, and precipitation of 3,577 mm. Neither zone could be said to have a rainy season defined by the calendar because November through April contributed only 57% of the total rainfall in the Northern zone and 48% of the rainfall in the Atlantic zone.

The plantations in the Atlantic zone are located mostly in flat lands drained by ditches used for nearby banana and pineapple plantations. Many of the farms in this area apply herbicides and insecticides frequently to manage pests. The Northern area has a more irregular topography and *D. marginata* is grown within a matrix of forest and other ornamental crops, such as *Codiaeum*, *Schefflera*, and other species of *Dracaena*. Relative to the Atlantic zone, herbicide, insecticide, and fertilizer use is less frequent (Prado et al. 2008).

Propagated Shoot Size. An observational study was carried out on commercial plantations of *D. marginata* to determine whether the size of harvested propa-

gated plant material can affect pest distribution and abundance on *Dracaena* plants under field conditions. Fifty-two plots within five farms in the Atlantic zone and nine in the Northern zone were selected randomly among those producing different sized *D. marginata*. To capture the cumulative effects of exposure to pests during the 16-wk propagation cycle, all samples were made at least 14 wk into the process. There were two measurements during the year in each production zone, one between November and April, and the second between May and October. Each selected farm had at least one plot of plants with propagated stem canes of ≤ 18 inches (46 cm) and a plot of plants with canes 18 inches (46 cm). All propagated canes used in this study fell in one of three size categories: small (6–18 in., 15–46 cm), medium (18–32 in., 46–81 cm), and large (32–60 in., 81–152 cm).

The mean density of pests per plot and the mean number of commercial tips per plot with pests of each category (leafhopper egg masses, leafhopper nymphs, katydid eggs, snails, and armored scales) were estimated for each plant size category. Abundance of armored scales was reported only as the number of infested tips because of the difficulty of accurately counting individuals in the field. Eggs of katydids and leafhoppers were categorized as viable, parasitized, parasitized-hatched, and viable-hatched. Sampling points within each plot were defined using a 10- by 10-m grid as reported by Prado et al. (2008). At each sampling point, the tips of nine propagated cane tips were selected at random from plants within a radius of 1 m from the center of the sampling point. Each of the 52 experimental plots had an approximate area of 2,100 m² with 32 sampling points.

Analysis of variance (ANOVA) was performed on the data using mixed model theory to determine whether cane size, growing zone, and season affected pest abundance. The analysis was performed with the statistical program InfoStat (Di Rienzo et al. 2010), using Fisher least significant difference (LSD) procedure with a significance of 0.05 to compare the means and Akaike (AIC) and Bayesian (BIC) Information Criteria to select the best model for this analysis.

Annual Pattern of Pest Abundance. To monitor pest abundance throughout the year, we selected three commercial plots of $\approx 2,100$ m² for each of the three most commonly grown varieties of *D. marginata* (Green, Bicolor, and Magenta), from each of the two zones, for a total of 18 plots. Plots were distributed over a total of seven farms: two in the Atlantic zone and five in the Northern. We used a 10- by 10-m sampling grid to locate 32 fixed sampling points in each plot. At each of these points, nine commercially marketable tips of *D. marginata* were randomly taken from plants found within a 1-m radius. Three tips were sampled from each of the three heights (strata) within the plants (>50, 50–100, and <100 cm).

Abundance of leafhopper eggs and nymphs, katydid eggs, and presence of armored scales and snails on marketable tips were assessed during each sampling period as described previously. Rate of parasitism in leafhoppers was examined by counting the number of

eggs with obvious signs of parasitism such as darkening or swelling. Leaves found with pests were removed from the sampled tips to avoid recounting during successive measurements. Removal of infested leaves was considered to have no significant effect on the overall pest population because of continual production of new plant tips and the presence of ≈ 60 tips within 1 m of each fixed sampling point. Plots were sampled monthly for an entire year from October 2006 through September 2007.

Data were analyzed using a factorial design in which the sources of variation were the Production Zone (with two levels: Atlantic and Northern areas), Variety (Green, Magenta, and Bicolor), and Sampling Date (12 monthly samples). We performed an ANOVA using linear mixed model theory to take into account the repeated measures in time using InfoStat (Di Rienzo et al. 2010). Means of significant sources of variation were compared using Fisher-protected LSD with a significance of $P = 0.05$.

Field Levels of Pest Infestation and Rates of Interception in U.S. Ports. To determine whether our estimates of monthly pest abundance on marketable tips in the field were related to the monthly interception rates at the Port of Miami, we used the information extracted from the U.S. Department of Agriculture–Animal and Plant Health Inspection Service Port Information Network (USDA–APHIS PIN) database provided by the Department of Plant Health of the Costa Rican Ministry of Agriculture. This confidential database provided detailed information on dates, exporter identification, number of plant tips per intercepted shipment, plant genus or species, and names of quarantine pest problems found. Shipment statistics for *D. marginata* were combined with other foliage ornamentals in the export data base from Costa Rica, making it impossible to determine the actual number of *D. marginata* shipments sent to the United States during this study. To establish the proportional relationship of interception rates to total exports, we used the mean number of *D. marginata* tips contained in each of the intercepted shipments as a proxy index of the monthly export volume.

To determine the relationship between interceptions of quarantine pests at the Port of Miami and populations in the field and shipment size, we plotted the standardized monthly values over the course of our study. To test the hypothesis that interception rates were driven by pests in the production field, we conducted a Spearman's rank correlation of the monthly standardized estimates of the proportion of infested tips in the field and standardized numbers of intercepted shipments. To test the hypothesis that interception rates were driven by the monthly volume of plants exported, we conducted a Spearman's correlation between the standardized monthly interceptions and our standardized index of monthly export volume.

Results

Propagated Shoot Size. The main leafhopper species found laying their eggs in leaves of *D. marginata* in

Table 1. Average abundance of pests and proportions of parasitized leafhopper eggs on *D. marginata* tips of three sizes (small, medium, and large) during the two sampling periods in Costa Rica during 2007

Measurement period	Cane size ^a	n	Leafhopper nymphs	Leafhopper egg masses	Proportion of parasitized leafhopper eggs	Proportion of tips infested with armored scales ^b	Katydid eggs	Snails
Nov. to April	Small	13	0.16 ± 0.03a ^c	0.10 ± 0.01a	0.64 ± 0.33a	0.10 ± 0.00a ^d	0.0003 ± 0.0003	0
	Medium	5	0.13 ± 0.05ab	0.06 ± 0.02ab	0.64 ± 0.37a	0.06 ± 0.02ab	0 ^d	0
	Large	9	0.08 ± 0.03bc	0.05 ± 0.01bc	0.74 ± 0.40a	0.05 ± 0.01bc	0.0004 ± 0.0004	0
May to Oct.	Small	14	0.04 ± 0.02bc	0.02 ± 0.01c	0.58 ± 0.32a	0.02 ± 0.01c	0.002 ± 0.001	0.003 ± 0.003
	Medium	8	0.01 ± 0.003c	0.02 ± 0.01c	0.5 ± 0.44a	0.02 ± 0.01c	0.004 ± 0.002	0
	Large	3	0.02 ± 0.002bc	0.02 ± 0.02bc	0.53 ± 0.17a	0.02 ± 0.02bc	0.001 ± 0.001	0

^a Small (6–18 in., 15–46 cm); medium (18–32 in., 46–81 cm); large (>32–60 in., 81–152 cm).

^b Incidence of armored scales was recorded as number of infested plant tips found in nine collected from each sampling point.

^c Means followed by the same letter are not significantly different according to a Fishers Protected LSD.

^d NF, not found.

both production zones were *Oncometopia clarior* (Walker), *Caldwellioliola reservata* (Fowler), and *Empoasca* sp. Counts of the three species were combined and tallied as leafhoppers. Micro-hymenopteran wasps from the genus *Gonatocerus* (Hymenoptera: Mymaridae) were found parasitizing *O. clarior* and *C. reservata* eggs in all of the sampled plots. Overall, cane size and zone did not have significant effects on the number of leafhopper egg masses found on shoot tips ($F = 0.64$; $df = 2, 42$; $P = 0.5321$ and $F = 0.08$; $df = 1, 42$; $P = 0.7770$, respectively). Similarly, there was no impact of cane size and zone on the abundance of leafhopper nymphs ($F = 1.28$; $df = 2, 42$; $P = 0.2895$ and $F = 3.59$; $df = 1, 42$; $P = 0.0651$, respectively).

There was an interaction between sampling time and plant size ($F = 3.28$; $df = 2, 42$; $P = 0.0476$), showing significantly higher incidence of eggs in the plants categorized in the small size range (6–18 in.) from November through April. The proportion of par-

asitized eggs ranged between 0.50 and 0.74, but there were no statistical differences associated with propagated cane size ($F = 0.40$; $df = 2, 35$; $P = 0.68$) nor season ($F = 0.14$; $df = 1, 35$; $P = 0.72$) (Table 1). Although the difference in abundance of nymphs per cane size was not statistically different, the highest populations were found on plant tips with cane sizes in the small category whereas the population in the large plant tips were equal or smaller than the population in medium-size plant tips (Table 1). The number of tips infested with armored scales was not significantly different among size classes ($F = 0.65$; $df = 2, 42$; $P = 0.5269$), zone ($F = 0.38$; $df = 1, 42$; $P = 0.5430$), or sampling period. There were too few katydids and snails recovered to determine an effect of shoot size on their abundance.

Annual Pest Abundance. Leafhopper eggs and nymphs, armored scales, katydid eggs, and snails were detected at low frequencies throughout the year (Table 2). These

Table 2. Mean proportion of plant tips (±SE) per plot infested with leafhopper eggs and nymphs, armored scales, snails, and katydid eggs, found during monthly sampling of 13 commercial plots of *D. marginata* in Costa Rica October 2006 to September 2007

Date	Mean ± SE ^a					
	Leafhopper eggs	Leafhopper nymphs	Armored scales	Katydid eggs	Snails	Any quarantined pest
Oct.	0.021 ± 0.025	0.021 ± 0.025	0.014 ± 0.023	0.001 ± 0.002	0.004 ± 0.010	0.06 ± 0.05
Nov.	0.008 ± 0.012	0.015 ± 0.029	0.021 ± 0.019	0.003 ± 0.003	0.001 ± 0.002	0.05 ± 0.05
Dec.	0.013 ± 0.021	0.013 ± 0.021	0.013 ± 0.023	0.000 ± 0.001	0.001 ± 0.003	0.04 ± 0.05
Jan.	0.026 ± 0.023	0.027 ± 0.024	0.004 ± 0.008	0.001 ± 0.002	0.001 ± 0.002	0.05 ± 0.05
Feb.	0.027 ± 0.024	0.027 ± 0.024	0.004 ± 0.010	0.003 ± 0.010	0.004 ± 0.012	0.06 ± 0.05
Mar.	0.023 ± 0.023	0.023 ± 0.023	0.004 ± 0.011	0.003 ± 0.008	0.004 ± 0.016	0.06 ± 0.05
April	0.025 ± 0.023	0.026 ± 0.026	0.006 ± 0.014	0.002 ± 0.007	0.000 ± 0.001	0.06 ± 0.05
May	0.026 ± 0.025	0.026 ± 0.026	0.005 ± 0.011	0.000 ± 0.001	0.000 ± 0	0.06 ± 0.05
June	0.051^b ± 0.051	0.051 ± 0.052	0.013 ± 0.032	0.003 ± 0.012	0.001 ± 0.002	0.11 ± 0.10
July	0.037 ± 0.035	0.037 ± 0.035	0.006 ± 0.011	0.000 ± 0	0.002 ± 0.007	0.08 ± 0.08
Aug.	0.029 ± 0.035	0.028 ± 0.035	0.005 ± 0.009	0.001 ± 0.002	0.000 ± 0.001	0.06 ± 0.05
Sep.	0.027 ± 0.041	0.025 ± 0.039	0.004 ± 0.011	0.000 ± 0.001	0.000 ± 0.001	0.06 ± 0.09
Effects of month						
P	0.0015	0.0145	0.0006	0.0121	0.1346	0.2190
F; df	2.96; 11,132	2.27; 11,132	3.25; 11,132	2.32; 11,132	1.51; 11,132	1.32; 11,132
Effects of zone						
P	0.0007	0.0015	0.1558	0.4232	0.1329	0.0076
F; df	20.27; 1,12	16.74; 1,12	2.29; 11,132	0.69; 1,12	2.60; 1,12	10.27; 1,12

^a Each plot has an average of 30 sampling points representing 270 plant tips. A sample is composed by nine marketable plant tips taken within 1 m of each sampling point on a 10- by 10-m grid.

^b Numbers in bold represent peak abundance over the course of a year for pests with significant month to month variation.

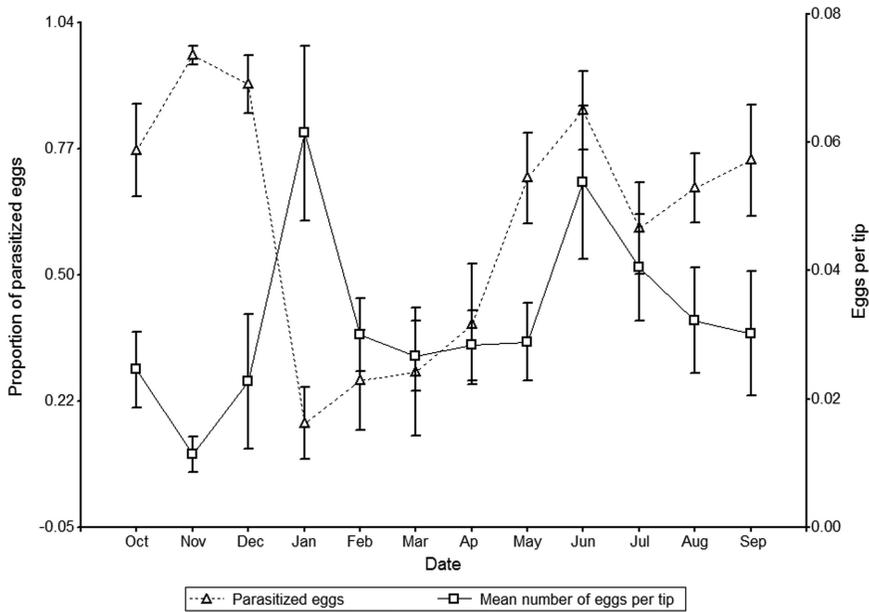


Fig. 2. Average number of leafhopper eggs (see text for species) per shoot tip of sampled *D. marginata* plants and average proportion of parasitized eggs sampling date, from 18 commercial plots in Costa Rica, sampled monthly from October 2006 through September 2007. Scale bars represent SEM.

frequencies were significantly affected by month, but not the zone in which plants were produced, or variety ($P < 0.05$). The maximum monthly estimate of the proportion of plant tips infested with leafhopper eggs or nymphs was ~1 in 20 (0.051). For armored scales, this value (0.021) was nearly 1 on 48 plant tips. In contrast, the maximum monthly values for katydid eggs (0.003) and snails (0.004) were far lower, one infested tip out of 333 and 250, respectively. Leafhopper eggs found in the plots were laid by *O. clarior* and *Caldwelliola* as well as *Diestostema* and *Gypona* sp. Although the small size and cryptic oviposition habit of *Empoasca* sp. made it impossible to detect their eggs during field measurements, their nymphs were found on leaf tips of *D. marginata* plants in all field sites.

Average monthly densities of leafhopper eggs on *Dracaena* shoot tips pooled across all varieties differed significantly with the highest densities occurring in January and June ($F = 2.81$; $df = 22, 132$; $P = 0.0001$) (Fig. 2). Monthly rates of parasitism pooled across all varieties differed significantly ($F = 2.09$; $df = 22, 132$; $P = 0.0057$). Percentages of parasitism were higher during the last 3 mo of 2006 but dropped drastically reaching the lowest point in January 2007, when the leafhopper egg population was at its peak. However, monthly estimates of parasitism were not directly correlated with the monthly numbers of eggs ($r_s = -0.48$; $n = 12$; $P = 0.1148$). Rather it would seem that rates of parasitism tracked egg abundance but lagged behind by a month or more. After leafhopper egg populations dropped in February, parasitism gradually increased throughout February–March and closely followed the trend of the relative abundance

curve of leafhopper eggs from May to September (Fig. 2).

Field Levels of Pest Infestation and Rates of Interception in U.S. Ports. The average proportion of plant tips per field infested with any of the quarantined pests ranged between 0.04 and 0.11 per month, with an annual average of 0.06. The average monthly proportion of tips in the field infested with any of the quarantine pests was significantly affected by the interaction between sampling date and variety ($F = 2.58$; $df = 22, 132$; $P = 0.0005$). The greatest variation was observed for the variety Bicolor, which had its maximum proportion of infested tips in June and its minimum in January (Fig. 3). The lowest proportion of infested tips for Magenta occurred in September and for Green in December.

The number of shipments intercepted for any of the regulated pests between December 2006 and September 2007 in the Port of Miami ranged between 4 and 55 per month, with an average of 21.75 ± 13.71 . The standardized curve of intercepted shipments increased gradually through the first 5 mo of 2007 reaching its first peak in May (Fig. 4). Numbers of interceptions decreased in June and July but then increased again in the following months to reach the highest point in September. The standardized curve coincided with the number of interceptions at the ports only in December when both values were at their lowest points. We used the monthly average number of plants contained in intercepted containers as our index of the volume of plants shipped to the United States each month from Costa Rica. This index ranged between 70 and 24,800 per month, with an average of 2,368. Our index of shipment volume

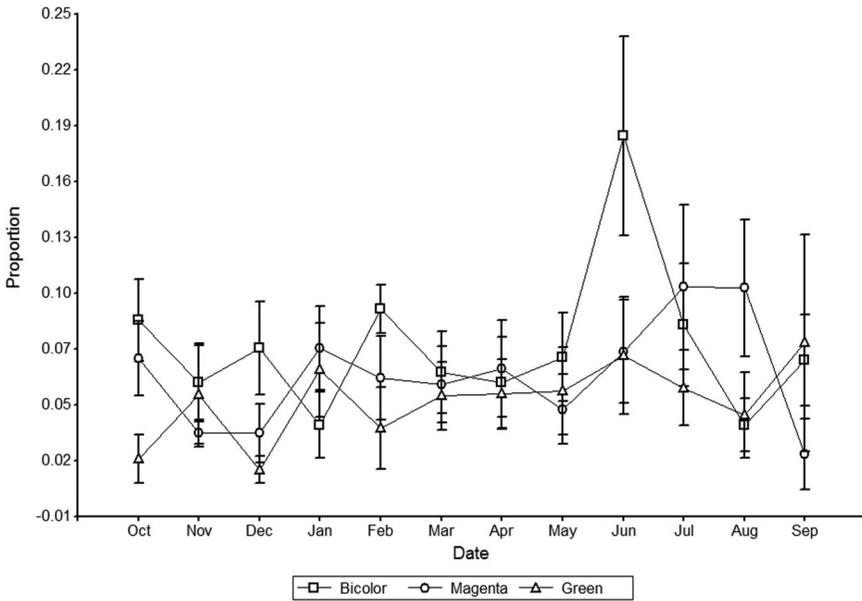


Fig. 3. Average monthly proportions of shoot tips infested with leafhoppers, katydid, armored scales, or snails collected monthly from three commonly grown varieties of *D. marginata* grown in 18 commercial plots in Costa Rica from November 2006 to October 2007. Scale bars represent SEM.

peaked in September, the same month that the number of interceptions was highest, and the density of infested tips was below the monthly average. Spearman's Rank correlation analysis showed a significant correlation between shipment size index and interceptions ($r_s = 0.69; n = 12; P = 0.02$), but no relation between the proportion of infested tips in the field and

the number of interceptions ($r_s = 0.09; n = 12; P = 0.76$) was found.

Discussion

Propagated Shoot Size. Larger cane length did not increase the proportion of propagated *D. marginata*

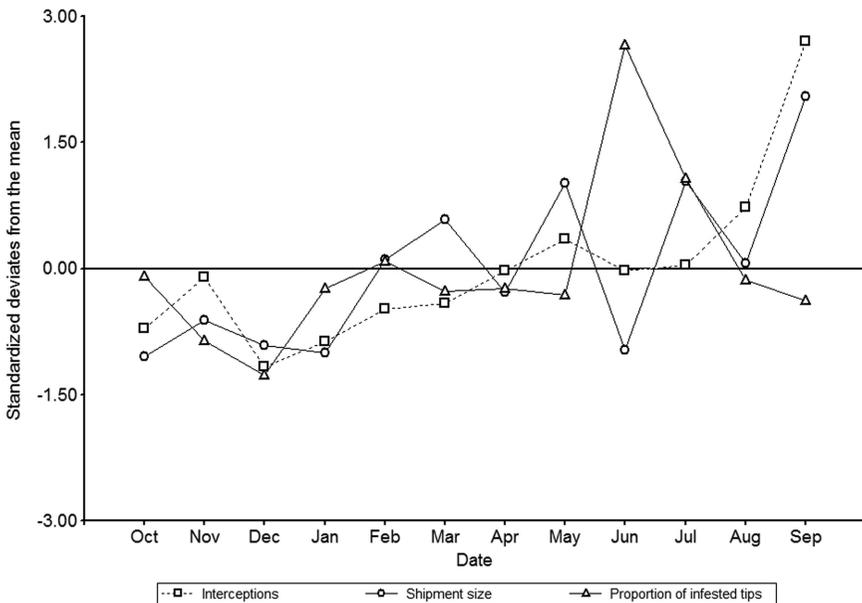


Fig. 4. Curves of standardized number, interceptions of *D. marginata* shipments from Costa Rica, average number of tips per intercepted shipment (shipment size), and pest abundance in the field represented as the proportion of plant tips infested with the studied pest, from October 2006 to September 2007.

growing tips infested with quarantine pests. Structural and physiological similarities of same aged leaves on different sized plants may help to explain the lack of significant differences among shoot tips of different sized plants. All these tips sprouted from buds that emerged from the host plant during the 14- to 16-wk period after the apical tips were removed.

Attraction of insects to their hosts can be influenced by plant age, secondary chemistry (Muticainem et al. 1996, Arimura et al. 2005, Munné-Bosch 2007), and the developmental stage of the insect (Schoonhoven et al. 2005). *D. marginata* appears to be one of many plant species where the availability and distribution of young leaves determines the abundance and diversity of herbivorous insects (Basset 2001). According to Schoonhoven et al. (2005), as plants age they go through chemical, morphological, and physiological changes that can affect the feeding behavior or oviposition preference of insects. Thus, physiological similarities of same-aged foliage on different-sized *D. marginata* shoots may contribute to the lack of an observed difference in pest abundance.

Of the pests we studied, the preference for young tissue has been best documented for leafhoppers. For example, Pedreira et al. (2008) report the preference of *Oncometopia facialis* (Signoret) for feeding on young shoots of citrus trees where the concentration of amino acids is higher. Similar increases from the abundance of succulent tissue have also been reported in shade grown coffee (Rojas et al. 1999) and in sugar cane (Hidalgo et al. 1999). In temperate systems ranging from forage crops such as alfalfa, grapes, and maple trees (*Acer*), oviposition of leafhoppers tends to be higher on succulent young stems than less succulent and more lignified tissue (Hoffman and Hogg 1992, Bentz and Townsend 1997, Daane and Williams 2003). Thus, our finding that leafhoppers respond more to the physiological age of leaf tissue rather than the overall plant would be consistent with recent models proposed to describe how leafhoppers track ephemeral resources on their host plants (Mizell et al. 2008).

Annual Pest Abundance. Each of the four quarantined pests was present at low frequencies on marketable plant tips in *D. marginata* production fields throughout the course of the entire year. Our monthly observations fill in temporal gaps of a previous study (Prado et al. 2008) where substantial variation was found between pest abundance on *D. marginata* during samples collected only twice in a year. Of all the pests we detected, leafhoppers were the most common pest found on the studied plants.

Our data collection in the field was sensitive enough to detect a cyclical fluctuation in the population dynamics of leafhoppers and their parasitoids. The two species that contributed most to the egg counts in the field (*O. clarior* and *C. reservata*) shared the same parasitoid: *Gonatocerus* spp. (Hymenoptera: Mymaridae). Although there was no significant correlation between the number of eggs in the field and the percentage of parasitism, the proportion of eggs parasitized in January was lowest when the number of leafhoppers in the field was highest. Relatively lower

numbers of parasitoids and eggs from November through December may have allowed populations of leafhoppers to exploit new flushes of leaf growth unfettered by attacks of arthropod natural enemies. Mizell et al. (2008) described a similar phenomenon for *Homalodisca variegata*, in which the insect used this enemy-free period to increase its population.

Field Levels of Pest Infestation and Rates of Interception in U.S. Ports. The density of pests per *D. marginata* tip was not a good predictor of the peaks in proportion of tips infested in the field. For leafhoppers, the distinct peak in January's pest density (Fig. 2) was absent from the table of proportion of tips infested with leafhopper eggs (Table 2). Only one of the three varieties, Bicolor, had a distinct monthly peak in the proportion of tips infested with any pest and that only occurred in June (Fig. 3). Thus, because the goal of our research was to reduce the export of infested plants, we used the proportion of infested tips as our best indicator of monthly pest abundance in *Dracaena* production fields. This value estimates the proportion of infested tips that could enter the production stream before rejecting infested tips during harvest and sorting in the packing house. Although we were unable to exhaustively sample all production farms in Costa Rica, the farms we sampled were representative of those in the major *Dracaena* growing areas.

We found no relationship between our estimates of the monthly proportion of total infested plant tips in the production field and the number of interceptions at the Port of Miami (Fig. 4). The greatest monthly average of intercepted shipments was detected in September when our estimate of the proportion of infested plant tips in the field was at the annual average of 6%. In contrast, both the number of interceptions and our standardized estimate of shipment volume in September were both nearly 2 SDs above the mean. This suggests that the spike in interceptions may have been caused a combination of two possible mechanisms. Growers were either less selective during harvest and inspection when they had to fill larger shipments, or the volume of plants infested in the packing house exceeded the capacity of the workers to effectively maintain quality control. Either way the lapse in plant quality was better explained by the monthly volume of plants shipped than the density of pests in the production fields.

Recent studies suggest that live plant imports are a major pathway for new pest invasions because the high volume of plants shipped into the United States exceeds the capacity of current port inspection procedures to prevent the establishment of new pests (Liebhold et al. 2012). Simply stated, even though inspections can reduce rates of exotic pest entries over time, this reduction is insufficient to keep pest densities below the levels necessary for establishing new populations. For this reason, the recommendation is that inspection procedures be bolstered by encouraging off-shore producers to use a set of best management practices to reduce the number of infested plants that enter the export stream before they reach U.S. port inspectors.

Our studies of pest abundance on *Dracaena* shoots of different sizes and in nurseries over the course of the year suggest that management practices in place produce shoots in the field with a consistently low level of pests over the course of a year. During most of our investigation, growers had enough clean plants to selectively reject infested plants before and after the harvest. Increases in infested plants only occurred when demand stripped the capacity to produce a clean supply of exported plants. For this reason, we suggest that efforts to create preclearance programs for *Dracaena* and other nursery crops should do more than simply provide guidelines that keep densities of pests low in fields. They must also provide research-based guidelines to assure a consistent level of postharvest inspection and processing to account for increased volume of plant shipments.

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References Cited

Acuña, B., A. C. Jiménez, J. A. Franco, G. Murillo, J. Ramírez, J. Gamboa, and A. Fernández. 1991. Tecnología Para La Producción de *Dracaena marginata* en Costa Rica. Editorial EUNED, San José.

Arimura, G., C. Kost, and W. Boland. 2005. Herbivore-induced, indirect plant defenses. *BBA Mol. Cell Biol. Lipids* 1734: 91–111.

Aukema, J., B. Leung, K. Kovacs, C. Chivers, K. O. Britton, J. Englin, S. J. Fraenkel, R. G. Haight, T. P. Holms, A. M. Liebhold, et al. 2011. Economic impacts of non-native forest insects in the continental United States. *PLoS ONE* 6: e24587.

Basset, Y. 2001. Communities of insect herbivores foraging on saplings versus mature trees of *Pourouma bicolor* (Cecropiaceae) in Panama. *Oecologia* 129: 253–260.

Bentz, J., and A. M. Townsend. 1997. Variation in adult populations of the potato leafhopper (Homoptera: Cicadellidae) and feeding injury among clones of red maple. *Environ. Entomol.* 26: 1091–1095.

Colpetzer, K. E., G. S. Chinchilla, and W. A. Guterrez. 2011. Importation of oversized *Dracaena* for ornamental purposes from Costa Rica into the United States. U.S. Dep. Agric. APHIS Pest Risk Assess. (<http://www.regulations.gov/#/documentDetail;D=APHIS-2011-0073-0004>).

Daane, K. M., and L. E. Williams. 2003. Manipulating vineyard irrigation amounts to reduce insect pest damage. *Ecol. Appl.* 3: 1650–1666.

Di Rienzo J. A., F. Casanoves, M. Balzarini, L. Gonzalez, M. Tablada, and C. W. Robledo. 2010. InfoStat versión 2010. Grupo InfoStat, FCA, Universidad Nacional de Córdoba, Argentina. (<http://www.infostat.com.ar>).

Hidalgo, G., M. M., L. R. Rodríguez, N. E. Ricardo, and H. Ferras. 1999. Dinámica poblacional de cicadélidos (Homoptera: Cicadellidae) en un agroecosistema cañero de Cuba. *Rev. Biol. Trop.* 47: 503–512.

Hoffman, G. D., and D. B. Hogg. 1992. Effect of alfalfa water stress on potato leafhopper (Homoptera: Cicadellidae) plant preference and oviposition rate. *Ann. Entomol. Soc. Am.* 85: 506–516.

IMN. 2010. Instituto Meteorológico Nacional de Costa Rica. (http://www.imn.ac.cr/IMN/MainAdmin.aspx?_EVENTTARGET=LinksInfoClimatica).

Liebhold, A. M., E. G. Brockerhoff, L. J. Garrett, J. L. Parke, and K. O. Britton. 2012. Live plant imports: the major pathway for forest insect and pathogen invasions of the US. *Front. Ecol. Environ.* 10: 135–143.

Mizell, R. F. III., C. Tipping, P. C. Andersen, B. V. Brodbeck, W. B. Hunter, and T. Northfield. 2008. Behavioral model for *Homalodisca vitripennis* (Hemiptera: Cicadellidae): optimization of host plant utilization and management implications. *Environ. Entomol.* 37: 1049–1062.

Muticainem, P., M. Walls, and J. Ovasca. 1996. Herbivore-induced resistance in *Betula pendula*: the role of plant vascular architecture. *Oecologia* 108: 723–727.

Munné-Bosch, S. 2007. Aging in perennials. *Crit. Rev. Plant Sci.* 26: 123–138.

Novotny, V., and Y. Basset. 1998. Seasonality of sap-sucking insects (Auchenorrhyncha: Hemiptera) feeding on *Ficus* (Moraceae) in a lowland rain forest in New Guinea. *Oecologia* 115: 514–522.

Panjiva. 2013. Panjiva trade intelligence platform. (<http://panjiva.com/about-panjiva/intelligence-platform>).

Pedreira de Miranda, M., D. N. Viola, R. N. Marques, J. P. Bonani, and J. R. Spotti Lopes. 2008. Locais e período de alimentação da cigarrinha vetor de *Xylella fastidiosa*, *Bucephalagonia xanthophis* (Berg) (Hemiptera: Cicadellidae), em mudas cítricas. *Rev. Bras. Fruticultura* 30: 913–918.

Prado, J., F. Casanoves, E. Hidalgo, T. Benjamin, and C. S. Sadof. 2008. Effects of production practices on the abundance of quarantine pests in *Dracaena marginata* in Costa Rican production fields. *J. Econ. Entomol.* 101: 1779–85.

Pimentel, D., R. Zuniga, and D. Morrison. 2005. Update on the environmental and economic costs associated with alien-invasive species in the United States. *Ecol. Econ.* 52: 273–288.

Rojas, L., C. Godoy, P. Hanson, C. Kleinn, and L. Hilje. 1999. Diversidad de homópteros en plantaciones de café con diferentes tipos de sombra, en Turrialba, Costa Rica. *Agroforestería Américas* 6: 33–35.

Shea, K. 2012. Importation of dracaena plants from Costa Rica. *Fed. Regist.* 77: 37997.

Schoonhoven, L. M., J.J.A. van Loon, and M. Dicke. 2005. *Insect-plant Biology*. Oxford University Press, London, United Kingdom.

Whitfield, T.J.S., V. Novotny, S. E. Miller, J. Hrcck, P. Klimes, and G. D. Weiblen. 2012. Predicting herbivore abundance from host plant traits and phylogeny. *Ecol.* 93: S211–S212.

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