

# Another Look at the Ficus Leaf-Rolling Psyllid

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In an earlier paper in these pages (Hodel et al. 2016), we reported on the rather sudden emergence in early 2016 of the Ficus leaf-rolling psyllid (FLRP) on *Ficus microcarpa* L. (Chinese banyan or Indian laurel fig (often erroneously referred to as *F. nitida* or *F. retusa*). This *Ficus* species is a common, useful, widespread, ornamental street, park, school, commercial building, and even home landscape tree in California, from San Diego to the Bay Area and from the coast into the low desert, and elsewhere in tropical and subtropical regions (**Fig. 1**). As the common name implies, the FLRP attacks the leaves, in this case the still pliable, newly emerging leaves, and severely distorts them by rolling one or both margins tightly inward on the adaxial surface (**Fig. 2**)

We monitored the FLRP over several months and were rather easily able to detect and identify winged adults and two immature stages. One immature stage was a mobile, dark brown and greenish, elongate oval with a distinctive fringe of white waxy hairs that we referred to as “slippers” because of their resemblance to the footwear. We found these mostly inside the tight leaf rolls. The other was a sedentary, orange oval with two conspicuous, red eyes that was embedded in a shallow pit in the leaf surface, which we referred to simply as “orange ovals.” The orange ovals were visible on the outside of the leaf roll and also inside the roll but in the latter case they were only visible if the leaf was unrolled, a difficult task because of the brittle nature of the rolled leaf.

Our observations and the literature (Mathur 1973) indicated that the orange ovals and slippers were early to late instars, perhaps the second and fourth or fifth, respectively, of four or five life stages. However, we were unable to detect transitional stages among the four or five stages, perhaps because much of this activity likely took place inside the tightly rolled leaves. Our failure to find transitional stages and especially our observation that the orange ovals would remain embedded in a pit for several months or more with no visible change in appearance and, in many cases, simply and mysteriously disappeared or died within a day or two, frustrated us yet piqued our interest in the natural history of this pest. Indeed, at times we even doubted that the orange ovals, slippers, and winged adults were actually the same species. Thus, we developed a one-year study to investigate the FLRP that focused on host leaf and shoot growth and pest developmental life forms and a correlation, if any, that existed between the host and the pest. Our objective was



1. *Ficus microcarpa* is one of the most common landscape trees for public spaces in Southern California. Here it is as a street tree in Lakewood, California. © D. R. Hodel.



2. The FLRP attacks the soft, pliable, newly emerging leaves, severely distorting them by rolling one or both margins tightly inward. © D. R. Hodel.

to understand the natural history of this new pest better, which perhaps would help to develop effective management strategies.

Here we provide an overview of the FLRP, the results of a one-year study investigating the FLRP interaction with its host tree and the host's growth response, and a discussion of management strategies.

## Overview of FLRP

### History

Forest entomologist Ram Nath Mathur (1903–1977) of the Forest Research Institute, Dehradun, India, named and described *Trioza brevigenae* in 1973, basing the new species on a small series of specimens that he had collected 10 years earlier in 1963 from *Ficus* sp. at New Forest, near Dehradun, Uttar Pradesh, India (Mathur 1973). When doing so, Mathur noted that the new psyllid was “On young leaves of *Ficus* sp., forming thick, hard, marginal rolls.” The holotype was a male and the allotype was a female; he deposited these and several paratypes and nymphs, all preserved in alcohol, in the National Entomological Museum at the Forest Research Institute. Mathur (1973), following the classification at the time, indicated that the new species was in subfamily Triozinae, which is in the family Triozidae. However, more recently, in a revised classification of the jumping plant-lice (Hemiptera: Psylloidea), Burckhardt and Ouvrard (2012) did away with the subfamily classification Triozinae, retaining only the family Triozidae.

Our first experience with this new pest began in February 2016, when co-author Ohara observed tightly rolled leaves on a *Ficus microcarpa* in her yard in Carson, California. This damage was remarkable in its rather sudden appearance because this same tree was inspected one month earlier for other pests and the rolled leaves were not observed. Ohara and co-author Hodel contacted co-author Arakelian about this distinctive leaf damage and he said that he, too, had just seen this damage and suspected it was a psyllid, perhaps a species of *Trioza*. Arakelian sent samples to entomologist and thrips specialist Alessandra Rung at the California Department of Food and Agriculture and she also tentatively identified it as a species of *Trioza*. Later in 2016, Rung shared specimens with Daniel Burckhardt, a psyllid specialist at the Natural History Museum of Basel, Switzerland, who identified it as the FLRP (*T. brevigenae*). This determination was the first record in the Western Hemisphere, and, indeed, the first record outside of India although the FLRP has since also been detected in the island nation of Cyprus in the Mediterranean basin (Compton et al. 2019).

By August of 2016, we had observed the distinctive rolled leaves and FLRPs on *Ficus microcarpa* in western Los Angeles, Pasadena, Duarte, Long Beach, Claremont, and Universal City (San Fernando Valley) in Los Angeles County; Irvine and Anaheim in Orange County; Montclair in





3. Adult FLRP (*Trioza brevigenae*). © G. Arakelian.



4. Adult FLRP (*Trioza brevigenae*). © G. Arakelian.

western San Bernardino County; and Corona in western Riverside County. It is now in Ventura County and perhaps elsewhere in California.

Toward the end of 2016, the California Department of Food and Agriculture had assigned a Pest Rating of **B** to the FLRP, basing it on five, accumulative, introduction criteria: 1) high probability of establishing widespread distribution in California; 2) low probability of spreading to other hosts; 3) high probability of high reproduction and dispersal potential; 4) low probability of loss of markets due to quarantines; 5) high probability of this pest triggering treatment programs and impacting cultural practices, home/urban gardening, or ornamental plantings. Subtracted from these five criteria is a medium rating because the pest was widespread in California but not yet fully established in the endangered area, or the pest is established in two contiguous suitable climate/host areas. Thus, because the FLRP is widespread in southern California and is likely to have significant economic and environmental impacts as it extends to other parts of the State, a **B** rating was justified (Leathers 2016).

### Description

The description is from Arakelian (2016), Hodel et al. (2016), and Mathur (1973). Adults are small, 2.6–2.8 mm long overall, and pale green to pale brown with a greenish tinge (**Figs. 3–4**). The long, slender bodies are rugulose and finely and sparsely pubescent. Bodies of males are 1.72 mm long, those of females 1.84 mm long.

The very narrow, hyaline, transparent wings lack a color pattern and are held tent-like above the body. Forewings are 2.3–2.6 mm long, 0.75 mm wide, about 3.5 times as long as broad, and extend well beyond the posterior end of the abdomen; those of males are 2.3 mm long while those of females are 2.6 mm long. Hind wings are small, long, and narrow, about 1.75 mm long and 0.5 mm wide.

The head, including the eyes, is 0.5 mm wide, nearly as wide as the thorax, slightly deflexed, and brownish green. The long, slender thorax is brownish green and not strongly arched and has a small, roof-shaped pronotum. The abdomen is long, slender, and green when young and brown when old. Eyes are conspicuous, red, bulbous, and protruding.

The slender legs are about 1.1 mm long, pubescent and with the femora shorter than the tibia.

Antennae are long, slender, 10-segmented, and about 0.6–0.8 mm long, which is slightly longer than the width of the head including the eyes.

Adult FLRPs are typically found outside and adjacent to rolled leaves; apparently, they exit the confines of the rolled leaf immediately upon reaching adulthood. They exhibit two peculiar behaviors. In one, the more common of the two observed, it sits on a leaf blade or perches on





5. FLRP adult (arrow) perched on the margin of a rolled leaf and doing the dog-wagging-its-tail behavior. © D. R. Hodel.



6. Two adult FLRPs at the base of the leaf doing their dog-wagging-its-tail behavior. © D. R. Hodel.





**7.** Three adult FLRPs are perched on the leaf curl with their abdomens raised at about a 45-degree angle. © D. R. Hodel.



**8.** Carefully peeling back the brittle, rolled leaf blades typically reveals various developmental stages of FLRP nymphs. © D. R. Hodel.





9. Likely the fifth instar, slippers have an oval body with a distinguishable head, thorax, and abdomen and have a fringe of white, waxy filaments-like hairs. © G. Arakelian.



10. A slipper emerges from the one sided-leaf roll. © D. R. Hodel.





**11.** Likely the second instar, orange ovals have distinctive red eyes, smaller, bud-like wing pads, and, although they have rudimentary legs, they are sedentary and immersed in shallow pits. © G. Arakelian.



**12.** These orange ovals immersed in their shallow pits will likely not develop further because that portion of the leaf has finished rolling, leaving them exposed and unprotected. © D. R. Hodel.

the margin of a rolled leaf, raises its abdomen until it is at about a 45-degree angle, and then moves it from side to side somewhat briskly like a dog wagging its tail (**Figs. 5–7**). In another, it extends one wing until it is at a right angle to the body, as if stretching prior to working out, then waves it back and forth while walking.

We have also observed that adult FLRP seemed much more active in warmer, still weather, with temperatures ranging from 25 to 30 C (76 to 86 F) or higher, underscoring its likely tropical origin. It is less conspicuous and active on cooler, cloudy, breezy days.

Peeling back the brittle, rolled leaf blades typically reveals various developmental stages of FLRP nymphs (**Fig. 8**). Metamorphosis is gradual. Immature and mature nymphs range from orange to pale yellowish, yellowish brown, grayish brown, or brownish green and have pinkish red to red eyes. Five nymphal stages or instars exist although not all are thoroughly described.

The fifth instar is mobile, 1.9–2.5 mm long, 0.5–6 mm wide, very narrowly oval to oblong, with wing-pads produced slightly beyond the posterior margins of the very small eyes. The head, thorax, and abdomen are distinguishable and the dark grayish tan to brownish green body is completely ringed around its margin with a distinctive skirt of densely placed, slender, white-waxy filaments, which are shorter on the sides and unusually long at the cranial and caudal ends. The fifth instar is what we refer to as “slippers” (**Figs. 9–10**)

The fourth instar is 1.3 mm long and resembles the fifth instar but has smaller wing pads and shorter antennae.

The second instar is 0.65 mm long, 0.4 mm wide, and differs from the other instars in its oval shape, orange color with distinctive red eyes, smaller, bud-like wing pads, and much shorter antennae. Although they have rudimentary legs, they are sedentary and immersed in shallow pits where they insert a stylus to feed, which securely attaches them to the leaf. The second instar is what we refer to as “orange oval” (**Figs. 11–12**).

## Damage

The only host of the FLRP so far is *Ficus microcarpa*, which is a magnet and unusually attractive to a suite of pests. Damage is fairly obvious and unusually conspicuous on heavily infested trees. Leaves at the branch and twig tips are tightly and typically completely rolled into a narrow cylinder, sometimes eventually compressed to only about three to five mm in diameter (**Figs. 13–14**). The rolling process begins at the distal end or leaf apex and, like two cresting waves, progresses adaxially along each margin and proximally toward the leaf base. One rolled margin eventually overtakes the other, actually forming a cylinder with two tubes. In some instances, only one margin rolls, in which case the rolling stops at the leaf blade midrib or rachis. Only the side of the leaf blade with orange ovals will roll. The rolled leaf is brittle but remains green





**13.** Typically tight leaf rolls are characteristic of the FLRP. Note how some leaves roll with both margins and some with only one. © D. R. Hodel.



**14.** Transverse view of the FLRP leaf rolls show that when both margins roll the structure is actually comprised of two rolls, one from each margin. © D. R. Hodel.

throughout although other pests, such as *Josephiella microcarpae* (Ficus gall wasp) and various mealybugs, might be present and discolor or further deform the cylinder of rolled leaves. Indeed, the rolled leaf provides protection and harborage for several other insects and spiders as well.

The rolled leaves could be mistaken initially for damage from *Gynaikothrips ficorum* (the Cuban laurel thrips), which creates a gall by folding the leaf blade adaxially along the midrib. However, careful observation will quickly show the distinct difference between the rolled leaf (cause by the FLRP) and folded leaf (caused by Cuban laurel thrips). Indeed, the FLRPs shape the leaf to look more like the Mexican food *taquito* (tightly rolled *tortilla*) while the Cuban laurel thrips cause the leaf to look more like a *taco* (folded *tortilla*). Also, the folded leaf gall from the Cuban laurel thrips typically has dark or purplish flecking or stippling on the abaxially leaf surface. Other insects, such as mealybugs, and even spiders can sometimes cause leaves to roll although in such instances the leaf is more loosely rolled and not nearly as distinctively tight as with the FLRP.

## Methods

In January 2017, we randomly selected 30 shoots (10 each from three *Ficus microcarpa* trees) in Carson, California. To enable easy access and identification, we selected shoots within two meters of the ground and marked each with a small piece of pink flagging tape. Shoots 1–10 were from the northern side of Tree 1, 11–20 were evenly distributed around Tree 2, and 21–30 were on the southern side of Tree 3. Trees 1 and 3 were old, large, mature trees about 20 m tall and wide while Tree 2, also mature, was a resprout from a cut stump and was about three m tall and wide. All trees were on the same property and primarily received the same type of care. We did not directly irrigate the trees and they survived mostly on rainfall although irrigation of potted plants near or under Trees 1 and 2 provided some additional water. We did not apply fertilizer or pesticides to the trees. We obtained weather data from NOAA (2020) and the Weather Underground (WU 2020).

Each Friday from January 13, 2017 through January 12, 2018, we examined each shoot and collected data. We marked the newest leaf present on January 13, 2017 and numbered leaves sequentially on the shoot in the order they were produced. At two intervals, on May 26, 2017 and January 13, 2018, we measured shoot lengths from the original starting leaf at the beginning of the study.

The data we collected each week included the quantity of leaves present and the quantity of orange oval immature FLRPs residing in pits on each leaf. Beginning on June 16, 2017, a new element was added to the data collection process. We had noticed some of the orange ovals had changed color and appeared to be dead but were still attached inside the pit. Others were absent, leaving an empty pit (**Fig. 15**). In other cases, orange ovals in their pits were rolled under the leaf when it curled, making them impossible to observe because the curled portion of the leaf is brittle





**15.** Some of the orange ovals changed color and appeared to be dead but were still attached inside the pit while others were absent, leaving an empty pit. © D. R. Hodel.



**16.** We noted the disposition of the orange ovals: alive, dead and in pit, and gone, leaving an empty pit. © D. R. Hodel.

and broke apart when we attempted to unfurl it. Thus, in addition to the original data collected, we recorded the disposition of the orange ovals present on each leaf. We differentiated three states of disposition: (1) alive and attached; (2) dead and attached; or (3) empty, pit devoid of an orange oval (**Fig. 16**). We also recorded the date of the first orange oval death on a leaf. We did not collect data on the number of empty pits or the death of attached orange ovals from January 13 through June 9.

As leaves began to senesce, their respective presence or absence was recorded as well.

After the study period, specimen samples were passed to the laboratory of Dr. Richard Stouthamer at the University of California, Riverside for DNA-based confirmation that the FLRP winged adults, orange ovals, and slippers were indeed life stages of the same species. DNA was extracted and the “barcoding” fragment of the mitochondrial COI gene was amplified and sequenced as Rugman-Jones et al. (2012) described.

## Results and Discussion

### Weather Conditions

Rainfall at the site over the course of the study was 138.0 mm, mostly occurring in January and February 2017 and January 2018 (**Table 1**). Monthly mean maximum daytime temperatures ranged from 17.8 C in January 2017 to 28.5 C in August 2017. Monthly mean minimum nighttime temperatures ranged from 8.2 C in December 2017 to 19.8 C in August 2017.

**Table 1.** Monthly precipitation (mm) and temperature range (C) at the study site in Carson, CA, January 13, 2017 through January 12, 2018<sup>z</sup>.

	Jan. <sup>y</sup>	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan. <sup>y</sup>
<b>Prec.</b>	58.7	27.2	2.5	4.6	5.3	0.0	0.0	0.0	1.8	0.0	0.8	0.0	37.6
<b>Mean Max. Temp.</b>	17.8	18.2	23.4	24.4	23.1	25.4	28.4	28.6	27.9	28.5	24.2	23.8	23.3
<b>Mean Min. Temp.</b>	8.6	10.8	11.4	13.4	14.4	16.4	19.6	19.8	18.4	16.4	13.4	8.2	10.6

<sup>z</sup>WU (2020) and NOAA (2020).

<sup>y</sup> Precipitation before January 13, 2017 and after January 12, 2018 was not included in the monthly totals.



## Molecular Analysis

We obtained sequences of the COI gene from three winged adults, two slippers, and four orange ovals. All three life forms had exactly the same sequence, confirming that all are the same species. The orange ovals are likely second instar nymphs; they clearly have six legs.

We placed the nine COI gene DNA sequences in the public repository GenBank and they have the accession numbers *MH633256* through *MH633264*.

Alcohol-preserved specimens of the three life forms were also deposited in the University of California Entomological Museum with the voucher numbers UCRC ENT 500175 and UCRC ENT 500176.

## Host Shoot and Leaf Growth

On Tree 1, shoots 1–10 had mean growth of 16.5 cm from January 13 through May 26, 2017, and mean growth of 21.2 cm from May 27, 2017 through January 12, 2018 with no significant outliers (**Fig. 17, Table 2**).

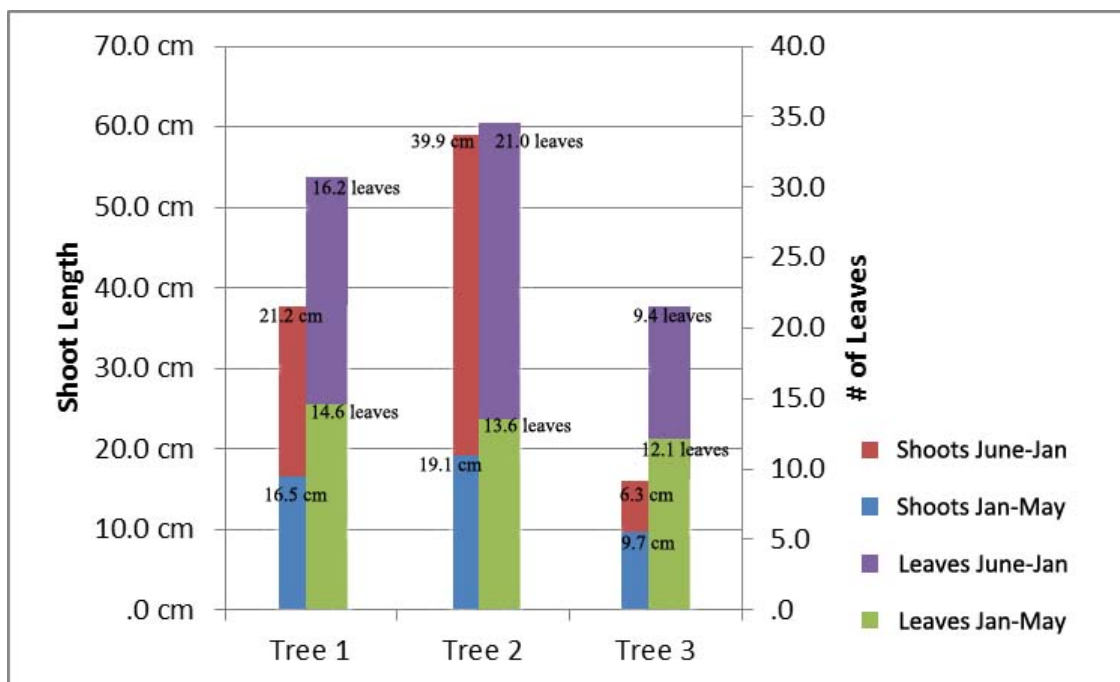
On Tree 2, shoots 11–19 had mean growth of 19.1 cm from January 13 through May 26, 2017. Considerable variation in shoot growth occurred from May 27, 2017 through January 12, 2018; mean shoot growth during this period was 39.9 cm but it was unusually variable, ranging from 5 cm to 91.2 cm (**Fig. 17, Table 2**). Shoot 20 on Tree 2 died three weeks into the study, so no growth data was recovered and it was excluded from this analysis.

On Tree 3, Shoots 21–30 had mean growth of 9.7 cm from January 13 through May 26, 2017 and mean growth of 6.3 cm from May 27 through January 13, 2018 with no significant outliers (**Fig. 17, Table 2**).

Shoots on Trees 1 and 2 grew significantly more than shoots on Tree 3. In Trees 1 and 2, shoots had mean growth of 41 cm while those in Tree 3 grew less than 16 cm. Shoot growth was not significantly different between Trees 1 and 2 but was significantly more than that of Tree 3 (**Table 2**).

The greater shoot growth in the second half of the study (June through December) likely is a reflection of the mostly tropical origin of the host, which is widespread from India and Sri Lanka east through China to southern Japan, south through Thailand, Indonesia, and Malaysia to Australia, and east into the Philippines and the western Pacific (Berg and Corner 2005).

We counted 802 leaves produced over the course of the one-year study. On Tree 1, Shoots 1–10, mean annual leaf production was 28.6. On Tree 2, Shoots 11–19, mean annual leaf production



**17.** Comparison of shoot and leaf growth among the three *Ficus microcarpa* trees in in Carson, CA in each of the two measurement periods.

**Table 2.** Shoot growth (cm) (mean and  $\pm$ Standard Deviation) of the three *Ficus microcarpa* trees in the study in Carson, CA, January 2017 to January 2018. Significance of any differences in each row and column is represented by upper case and lower-case letters, respectively. Cells with the same letter are not significantly different, those with different letters are significantly different ( $p < 0.05$ ).

Tree	Jan-May	June-Jan	Jan-Jan
1	16.5 $\pm$ 3.9 (A,a)	21.2 $\pm$ 13.8 (A,a)	37.8 $\pm$ 17.2 (B,a)
2	19.1 $\pm$ 10.9 (A,a)	39.9 $\pm$ 36.6 (B,a)	59.0 $\pm$ 47.0 (C,a)
3	9.7 $\pm$ 3.1 (A,b)	6.3 $\pm$ 3.8 (B,b)	16.0 $\pm$ 5.3 (C,b)

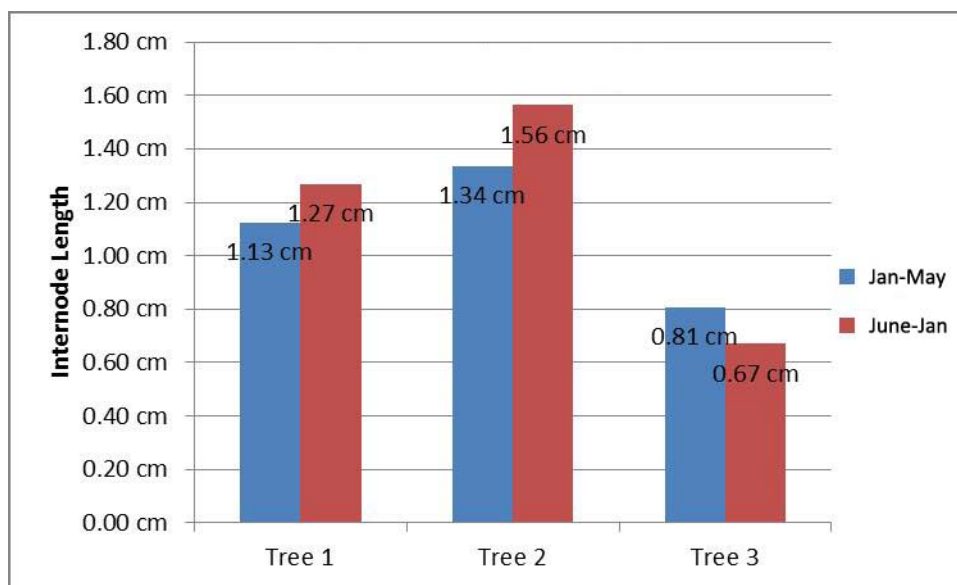
was 34.6. On Tree 3, Shoots 21–30, mean annual leaf production was 20.2 (**Table 3**). Leaf production was not significantly different between Trees 1 and 2 but each tended to produce more leaves than did Tree 3 but not significantly so (**Table 3**).

Considering shoot growth and leaf production together, Trees 1 and 2 grew significantly longer shoots ( $p < 0.02$  and  $p < 0.03$ ) and produced significantly more leaves ( $p < 0.09$  and  $p < 0.04$ ) than Tree 3 (**Fig. 17**, **Tables 2–3**). A possible explanation for this difference in growth response is that Trees 1 and 2 had some containerized plants beneath or near them that were regularly irrigated;



**Table 3.** Leaf production (mean and  $\pm$ Standard Deviation) of the three *Ficus microcarpa* trees in Carson, CA, January 2017 to January 2018. Significance of any differences in each row and column is represented by upper case and lower-case letters, respectively. Cells with the same letter are not significantly different, those with different letters are significantly different ( $p < 0.05$ ).

Tree	Jan-May	May-Jan	Jan-Jan
1	13.7 $\pm$ 3.2 (A,a)	14.9 $\pm$ 9.1 (A,a)	28.6 $\pm$ 11.8 (B,a)
2	12.5 $\pm$ 4.0 (A,a)	18.9 $\pm$ 12.7 (A,a)	31.4 $\pm$ 16.4 (B,a)
3	11.7 $\pm$ 3.5 (A,a)	8.5 $\pm$ 6.1 (A,a)	20.2 $\pm$ 8.0 (B,a)



**18.** Comparison of internode length on each of the three *Ficus microcarpa* trees in each of the two measurement periods in Carson, CA, January 2017 to January 2018. (Tree 1: Shoots 1–10; Tree 2: Shoots 11–19; Tree 3: Shoots 21–30).

**Table 4.** Internode length (cm) (mean and  $\pm$ Standard Deviation) of the three *Ficus microcarpa* trees in Carson, CA, January 2017 to January 2018. Significance of any differences in each row and column is represented by upper case and lower-case letters, respectively. Cells with the same letter are not significantly different, those with different letters are significantly different ( $p < 0.05$ ).

Tree	Jan-May	May-Jan	Jan-Jan
1	1.13 $\pm$ 0.15 (A,a)	1.27 $\pm$ 0.26 (A,a)	1.19 $\pm$ 0.18 (A,a)
2	1.34 $\pm$ 0.54 (A,a)	1.56 $\pm$ 0.83 (A,a)	1.49 $\pm$ 0.72 (A,a)
3	0.81 $\pm$ 0.14 (A,b)	0.67 $\pm$ 0.23 (A,b)	0.74 $\pm$ 0.05 (A,b)

thus, they received supplemental water. In contrast, Tree 3 had no plants beneath it and survived only on the meager rainfall.

Another possible explanation or contributing factor for these differences in shoot growth and leaf production was that shoots on Tree 1 were on the shadier northern side and those on Tree 2 were randomly distributed around the canopy, where lower light conditions could have led to greater shoot elongation, while shoots on Tree 3 were on the sunnier southern side of the tree.

We calculated mean internode length by dividing shoot growth by the number of leaves produced (**Fig. 18, Table 4**). The mean internode length on Tree 1 (Shoots 1–10) was 1.13 cm. The mean internode length on Tree 2 (Shoots 11–19) was 1.34 cm. The mean internode length on Tree 3 (Shoots 21–30) was 0.81 cm. The mean internode length on Tree 3 was significantly shorter than those of Trees 1 and 2. No significant differences in internode length were present between the first and second halves of the study although there was a tendency for Trees 1 and 2 to have longer internodes in the second half of the study. Tree 3 had a lower standard deviation in internode length.

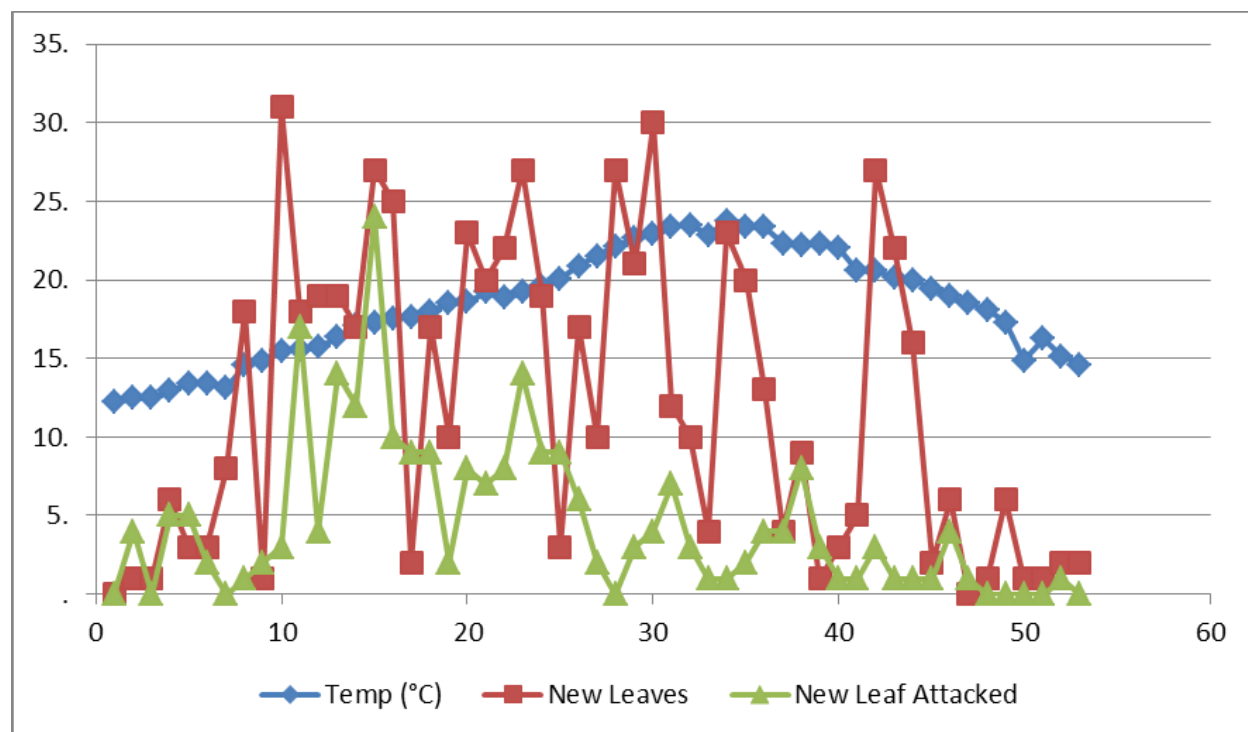
Leaf production occurred in random flushes from February 24 through November 10 (**Fig. 19**). New leaf production did not significantly correlate with weekly mean temperature. Indeed, no correlation existed between a suite of more than a dozen weather factors and leaf production (**Table 5**). The mechanism for stimulating growth flushes was not examined in this study, but the lack of correlation with weekly mean temperatures or precipitation suggests another stimulus is present.

Mean life span of a leaf (from emergence to dropping) was 28 weeks (**Table 9**). Leaf drop was heaviest from November 10 through December 8, 2017, with 110 of the 161 dropped leaves falling during that period; 76 leaves alone dropped during the week of November 24.

*Ficus microcarpa* is in subgenus *Urostigma*, section *Urostigma*, subsection *Conosycea* (Berg and Corner 2005). In contrast to subsection *Urostigma*, which is characterized by mostly intermittent, seasonal growth, often accompanied by partial or full deciduousness, and is associated with climatic conditions, species in subsection *Conosycea* show no intermittent, seasonal growth and are mostly evergreen although they do naturally have brief periods of partial deciduousness, which might simply be a mechanism for shedding senescent leaves and/or is a response to climatic conditions.

The most likely explanation is that the big leaf drop event, which occurred only two weeks after the last growth flush on November 10, was the shoot recalibrating or rebalancing its leaf-to-shoot

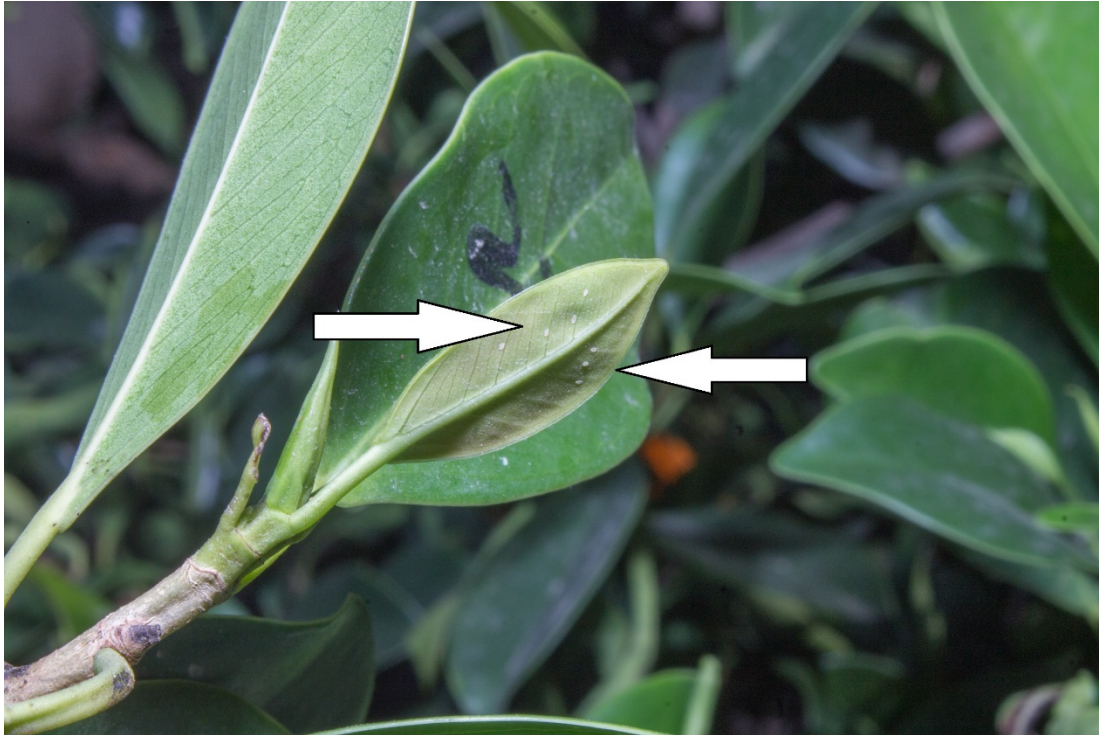




**19.** Weekly new leaf production, weekly new attacked leaves, and weekly mean temperature over the 52-week study on the three *Ficus microcarpa* trees in Carson, CA, January 2017 to January 2018. A correlation ( $r^2 = 0.31$ ) was present between leaf production and infestation of new leaves only in the first 26 weeks of the study. No substantial correlation was present between weekly mean temperature and the number of new FLRP-infested leaves ( $r^2 < 0.001$ ).

**Table 5.** Table showing the correlation ( $r^2$ ) of weekly weather data to the changes in leaves and pest population on the three *Ficus microcarpa* trees in Carson, CA, January 2017 to January 2018. No significant correlation existed between any of the shown variables.

	New Leaves	New Leaves Atkd	Change in Pest Pop	Dropped Leaves
WEEKLYMaximumDryBulbTemp	0.07	0.00	0.01	0.00
WEEKLYMinimumDryBulbTemp	0.06	0.00	0.02	0.00
WEEKLYAverageDryBulbTemp	0.07	0.00	0.01	0.00
WEEKLYDeptFromNormalAverageTemp	0.04	0.03	0.00	0.04
WEEKLYPrecip	0.02	0.01	0.02	0.02
WEEKLYAverageWindSpeed	0.19	0.18	0.02	0.05
WEEKLYPeakWindSpeed	0.08	0.25	0.00	0.05
WEEKLYPeakWindDirection	0.10	0.10	0.01	0.02
WEEKLYSustainedWindSpeed	0.11	0.33	0.00	0.04
WEEKLYSustainedWindDirection	0.01	0.03	0.00	0.02



**20.** At least seven likely first instars of the FLRP (arrows) are on this few-day-old leaf.  
© D. R. Hodel.



**21.** This leaf is only a few days old and already it is infested with several likely first instars of the FLRP (arrows) and is beginning to roll. © D. R. Hodel.





**22.** This leaf is only a few days old and already it is infested with several likely first instars of the FLRP and is beginning to roll. © D. R. Hodel.

ratio. Perhaps shoots have a set number of leaves they can adequately support under a given set of factors, such as tree health, vigor, water status, weather conditions, and light levels, among others, and shoots were dropping leaves to compensate for the increased leaf production over the summer and fall growing season. Or, it is also possible most of the leaf drop of *Ficus microcarpa* takes place in the late fall naturally, which still might be related to higher summer and fall leaf production. Extreme heat might lead to some leaf drop, especially on under irrigated trees, as a physiological mechanism to cope with inadequate water. A significant heat wave occurred the week of October 6. Daytime temperatures exceeded 32.3 C (90 F) for two days. This heat wave might have stimulated the big leaf drop event November 24 although this potential precipitating event was about six weeks prior to the leaf drop, which makes it seem unlikely as a factor. Nonetheless, we have observed *Ficus microcarpa* drop some leaves during or immediately after an extreme heat event; further work is needed to determine if the heat event and leaf drop are correlated. Unfortunately, from the data we collected, we are unable to arrive at a convincing solution to the cause of leaf drop.

### FLRP/Host Interaction

Based on the presence of orange oval FLRP immatures, leaf infestation generally occurred within about one week following each flush of new leaves, which seems logical because new leaves are soft and pliable and their tissues easily penetrated or compromised for egg laying, pit development, and rolling of the leaf (**Figs. 20–22**). On Trees 1 and 2, they appeared on average within 0.7 week (ca. five days) (stdv = 1.0 week) of emergence while on Tree 3 they appeared on average within 0.9 week (ca. 6 days) (stdv = 1.4 weeks). Our observations support this finding as we saw likely first instars and pits within only a few days of leaf emergence and before the leaf had even attained full size.

A moderate correlation ( $r^2 = 0.31$ ) between leaf production and the number of new leaves infested was present in the first 26 weeks of the study (**Fig. 19**) while the same correlation but over the entire one-year study was weak ( $r^2 < 0.001$ ). No substantial correlations existed between weekly mean temperature, precipitation, and nearly a dozen other weather factors and the number of new leaves infested, which is logical because no correlation was present between leaf production and precipitation and temperature (**Table 5**). Thus, the FLRP attacks new leaves shortly after they appear, which is typically in the spring months when FLRP activity increases. Why attacks slowed in the second half of the year is unclear because new growth flushes appeared into November, offering ample opportunity for attacks. Perhaps a predator or some other factor was active that suppressed the FLRP population.

On shoots 1–10 of Tree 1, the mean quantity of leaves attacked was 9.0 (29% of total) (**Table 6**). On shoots 11–19 of Tree 2, the mean quantity of leaves attacked was 9.8 (28% of total). On shoots

**Table 6.** Mean (and  $\pm$ Standard Deviation) quantity of leaves and percent of leaves per shoot attacked by FLRP on the three *Ficus microcarpa* trees in Carson, CA, January 2017 to January 2018.

Tree	Mean	% Leaves Attacked
1	9.0 $\pm$ 4.7	29.0
2	9.8 $\pm$ 4.3	28.0
3	6.2 $\pm$ 3.2	30.0

**Table 7.** Disposition, quantity, and percent of total of orange ovals and pits on leaves of on the three *Ficus microcarpa* trees in Carson, CA, January 2017 to January 2018.

Disposition	Quantity	% of Total
Total quantity of pits with orange ovals.	540	100
Quantity of pits at end of study.	312	57.7
Quantity of pits remaining at end of study that were empty.	268	49.6
Quantity of pits rolled inside leaf.	228	42.2
Quantity of pits with living orange oval at end of study.	44	8.1
Mean lifespan (weeks) of orange oval.	20	NA

**Table 8.** Mean (and  $\pm$  Standard Deviation) quantity of orange ovals per leaf of the three *Ficus microcarpa* trees in Carson, CA, January 2017 to January 2018.

Tree	Quantity
1	0.67 $\pm$ 0.25
2	0.69 $\pm$ 0.39
3	0.67 $\pm$ 0.47
Total	0.68 $\pm$ 0.37

21–30 of Tree 3, the mean quantity of leaves attacked was 6.2 (30% of total). The percentage of total leaves attacked on Trees 1, 2, and 3 was nearly the same.

The FLRPs did not show preference for one tree over another. Fewer leaves were attacked on Tree 3, but there was also proportionately smaller leaf production. On all trees, the time between leaf production and infestation was similar, suggesting that the FLRP infests young leaves, regardless of the age or size of the tree that produces them.

We counted a total of 540 pits with orange oval FLRP immatures during the one-year study, but only 312 (57.8%) remained at the end of the study, of which 268 (49.6%) were empty. We infer that 228 pits (42.2%) were rolled under the curled portion of the leaf by the end of the study or



were on leaves that dropped. At the end of the study, 44 (8.1%) orange ovals were alive and attached in their pits while 29 (5.4%) were dead but still attached in the pit. The mean time for the orange oval to be alive in a pit was 20 weeks (stdv = 11.3 weeks) (**Table 7**).

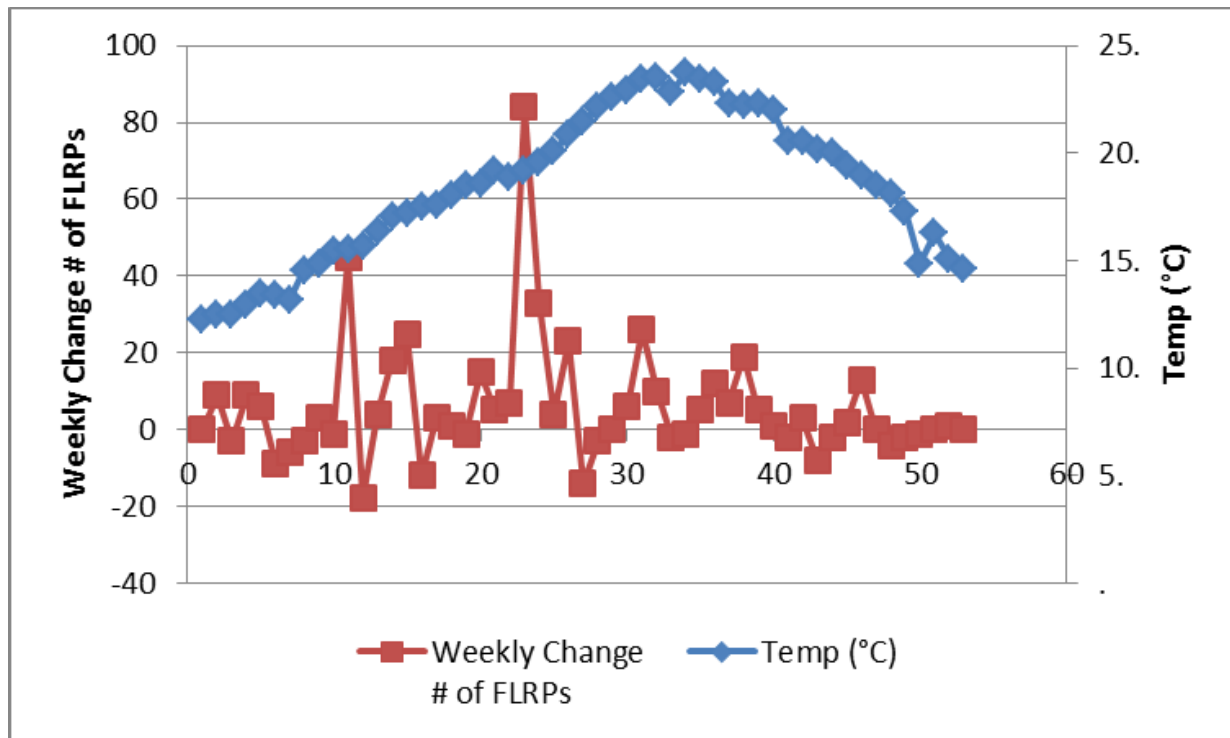
The mean quantity of orange ovals on all counted leaves was 0.68. Broken down by tree, Tree 1 was 0.67, Tree 2 was 0.69, and Tree 3 was 0.67. No significant differences existed among the trees, indicating the FLRPs preferred all three trees equally (**Table 8**).

Of the leaves that were attacked, the maximum number of FLRP pits on a single leaf was 13, but the mean number was 2.4 (stdv = 2.1). The maximum number of FLRP pits on a leaf on Tree 1 was 8, on Tree 2 was 11, and on Tree 3 was 13 (**Table 9**). However, no significant difference existed in the maximum number of pits on a given leaf ( $p > 0.12$ ).

Two substantial increases in the orange oval populations occurred: one on March 24 (45, 14.4%) and a larger one on June 16 (84, 26.9%) (**Fig. 23**). Over the full one-year study, no significant correlation existed between the number of new leaves produced and the total change in pest population ( $r^2 = 0.06$ ), which might be because pest populations did not increase in the second half of the study despite the ample opportunity afforded by new leaf growth.

**Table 9.** Mean and standard deviation of the week number during the year (date) that a leaf was first attacked (First Attack); the quantity of weeks from leaf emergence to the first attack (Until Attack); the week number (date) that a leaf was lost (dropped) (Leaf Loss WK#); the quantity of weeks from leaf first attacked until leaf lost(dropped) (ATK Until Leaf loss); the quantity of weeks from leaf emergence until dropped leaf lost (dropped) (Leaf Until Loss); the maximum number of orange ovals (hits) per leaf (Max Hits if hit); and the quantity of weeks a leaf was infested (Wks Infested If Attacked). N = the quantity of data points (leaves) for that observation.

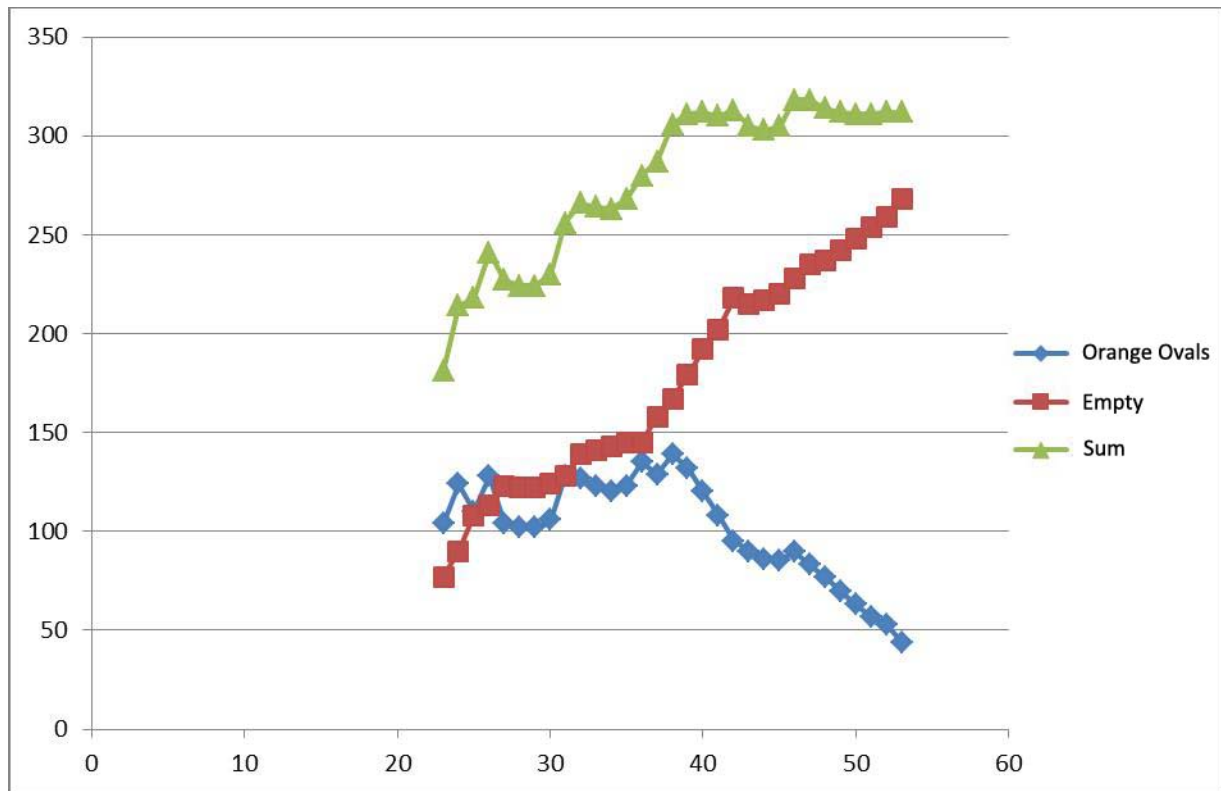
	All Trees				Tree 1				Tree 2				Tree 3			
	Mean	Stdv	N	Max overall	Mean	Stdv	N	Max overall	Mean	Stdv	N	Max overall	Mean	Stdv	N	Max overall
First Attack Wk#	20.9	10.4	240		20.7	9.1	90		23.0	11.6	88		18.4	9.8	62	
Wks Until Attack	0.7	1.1	240		0.6	0.9	90		0.8	1.1	88		0.9	1.4	62	
Leaf Loss Wk#	42.2	10.0	168		42.8	9.3	59		42.8	10.1	56		40.9	10.6	53	
Wks ATK Until Leaf Loss	22.9	13.7	42	44	24.8	14.7	11	44	26.4	14.4	12	44	19.5	11.7	19	42
Leaf Until Loss	28.3	15.5	168	52	30.0	16.3	59	47	28.6	15.2	56	45	26.1	14.7	53	52
Max Orange Ovals If ATK	2.4	2.1		13	2.3	1.7		8	2.7	2.3		11	2.1	2.1		13
Wks Infested If ATK	20.6	14.2		44	22.4	13.9		41	20.1	14.0		43	18.8	14.8		44



**23.** Weekly change in FLRPs and mean weekly temperature. Two substantial increases in the FLRP population occurred on March 24 and June 16.

The sum total of pits, either empty or with an orange oval, steadily increased, from June 16 through October 6 at a rate of about eight per week (4% of the population) and then remained approximately level from October 6 through the end of the study (**Fig. 24**). However, after October 6, the number of empty pits increased, which implies that some orange ovals died and dropped out of their pits. The notion that the orange ovals might have metamorphosed into a later, mobile instar stage and departed the pit seems unlikely because during weekly examinations of the leaves and pits during one year we never once saw this phenomenon occur; we suspect that the metamorphosis into a later, mobile instar only occurs within the protective confines of the rolled leaf where it is largely unobservable. In a corresponding manner, after October 6 the number of orange ovals began to decline steadily at a rate of about 10 per week (10% of the population). Leaf production continued to occur after October 6 but no associated rise in pest population occurred. Perhaps, as alluded to earlier, another factor was present that suppressed the pest population.

Of the 802 leaves produced during the study, the orange ovals attacked 240 (29.9%) but only 40 (16.6% of attacked, 5% of total) of those attacked leaves were dropped. Of the 802 total leaves, 562 (70.1%) were not attacked and 126 (22.2% of not attacked, 16% of total) were dropped (**Fig. 25**). The percentage of non-attacked leaves that was dropped was greater than the percentage



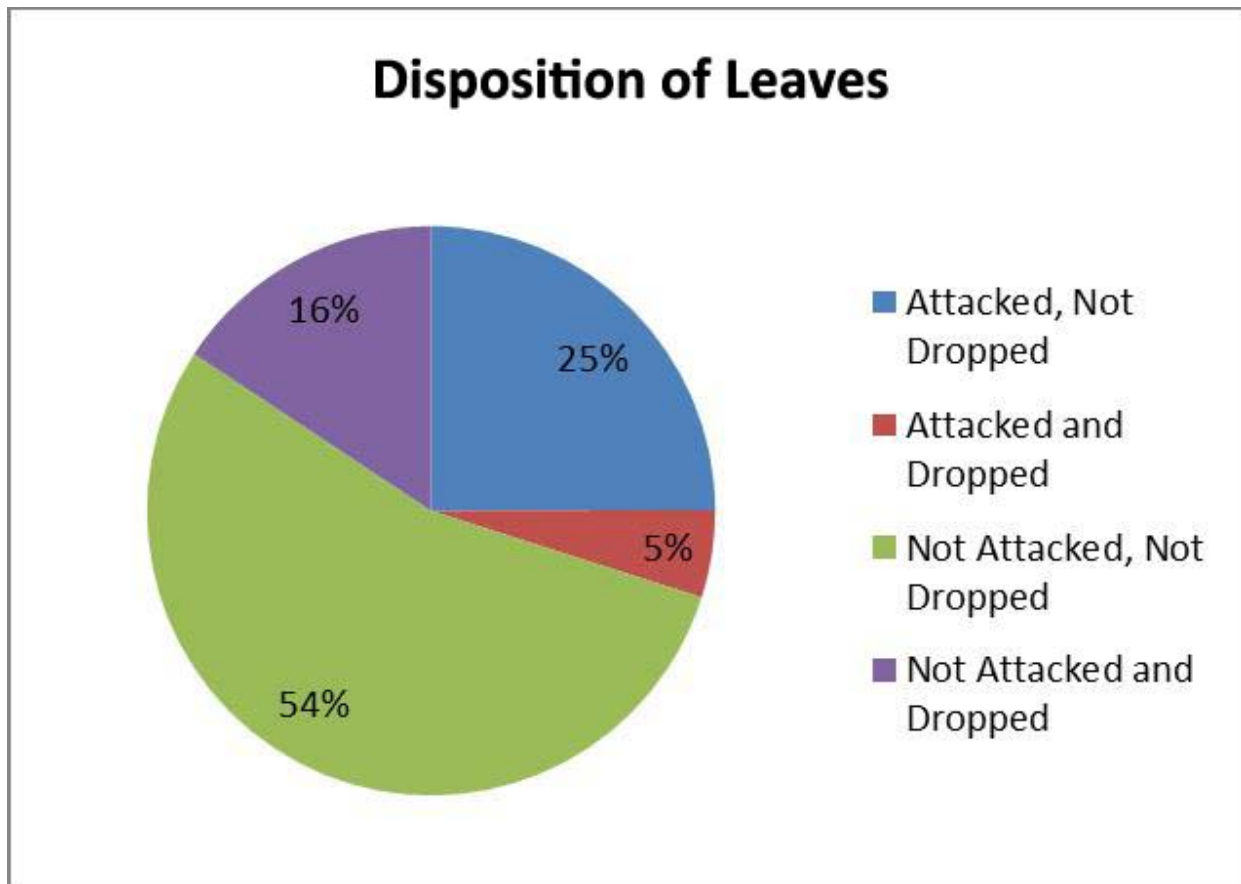
**24.** Weekly population of FLRP orange ovals in pits, empty pits, and total attack sites (the sum of the two). Data begins on June 16, 2018, week 23 of the study.

of attacked leaves that was dropped, indicating the psyllids did not cause an increase in the rate of leaf senescence or leaf drop. If the psyllids had increased the rate of leaf senescence, the trend would have been reversed.

For all three trees, week 20 (or about June 15) was the mean time that a leaf was first observed with orange ovals in pits. The mean quantity of weeks from leaf emergence until orange ovals were observed was 0.7 week or about five days. Week 42.2 (or about November 15) was the mean time when a leaf was lost (dropped). The mean quantity of weeks from when orange ovals were first observed until the leaf was lost was 22.9 weeks. Of leaves that were attacked, the mean quantity of orange ovals per leaf was 2.4. Of attacked leaves, the mean quantity of weeks the leaves remained with living orange ovals was 20.6 (**Table 9**).

One major question that this research failed to answer adequately is the whereabouts of some of the FLRP instars, especially the third instar, the one between the orange oval (second instar) and the slipper (fourth or fifth instars). Metamorphosis from the sedentary second instar to the third and mobile fourth instars likely occurs within the leaf roll, which offers a better environment





**25.** Disposition of 802 counted leaves in each of the four permutations, attacked or not and dropped or not, on the three *Ficus microcarpa* trees in Carson, CA, January 2017 to January 2018.

and protection from predators and the elements but is unobservable unless the leaf is forcibly unfurled.

In summary, a possible life-stage scenario for the FLRP might be as follows:

1. Adult female deposits eggs on the abaxial or perhaps adaxial leaf blade surface of soft, pliable, newly emerging leaves.

2. Eggs hatch into first instar, which we have likely observed as tiny, clear- to white-colored crawlers (**Figs. 20–22**).

3. These migrate to the abaxial leaf blade surface, become sedentary in a shallow pit, and morph into the orange oval or second instar (**Figs. 11–12**). Early feeding likely releases a chemical compound that causes the plant to develop the protective pit and begin the leaf-rolling process. If the pit is too close to the leaf blade midrib, the curling leaf will not enclose it; only pits closer

to the leaf margin will be enclosed in the leaf roll. Orange ovals not enclosed in the roll do not metamorphosize but can live for several months before eventually dying.

4. Once enclosed in the leaf roll, the orange oval morphs into the third instar, which is likely mobile, and completes its morphogenesis into the mobile fourth and fifth instars (slippers) within the protective confines of the leaf role although they sometimes can be observed on the outside perimeter of the roll (**Figs. 8–10**).

5. Adults likely emerge from the fifth instar just outside the role where their emergence is unencumbered by the tight confines of the role although they might still be hidden or protected under a leaf (**Figs. 3–7**).

## Management

Unfortunately, little is known about the management of the FLRP; however, damage appears not to be serious and is primarily only a nuisance esthetic issue, and then only when viewed closely. Thus, pesticide-based treatments are mostly unjustified and unwarranted. The spectrum of natural enemies of FLRP has not been studied although we have found lacewings, lady beetles, and pirate bugs among the leaves, and perhaps these are responsible for the decline of pest activity in the latter half of the study and the overall general decline of this pest that we have anecdotally observed over four years. Management strategies include vigilant scouting, followed by judicious and immediate removal, bagging, and disposal of shoot tips with infested leaves, which could be combined with ground and foliar treatment with systemic pesticides, but only for rare, exceptional, noteworthy, and valuable tree specimens.

If a treatment program using non-systemic materials is implemented, timing of applications to coincide and protect newly emerging leaves would be critical. Because leaves are attacked within five to six days of emergence, leaf emergence is random, and we were unable to determine predictors of leaf emergence, landscape managers must judiciously monitor potential host trees for the first signs of leaf emergence and act swiftly. Long-term systemic materials largely avoid the timing issue but they should still be applied in anticipation of the time of year when growth flushes are expected, in our case from late February to early November. However, carefully weigh the damage that pesticides can do to the environment, including to beneficials and other non-target and desirable wildlife, against the perceived outcome of their use.

Frequent, periodic pruning, as is done for hedges and topiary, might be effective by constantly removing infested leaves. Such regularly pruned specimens frequently have been observed with less damage from other pests like the Ficus gall wasp and Indian laurel thrips. However, pruning could stimulate new growth that is susceptible to attack. Similarly, excessive fertilizer and water could also stimulate new growth that could invite attacks.

Unfortunately, the cultivar *Ficus microcarpa* ‘Green Gem’, which appears more resistant to some pests, does not appear to be resistant to the FLRP.

## Conclusions

When viewed closely, the FLRP causes unsightly, distorted, rolled leaves on its host tree, *Ficus microcarpa*. The FLRP exclusively attacks the newest developing leaves, typically within five to eight days of emergence, because they are softer, more pliable, and roll more readily. Host trees produced random flushes of new leaves from late February to early November but we were unable to determine predictors of these flushes. In our study of three trees, annual mean shoot growth ranged from 16 to 59 cm while annual mean leaf production per shoot ranged from 20 to 31, and 28 to 30% (just under one-third) of all leaves produced were attacked. The FLRP had two periods of rapid population growth: one in March and one in June. FLRP population growth coincided with spring leaf growth flushes but the population leveled off and declined in the summer and fall, irrespective of temperature and late-season leaf growth. No correlation existed between a suite of nearly a dozen weather factors and four major host/FLRP interactions. Host leaf drop was highly concentrated in late fall but was not correlated with FLRP activity.

Because the FLRP is a relatively new arrival, we know little about its long-term impact on tree health. However, after more than four years since its arrival, attacked *Ficus microcarpa* trees, some severely so, continue to thrive and provide the expected landscape amenities, which is partly a testament to the host trees’ tough nature, especially when considering the suite of other pests the trees likely have in addition to the FLRP. At least at this point, fortunately, the damage inflicted by the FLRP seems to be more of a nuisance esthetic issue, which is really only apparent when viewed closely, and does not pose a serious threat to the health of host trees when populations are at the level observed in this study.

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