A Preliminary Investigation of the New and Serious Malady of *Schinus molle* Canopy Thinning

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Although in California it goes by the common name California pepper tree, *Schinus molle* is not a native of our State. Nonetheless, this common name suggests the prominent, iconic role this tree has played in its namesake state's culture, history, and landscape horticulture. Much revered but sometimes reviled, *S. molle* is one of the more common landscape trees in the coastal plains and valleys of southern and central California, from San Diego to the Bay Area. It has been widely planted along public highways in rural and urban areas and is a common park, street, and home landscape tree (**Figs. 1–3**). Native to dry areas of South America and Mexico, *S. molle* is considered a Mediterranean-climate plant and well adapted to California's similar climate of cool, moist winters and warm to hot, rainless summers. Indeed, it is now promoted as an acceptable species for drought-tolerant plant palettes in ever-drying California.

Thus, considering the importance of this tree in the California landscape, it is disconcerting that the new and serious malady of *Schinus molle* canopy thinning has appeared in the last several years. Here, we discuss the host tree and provide the history and suspected causes, symptoms, and potential management strategies for canopy thinning.

Schinus molle

A typically much prized tree in California, *Schinus molle* is valued for is handsome weeping habit (**Figs. 4–5**) and tolerance of a wide array of adverse conditions, including heat, moderate cold (hardy to -12 C), drought, poor soil, smog, wind, and other adverse conditions that make it well adapted to California's ever-drying and increasingly arid climate (Baldwin 2024, Iponga et al. 2008, UFEI 2024). With older specimens especially, the stout, rough, gnarly trunks, often with numerous, rounded protuberances, and typically broad, canopies with gracefully pendulous branches and foliage, make this tree immediately recognizable (**Figs. 6–7**).

Carl Linnaeus (1707–1778), Swedish biologist and physician who formalized binomial nomenclature, the modern system for naming organisms (Britannica 2024, Calisher 2007), named

1. *Schinus molle* has been widely planted in urban areas in California, as here in San Diego. Not the handsome, weeping habit of this old specimen.

2. Schinus *molle* is frequently used as a home landscape tree, Lakewood, California.

3. Here *Schinus molle* is used in a common area of a homeowners' association, Seal Beach, California.

4. At El Dorado Park, Long Beach, California, *Schinus molle* is valued for its handsome weeping habit among several other attributes.

5. Also at El Dorado Park, Long Beach, California, *Schinus molle* makes an impressive group planting of trees with weeping habit.

6. Marianne Hodel complements an especially venerable, old specimen of *Schinus molle*, Balboa Park, San Diego, California with weeping habit and a stout, gnarly trunk.

7. The trunk of the *Schinus molle* in Figure 6 is stout, rough, and gnarly and has numerous, rounded protuberances, with Marianne Hodel.

8. Father Antonio Peyri planted this first specimen of *Schinus molle* in California in the early 1830s at the Mission San Luis Rey de Francia in Oceanside, where it still exists today, with Marianne Hodel.

9. The trunk of the *Schinus molle* in Figure 8 is exceedingly large, with rounded protuberances and several hollow portions, and its branches have artificial support.

and described *Schinus molle* in 1753 in his epic, two-volume *Species Plantarum*, a listing of all plants known at the time (Britannica 2024). He based this species on others' earlier, illustrated accounts.

Father Antonio Peyri first planted *Schinus molle* in California in the early 1830s at the Mission San Luis Rey de Francia in Oceanside, where the original tree still exists (**Figs. 8–9**). Well adapted to California and providing much-needed shade with little or no care, it quickly gained wide popularity and was planted abundantly in the middle and late 19th century, where it became closely associated with the Spanish missions and known as the California pepper tree (Masters 2013). Briefly in the early 20th century it fell out of favor because it was an alternate host of black scale, a serious threat to citrus crops (Masters 2013); however, as citrus production shifted to the San Joaquin Valley, black scale became less of a problem there, occurring only on grapefruit and then only near olive trees (Grafton-Cardwell 2017).

Schinus molle has numerous common names, including Peruvian pepper, Peruvian peppertree, American pepper, California peppertree, California pepper tree, false pepper, rosé pepper, *molle de Peru*, pepper tree, peppercorn tree, *pirul*, Peruvian mastic, Peruvian mastic tree, *anacahuita*, *aguaribag*, *escobilla*, pepperina (Baldwin 2024, Hanrow 2024, PP USDA 2024, UACM, QPIC 2024).

The botanical genus name *Schinus* is from the Greek word for the related mastic tree, *shinos*, while the specific epithet is derived from *mulli*, the Quechua word for tree (AMLQ 2005), or the Latin word *molle*, meaning soft (Ritter 2011), the latter likely alluding to the pendulous, relatively fine-textured foliage.

Our description of *Schinus molle* is taken from Baldwin (2024), Barkley (1944), Blood (2001), Goldstein and Coleman (2004), Macbride (1951), Miller and Wilken (2012), TSO (2024), and our observations of living plants.

The species is a fast-growing, polygamodioecious (staminate and pistillate flowers are on separate plants but each plant also has bisexual flowers), aromatic, large, multibranched shrub to more typically medium to large evergreen tree, eventually to about 20 m tall and wide. Branch ends tend to droop, lending a weeping or pendulous appearance to the tree (**Figs. 1–6, 8**). Root suckering or sprouting is common.

Trunks of *Schinus molle* are often short and stout, mostly solitary, sometimes multi-trunked or with two or more main branches rising near or at ground level, typically less than 1 m in diameter at standard height. Old trees can have much larger trunks, to 2 m in diameter or even larger. In many of these situations, interior portions of these trunks become hollow. Bark is rough, fissured, scaly, and gray to tan or grayish brown (**Fig. 10**). Older trees sometimes develop burl-like protuberances, the cause of which is not well documented (**Figs. 7, 9, 11**).

10. Bark of *Schinus molle* is rough, fissured, scaly, and gray to tan or grayish brown, Seal Beach, California.

11. Trunks of old specimens of *Schinus molle* frequently develop burl-like protuberances, as on this specimen at the Los Angeles County Arboretum and Botanic Garden, Arcadia, with Marianne Hodel.

12. Leaves of *Schinus molle* are pinnately compound and drooping.

13. Pinnae margins of *Schinus molle* are entire to coarsely toothed.

14. Inflorescences of *Schinus molle* are a lateral panicle or terminal thyrse, and shorter to but typically longer than the leaf.

15. Flowers of *Schinus molle* are small, white to cream-colored, fragrant, and mostly in the spring and summer.

16. Clusters of mature fruits of *Schinus molle* are quite showy.

17. The small, spherical, red, pink, or purplish fruits of *Schinus molle* are a drupe, and mostly appear in the fall or winter but can persist year-round.

Leaves are pinnately compound, 8–30 × 4–9 cm, mostly drooping or pendulous, imparipinnate, and bright green (**Fig. 12**). Petioles are 2–3 cm long while the rachis is slightly winged. Pinnae number 19–41 and are 0.8–6 × 0.4–0.8 cm, lanceolate to linear-lanceolate, sessile, and with an acute, slightly curved apex. Margins are entire to coarsely toothed (**Fig. 13**).

Inflorescences of *Schinus molle* are a lateral panicle or terminal thyrse, 8–40 cm long, and shorter to but typically longer than leaf (**Fig. 14**).

Flowers are small, 3–4 mm diam., white to cream-colored, fragrant, and mostly in the spring and summer (**Fig. 15**).

Fruits of *Schinus molle* are in showy clusters, a drupe, 5–7 mm in diameter, spherical, red, pink, or purplish when mature, with a shiny, brittle epicarp, and held on a short pedicel 2–5 mm long (**Figs. 16–17**). Fruits are mostly present in fall and winter but can be found year-round.

Bark, leaves, and fruits are aromatic (Blood 2001) while branches and twigs can secrete a white or clear sap when cut (TSO 2024).

As broadly interpreted, *Schinus molle* is widespread in arid zones of South America, including Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Paraguay, Peru, Uruguay, and Venezuela, and Mexico (TSO 2024), to 3,650 m elevation (Baldwin 2024) although in California it occurs only up to 700 m elevation (Miller and Wilken 2012). Its natural range is difficult to discern, though, because it has become so widely planted and has escaped cultivation to become naturalized and invasive (TSO 2024). Also, the extent of its distribution depends on whether one accepts its variety, *S. molle* var. *areira*, which occurs from Mexico to Chile, as a separate species. If so, then as more narrowly interpreted, *S. molle* is restricted mostly to south central South America (TSO 2024), from Peru and Chile's intermountain Andean deserts to central Argentina (Baldwin 2024, Blood 2001).

Schinus molle occurs in mixed savannas and scrub, typically near water courses but not always (TSO 2024). It is common to see escaped specimens on dry hillsides in California where they rely only on the unreliable rain for sustenance and survival.

Because *Schinus molle* is tolerant of a wide array of adverse conditions and grows with little or no care, it has become widely naturalized around the world and a serious, invasive weed, especially in South Africa (Iponga et al. 2008) and Australia (Blood 2001). It is listed as mildly invasive in Californian because its impacts are minor at the state-wide level and/or information is insufficient to justify a higher or more severe score (Cal-IPC 2024).

Schinus molle has a reputation for damaging hardscape with roots and root suckers, and also interfering with buried utility lines and water and sewer pipes (Master 2013, Masters and Farmer

2014). It is said that this species litters the ground under the tree's canopy with an excessive quantity of leaves, fruits, and twigs (Hoang 2019, UFEI 2024). Indeed, when walking under a tree with such an accumulation of litter, especially leaves, one can hear the unforgettable, distinctive, tell-tale sound of crunching dried leaves and smell the characteristic aromatic foliage. It is also stated that oils in the leaves make it difficult to grow other plants under *S.* molle, but this statement is untrue. Plants will grow under *S. molle,* and it is more likely simply the depth of the leaf litter, shade, and lack of water that tend to inhibit plant growth.

Where it grows, *Schinus molle* is recognized for its hard, durable wood much prized for saddlery and fruits for spice production. Its fruits are often sold as "pink peppercorns" although *S. molle* is not closely related to black pepper. Still, its fruits are used in the culinary arts and typically blended with commercial black peppers (UFEI 2024). Once thought to be mildly to highly toxic (Taylor 2005), its fruits are now considered not toxic but can be mildly irritating, especially to children (Hoang 2019). Parts of the tree are used as antiseptic/antibacterial agents in traditional medicines and as a textile dye (UFEI 224).

Schinus molle has been mostly pest- and disease-free in California although pests, such as psyllids, aphids, thrips, and scales, and diseases, including Armillaria, Phytophthora, and Texas root rot have been documented (UFEI 2024). Until the advent of canopy thinning, the most damaging malady of *S. molle* here was the pepper tree psyllid (*Calophya schini*), which appeared in July 1984 in Long Beach, and caused extensive and severe damage on trees, including distorted new growth and especially unsightly, deep prominent leaf pitting (Downer et al. 1988). Fortunately, an introduced parasitic wasp (*Tamarixia schina*) has largely controlled this pest (Kabashima et al. 2014).

In California, *Schinus molle* is primarily an ornamental tree for roads and highways, parks and other public areas, urban streets, and home landscapes. Extremely well adapted to California's climate and tolerant of a wide array of adverse conditions, this prominent, iconic tree is steeped the State's culture, history, and landscape horticulture; thus, canopy thinning is a disconcerting development.

History of *Schinus molle* Canopy Thinning

Co-author Hodel noticed this malady in early 2020 during one of his early morning walks around his Seal Beach neighborhood in Orange County. What caught Hodel's attention were the canopy thinning and stunted, deformed, "bunchy" new growth on several but not all trees of *Schinus molle* (**Figs. 18–20**). The malady was localized, and Hodel did not observe it in other areas. Nonetheless, Hodel was reminded of this malady every time he took his early-morning walk.

18. The canopy thinning and stunted, deformed, "bunchy" new growth of this *Schinus molle*, Seal Beach, California, were what caught Hodel's attention; here it is in October 2020.

19. Co-author Paul Santos checks the roots on the *Schinus molle* specimen in Figure 18 six months later in April 2021. Note the further decline.

20. The same *Schinus molle* specimen in Figures 18 and 19 but in December 2022 and now much defoliated. It would die and be removed in 2023.

21. A potentially big break in our study of *Schinus molle* canopy thinning came in October, 2023 when co-author Santos found small, green leafhoppers on these much affected parkway trees, Tustin, California.

About six months later, Hodel shared his concern with co-author Santos, who had also noticed this malady but earlier in 2019. Together and independently, we collected leaf and twig material and soil from root zones of symptomatic trees, compiled horticultural histories, and screened the material for pests (insects and mites), culturable diseases (powdery mildew and other foliar diseases, collar and root rots, cankerous lesions), and abiotic disorders. We observed no internal staining or necrosis, and symptoms were inconsistent with root rots. We detected no pathogens after plating out symptomatic material. Despite this work, a definitive answer to the cause of this malady was elusive.

In middle 2023, we sent affected material of *Schinus molle* to the Plant Diagnostic Center at the California Department of Food and Agriculture (CDFA) where two bacterial pathogens, *Pantoa agglomerans* (C-rated) and *Erwinia billingiae* (Z-rated), were detected on affected samples. These were detected in culture and confirmed by PCR and DNA sequencing. Both have been reported as somewhat weak pathogens on certain plant hosts but neither has been reported to infect *Schinus molle*. We doubt these are the cause of this malady, but, nonetheless, pathogenicity tests should be conducted to determine susceptibility of *S. molle*.

A potentially big break came in October 2023 when Santos collected small, green leafhoppers from much affected, symptomatic *Schinus molle* in Tustin, in Orange County, California (**Fig. 21**). He tipped Hodel off and immediately Hodel and co-author Ohara found the same leaf hopper on symptomatic trees in Long Beach, Lakewood, and Azusa, all in Los Angeles County and at the same site in Orange County where Santos had first found them. These leafhoppers have now been collected from symptomatic *S. molle* in adjacent Riverside and San Bernardino counties.

In November and December 2023, we sent leafhoppers and symptomatic leaves and twigs collected from the affected *Schinus molle* in Long Beach to entomologist Alessandra Rung and plant pathologist Cheryl Blomquist at CDFA. Rung performed molecular work on the leafhopper to determine its identity while Blomquist performed molecular work on the plant samples and leafhopper to check for phytoplasmas that the leafhoppers might be vectoring. Also, at Rung's suggestion, we sent leafhoppers to co-author Christopher Dietrich at the University of Illinois for identification based on morphological characters.

Dietrich found two leafhoppers in the samples we sent him, which he tentatively identified as *Empoasca sativae*, the smaller but more common of the two and comprising most of the leafhoppers in the sample, and *Kybos carsosna*, the larger but less common of the two and closely related to and formerly included in *Empoasca*. Dietrich suspected that *E. sativae* was likely the primary suspect because of its polyphagous nature, much higher numbers in the sample, and that it appeared to be feeding on petioles and leaf rachises in photographs that Hodel shared with him. On the other hand, *K. carsosna* is known nearly exclusively to occur on plants in the

22. The primary suspect in *Schinus molle* canopy thinning is a small, green leafhopper tentatively identified as *Empoasca sativae*, here in Long Beach, California.

23. Two *Empoasca sativae* are perched on this young, fresh, green twig of *Schinus molle*, Long Beach, California. Note the dark, minute, pint-point spots, likely wounds where the leafhoppers' stylets were inserted to feed.

24. An *Empoasca sativae* has its stylet inserted into a fresh, green leaf rachis on *Schinus molle*, Lang Beach, California.

25. A feeding *Empoasca sativae* likely has its stylet inserted into the pinnae midrib on *Schinus molle*, Long Beach, California.

genera *Populus* (cottonwood) and *Salix* (willow). Dietrich suspected that the *Kybos* leafhoppers had shifted to *Schinus molle* as its primary hosts became deciduous and, if we had made our collections earlier in the year during the summer, we would have likely collected only *E. sativae*, not *K. carsosna*.

Rung's molecular analyses were inconclusive and did not match any known leafhopper in the genetic databases. This troubling and frustrating result could simply be because sequence data matching our leafhoppers had yet to be entered in the databases and/or unknowingly the leafhopper samples actually comprised the two species, *Empoasca sativae* and *Kybos carsosna*. Blomquist found no phytoplasmas in the affected *Schinus molle* samples.

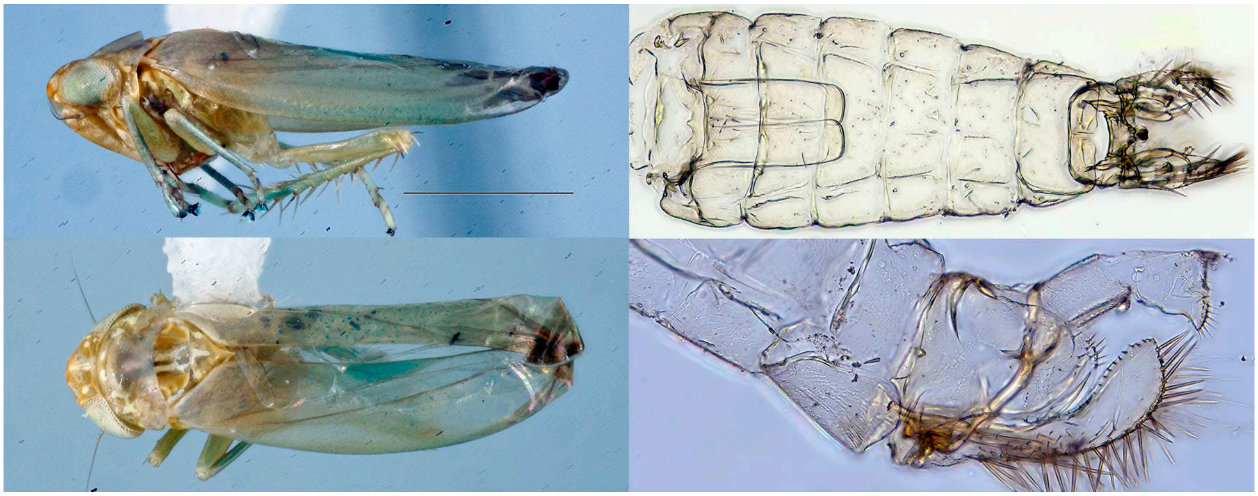
Thus, considering that we found no culturable pathogens, abiotic disorders, other insect or mite pests, and that the leafhopper *Empoasca sativae* was always associated with symptomatic trees, we conclude that it is the primary suspect in *Schinus molle* canopy thinning.

Empoasca sativae

Frederick W. Poos, an entomologist for the United States Department of Agriculture, named and described *Empoasca sativae* in 1933, basing it strictly on a large series of male leafhoppers that he had collected on alfalfa at Leavenworth, Kansas in August 1930. Other important taxonomic accounts of this leafhopper include DeLong and Knull (1946), who placed it in subgenus *Empoasca*, which comprised the American species, and Xu et al. (2021), who moved *E. sativae*, along with other species, to the genus *Hebata*, making *Hebata sativae*. Nonetheless, the male subgenital plate of *E. sativae* has a basolateral extension which, in addition to the preapically excavated pygofer appendage, supports retaining it in *Empoasca sensu stricto*. Additional, mostly general information about *E. sativae* can be found in BugGuide (2024), Dmitriev et al. (2022), GBIF (2024), and Oman (1949). Strangely, iNaturalist (2024) has no observations yet posted for *E. sativae*.

The following description of *Empoasca sativae* is mostly from Poos (1933), who primarily was providing information to distinguish the species from *E. fabae* and *E. abrupta*, and supplemented from Fegley (1989) and our field observations.

Males are about 3 mm long, slender, and green with variable markings (**Figs. 22–26**). The vertex, that area of the head between the two eyes, frequently has a pale or dark spot near the anterior margin on each side of the median line. The pronotum, that section of the thorax between the wing bases just anterior to the sections that bear the legs and wings, typically has 4–6 pale spots along the anterior margins. The scutellum, the large, triangular, shield-like spot on the back of some insects, including Hemiptera, has a white line on each side of the median line to the apical



26. *Empoasca sativae* Poos, from material collected in Long Beach, California. Adult male: lateral view (top left, scale bar = 1 mm); dorsal view (bottom left); abdomen, ventral view (top right); distal part of abdomen, lateral view (bottom right). © 2024 C. H. Dietrich.

half, which has three white spots forming an irregular transverse band just back of the middle. The elytra or forewings are greenish yellow and sub-hyaline.

Male genitalia are critical for identifying leafhoppers, especially *Empoasca* because many species of this genus and related Empoascini are apparently identical in external appearance. The main features distinguishing *E. sativae* from the common and widespread *E. fabae* (the potato leafhopper) are the relatively long, parallel-sided apodemes, the inward, ridge-like growth of the exoskeleton, at the base of the male abdomen (see **Fig. 26**, especially abdomen in ventral view), which are only visible after clearing the male abdomen in a KOH solution.

Empoasca once included over 600 species (Ross et al. 1964). However, as recently redefined by Xu et al. (2021), it now includes only about 40 species restricted to the New World, but several related genera of tribe Empoascini include several hundred additional species distributed worldwide, many of which closely resemble *Empoasca* in external appearance.

Ross et al. (1964) theorized that *Empoasca sativae* evolved primarily as a tropical species that extended its range into temperate regions by a two-step process. First, some northern peripheral populations of *E. sativae* were able to survive lower temperatures and extended their range in subtropical regions like the U. S. Gulf Coast from Texas to Florida. Then some of these subtropical populations acquired tolerance of even colder temperatures and moved into temperate regions, at least for the spring, summer, and fall. Because *E. sativae* is not cold hardy, the cold temperate winters destroyed these temperate populations but the northern edge of the overwintering

27. The first symptom of *Schinus molle* canopy thinning might be pinnae drop on newer leaves on the canopy periphery, Long Beach, California.

28. An early symptom of *Schinus molle* canopy thinning might be pinnae necrosis, Long Beach, California. The dark spots on the leaf rachis might be feeding sites while the white spots on pinnae could be dried sap secretions from feeding sites.

29. One early symptom of *Schinus molle* canopy thinning might be twig dieback, Long Beach, California.

30. Extensive dieback on the canopy periphery seems to be typical of *Schinus molle* canopy thinning, Long Beach, California.

31. Extensive dieback and pinnae drop might be symptoms of *Schinus molle* canopy thinning, which lead to bare twigs and leaf rachises, Long Beach, California.

32. As *Schinus molle* canopy thinning progresses, the canopy periphery has a distinctive appearance, seeming to be composed of erect or spreading, naked twigs, Seal Beach, California.

population along the Gulf Coast survived to generate new populations that moved into temperate regions the next spring.

We can see this seasonality in *Empoasca sativae* attacking *Schinus molle* in southern California. Populations were abundant and it was easy to collect 100s of leafhoppers in a few minutes in October and November but after December cold spells with night temperatures of 2 to 7 C, numbers plummeted, and it took 30 minutes to collect 10 leafhoppers. Because we find some *E. sativae* here throughout the winter, we suspect that southern California, like the Gulf Coast, has the northern periphery of the overwintering population.

Symptoms of *Schinus molle* Canopy Thinning

A suite of symptoms characterizes canopy thinning on *Schinus molle*, some conspicuous and spectacular and others more discrete and subtle. Symptoms vary depending on the stage of development of this malady. The first symptom might be general yellowing of distal pinnae accompanied by some pinna necrosis and drop on newer leaves on the canopy periphery, especially at the top (**Fig. 27–28**), although these symptoms could easily go unnoticed because of their somewhat subtle nature and distance from the viewer.

The more easily recognizable symptom is probably more severe thinning on the canopy periphery, again especially at the top. Extensive dieback and pinna drop leave bare leaf rachises, which from a distance appear as erect or spreading, naked twigs (**Figs. 29–32**). New growth that does appear is typically malformed, misshapen, or distorted and often epinastic in nature, with twisted twigs and leaves (**Fig. 33**).

As the malady progresses, canopy thinning, twig dieback, and pinna drop and necrosis become more severe (**Fig. 34**), and twig growth is stunted, malformed, epinastic, and "bunchy" (**Figs. 35–40**), somewhat like witch's broom, with numerous, short, deformed twigs arising close together, eventually from a swollen, nearly tubercular, sometimes "corky" growth (**Figs. 41–45**). Bark sometimes peels away at this stage (**Fig. 46**) and the "bunchy" growth can occur at several places along a branch (**Fig. 47**). The canopy at this latter stage typically is severely thinned out (**Fig. 48**).

Even at this advanced stage, most symptoms are still at the top and upper part of the canopy **(Fig. 49**). Eventually, symptoms move lower in the canopy and, by the time they reach the lower part, the tree is much defoliated (**Fig. 50**).

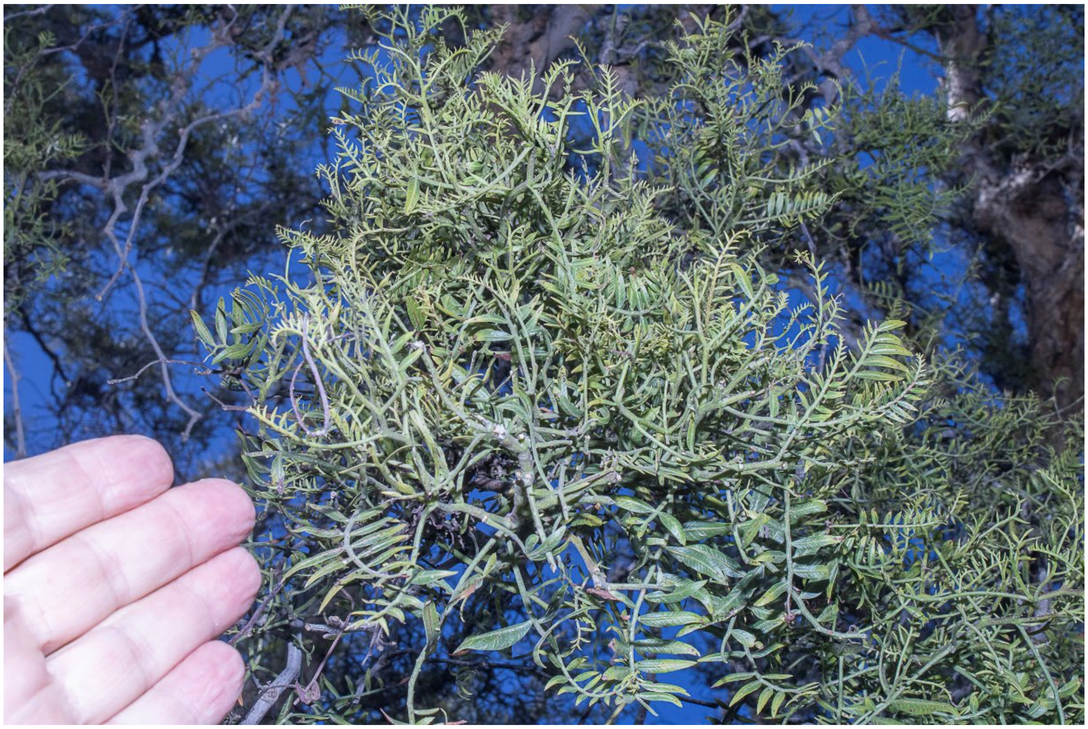
Eventually, the tree is nearly completely defoliated and near death (**Fig. 51**). We have observed at least one tree that died (**Figs. 18–20**) although other factors might have been involved in its death. Because so much leaf area is lost with this malady, photosynthesis is much reduced, which by itself can lead to stress, decline, and serious secondary problems.

33. New growth that does appear during *Schinus molle* canopy thinning is typically deformed or distorted and often epinastic, with twisted twigs and leaves, Long Beach, California.

34. As *Schinus molle* canopy thinning progresses, canopy thinning, twig dieback, and pinna drop and necrosis become more severe, Lakewood, California.

35. One of the most spectacular and characteristic symptoms of more advanced *Schinus molle* canopy thinning is stunted, malformed, epinastic, and “bunchy” or congested shoot growth, Tustin, California.

36. This “bunchy” new growth is characteristic of *Schinus molle* canopy thinning, Tustin, California.



37. “Bunchy” new growth of *Schinus molle* canopy thinning can be spectacular, Seal Beach, California.

38. This deformed, “bunchy” new growth is characteristic of *Schinus molle* canopy thinning, Seal Beach, California.

39. Severely congested, "bunchy" new growth characterizes *Schinus molle* canopy thinning, Lakewood, California.

40. Here is comparison of normal foliage (left) and symptomatic "bunchy" growth of *Schinus molle* canopy thinning (right), Seal Beach, California.

41. In older, more advanced stages of *Schinus molle* canopy thinning, the "bunchy" growth eventually arises from a swollen, nearly tubercular growth, Seal Beach, California.

42. In *Schinus molle* canopy thinning, the "bunchy" growth eventually arises from a swollen, nearly tubercular growth, Seal Beach, California.

43. In older, more advanced stages of *Schinus molle* canopy thinning, the "bunchy" growth eventually arises from a swollen, nearly tubercular growth, Seal Beach, California.

44. The swollen, tubercular growth from which the "bunchy" shoots arise in *Schinus molle* canopy thinning sometimes have a "corky" appearance, Seal Beach, California.

45. The “bunchy” growth of *Schinus molle* canopy thinning eventually arises from a swollen, nearly tubercular growth, Seal Beach, California.

46. Bark sometimes peels away at this later stage of *Schinus molle* canopy thinning, Seal beach, California.

47. In these later stages of *Schinus molle* canopy thinning, the “bunchy” growth can occur at several places along a branch, Seal Beach, California.

48. In these later stages of this *Schinus molle* malady, the canopy is severely thinned out, Seal Beach, California.

49. Even at this advanced stage of *Schinus molle* canopy thinning, most symptoms are still at the top and upper part of the canopy, Long Beach, California.

50. Eventually, symptoms of *Schinus molle* canopy thinning move lower, but at this stage the lower part of the canopy is much defoliated, Long Beach, California.

51. Eventually, *Schinus molle* trees with canopy thinning become nearly completely defoliated and near death or die, Seal Beach, California.

Symptoms can progress slow to moderately, from a healthy, symptom-free tree to showing severe symptoms over the upper two-thirds to three-fourths of its canopy within two to three years (**Figs. 52–55**) or were in the initial stages of canopy thinning but symptoms became much more severe in a similar or shorter time period (**Figs. 56–57**). Sometimes symptoms are first mostly confined to a major branch in the canopy, with the remaining part of the canopy appearing symptom free (**Fig. 58**); eventually, though, the entire canopy becomes affected.

We also observed minute, pin-point size, dark spots on young twigs (**Fig. 23**), leaf rachises, and pinna midribs and primary nerves (**Figs. 23, 27, 59–60**), which we interpret as feeding sites where the leaf hopper inserted its stylet. Some of these spots tend to enlarge, forming more conspicuous necrotic areas often accompanied by a white substance, the latter likely dried sap from the leafhopper feeding wound (**Fig. 61**).

Management of *Schinus molle* Canopy Thinning

Because we do not yet know the precise cause of canopy thinning, it is difficult to devise a management strategy. Nonetheless, providing optimal cultivation is the foundation for any management strategy, no matter the cause.

Remember that *Schinus molle* is well adapted to summer drought and needs little or no water once established. Avoid planting in clay soils in lawns and other summer-irrigated landscapes, which can promote root diseases and disorders leading to decline and death. Plant in the full sun and preferably on well drained soils, or, if planting in heavy clays, irrigate appropriately. Keep summer-irrigated landscape at least three to four meters from the trunk; maintain five cm of good quality mulch within this area. Train and prune young plants for optimal structure, using appropriate pruning techniques.

If proven that leafhoppers and/or disease are responsible for canopy thinning, employ optimal cultivation practices described above and, in consultation with a licensed, qualified pest control adviser/operator, consider appropriate pesticide applications, if necessary.

Some people have already treated symptomatic *Schinus molle* with systemic insecticides, such as dinotefuran, flonicamid, and flupyradifuron, and observed a positive growth response and improved tree health. They also implemented some of the optimal cultivation practices discussed above and applied bioactive kelp.

Summary

While the leafhopper associated with *Schinus molle* canopy thinning has been identified as *Empoasca sativae*, its role in this malady needs confirmation.

52. This *Schinus molle* was symptomless in 2021, Lakewood, California.

53. The same *Schinus molle* in Figure 52 two years later in 2023 had severe canopy thinning, Lakewood, California.

54. This *Schinus molle* was symptomless in 2017, Seal Beach, California.

55. The same *Schinus molle* in Figure 54 three years later in 2020 had severe canopy thinning, Seal Beach, California.

56. This *Schinus molle* had canopy thinning in 2020, Seal Beach, California.

57. The same *Schinus molle* in Figure 56 two years later in 2022 had more severe canopy thinning, Seal Beach, California.

58. Sometimes symptoms of *Schinus molle* canopy thinning are first mostly confined to one major branch in the canopy (right), Seal Beach, California.

59. These small, brown to dark spots on leaf rachises and pinna midribs and primary nerves on this *Schinus molle* with canopy thinning are likely leafhopper feeding wounds.

60. Minute, pin-point size, dark spots on pinna midribs and primary nerves and darkened areas on the leaf rachis of this *Schinus molle* with canopy thinning are likely leafhopper feeding wounds.

61. These spots on *Schinus molle* with canopy thinning and illustrated in Figures 59 and 60 tend to enlarge, forming more conspicuous necrotic areas often accompanied by a white substance; some of the latter are likely dried sap from the leafhopper feeding wound.

One aspect of this study that has always troubled us is why we did not detect the leafhopper for nearly four years, even while we were periodically examining symptomatic trees during that time span. Surely, the leafhopper is a small, green, highly mobile pest, which makes it elusive; however, we probably would have detected it if present, suggesting that its activity might be highly cyclical. We might have simply been examining symptomatic trees at the wrong time of year; perhaps if we had examined trees in late summer or fall when population numbers are high, we would have detected it sooner.

Because leafhoppers typically inject substances into the host plant as they feed, some of which can be phytotoxic, the symptoms might be solely the plants' response to these phytotoxic substances and are not due to a microscopic, non-culturable, vectored pathogen. However, leafhoppers are notorious for vectoring pathogens causing these types of diseases, and we feel that the damage is so distinctive and severe that a vectored pathogen cannot be dismissed.

Thus, more work is needed, such as additional leafhopper collections in the spring, summer, and fall, and new molecular analyses, to determine if the symptoms are simply a response to substances leafhoppers inject while feeding or to pathogens leafhoppers might be vectoring, such as viruses or viroids, or a combination of both. We have not ruled out even more complex causes, such as multiple factors like pathogens, pests, and/or abiotic disorders combining to cause this severe and worrisome malady. Indeed, anecdotal observations of *Schinus molle* in unkempt, non-irrigated situations seem to be less frequently and severely affected than specimens in maintained, irrigated landscapes.

In summary, while we strongly suspect that the leafhopper *Empoasca sativae* plays a major role in *Schinus molle* canopy thinning, more work needs to be done to confirm this supposition and identify any vectored pathogen.

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A Preliminary Investigation of the New and Serious Malady of *Schinus molle* Canopy Thinning. Part 2.

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In a preliminary paper in these pages, Hodel et al. (2024) discussed and illustrated the malady of *Schinus molle* canopy thinning and identified the leafhopper *Empoasca sativa* as a possible causal agent (although not identified so, that paper is Part 1 of this study). Now we are able to report several new findings associated with canopy thinning on *S. molle*: co-author Paul Santos, who first discovered the leafhopper on *S. molle*, recently found the mite *Brachytydeus formosus* (*Lorryia formosa*); we detected the typically pathogenic fungus *Botryosphaeria* sp. on new, young growth; and we estimated relative soil moisture and measured tree diameter at standard height and compared them to relative severity of canopy thinning, and found that wetter soils typically were associated with more severely affected trees. Here, we present and discuss these new findings and explore their possible effects on *S. molle* canopy thinning.

The Mite *Brachytydeus formosus*

Co-author Paul Santos discovered this microscopic mite in early March, 2024 on severely affected and symptomatic *Schinus molle* in the Talega neighborhood of San Clemente, California. He and co-author Hodel visited the site later in March, and Hodel was astonished to see how severe the canopy thinning was on trees in common public areas and along streets in the region. Many of the trees looked dead or nearly so with few or no green leaves in the canopy although bark scraping on twigs mostly revealed green tissue (**Figs. 1–2**).

Santos and Hodel made collections of the mites and sent them to the California Department of Food and Agriculture (CDFA) for identification via the entomology and plant pathology departments in the Los Angeles County Agriculture Commissioner office. Dr. Peter Kerr of the CDFA Plant Pest Diagnostic Center, identified the mite to the Tydeidae family but was unable to provide a more precise identification.

1. We collected mites from these severely affected, seemingly dead *Schinus molle* trees in the Talega neighborhood of San Clemente, California.

2. Here is another view of the severely affected *Schinus molle* trees in the Talega neighborhood in San Clemente, California from which we collected mites.

Co-author Gevork Arakelian suggested we contact the Tydeidae mite specialist Dr. Guilherme Liberato da Silva of the Universidade do Vale do Taquari – Univates, Lajeado, Brazil for identification. Dr. Guilherme Liberato said it is too difficult to send him mite specimens and suggested we photograph the mite, and with sufficient quality and detail, and he could provide identification from the images.

Co-author Chris Shogren approached Dr. Amy Murillo in the Entomology Department at the University of California, Riverside about photographing the mites for identification. She agreed and Hodel brought her mite samples from affected trees in Long Beach, California that co-author Ben Fisher had located.

Hodel forwarded Murillo's images to Dr. Guilherme Liberato in Brazil, who quickly identified the mite as *Brachytydeus formosus*, the yellow or citrus yellow mite. Our report might be the first record of this mite on *Schinus molle*.

History

Jean Cooreman (1911–1983), a Belgian acarologist, first named and described *Brachytydeus formosus* as *Lorryia formosa* (Cooreman 1958), basing it on material that M. W. Smirnoff had collected on citrus plants in the region of Rharb, Morocco. The holotype is in the Royal Belgian Institute of Natural Sciences, Belgium. Several nomenclatural changes with this mite have occurred since it was first named. André (1980), in a revision of the mite family Tydeidae, synonymized *Lorryia* into *Tydeus*, with Flechtmann (1987) later using the subsequent combination, *Tydeus formosus*. Kaźmierski (1998) later reestablished *Lorryia*. Finally, André (2005) suggested that the species Kaźmierski (1998, 2008) had listed for *Lorryia* should be moved to *Brachytydeus*, with Kaźmierski (2008) and Silva et al. (2016) later using the subsequent combination *Brachytydeus formosus*, now the most currently accepted name although many current internet sources still use *Lorryia formosa*.

Taxonomy and Nomenclature

The taxonomic hierarchy of *Brachytydeus formosus* is presented in **Fig. 3**.

Brachytydeus is in the family Tydeidae, which comprises 328 species in 30 genera of cosmopolitan, soft-bodies, striated or reticulated, microscopic mites (Silva et al. 2016). Although their ecology is largely unknown, they are often found on plants but also occur in other habitats, including caves, soils, lichens, mosses, and stored products (Walter et al. 2009). Some are plant feeders, pollen feeders, or predators but most are scavengers of organic matter or fungal feeders (English-Loeb et al. 1999; Gerson et al. 2003; Hernandes and Feres 2006; Silva et al. 2014a, b). Predators and fungal feeding mites have potential as biological control agents. Indeed, some of the fungal feeders suppress powdery and downy mildews on grapes (*Vitis* spp.) (Duso et al. 2005;

Fig. 3. Taxonomic Hierarchy of *Brachytydeus formosus* (Wikispecies 2024).

- Phyllum Arthropoda
  - Subphyllum Chelicerata
    - Class Arachnida
      - Subclass Acari
        - Superorder Acariformes
          - Order Trombidiformes
            - Suborder Prostigmata
              - Cohort Eupodina
                - Superfamily Tydeoidea
                  - Family Tydeidae
                    - Subfamily Tydeinae
                      - Genus *Brachytydeus*
                        - Species *formosus*

4. *Brachytydeus formosus* is a small mite with a reticulated idiosoma. © 2019 by Eric Erbe and Chris Pooley, United States Department of Agriculture.

English-Loeb et al. 1999, 2007; Hernandes and Feres 2006, Melidossian et al. 2005; Norton et al. 2000) and sooty mold on citrus (Gautam et al. 2017, 2018b, 2021).

With about 200 species, *Brachytydeus* is the largest genus in the Tydeidae. Most species in this genus were previously in *Lorryia* but André (2005) synonymized all species except one into *Brachytydeus*, only the anomalous *L. superba* remaining in *Lorryia* (Silva et al. 2016).

Description

Brachytydeus formosus is a small mite less than 250 um (0.01 inch) long (Proctor and Walter 1999) (**Figs. 4–5**). It is pale lemon-yellow but slightly darker dorsally (Smirnoff (1957). Like all Acariformes mites, the small head segment with piercing, sucking mouth parts is called the capitulum and is attached to the front of the much larger body segment called the idiosoma. The striated and reticulated idiosoma is divided into three sections: the propodosoma (anterior or front segment), metaprodosoma (middle segment), and opisthosoma (posterior or end segment). Mites of subfamily Tydeinae have a pair of eyes positioned laterally on the propodosoma, which also holds the first two pairs of legs. The remaining two pairs of legs are held farther back on the idiosoma (Proctor and Walter 1999). The smooth, lanceolate, dorsal, body setae and the reticulate pattern divided into discrete areas distinguish *B. formosus* from similar species (Baker 1968).

Life Cycle

The mean lifespan of *Brachytydeus formosus* is 37 days, 60% of which is an adult. Six discrete developmental stages are recognized: egg; larva; three nymphal stages, including protonymph, deutonymph, and tritonymph; and adult (Hernandes et al. 2006). Larvae and nymphs are whitish but the latter become yellow during molting. (Smirnoff 1957).

Reproduction occurs asexually through a form of parthenogenesis called thelytoky where females produce embryos without male fertilization (Hernandes et al. 2006). It is unknown whether *Wolbachia*, a genus of inherited bacteria known to alter gender ratios of offspring in arthropods, including mites (Werren et al. 2008), does so in *Brachytydeus formosus* (Hernandes et al. 2006). The host plant species can also greatly influence gender ratios in offspring (Hernandes et al. 2006, Badii et al. 2001, Ferla et al 2002, Feres et al. 2002).

Eggs, densely deposited in two to three layers, are oval, white, faintly translucent, and become very slightly yellow prior to hatching. Incubation takes about three to four days (Smirnoff (1957).

Gautam et al. (2018b) found that adults and immatures of *Brachytydeus formosus* were present year-round on citrus in California but increased from February through April and June through October, peaking in July.

5. A front view of a *Brachytydeus formosus* mite shows its mouth parts, legs, and reticulated idiosoma. © 2019 by Eric Erbe and Chris Pooley, United States Department of Agriculture.

Smirnoff (1957) observed that spring population increases of *Brachytydeus formosus* coincided with young female black scales (*Saissetia oleae*, an important pest of citrus and olives) secreting abundant honeydew. Colonies settled on the abaxial leaf surface where the larvae remained until the first molt; later they abandoned the leaf. He observed no sucking of leaf or other vegetative tissues and no predators of *B. formosus*, even those that typically prey on other citrus mites.

Distribution and Ecology

Brachytydeus formosus occurs nearly worldwide and on a variety of plants. For example, it has been found on chayote squash, pear, papaya, mango, and parana pine in Brazil (Flechtmann 1973; various stone fruits, apple, and bell pepper in Portugal (Carmona 1970); avocado in Ecuador (Baker 1968); and hibiscus in Guadeloupe, French Antilles (Flechtmann et al. 1999).

However, *Brachytydeus formosus* is best known and most closely associated with citrus plants around the world, including in Algeria, Italy, Morocco, Libya, Portugal, and Spain and France in the Mediterranean region (Baker 1968, Vacante and Nuciflora 1984-1985, Vacante et al. 1988); Argentina, Brazil, Chile, and Uruguay in South America (Baker 1968); and Florida (Aguilar and Childress 2000) and California (Gautam et al. 2017, 2018b, 2021) in the U. S. A. However, none of these accounts attributes any host plant damage to *B. formosus* although Ueckermann and Grout (2007) noted it was the only species of Tydeinae thought to be a citrus pest, likely alluding to Smirnoff's original account (Smirnoff 1957).

Smirnoff (1957) is the first and only mention of *Brachytydeus formosus* as a possible citrus pest, primarily because it was present in such large quantities, suggesting it might have an economic impact although he reported little damage, and then mostly on fruit. He noted that by midsummer larvae were abundant under the perianth of young fruits, where they began to "prick and suck" the fruit, leaving a ring of dead, brown tissue as the fruit enlarged. He also noted sclerification of young, green twig and leaf tissue followed by shedding of the epidermis, damage that might be due to the black scale (Gautam et al. 2018b). Smirnoff (1957) concluded that *B. formosus* could be phytophagous on citrus under certain circumstances.

Nonetheless, other reports show that *Brachytydeus formosus* is strongly associated with sap-sucking, honeydew-producing insects like black scale and subsequent sooty mold and does not damage the host citrus plant. Aguilar-Piedra (2001), who found *B. formosus* on citrus in several U. S. states and eight countries, noted that it had a complex feeding behavior and concluded it was not responsible for any damage to the host plant because it fed on honeydew, sooty mold, and pollen only. Mendel and Gerson (1982) reported that *B. formosus* was detrivorous (detritus feeder) and was actually a sanitizing agent on citrus. Hernandes et al. (2006) found large quantities of *B. formosus* at the base of rubber tree leaves (*Hevea brasiliensis*) but it caused no damage. Smirnoff (1957) noted that *B. formosus* was always associated with the honeydew-

6. White patches at the twig and leaf axils of affected *Schinus molle* typically support abundant *Brachytydeus formosus* mite populations.

7. White patches at leaf and twig axils of affected *Schinus molle* are composed of immature *Brachytydeus formosus* mites, mite detritus, and/or plant exudate.

8. In these white patches in the twig axils of affected *Schinus molle*, one can barely make out the yellow of congregated *Brachytydeus formosus* mites.

9. Yellow *Brachytydeus formosus* mites congregate on the white patches in the leaf and twig axils of affected *Schinus molle*.

producing black scale insects on citrus leaves. Not only was it attracted to the honeydew but it also it was equally attracted to the sooty mold, which held sugary droplets on the tips of the mycelia.

In laboratory studies, Badii et al. (2001) reared large colonies of *Brachytydeus formosus* on orange leaves but reported no damage. Gautam et al. (2018b) found that *B. formosus* could not survive beyond seven days on leaves of mandarin citrus only, but if sugar water, honeydew, or the sap-sucking cottony cushion scale insects were present, it survived for the duration of the study (26 days) and produced additional generations.

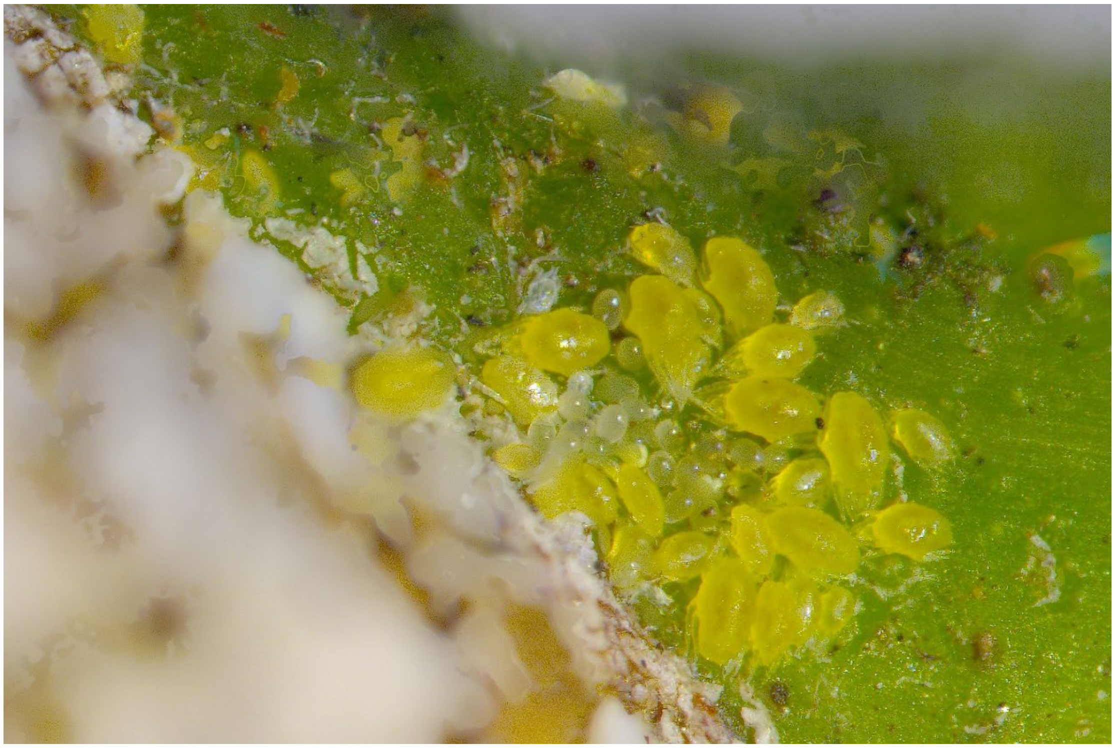
Gautam et al. (2017, 2018b) and Gautam and Grafton-Cardwell (2021) documented that *Brachytydeus formosus* mites are not citrus pests, do not damage leaves, need honeydew and/or sooty mold to grow and reproduce, and cannot survive and sustain their populations on leaf tissue alone.

In his original account of *Brachytydeus formosus* on citrus, Smirnoff (1957) provided a detailed and interesting summary that parallels several of our observations of this mite on *Schinus molle*. He noted that the mites swarm around honeydew-producing female black scales and are particularly visible at the base of twigs, petioles, and rough areas of branches. There, white patches 2 to 3 cm in diameter made by the larvae and their shed exoskeletons and yellow patches from the congregated adults, are unusually conspicuous. A white patch illustrated in his account (Smirnoff 1957, Fig. 1) is nearly identical in appearance and location to what we observed on *Schinus molle*.

Our observations show that while also roaming leaves and green twigs, *Brachytydeus formosus* tended to congregate on or near conspicuous white patches typically in leaf and twig axils, swarming on top of one another like a rugby scrum (**Figs. 6–11**). When doing so, they impart a yellowish tinge on or adjacent to the white patch and just barely visible to the unaided eye. These white patches, 0.5 to 1.5 cm in diameter, are likely composed of immature mites, mite detritus, and/or plant exudate, the latter of which might have occurred in response to plant stress and/or infections by the plant pathogenic fungus *Botryosphaeria* sp. (see below). Or perhaps the mites are feeding on the *Botryosphaeria* sp. itself. We often observed eggs just underneath the clusters of congregated mites. We did not observe black scale or sooty mold on the *S. molle*. Dark brown, platy, sclerified tissues might be from mite feeding activity as Smirnoff (1957) theorized for citrus or damage from the pathogen *Botryosphaeria* sp. (see below) (**Fig. 12**).

Thus, while we feel that *Brachytydeus formosus* is an unlikely pest of *Schinus molle* and might be feeding on stress- and/or disease-induced host exudate (**Fig. 13**) and/or host detritus and non-pathogenic fungi, it is possible that it is an opportunistic, facultative feeder and, under the right circumstances, might attack *S. molle*.

10. Yellow *Brachytydeus formosus* mites on and to the side of the white patch at twig axils of affected *Schinus molle*. © 2024 by G. Arakelian.



11. Yellow *Brachytydeus formosus* mites congregate like a rugby scrum adjacent to a white patch in a twig axil of affected *Schinus molle*. Note the rounded, clear-colored eggs under the mites. © 2024 by G. Arakelian.

12. Dark brown, sclerotized, platy tissues might be due to *Brachytydeus formosus* mites or the disease *Botryosphaeria* sp.

13. *Brachytydeus formosus* mites might be feeding on this abiotic stress- and/or *Botryosphaeria*-induced white exudate, which might be a component of the white patches in leaf and twig axils.

14. Dark, necrotic spotting and lesions on twigs are symptoms associated with *Botryosphaeria* sp. on *Schinus molle* with canopy thinning.

15. Dark, necrotic spotting and lesions on twigs are symptoms associated with *Botryosphaeria* sp. on *Schinus molle* with canopy thinning.

Botryosphaeria sp.

Botryosphaeria is a genus of six (Phillips et al. 2013) to about ten species (Dissanayake et al. 2016, Wijayawardene et al. 2022) of mostly pathogenic fungi in the family Botryosphaeriaceae. The Botryosphaeriaceae are Ascomycetes or sac fungi; morphologically diverse pathogens, endophytes (living on a plant but not producing disease symptoms), and/or saprophytes (living on dead, decaying organic matter); occurring primarily on woody plants; distributed worldwide except the polar regions; and frequently associated with destructive vascular diseases of woody plants (Garcia et al. 2021, Luo et al. 2019, Phillips et al. 2103, Slippers and Wingfield 2007).

Botryosphaeriaceae is estimated to include about 25 genera and from 1,500 species (Kirk et al. 2008) to as few as 222 (Burgess et al. 2019). The advent of molecular data to sort out phylogenetic lineages and species has led to numerous changes in species interpretations, especially as they concern different sexual stages of the same fungus named or identified as different species.

Climate change and its attendant array of plant stressing impacts, including global warming, temperature extremes, drought, aridification, excessive rain, enhanced storm severity, natural wounds, and other existing pests and diseases, have ushered in the age of the opportunistic Botryosphaeriaceae. Furthermore, abiotic stresses related to cultivation, such as light exposure (too much or too little sun), nutrient deficiencies, adverse soil pH, saline conditions, soil compaction, too deep planting, above- or below-ground mechanical damage, insufficient growth space, extremes of soil moisture, lack of mulch or excessive mulch, and poor pruning and human-made wounds, can enhance Botryosphaeriaceae disease symptom severity (Lawrence et al. 2018, Mullen 1991, Old et al. 1990, Pusey 1989, Smith et al. 1994) and/or increase disease susceptibility, in some instances taking seemingly innocuous endophytic fungi and transforming them into pathogens (Desprez-Loustan et al. 2006, Downer et al. 2022, Flor et al. 2019, Luo et al. 2019, Slippers et al. 2007).

The Botryosphaeriaceae causes common diseases on a wide array of ornamental woody landscape plants. Symptoms include wilting, discolored foliage, dieback, and cankers. Botryosphaeriaceae pathogens can infect through wounds and natural openings, such as lenticels and stomata, and produce enzymes and/or toxins that damage and kill cells and tissues (Flor et al. 2019, Garcia et al. 2021). One of the more common *Botryosphaeria* diseases on landscape trees in southern California is *Ficus* branch dieback of *Ficus microcarpa* (Hodel 2009, Hodel et al. 2009, Mayorquin et al 2011, 2012).

Symptomatic tissue on *Schinus molle* from which we detected *Botryosphaeria* was on the spring flush of new, green, current year's growth. Symptoms included dark brown to black, sclerified, platy lesions (**Fig. 12**), dark, necrotic spotting and lesions on leaves and twigs (**Figs. 14–15**), shoot

16. Shoot tip dieback is a symptom associated with *Botryosphaeria* sp. on *Schinus molle* with canopy thinning.

17. A white exudate is a symptom associated with *Botryosphaeria* sp. on *Schinus molle* with canopy thinning.

18. A white exudate, typically at leaf and twig axils, is a symptom associated with *Botryosphaeria* sp. on *Schinus molle* with canopy thinning.

19. Leaf necrosis is a symptom associated with *Botryosphaeria* sp. on *Schinus molle* with canopy thinning.

20. Leaf necrosis and drop are symptoms associated with *Botryosphaeria* sp. on *Schinus molle* with canopy thinning.

21. Leaf necrosis and drop are symptoms associated with *Botryosphaeria* sp. on *Schinus molle* with canopy thinning.

tip blackening and dieback (**Fig. 16**), white exudate typically in leaf and twig axils (**Figs. 13, 17–18**), and perhaps some of the other symptoms described and illustrated in Hodel at al. (2024), including a general yellowing of distal pinnae accompanied by some leaf necrosis and drop (**Figs. 19–20**), leaving bare leaf rachises and dieback (**Fig. 21**), and canopy thinning. Other symptoms we observed (Hodel et al 2024), such as deformed or distorted and often epinastic, "bunchy" shoot growth, somewhat like witch's broom, are more difficult to associate with typical *Botryosphaeria* infections until we have stronger corroborating evidence.

Effect of Root Zone Moisture and Trunk Diameter/Age on *Schinus molle* Canopy Thinning

Because *Schinus molle* naturally occurs in seasonally dry areas of South America and Mexico and is considered a Mediterranean-climate plant (Hodel et al. 2024), we wanted to determine what impact varying root zone moisture levels have on canopy thinning. We also wanted to check if plant size, and by extension age, played a role in canopy thinning. Thus, we assessed *S. molle* street trees in a several-block area of Long Beach.

Materials and Methods

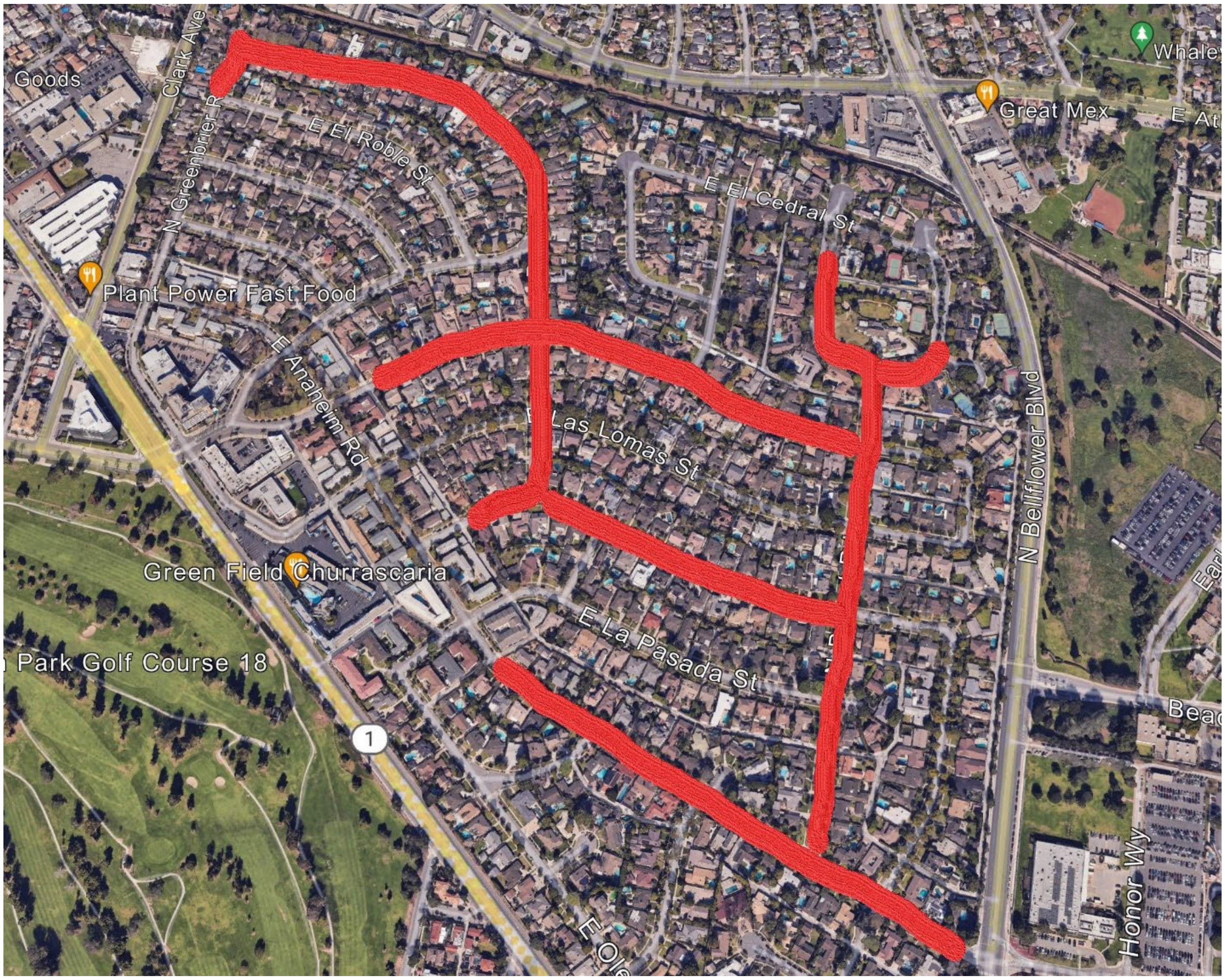
In May, 2024, in two samplings, we collected data on 310 street trees of *Schinus molle* in the Park Estates neighborhood of Long Beach, California. These trees were lining the streets of 5406–5654 E. Anaheim Rd.; 1151–1465 N. Bryant Rd.; 1410–1420 E. Bryant Dr.; 5350–5560 E. El Jardin St.; 5301–5542 E. El Parque St.; 1351–1591 Ramillo Ave.; 5107–5270 E. El Cedral St.; and 1561–1661 N. Greenbrier Rd (**Fig. 22**). The trees were in varying states of root zone moisture, were of various sizes/ages, and displayed a range of severity of canopy thinning.

We estimated relative root zone moisture by species and condition or appearance of tree companion plants, which were mostly turfgrass but also occasionally included groundcovers and shrubs. We rated estimated relative root zone moisture on a scale of 1 to 3, where 1 = low, 2 = medium, and 3 = high (**Figs. 23–25)**. For condition of companion plants, we assessed leaf color and plant density and dieback. We also considered the presence of weeds, lichens, and mosses.

We measured trunk diameter at standard height, ca. 1.4 m above the ground, with an arborist's D-tape.

We estimated relative tree canopy appearance or condition on a scale of 1 to 5, where 1 = dead or nearly so and 5 = optimal (**Figs. 26–27**). For tree appearance we considered leaf color, canopy density and dieback (thinning), and presence of epicormic growth.

We conducted an analysis of variance using a model that included the effects of sampling date, estimated root zone moisture and tree diameter using R base package (R Core Team 2021) to



22. Residential streets marked in red where we assessed 310 street trees of *Schinus molle* for relative severity of canopy thinning, rated for estimated relative soil moisture, and measured for DSH, Estate Park neighborhood, between Pacific Coast Highway (Highway 1) and Bellflower Blvd., Long Beach, California, May 2024. Image adapted from Google Earth.

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analyze the data and determine if treatments differed significantly. Means for significant effects were estimated and significance levels presented.

Results

Date of sampling and trunk diameter/age had no effect on tree canopy appearance. However, a significant effect existed between estimated relative root zone moisture and estimated relative tree canopy appearance. (**Table 1**).

When considering the natural habitat of *Schinus molle* in seasonally dry areas and its designation as a Mediterranean-climate plant, it is no surprise that trees in lush, heavily irrigated landscapes (high water) had more severe canopy thinning than trees in low-water situations. Mediterranean-

Table 1. Effect of estimated relative root zone moisture on *Schinus molle* tree canopy relative appearance, Park Estates, Long Beach, California, May 2024.

Estimated Soil Moisture[z]	**Mean Tree Canopy Appearance**[y]
1 (low)	**3.3c**
2 (medium)	**2.7b**
3 (high)	**2.4a**

[z]Root zone moisture rated on a scale of 1 to 3, where 1 = low, 2 = medium, and 3 = high.

[y] Tree canopy appearance rated on a scale of 1 to 5, where 1 = dead or nearly so and 5 = optimal. Different letters following means indicate that the value was significantly different, P < .001.

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climate plants typically perform poorly in year-round, lush well irrigated landscapes, suffering root damage and subsequent canopy thinning and dieback. Also, trees stressed from inappropriate irrigation are more susceptible to secondary problems, like pests and diseases. Thus, we suspect that if a primary cause of *S. molle* canopy thinning exists, excessive, inappropriate irrigation is likely exacerbating it if not causing it. Conversely, and somewhat surprisingly considering *S. molle* is a drought tolerant species, insufficient water, like the several years of consecutive drought from 2013 to 2017 and 2020 to 2022, could also stress trees, predisposing them to a myriad of problems, including abiotic and biotic, such as pests and diseases.

Conclusions and Management

The mite *Brachytydeus formosus*, the disease *Botryosphaeria* sp., and the abiotic stress of improper irrigation (excessively moist soil and/or perhaps even prolonged drought) can now be added to the leafhopper *Empoasca sativa* as possible causal agents of *Schinus molle* canopy thinning. It seems probable that any one of these factors is not acting alone but that two or more are acting in combination. A likely scenario is that excessively wet soil or prolonged, consecutive years of drought could not only stress trees and lead to canopy thinning on its own but could initiate or predispose trees to disease (*Botryosphaeria* sp.) and pests (*E. sativa* and *B. formosus*). Also, improper soil moisture could enhance pest and disease damage, making them more severe than they would be on a healthy, stress-free tree.

Thus, until we know more about the roles that each of these possible causal agents plays in *Schinus molle* canopy thinning, the best strategy for managing this malady is to provide proper cultivation, primarily appropriate water, mulch, and pruning, to ensure optimal tree health.

Ensure *Schinus molle* is an appropriate species for your area, site in full sun, and provide adequate space to accommodate future shoot and root growth to reduce wounds from pruning for size control.

23. Dryland plants, including groundcovers and succulents, suggested low relative soil moisture and was rated a "1."

24. Spotty, uneven turfgrass coverage suggested medium relative soil moisture and was rated a "2."

25. Lush, green turfgrass suggested high relative soil moisture and was rated a "3."

Irrigate judiciously; if winter rains are average, perhaps only an occasional summer deep irrigation, for example once every four to eight weeks in cooler, more humid coastal areas and once every three to four weeks in hotter, more arid inland areas, might be beneficial. During consecutive years of drought, when winter rains are lacking, consider supplemental winter and spring irrigation. Keep irrigation water off trunks and foliage and maintain mulch to decrease soil evaporation.

To avoid wounds, prune judiciously, only when necessary and then mostly to achieve, preserve, and/or enhance proper structure; avoid pruning for size control. Employ proper pruning principles, practices, and tools.

Maintain five to seven cm of good quality mulch from the trunk out to at least two m, or ideally to the canopy dripline, if possible. The naturally shedding leaves of *Schinus molle* make a good mulch. Remove companion plants at least close to the trunk or out to the canopy dripline, if possible.

Also, for diseases, Downer et al. (2022) suggested removal and disposal of infected growth, pruning 10 to 15 cm proximal of visible infections. Clean pruning tools of plant debris and then

26. The severely thinned out canopy earned this tree a “1” rating. Note the lush, green turfgrass indicating relatively high soil moisture.

27. This tree was in good condition and we rated it a "4." Note the companion plants of *Ceanothus*, a California native, and other dryland plants, suggesting the relative soil moisture was low.

sanitize them for 30 minutes in a solution of one part household bleach (5.25% sodium hypochlorite) and nine parts of water prior to making new cuts. A solution of 70% alcohol can also be used to sanitize pruning tools.

Monitor and control sap-sucking insects like aphids, scales, mealybugs, and leafhoppers; they can predispose plants to disease and aid in spreading disease.

As a last resort for diseases, consider phosphorous acid-based fungicides that induce a plant immune response to protect new growth. However, once the disease progresses deeper into the main branches and trunk it is typically best to consider removal.

At this time pesticide applications aimed specifically at *Empoasca sativa* and *Brachytydeus formosus* seem unwarranted. We are unsure what damage, if any, *E. sativa* is causing to *S. molle*. Also, because they are so mobile, leafhoppers like *E. sativa* are difficult to control with pesticides.

In the case of *Brachytydeus formosus*, because it is likely not a primary pest of *Schinus molle*, its control is not an urgent concern. Indeed, because it is likely beneficial and cleaning up or sanitizing non-pathogenic and pathogenic fungi, to suppress or eliminate it might be detrimental to the trees' health. However, if proven to be an important pest of *S. molle*, Gautam et al. (2018a) reported that it is rather easily controlled by several miticides.

Anecdotally, several landscape managers have reported improved tree appearance after applications of a combination of fertilizer, kelp extract, and dinotefuran. Unfortunately, we do not know which of these three ingredients, if any, are responsible for the positive outcome.

We observed that trees afflicted with *Schinus molle* canopy thinning tend to be somewhat cyclical in severity of symptom expression. If trees are not yet severely affected, they tend to look best in spring, benefitting from surges of fresh, new growth typical of Mediterranean climate plants, masking the previous damage. Yet, by the fall and winter, after a long warm summer of little new growth, they tend to look their worst. On the other hand, trees severely affected, such as those in the Talega neighborhood of San Clemente, might recover only slightly, if at all, in the spring, which after several years of poor growth might lead to their decline and eventual death.

We feel that future work on *Schinus molle* canopy thinning should focus on determining what role the three biotic causal agents play in this malady. Perhaps growth chamber studies with plants of *S. molle* with *Empoasca sativa*, *Brachytydeus formosus* and other sap-sucking insects, and *Botryosphaeria* sp., alone and in combination, could prove useful.

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