

Integrated Pest Management of California Citrus



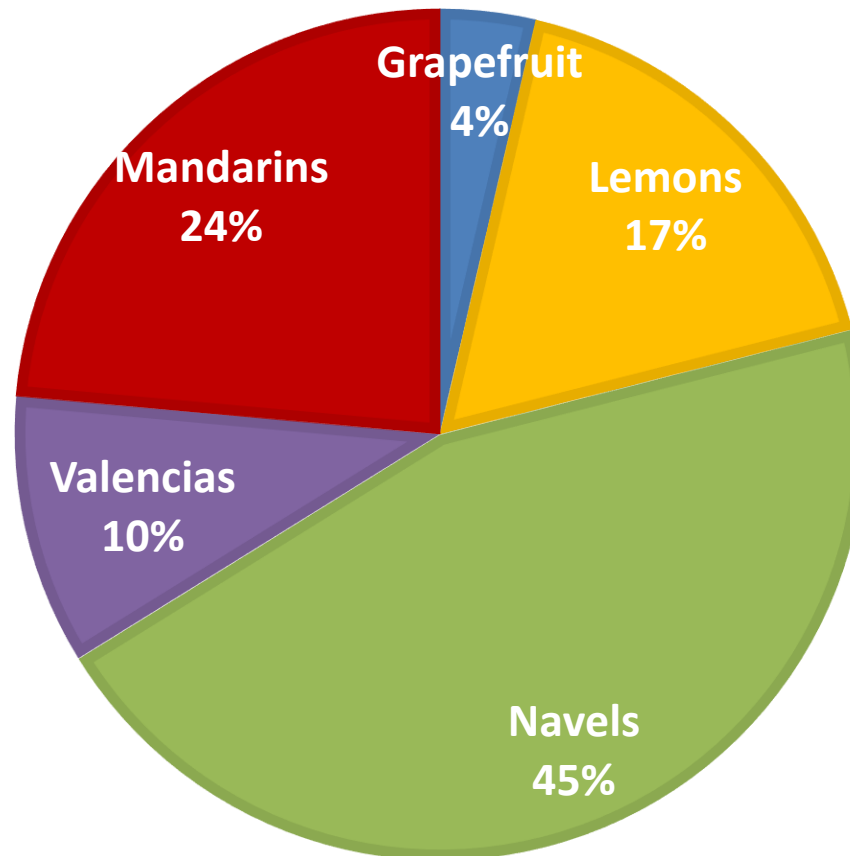
Dr. Beth Grafton-Cardwell

Dept of Entomology, UC Riverside
and Director of Lindcove Research and Extension Center
eegraftoncardwell@ucanr.edu

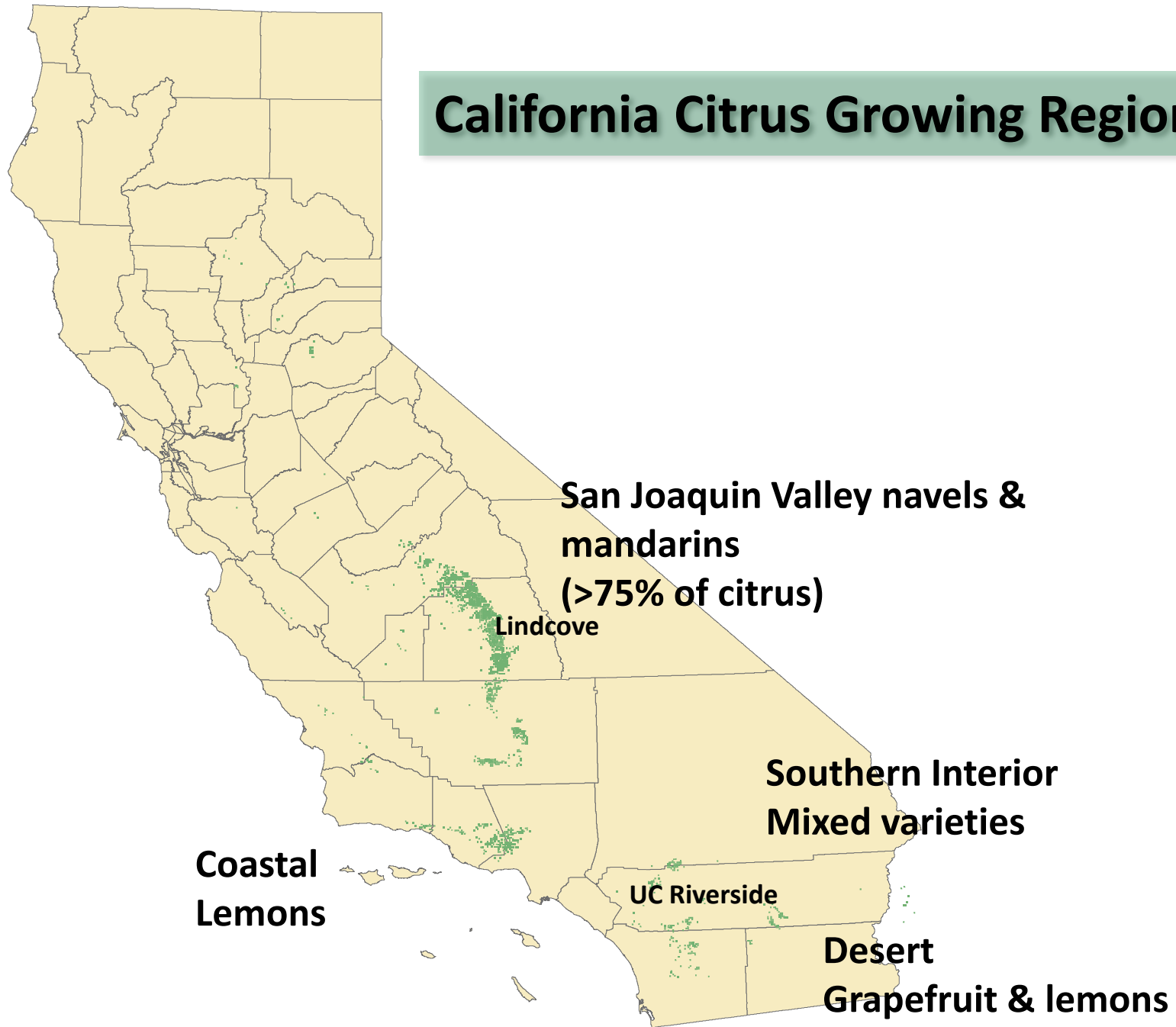
CALIFORNIA CITRUS ACREAGE 2018

262,700 ACRES (106,310 HA)

■ Grapefruit ■ Lemons ■ Navels ■ Valencias ■ Mandarins



California Citrus Growing Regions



Fresh fruit market

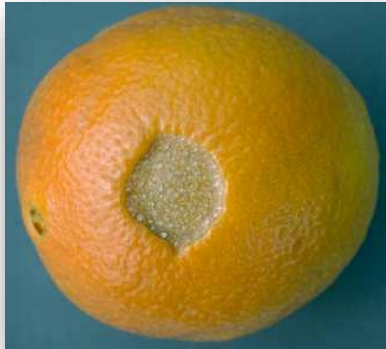
Export markets

Japan
S. Korea
China
Australia
New Zealand
Canada

Cutworm/Earwig



Katydid



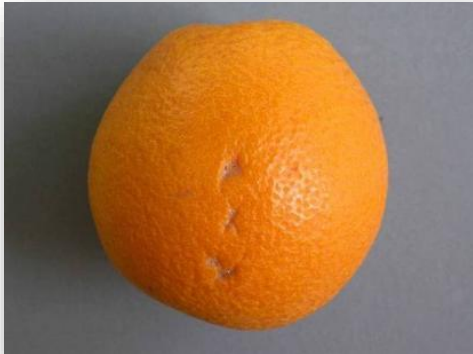
Thrips



Equipment



Hail



Wind/sand



Branch rubbing



Price per box	Juice	Choice	Fancy
Navels	\$1.50	\$13.13	\$25.30
Valencias	\$1.60	\$12.50	\$20.50
Mandarins	\$0.28	\$17.50	\$29.70

These numbers vary from year to year, as the season progresses and for different citrus varieties

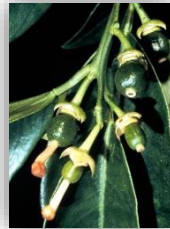
San Joaquin Valley Citrus IPM

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
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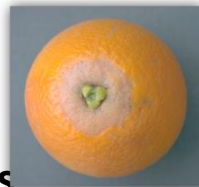
UC IPM Guidelines for Citrus



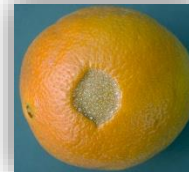
Citrus Red Mite



Citrus Thrips



Katydid



Citricola scale



California red scale

Citrus Red Mite, *Panonychus citri*



Fairly easily controlled by natural enemies and soft pesticides such as oils and miticides

Predatory mite, *Euseius tularensis*



Summer heat
+ virus



Rind damage
Lower yield
Threshold: 8 adult mites/leaf

Citrus Thrips, *Scirtothrips citri*



Winged, adult citrus thrips



Rind damage



Wingless, 1st and 2nd instar thrips

Natural enemies help, but don't bring scarring below an economic threshold.

Treatments are applied from petal fall until the fruit is 2.5 cm in diam.

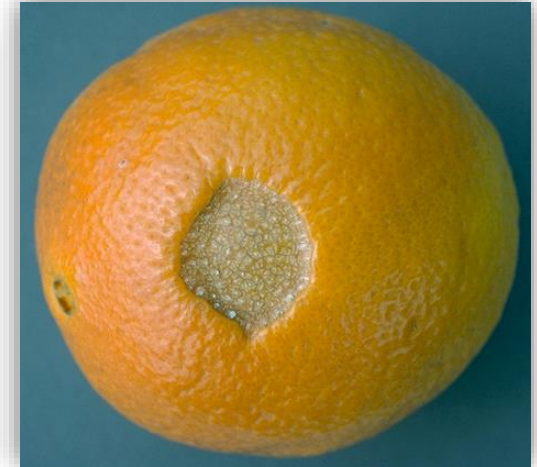
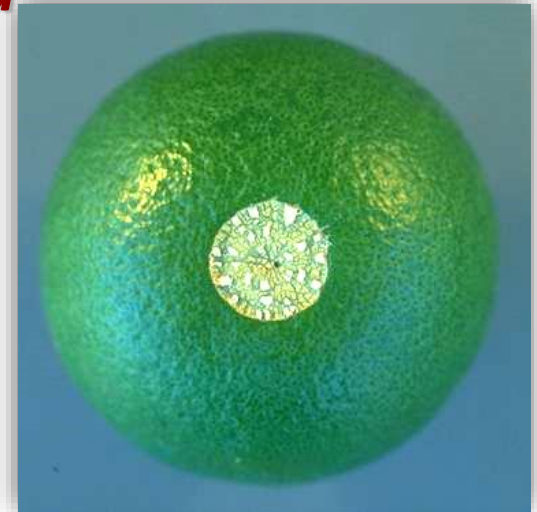


Predatory mite, *Euseius tularensis*

Forktailed Bush Katydid, *Scudderia furcata*



Rind damage



Biological control is minimal and damage is heavy = pesticides are necessary

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
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Citrus Red Mite

Oils, miticides



San Joaquin Valley
Pest Management
Navels & Mandarins

Citrus thrips + katydids



Thrips: **spinetoram**, **cyantraniliprole**, **spinosad**, **abamectin**, **formetanate**

Katydid: **pyrethroid**, **diflubenzuron**, **kryocide**



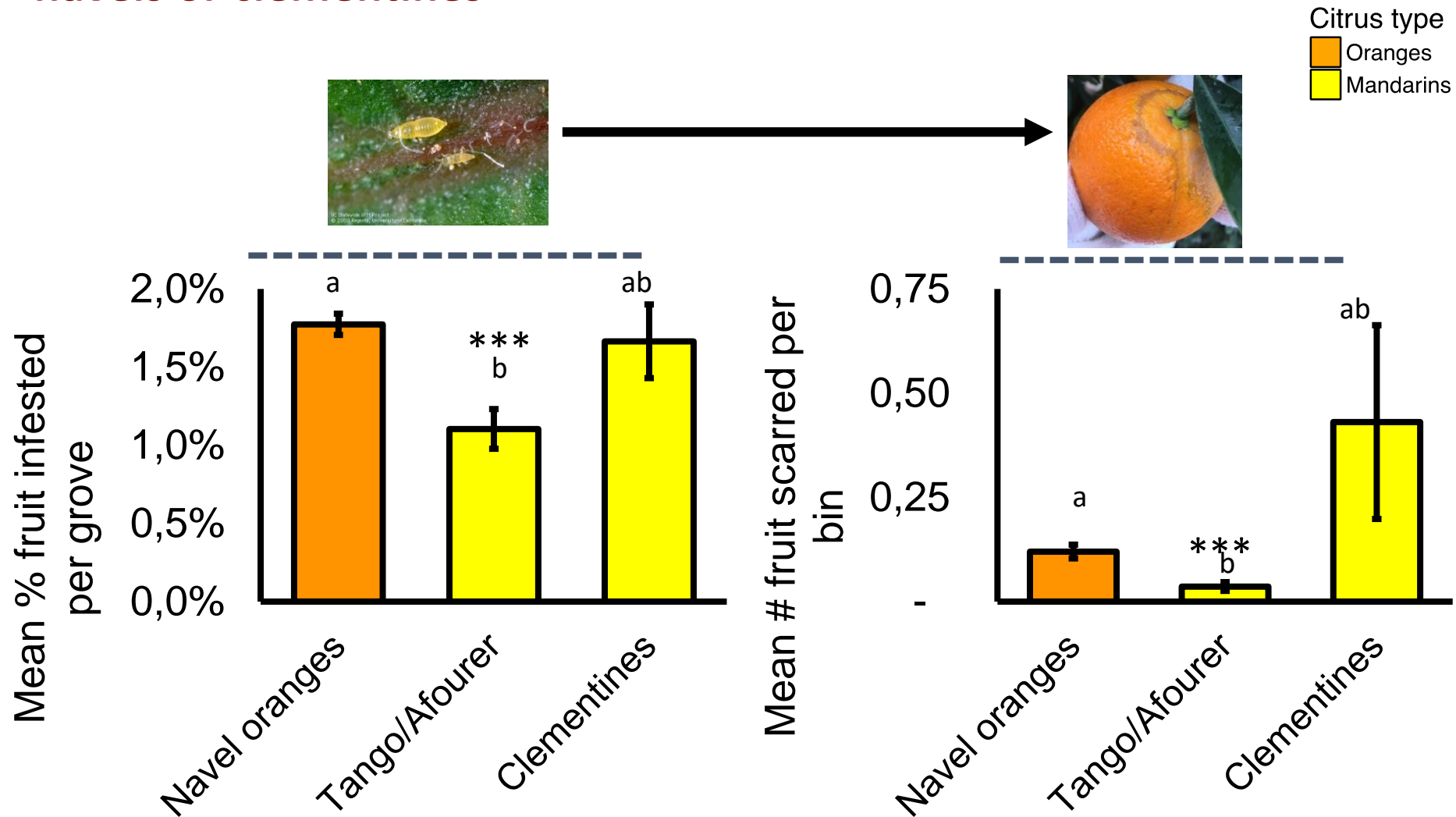
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Broad spectrum

Soft on natural enemies

3-4 insecticides/year

Thrips, katydids and earwigs cause less damage to Afourer than navels or clementines



Mandarins need specific citrus thrips guidelines

Citricola Scale, *Coccus pseudomagnoliarum*



Sooty mold
Yield



Biological control is very
poor and broad
spectrum insecticides
are needed



California Red Scale, *Aonidiella aurantii*

Biological control is very effective if broad spectrum insecticides are avoided and trees are cared for



Downgrading of fruit
Yield Loss

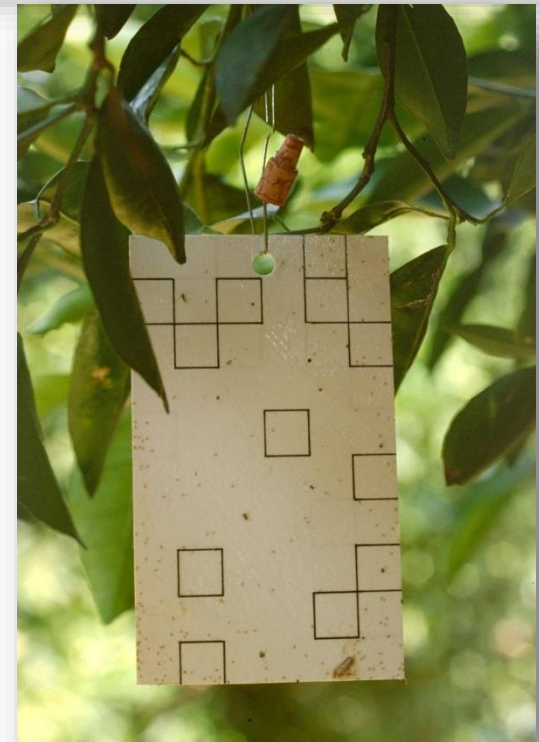
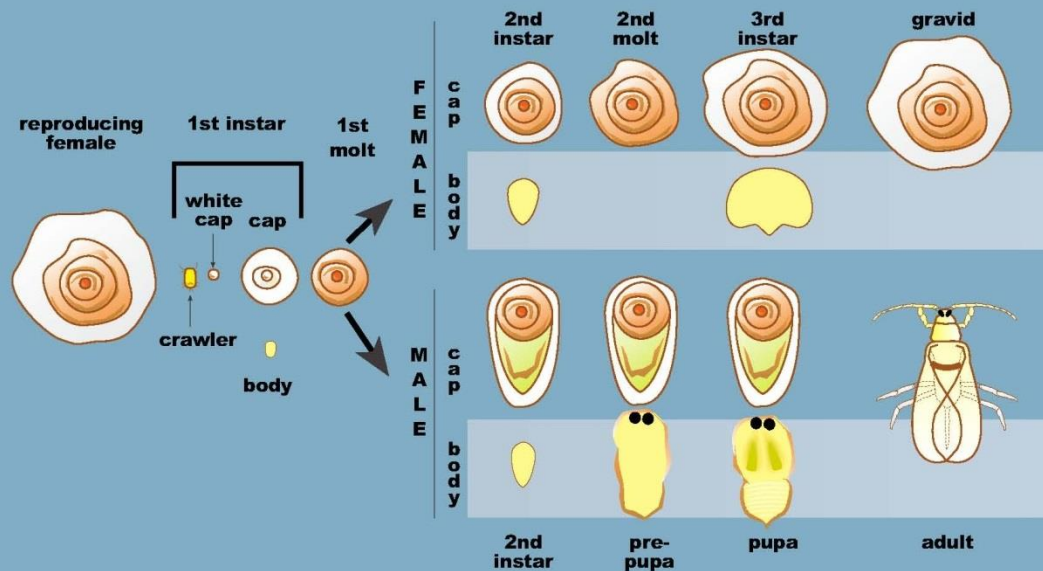


California Red Scale

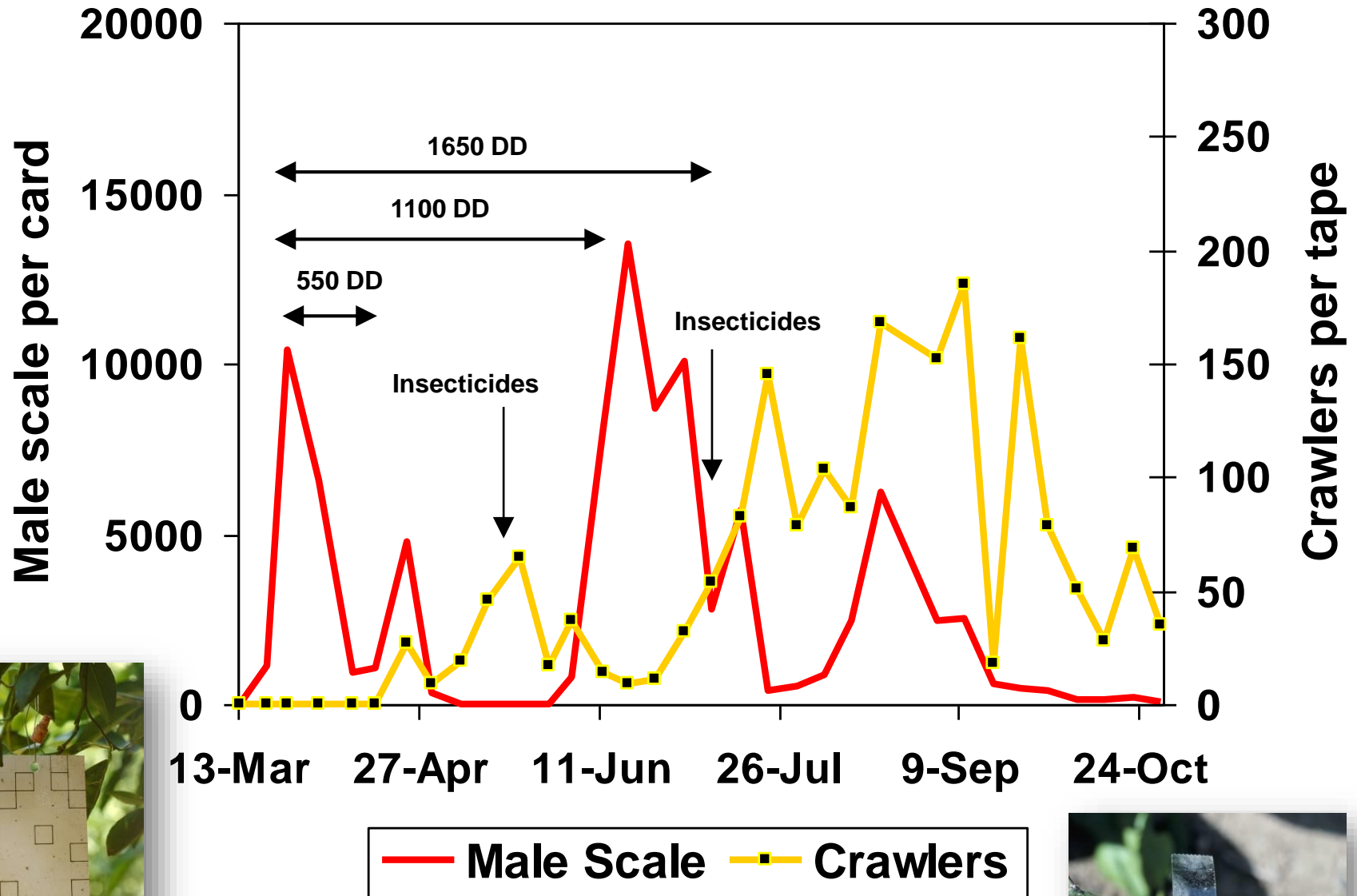
Monitoring: pheromone traps, % infested fruits, crawler tapes



California Red Scale Life Cycle



Pesticide treatments timed using degree days = accumulation of the average daily temperature above the lower developmental threshold (53°F)



California red scale management

Chemical control:

Soft pesticides:

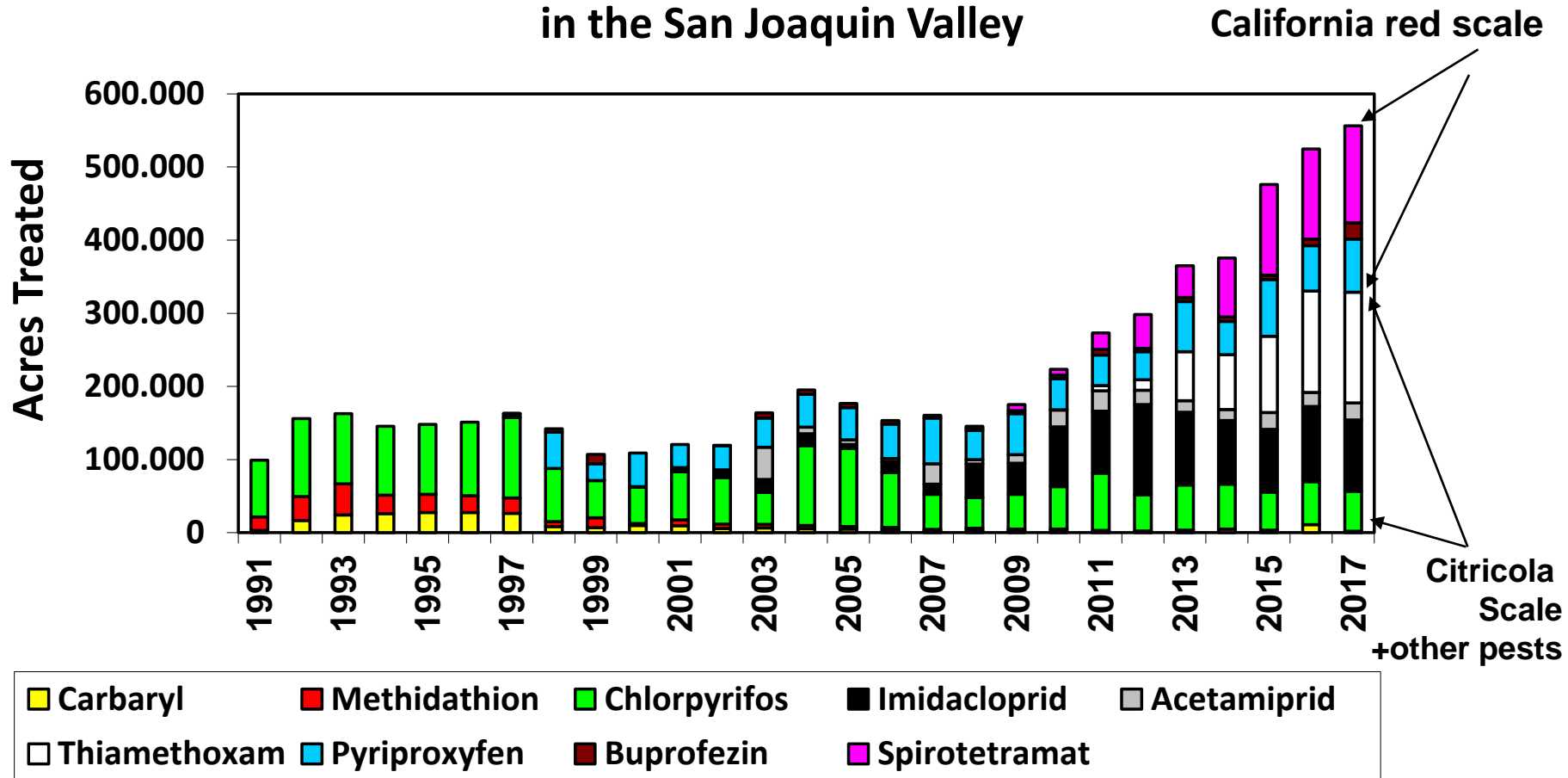
- Oil
- pyriproxyfen* (Esteem) (1998)
- buprofezin (Applaud/Centaur) (1998)
- spirotetramat (Movento) (2008)

Broad spectrum pesticides:

- chlorpyrifos* (Lorsban)
- carbaryl* (Sevin)

*resistant populations

Insecticides Used for Scale Control in the San Joaquin Valley

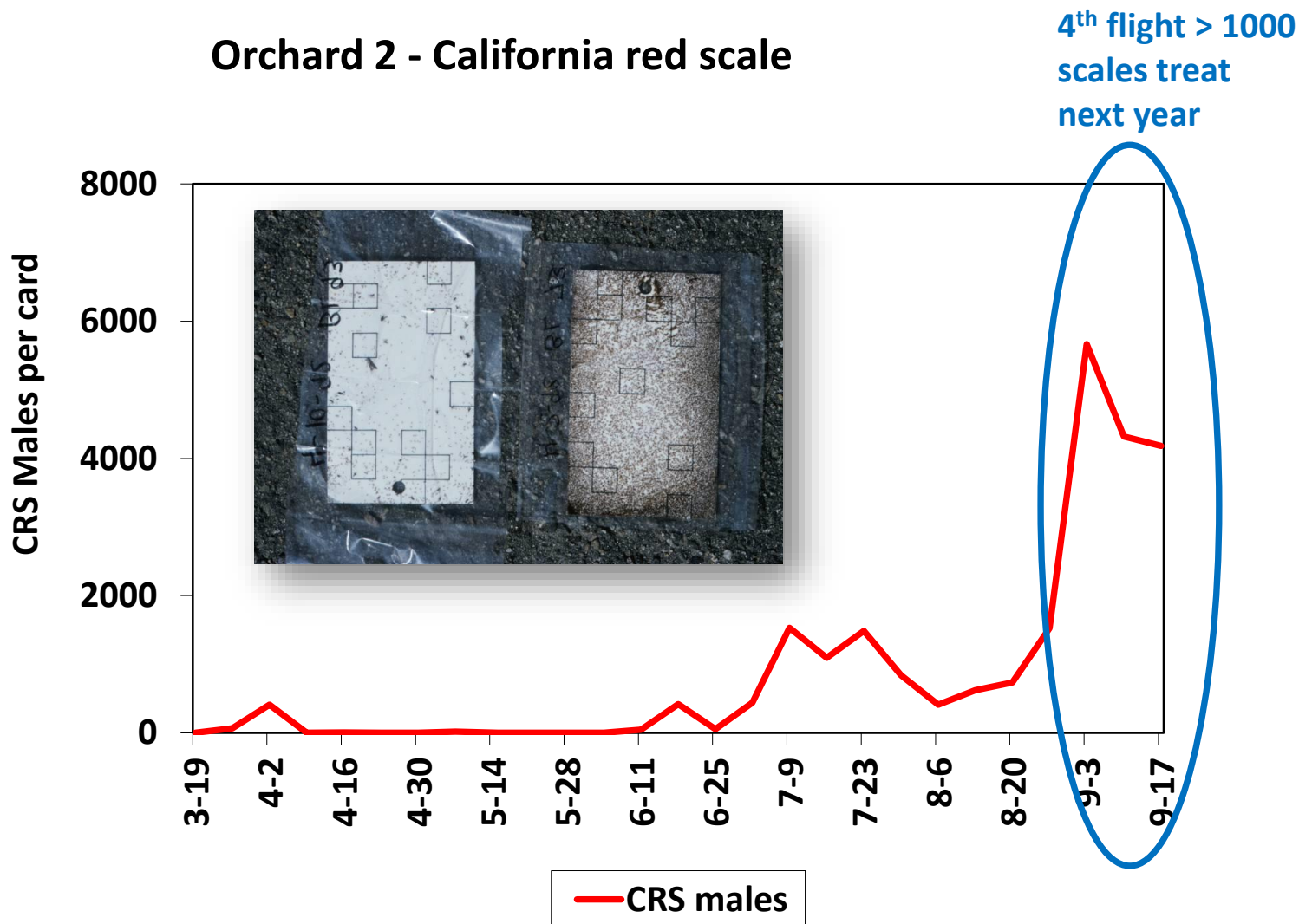


Chlorpyrifos is also used for caterpillars, katydid, ants, and soft scale pests
 Methidathion, malathion, and carbaryl are also used for cottony cushion scale
 Imidacloprid and acetamiprid are used for GWSS, but provide some scale control

When to spray: decision making

Pest Control Advisors have traditionally used pheromone cards to watch populations on a weekly basis – or put them out during the 4th flight to decide which orchards to spray next year.

Orchard 2 - California red scale



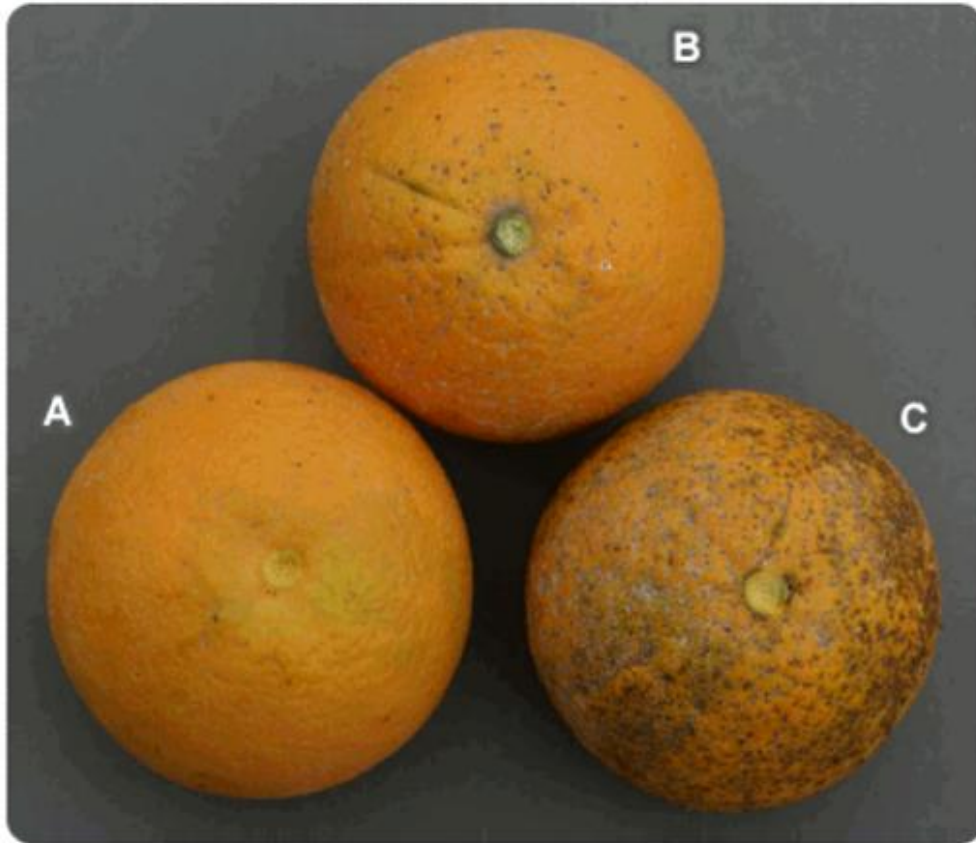
During the season: check leaves and twigs and the wood for live scale



- Is the scale just on the dusty roads or throughout the orchard? (edge effect)
- Look at the interior and tops of the tree to see if scale is building there (improve coverage)
- Rub your thumb lightly over the scales and see if they easily rub off (get to know live vs dead scale)
- One month after treatment, take samples back to the office and look closely at 2nd and 3rd instar scales to see if they are healthy or parasitized (is biological control helping?)

Walk the orchard and check fruit for live scale

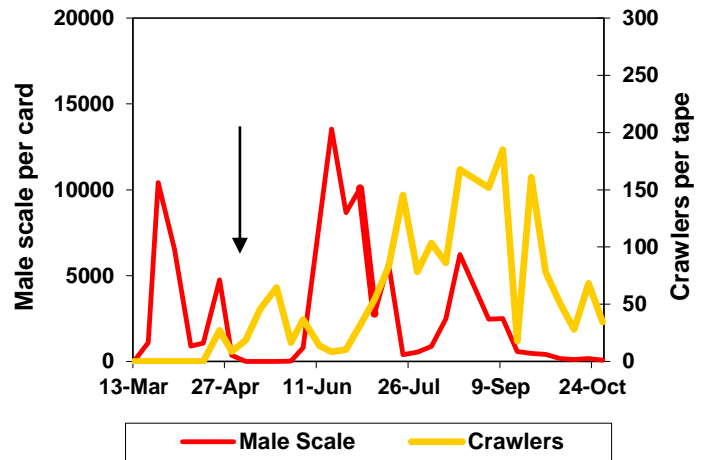
At harvest check bins of fruit



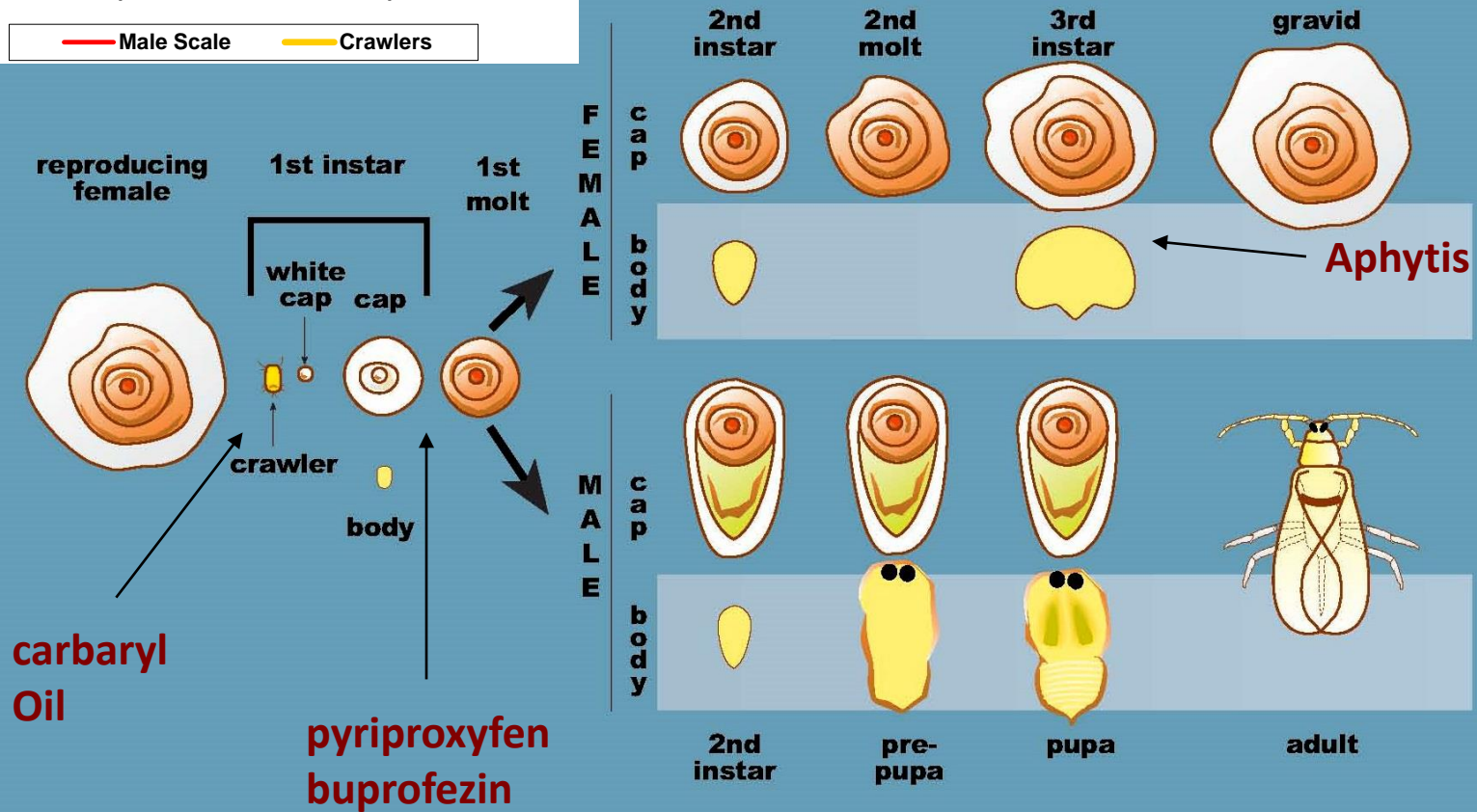
Estimate the % of fruit with >10 scales

If you find more than 5% of fruit infested, the block likely needs a treatment next year





nia Red Scale fe Cycle



spirotetramat – all stages, but mostly on leaves and fruit

Recommendations for chemical control of California red scale:

- **Timing: treat the stage that is most sensitive**
- **Treat generations 1 or 2 when the scale population is uniform in stage (exception is spirotetramat, which seems to work in fall)**
- **Use the selective insecticides that allow natural enemies to survive when you can**
- **Rotate products to avoid resistance**
- **Good coverage: 750-1500 gpa (7000-15000 l/ha) (spirotetramat 2500-5000 l/ha)**
- **Drive slowly! < 1.5 mph (2.4 kph)**



***Aphytis melinus* parasitoid releases**



Release 5,000 wasps/acre every two weeks, every six tree in every sixth row from March 1 to October 31 = 100,000/acre for the entire season

California red scale management

Cultural Control:

Reduce dust, prune trees, high pressure washer,
minimize broad spectrum insecticides

Biological Control:

Aphytis melinus: Release 5,000/acre every two weeks
from March 1 to October 31 = 100,000/acre (250,000/hectare)
Cost: \$.85/1,000 wasps = \$85/acre (\$200 USD/hectare)



*resistant populations

Issues that are game-changers for citrus IPM

- **Weather**

Dry hot years promote these pests :

***California red scale

Citrus red mite

Citrus thrips

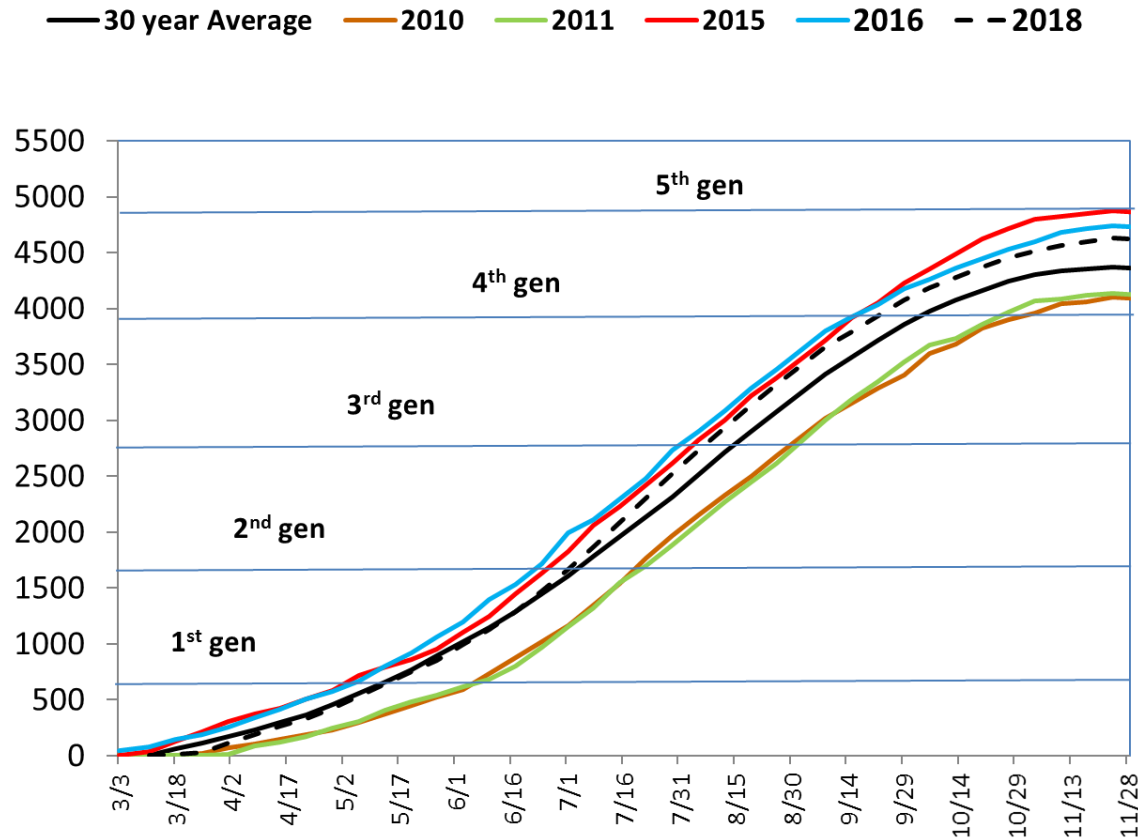
Cool wet years promote these pests:

Citricola scale

Snails

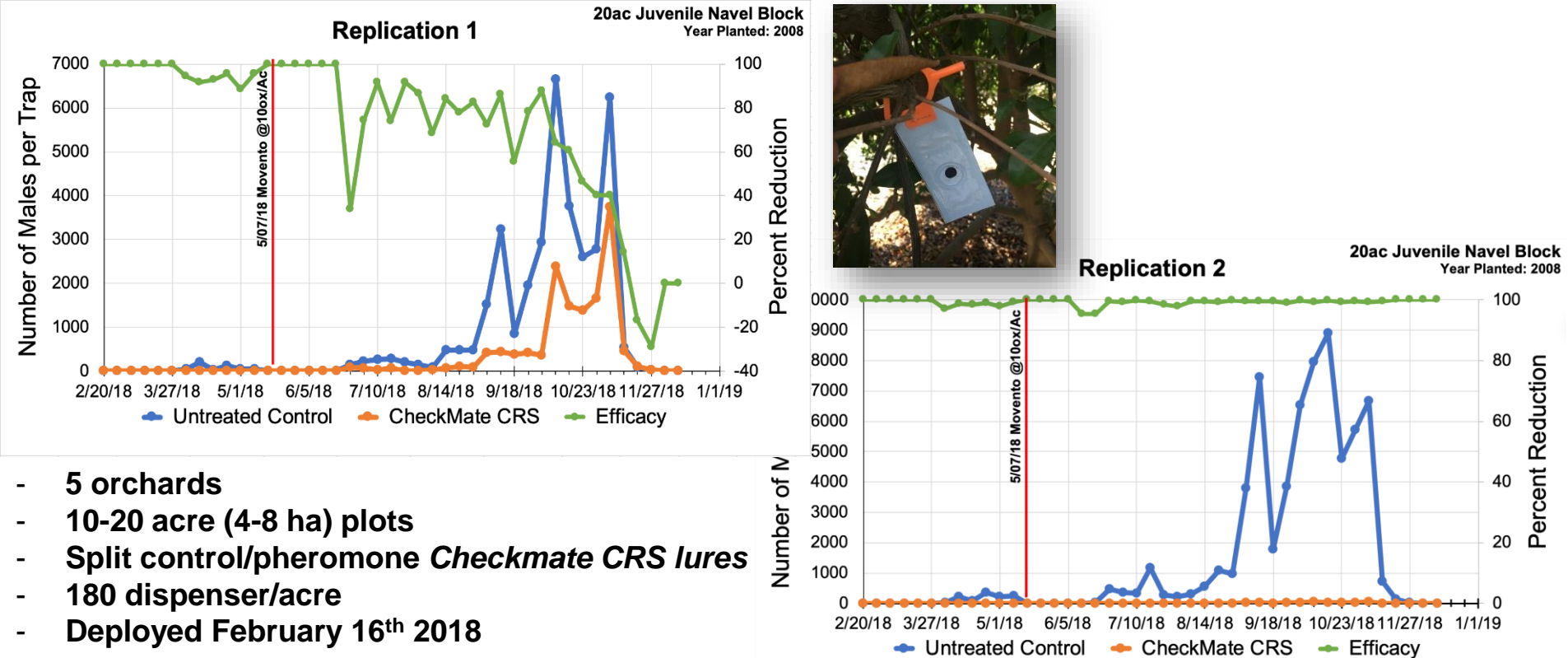
California Red Scale Degree Days

Lindcove Research and Extension Center



Factors that caused red scale problems to escalate in 2012-2019?

1. Heat = fast development of scale, more generations and the parasites don't keep up
2. Warm winter = scales of all stages developing at all times, less overwintering mortality
3. In season drought – dusty, stressed trees have more scale, parasites don't work as well
4. Insecticide treatments only last about 1 generation – forcing growers to treat more often
5. Some insecticides don't control scales on wood (imidacloprid, spirotetramat)



- 5 orchards
- 10-20 acre (4-8 ha) plots
- Split control/pheromone *Checkmate CRS* lures
- 180 dispenser/acre
- Deployed February 16th 2018

Treatment Rep	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5
	% Fruit with >10 Scale				
Date	Dec 7th, 2018	Dec 3rd, 2018	Dec 8th, 2018	Dec 10th, 2018	Dec 11th, 2018
Untreated Control	6.62	11.63	2.09	0.63	5.03
Suterra pheromone dispenser	7.23	0.18	0.19	0.01	0.28
Percentage Reduction	0	98.4	91.1	98.7	94.5
Chemical Application (In Both Control & Treatment)	5/07/18 Movento @ 10oz/ac	5/07/18 Movento @ 10oz/ac	5/07/18 Movento @ 10oz/ac	No	5/21/18 Movento @ 10oz/ac

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**San Joaquin Valley
Pest Management
Navels & Mandarins**

Citrus Red Mite Oils, miticides



Citrus thrips + katydids



Thrips: **spinetoram**, **cyantraniliprole**, **abamectin**, **formetanate**
 Katydids: **pyrethroid**, **diflubenzuron**, **kryocide**

Citricola scale **buprofezin**, **acetamiprid**, **thiamethoxam**,
imidacloprid



California red scale **pyriproxyfen**, **spirotetramat**,
carbaryl, **oil** + pheromone



Broad spectrum
Soft on natural enemies

4-5 insecticides/year

California Red Scale and its Natural Enemies

A study of the biology and management

<https://campus.extension.org>



Beth Grafton Cardwell

next »

Dept. of Entomology, University of California Riverside

Issues that are game-changers for citrus IPM

- **Weather**
 - Dry conditions promote red scale and thrips
- **Pests of Export Concern and MRLs**
 - South Korea
 - Australia/New Zealand

Pests of Export significance – reduction in MeBr use requires in-field treatments

S. Korea

Fuller rose beetle

California red scale



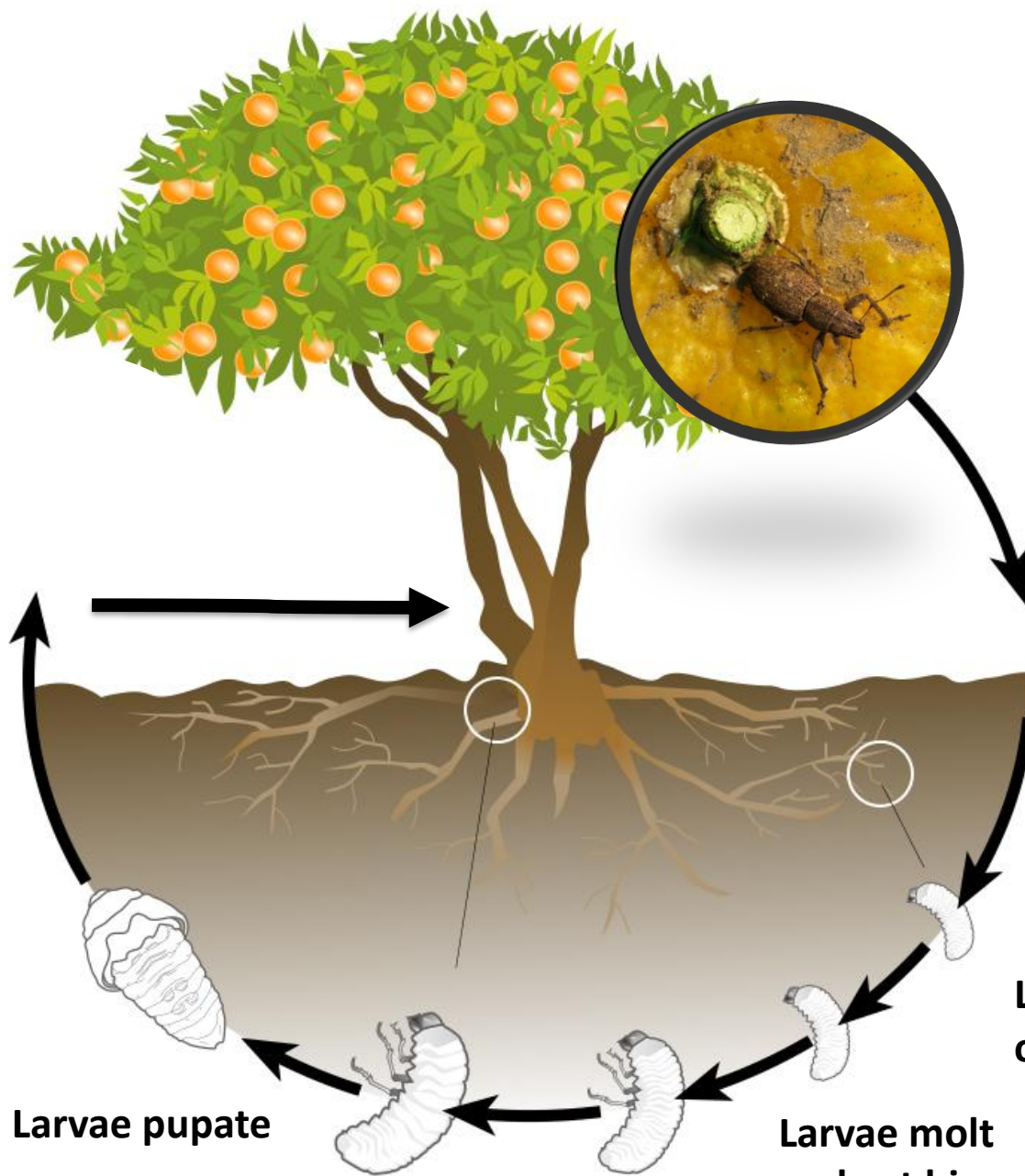
Australia & New Zealand

Bean thrips

Mites



**Adult
emerges and
climbs up the
tree**



**Eggs laid
under the
sepals**

**1st instar
larvae drop to
the ground**

**Larvae feed
on roots**

**Larvae molt
and get bigger
9 months**

Larvae pupate

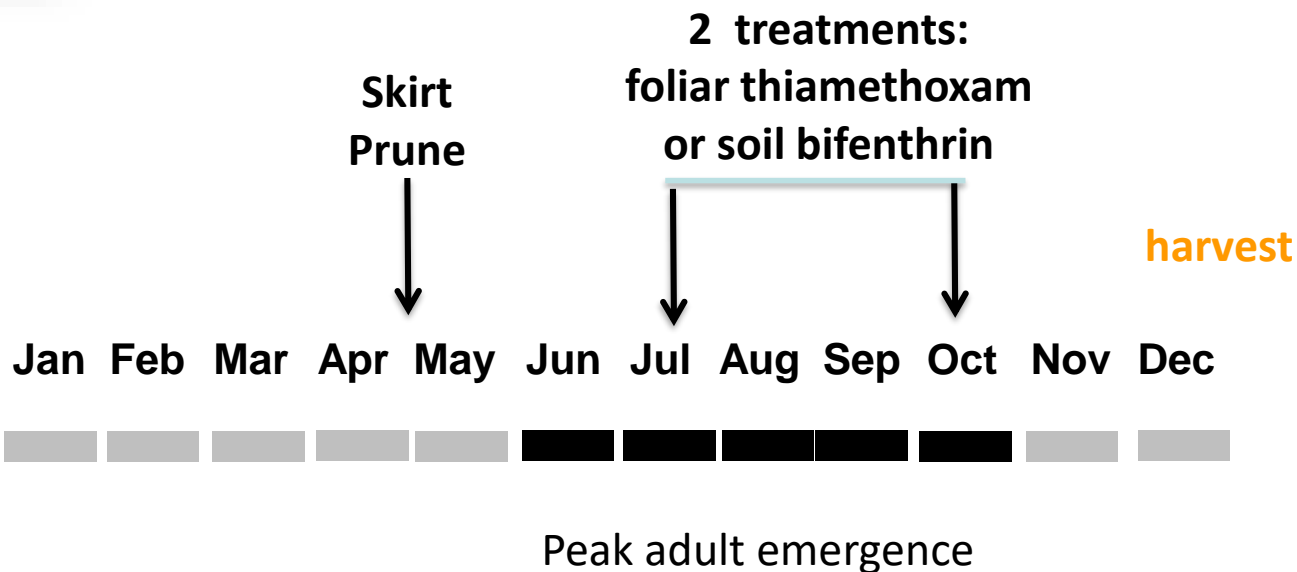
Protocol to ship to S. Korea: Fuller rose beetle



Eggs deposited under the calyx of fruit

Larvae/pupae in the ground.

Adults emerge year round and climb trees





Growers eliminate groves from Korean export if they find high numbers of adult beetles using a beating sheet



Orchards are also checked for FRB eggs prior to harvesting, using a metal tool to lift up the sepals and look for eggs.



Live eggs

– whitish or yellowish
and plump



Dead or hatched eggs

– dried out

Issues that are game-changers for citrus IPM

- **Weather**
 - Dry conditions promote red scale and thrips
- **Pests of Export Concern and MRLs**
 - South Korea
 - Australia/New Zealand
- **Invasive Pests**

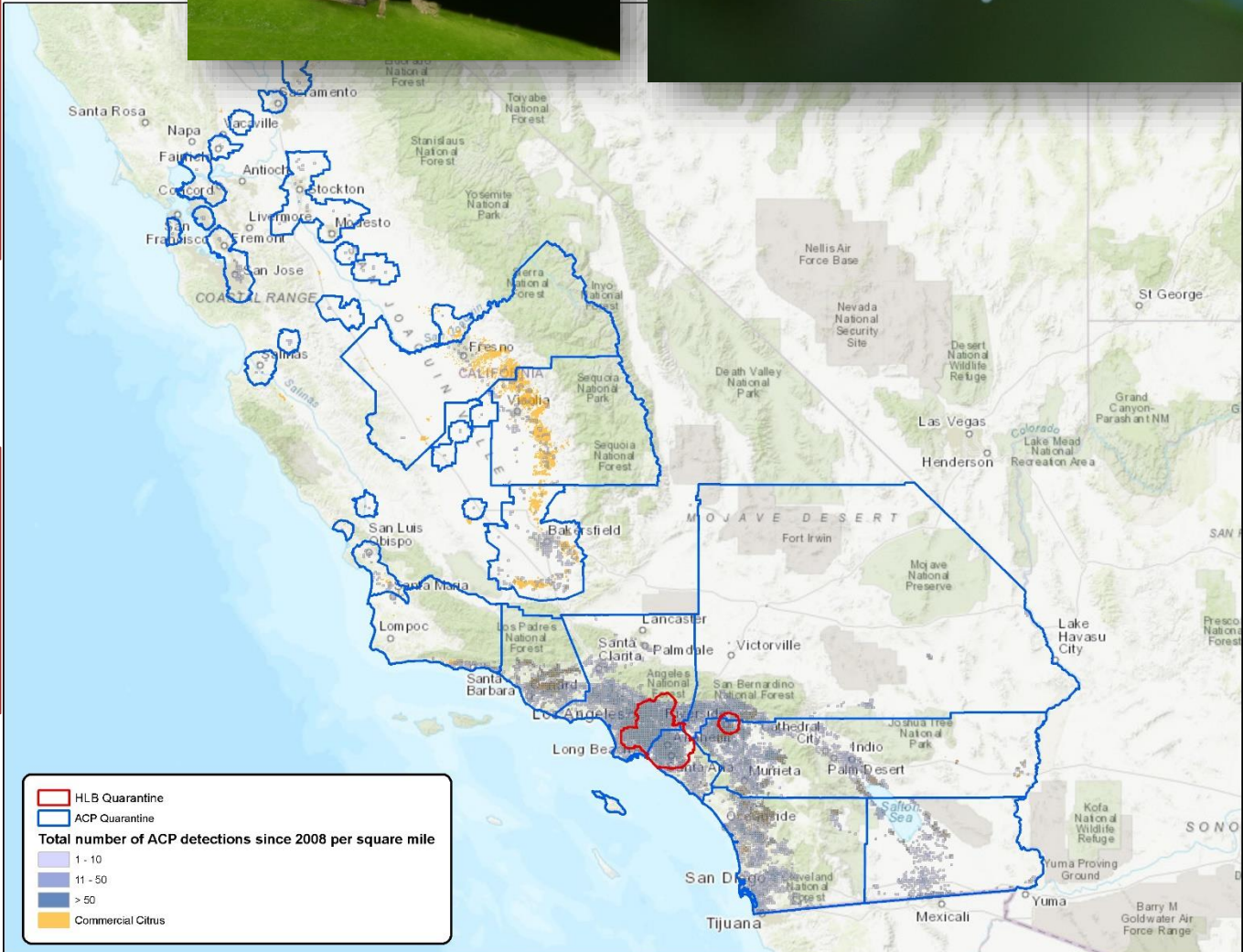
The California Situation

Goal: reduce psyllids to reduce the spread of disease

<http://ucanr.edu/sites/ACP/>

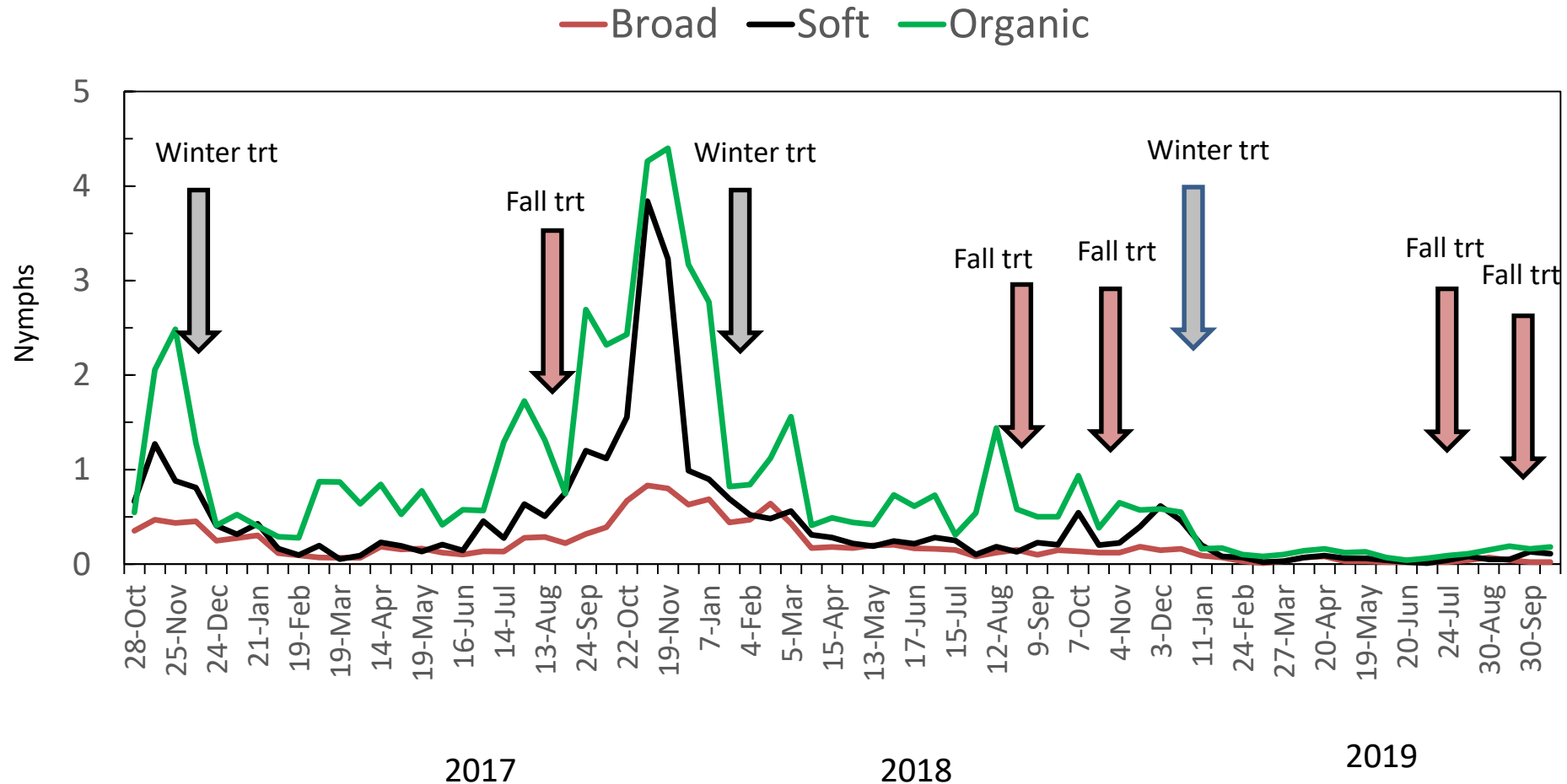
Central/Northern CA:
Eradicative/ Coordinated
Treatments – treat find sites
with two insecticides
Commercial citrus: 800 meters
or coordinated treatments
Urban: 400 meters

Southern California:
Area-wide treatment program
Commercial citrus: Growers
treat together over a 2-3 week
window (early winter & fall)
Urban: parasites released



Average of 44 Ventura Sites by Management Strategy

Nymphs per Flush



Broad: pyrethroids, imidacloprid, thiamethoxam, flupyradifurone, OPs

Soft: spinetoram, spirotetramat, cyantraniliprole, abamectin

Organic: pyrethrins, spinosad, Oil, kaolin

<https://ucanr.edu/acpmap>

2012

1665 HLB-infected tree removals
from residences

HLB Quarantine

ACP Quarantine

HLB Detections (Trees)

1 - 5

6 - 50

> 50

HLB Detections (Psyllids)

1 - 5

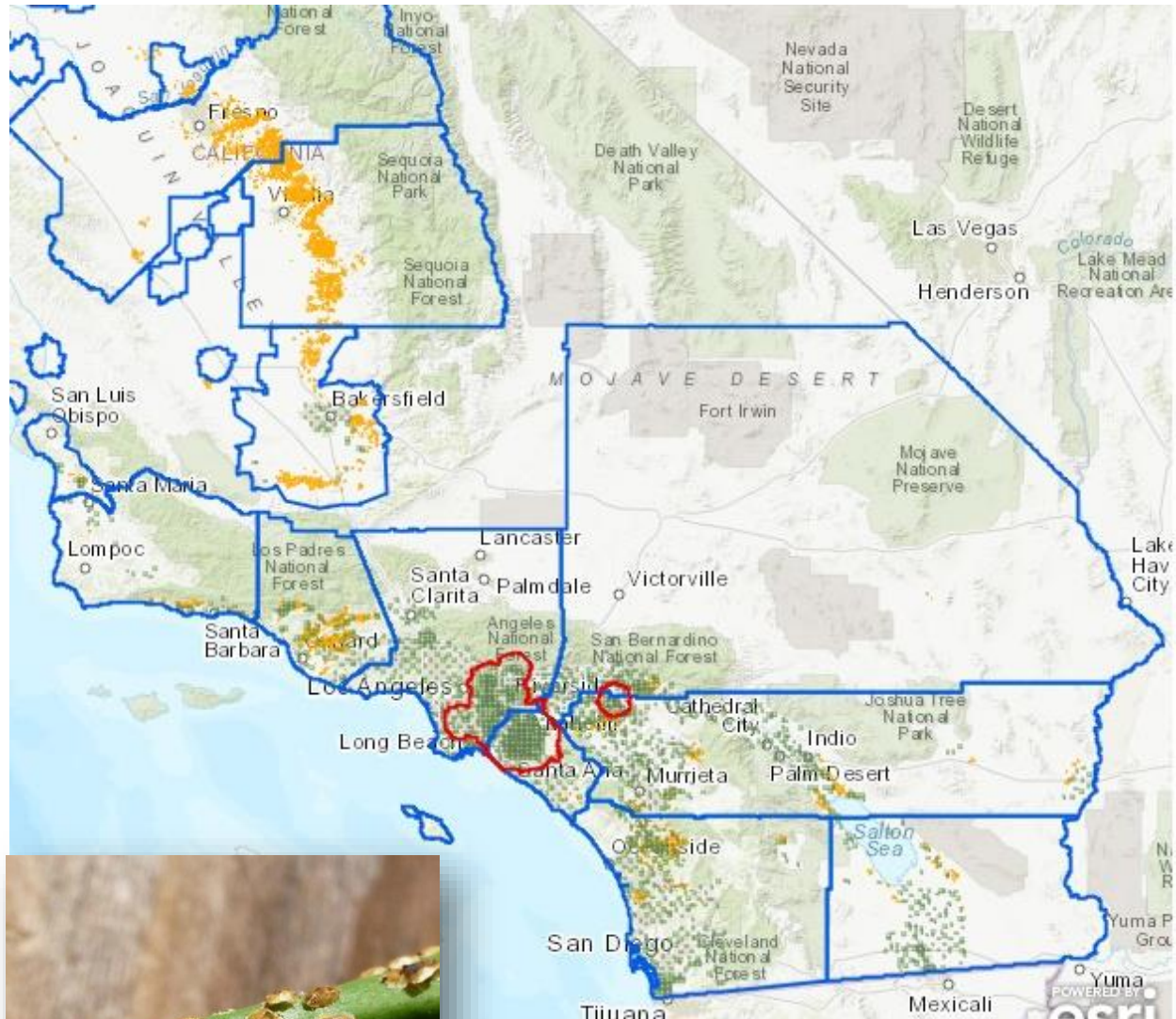
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Commercial Citrus

Tamarixia radiata parasite releases



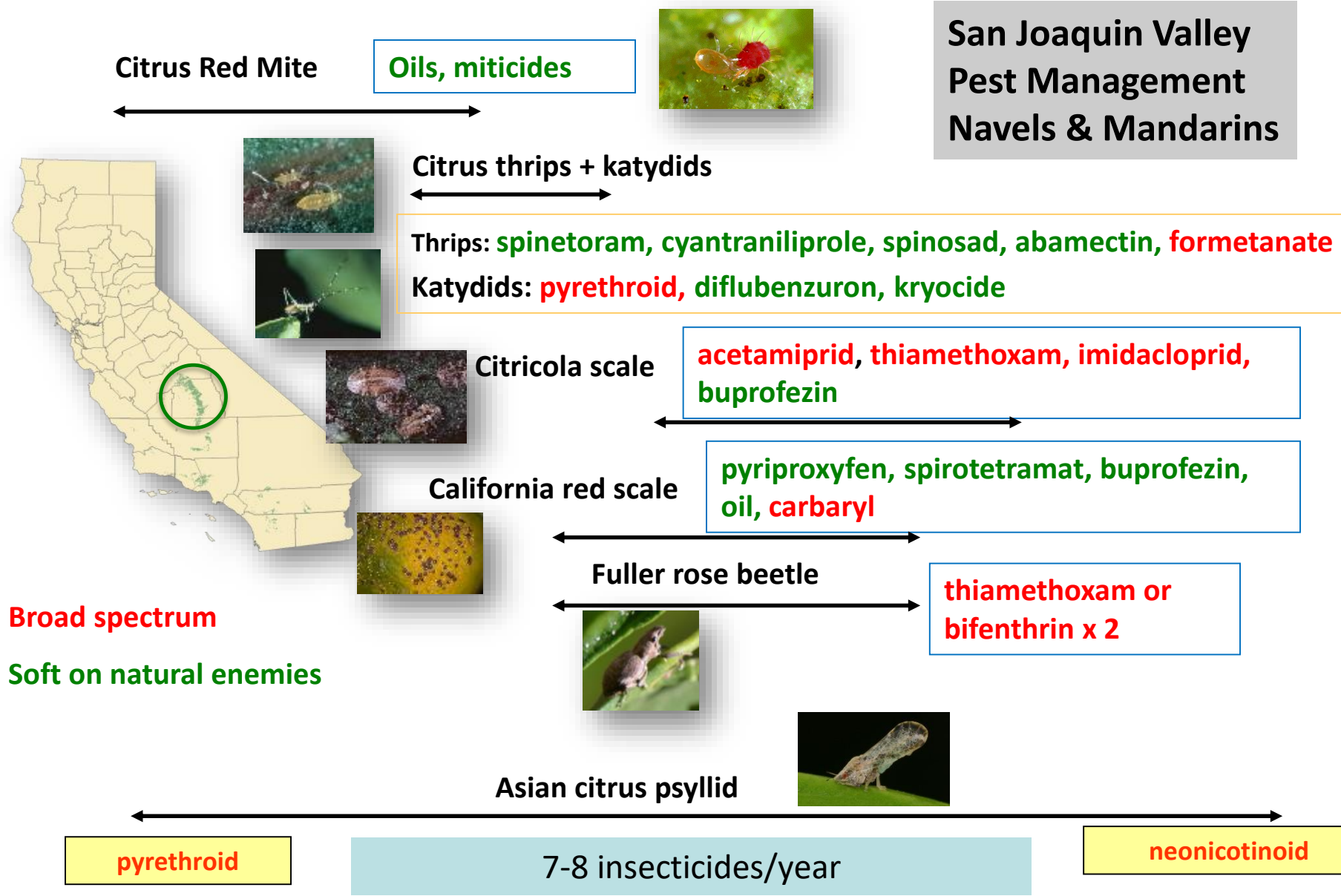
USDA/UC Releases have been successful, the parasites are spreading – however parasitism is not enough to prevent disease spread.



www.ucanr.edu/sites/acp

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**San Joaquin Valley
Pest Management
Navels & Mandarins**





Science for Citrus Health

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Background

Research Snapshots

- General Topics

- Early Detection Techniques (EDT)

- Disease Management

- Psyllid Management

- Tools

Outreach Resources

Contact Us

Research Snapshots



We have developed short, descriptions of research projects that aim to help in the fight against HLB. These projects include traditional breeding and genetic engineering to create resistant citrus varieties, psyllid modification, using other organisms to deliver HLB-resistance genes, and early detection of the bacterium in trees. Click on the links below to explore Science for Citrus Health.

- Available
- In progress

Research Snapshot Categories



General Topics

New genome editing technologies - CRISPR

Drs. Peggy Lemaux, Becky Mackelprang (UC Berkeley) and Elizabeth Grafton-Cardvill (UC Riverside). Updated 12/20/18.

Genes, Genomes and Genetic Engineering in Citrus

Drs. Peggy Lemaux (UC Berkeley) and Elizabeth Grafton-Cardvill (UC Riverside). Updated 12/20/18.

How is the HLB-associated bacterium detected in citrus trees and Asian citrus psyllids?

Dr. Greg McCollum, USDA, ARS, Fort Pierce, FL. Updated 7/24/18.

The value of early detection technologies (EDTs) for HLB management

Dr. Neil McRoberts, University of California, Davis. Updated 6/4/18.

Early Detection Techniques

● Starch accumulation sensor for early detection of HLB

Dr. Alireza Pourreza, Department of Biological and Agricultural Engineering, University of California, Davis. Updated 6/21/18.

The value of early detection technologies (EDTs) for HLB management

Dr. Neil McRoberts, University of California, Davis. Updated 6/4/18.

SHARE PRINT



Metabolite changes in the tree can help detect Huanglongbing

Research by Dr. Carolyn Slapley, University of California, Davis
Article written by Carolyn Slapley, Elizabeth Cho, Elizabeth Grafton-Cardvill, Peggy Lemaux, & Lukasz Stoklosa
Revised July 24, 2017. <https://ucanr.edu/sites/scienceforcitrushealth/>

What is the technique?

Metabolism is all of the processes an organism carries out in order to stay alive. There are two types of molecules involved in an organism's metabolism: proteins and small molecular weight chemicals called *metabolites*. These molecules change in abundance when the metabolism of a living organism, such as a human, insect, or tree, is altered. Measuring these molecules provides a 'snapshot' of an organism's metabolism. During infection, an organism's metabolism is busy responding to the pathogen, so it works to protect itself. Thus, the 'metabolite profile' is different for healthy versus infected organisms. Carolyn Slapley is developing methods to measure metabolite profiles of citrus trees, and to identify one that indicates early CLas (the bacteria that causes HLB) infection.

How can metabolites be used to identify infected trees?



A single leaf, clipped from a tree of citrus infected with CLas, can be used to identify the resulting infection. The leaf is analyzed by NMR to measure metabolite concentrations. Some metabolites are higher and some are lower in infected leaves than in healthy leaves. The NMR spectrum is then compared to that of infected and healthy leaves.

Early detection of CLas infection is critical for infected citrus trees and reducing HLB response to CLas occurs throughout infection, even before symptoms of HLB fruit or roots. The changes in metabolites measured and used to identify infected trees is a technique called ¹H NMR (proton magnetic resonance spectroscopy) to measure these changes in a tree and ground, and metabolites specific chemicals. The resulting extra and the output, called a 'spectrum', is an NMR spectrum. Each spectrum has many peaks, and of peaks corresponds to specific metabolites (e.g., glucose and sucrose), and

ing blocks of proteins), and other small molecules. The area under each peak provides information about the metabolite concentration, so the pattern of metabolite peaks during CLas infection defines the metabolite profile (Fig. 1). Metabolite profiles of unknown leaf samples can be compared to known profiles of CLas infected and non infected leaves. Then, unknown leaf samples can be categorized as infected or non infected. This method, requiring only one leaf per tree, allows for rapid and noninvasive sampling.

Who is working on this project?

Carolyn Slapley, a Professor in the Department of Food Science and Technology at the University of California, Davis, and her research team are using these methods to establish and validate metabolite-based markers for early detection of HLB.

What are the challenges and opportunities?

The main challenge is field validation, because truly healthy, non-CLas infected trees are not guaranteed in the field if the psyllid vector is present. However, this method has been successful in correctly identifying CLas-infected field trees in trees, and more field trials using screen-protected healthy control trees are underway. Preliminary data shows that the metabolite profiles of leaves infected with citrus tristeza virus (CTV), canker, or citrus stubborn infections are different from the metabolite profile of leaves infected with CLas. Although sampling is as easy as clipping one leaf from a tree, analysis of the NMR spectrum is currently a bottleneck.



Canines can detect trees infected with the bacterium that causes huanglongbing

Research by Dr. Tim Gottwald, USDA-ARS, Fort Pierce, Florida
Article written by Tim Gottwald, Holly Denison-Shields and Beth Graham-Cardwell
Revised June 12, 2018. <https://ucanr.edu/sites/scienceforcitrushealth/>

What is the technique?

Canines have a highly sensitive scent detection capability that is significantly better (parts per trillion) than most laboratory instruments and they can be trained to "alert" (either sit or lay) when they detect specific "smells" (known as scent signatures). Most people are familiar with their ability to detect bombs, drugs, and plant material at airports. However, canines are also used to detect human pests, such as bed bugs, and agricultural pests, such as stink bugs, date palm weevils and imported fire ants. With regard to agricultural pathogens, canines have been shown to detect with greater than 98% accuracy the fungal pathogen that causes leafy disease in avocado, the bacterium that causes citrus canker disease in citrus, and plum pox virus in peach orchards.

Researchers have been training and evaluating the efficacy of canines for detecting "Candidatus Liberibacter asiaticus" (CLas), the bacterium that causes huanglongbing (HLB), for 5 years in Florida, and CLas detection efforts with canines have recently begun in California. Dogs have been trained in both the laboratory environment and in the field. Researchers have demonstrated that well-trained canines can detect CLas over 95% of the time in commercial trees and over 92% of the time in residential trees. Researchers did not observe any differences in canine performance between citrus species and varieties. The training that the canines receive is very specific to CLas. When they are taken into citrus orchards infected with Citrus tristeza virus, viridula, the fungal pathogen Phytophthora, or the bacterium that causes citrus stubborn, the CLas-trained canines do not respond to these diseases.



The canines provide a significant opportunity to be used as an Early Detection Technology (EDT) in California. In a field study using potted citrus in Florida, dogs could detect CLas in some of the trees as early

as 2 weeks after CLas-infected psyllids fed on the trees. In contrast, it can take 1-2 years for CLas to distribute itself in a mature citrus tree sufficiently for the bacterium to be present in sampled leaves, which are then tested and shown to be infected using laboratory techniques, such as Polymerase Chain Reaction (PCR). Using canines to detect early infections could significantly help reduce disease spread in California, where HLB is currently limited to southern areas of the state and identify areas where increased psyllid control measures are needed.

Who is working on the project?

Dr. Tim Gottwald, Research Leader and Epidemiologist at the USDA, U.S. Horticultural Research Laboratory in Fort Pierce, Florida, and additional collaborators with FHRI laboratories, USDA, North Carolina State University, Texas A&M University and the California Department of Food and Agriculture.

What are the challenges and opportunities?

The volatile scent signature associated with CLas infection settles from the canopy and simultaneously emanates from root infections pooling at the base of the tree. The detector dog interrogates the tree holistically by alerting in seconds on the scent signature regardless of its origin (i.e., a single leaf, root, stem or the entire tree if systemically infected). Conversely, other detection technologies, like PCR, are reliant on selecting and processing a small amount of tissue from large trees and often miss incipient infections because infected tissue is so rare in newly infected trees. Early detection via dogs is devoid of these sampling issues. Therefore, it is difficult to confirm CLas detections by dogs using currently available molecular or chemical detection methods. Dogs have been tested in hot and cold temperatures and with wind speeds up to 20 MPH with no perceptible degradation in detection.

Human scouts require several minutes per tree to visually examine it for symptoms, then they must collect tissue which must be transported to a diagnostic lab for processing and analysis, which is time consuming and labor-intensive. Whereas, in a residential environment dogs can assess all trees in even large yards in a couple of minutes. The major limitation to the number of trees a dog can assess per day is access to these residential properties and the time required to relocate from property to property. In commercial groves a team of two dogs and one handler can survey a 10-acre planting (~1500 trees) in 1-2 hours depending on the number

Goals of California Citrus IPM

Manage pests in a way that is economical and sustainable. Minimize broad spectrum pesticide use to maximize natural enemies. Address pesticide resistance, worker safety, bee health and environmental issues.

Biggest issues affecting the citrus IPM program:

- **Weather changes**
- **Export Issues**
- **Invasive Pests**
- **Availability of pest control tools and pesticide resistance**