# Evaluating Asian Chestnut Gall Wasp and Developing an Integrated Management Strategy

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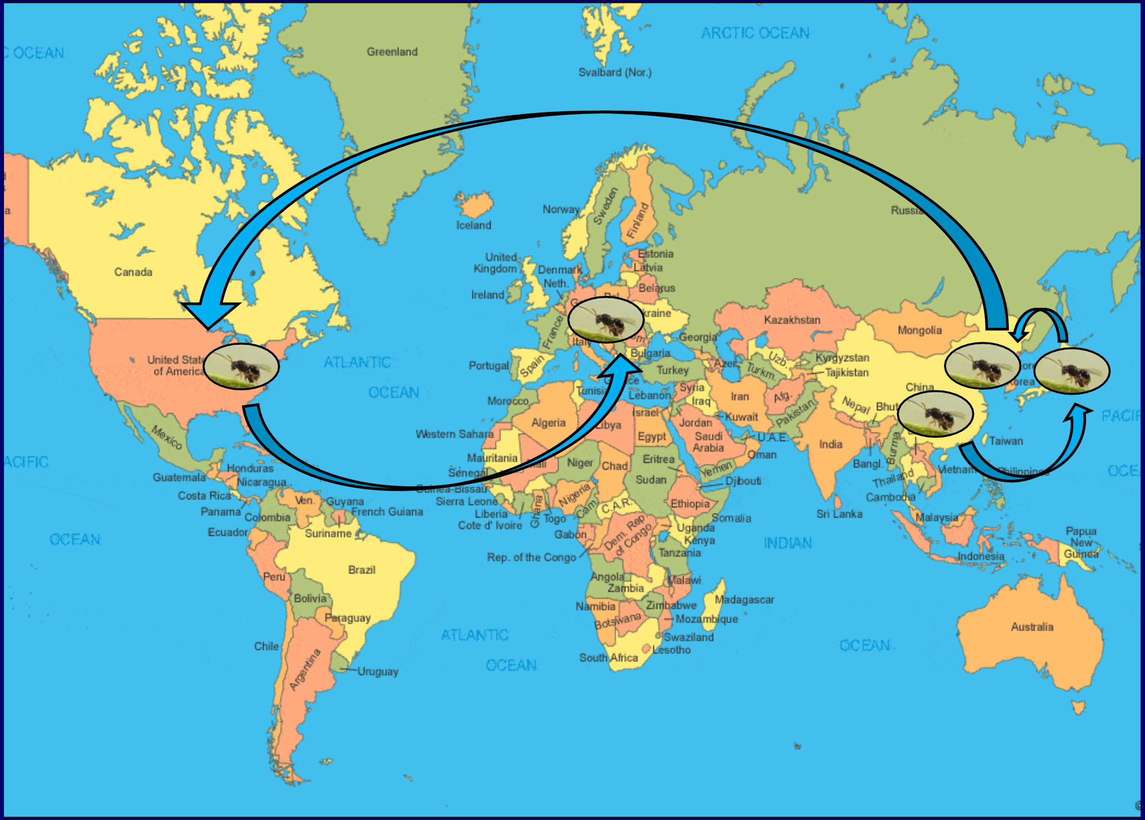
# Asian chestnut gall wasp - *Dryocosmus kuriphilus* Yasumatsu (Hymenoptera: Cynipidae)

## Invasion History

- Native to China
- Japan 1941
- Korea 1961
- United States 1974
- Europe 2002



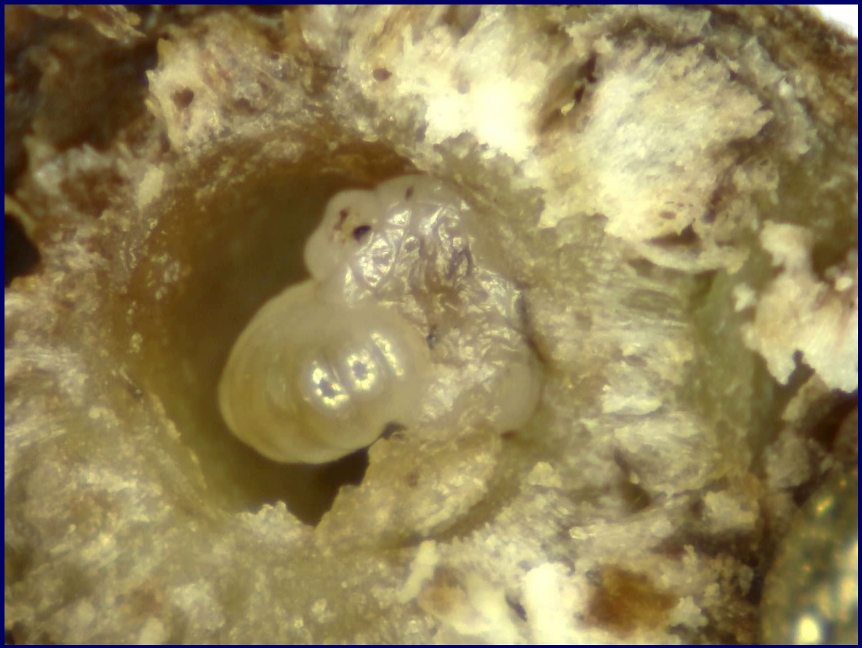
# Asian Chestnut Gall Wasp

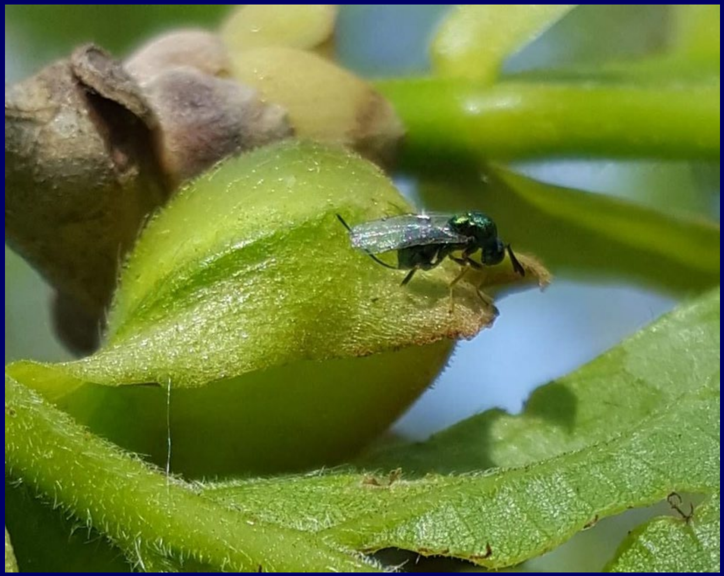
## Life Cycle

- Parthenogenic
- Univoltine
- Fall: Adults oviposit in buds
- Winter: 1st instar larvae overwinter in buds
- Spring: Larval feeding induces galls
- Summer: Adults emerge & lay eggs

# ACGW classical biocontrol with *Torymus sinensis*

- *Torymus sinensis* was first released in 1975 in Japan for ACGW biocontrol
- Phenologically synchronized with ACGW
  - Adults emerge in early spring as galls are forming
  - Lay 1 egg on an early instar ACGW larva (in gall)
  - *T. sinensis* larvae feed on ACGW larvae
  - Pupate in late winter; remain in galls all winter



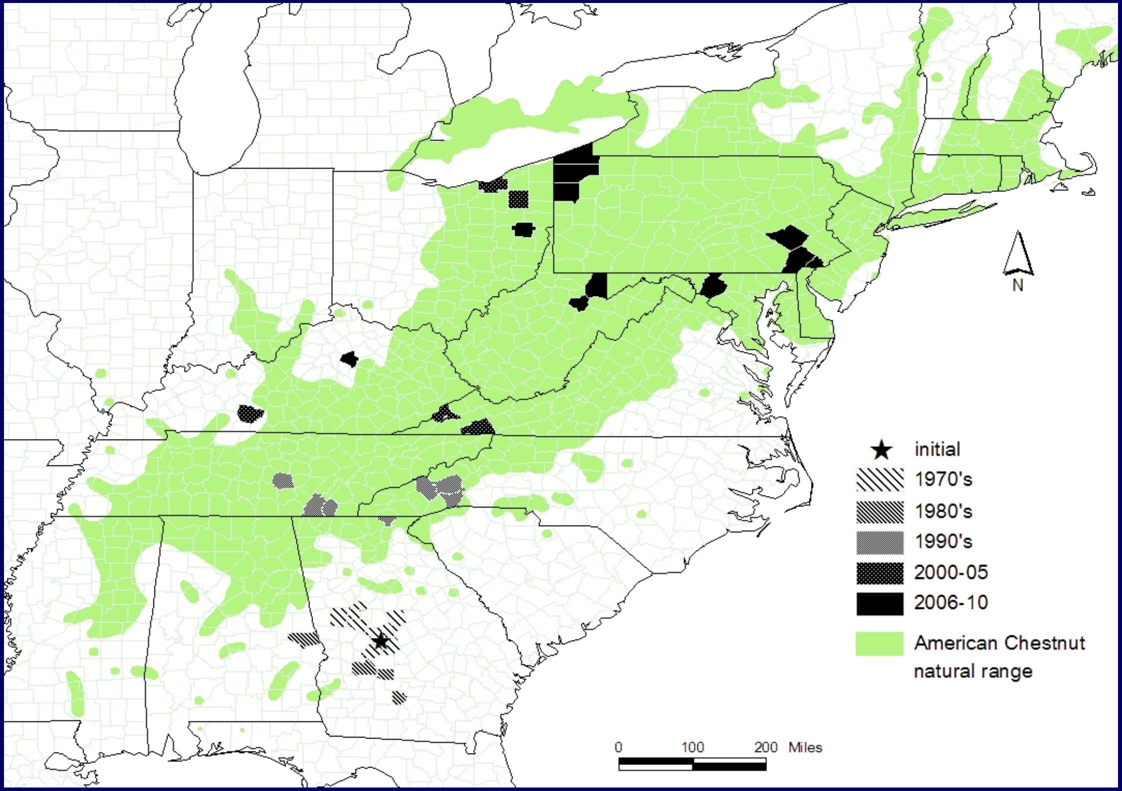


# Asian Chestnut Gall Wasp Spread

- Natural dispersal - flight
  - Short range
  - Wind-aided
- Artificial dispersal
  - Chestnut cuttings
  - Scion wood
  - Nursery trees

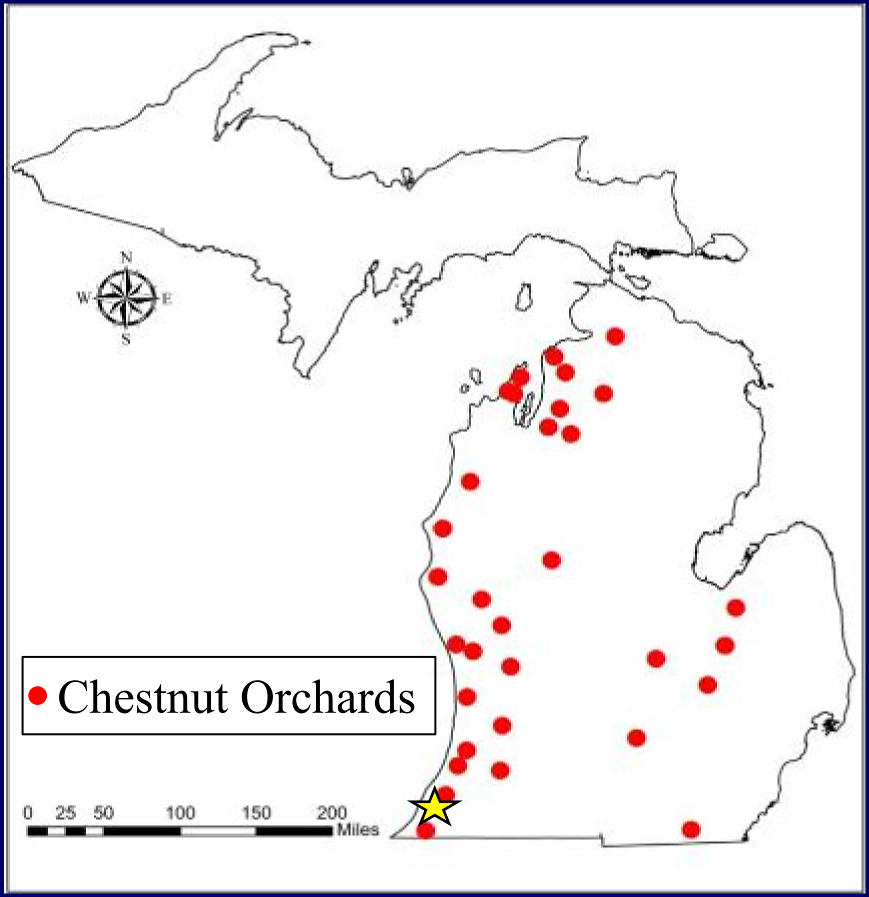
# ACGW in the United States

- First detected in Georgia in 1974 & was established in 11 other states by 2012
- Native parasitoids occasionally observed in galls
- *T. sinensis* parasitoid first released in Georgia in 1977



# ACGW in Michigan

- First Michigan detection was in 2015 in Berrien County
- By spring 2018, 10 chestnut orchards were infested, all within 45 miles of the first ACGW detection.




Locations in red represent 32 of at least 115 commercial chestnut orchards

# Asian Chestnut Gall Wasp

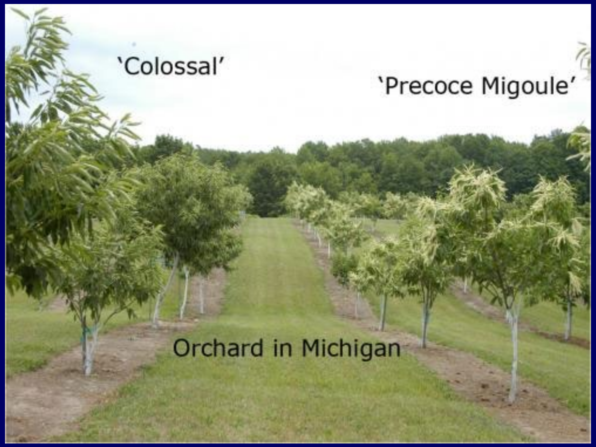
Damage Caused by ACGW

- Galls form on leaves & shoots
- Shoot growth & leaf area reduced
- Apical galls prevent flower & burr production

Yield Loss
$$$

# Current ACGW Management Options

- Insecticide cover spray – effectiveness often limited; drift & non-target impacts can be problems
- Prune & destroy infested shoots - labor intensive, can result in major yield loss
- Resistant cultivars – some promise, ACGW adaptation; only relevant for new plantings
- Classical biocontrol with the *Torymus sinensis* parasitoid from China




# Why Study ACGW in Michigan?

- Harsh climate
- New invasion
  - ACGW spread
  - *T. sinensis* spread
  - Native parasitoids?
  - Invasion biology, spread, population dynamics

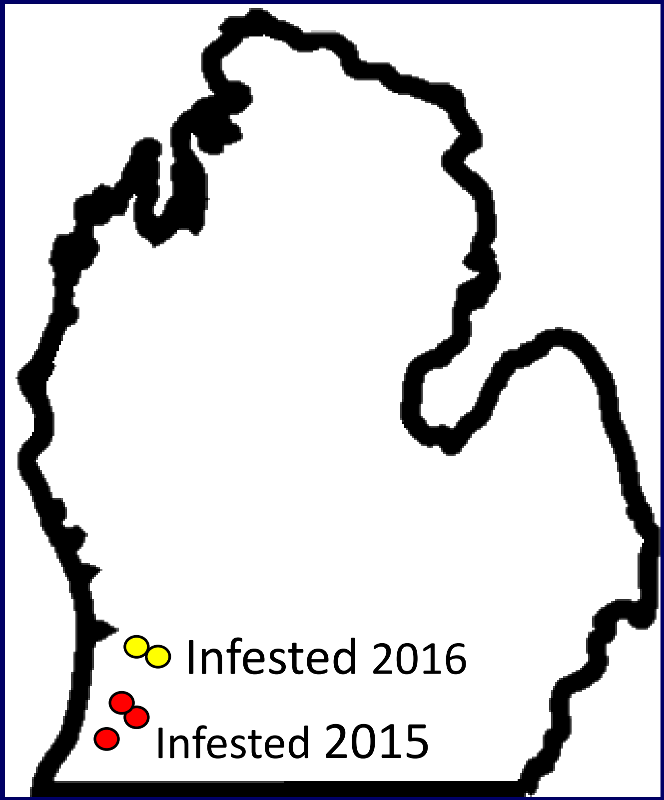

# Objectives

- Monitor phenology of chestnut trees & ACGW; Relate key stages to cumulative degree days (base 50 F)
- Quantify gall densities on selected chestnut cultivars & relate to shoot growth & burr production
- Evaluate parasitism: *Torymus sinensis* presence & rates
- Evaluate systemic insecticides: assess control of ACGW & persistence in selected chestnut tissues
- Assess spatial and temporal dynamics of ACGW & the *T. sinensis* parasitoid in commercial orchards in southwest Michigan.

# Study Sites - 2017

- 5 infested chestnut orchards
- Size ranged from 0.8 acres to 8 acres
- Sites located within 36 miles of each other
- Up to seven cultivars available for study

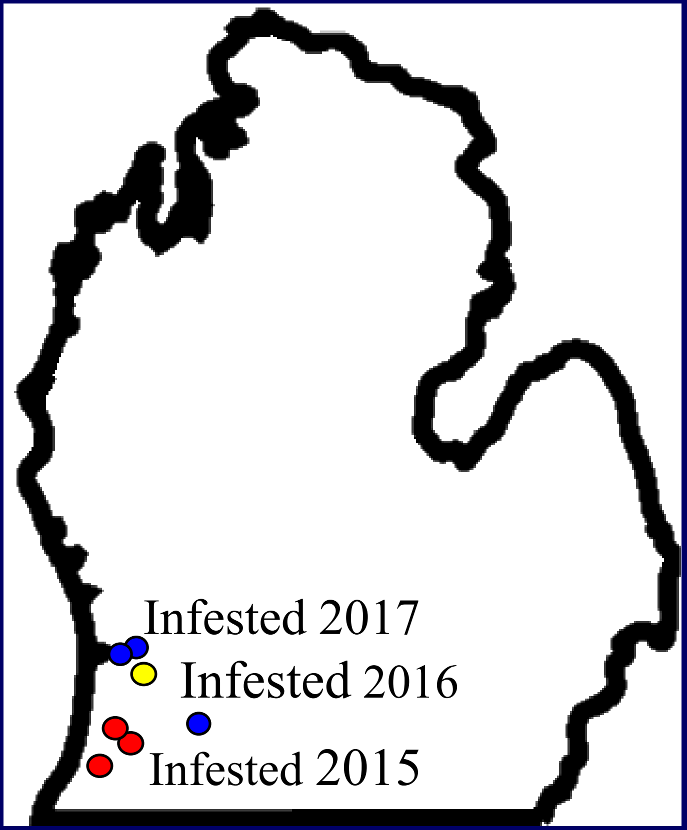
| Site | Species | Infested |
|---|---|---|
| 1 | Chinese, Euro x Japan, Korean | 2015 |
| 2 | Chinese | 2015 |
| 3 | Chinese, Euro x Japan | 2015 |
| 4 | Chinese | 2016 |
| 5 | Chinese | 2016 |



# Study Sites - 2018

- 7 infested chestnut orchards
- Size ranged from 0.7 acres to 6.3 acres
- Sites located within 52 miles of each other
- Up to seven cultivars available for study

| Site | Species | Infested |
|---|---|---|
| 1 | Chinese, Euro x Japan, Korean | 2015 (red) |
| 2 | Chinese | 2015 (red) |
| 3 | Chinese, Euro x Japan | 2015 (red) |
| 4 | Chinese | 2016 (yellow) |
| 5 | Chinese | 2017 (blue) |
| 6 | Chinese, Euro x Japan | 2017 (blue) |
| 7 | Chinese | 2017 (blue) |



# Chestnut Phenology

- Visually monitored chestnut trees to track developmental stages
  - Bud break
  - Catkin development
  - Pollen development
  - Burr production
- Degree days acquired from MSU Enviro-Weather station at SWMREC (all sites within 45 miles)



# Growing Degree Days Base 50 º F

- Threshold (base temperature) is 50º F. Little or no insect development or activity occurs below 50 º F.
- $DD_{50F}$ = maximum temperature minus the minimum temperature divided by 2, then subtract 50.
- MSU Enviro-weather stations across Michigan calculate cumulative $DD_{50\ F}$ (Baskerville-Emin method).
- Degree days provide a means to track & anticipate development, regardless of calendar date.
- https://enviroweather.msu.edu/

# Chestnut Phenology & Cumulative Degree Days$_{50F}$

| Chestnut Phenology | 2017 $DD_{50F}$ | 2018 $DD_{50F}$ |
|---|---|---|
| Bud Break | 273 | 184 |
| Leaves expanding | 354 to 615 | 238 to 529 |
| 1st evidence of catkins | 354 | 293 |
| 1st evidence of pollen | 948 | 905 |
| Peak pollen | 1048 | 1051 |
| 1st evidence of burrs | 1368 | 1138 |
| Burrs mostly fallen | 2809 | 3047 |

- Early May: Bud break
- Late June: Peak pollen
- Early July: 1st burrs

# Potential Relevance

- Weather varies among years & regions.  Degree days are more reliable than calendar dates.
- Relating developmental stages to degree days means information is applicable to other areas of the state.
- Comparing tree development to ACGW phenology can be useful for timing scouting or control activities.

# Gall Density – Methods 2017 & 2018

- Sites were visited every 2 weeks; mid May to mid July
- 2017: Sampled 2 shoots per tree from 9 to 18 trees per site in (613 shoots total)
- 2018: Sampled 1 shoot per tree from 4 to 40 trees per site (370 shoots total)
- Recorded gall location & density on collected shoots

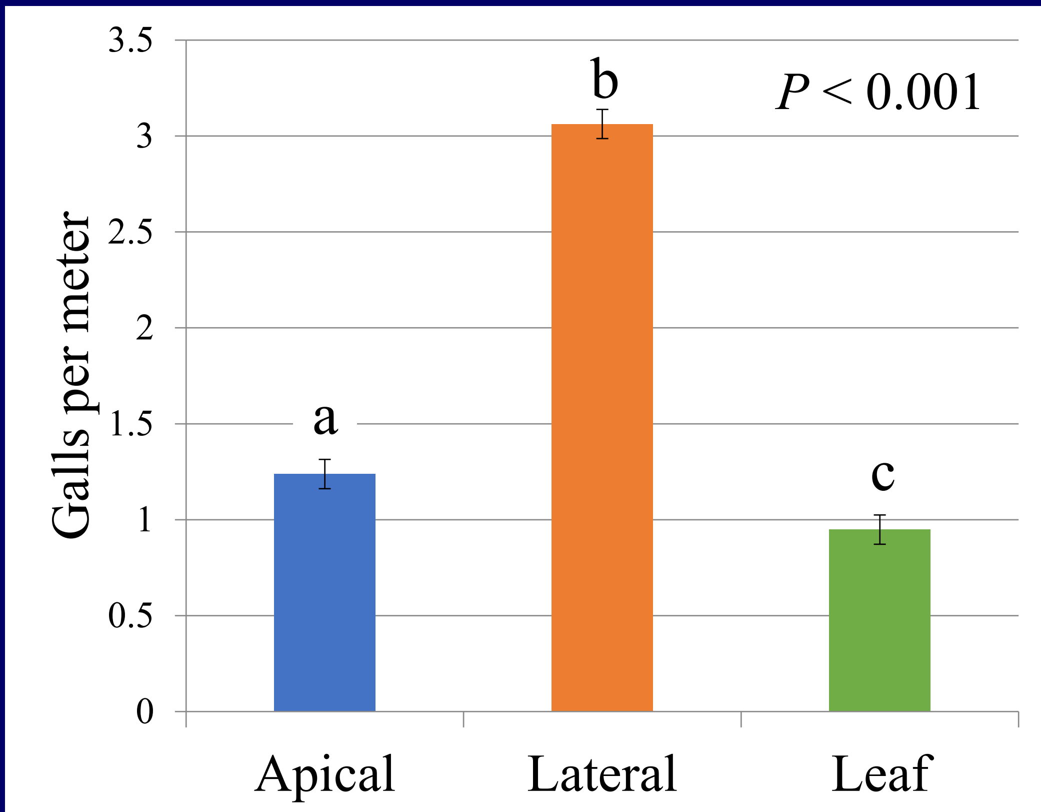
# Gall Location

- Leaf galls
  - Within leaf or petiole
  - Minimal impact on trees

- Lateral galls
  - Along branches
  - May limit lateral shoot production

- Apical galls
  - Ends of branches
  - Potentially most damaging

# Average (± SE) density of current-year galls from 2017 & 2018 by gall location (n = 978 shoots)




Out of 6,488 total galls:

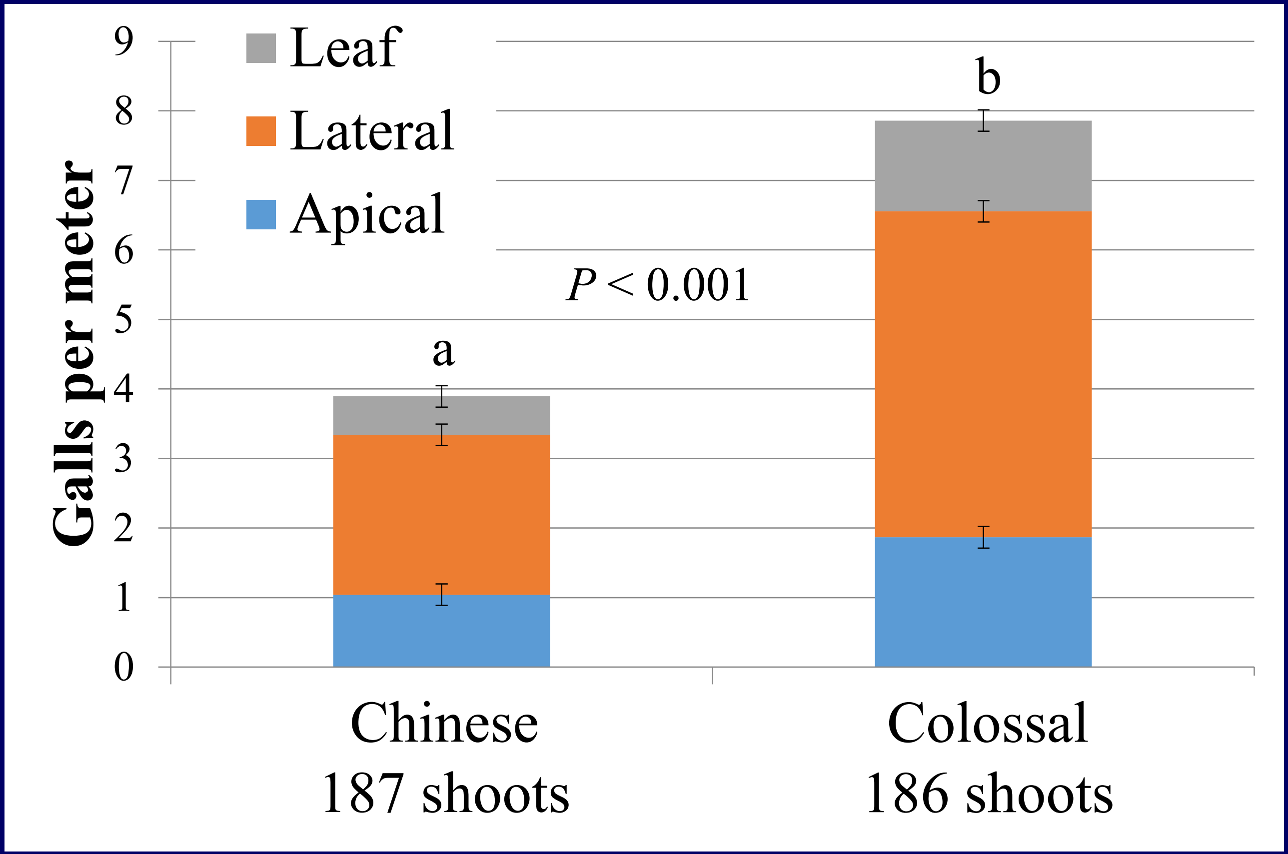
- 23% Apical
- 58% Lateral
- 19% Leaf

# Evaluating relative resistance or tolerance of two common cultivars to ACGW

Colossal Chestnut

Chinese Chestnut

# Average (± SE) Density of Galls by Location on Colossal & Chinese Trees




Lateral Density:
Different
$P < 0.001$

Leaf Density:
Different
$P < 0.001$

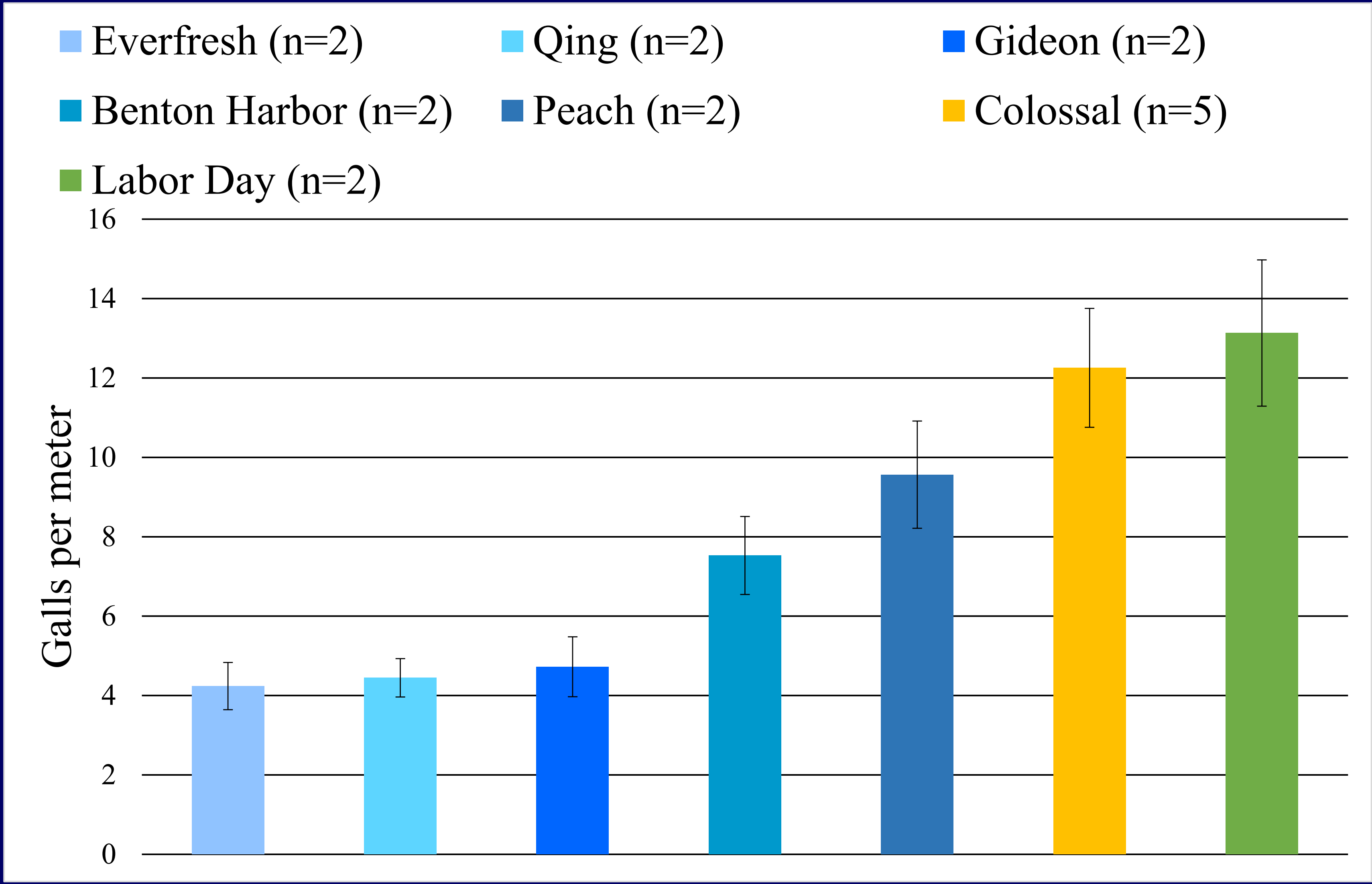
Apical Density:
Different
$P < 0.001$

- Total gall density is lower on Chinese trees
- Density of all gall types is lower on Chinese trees

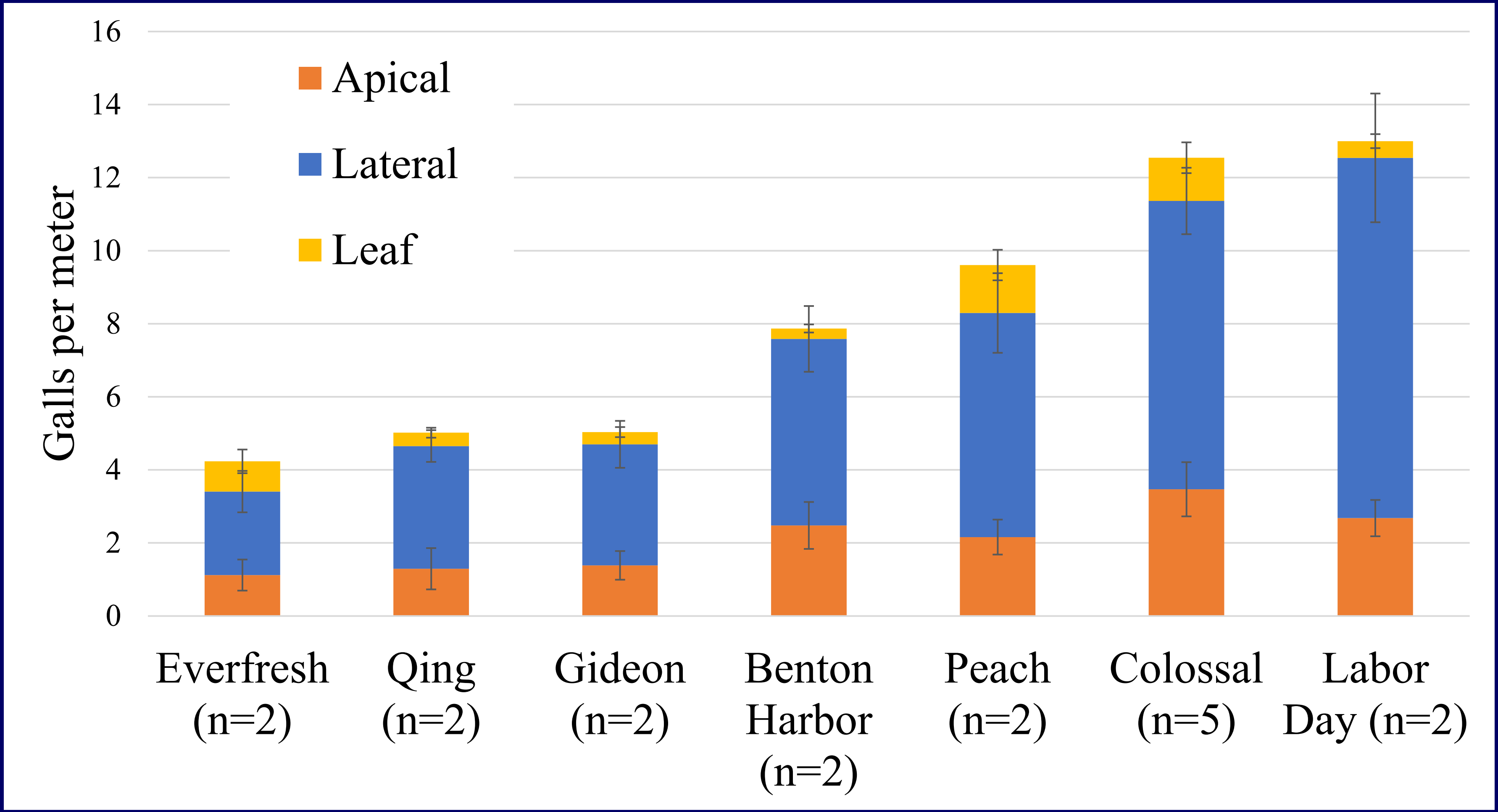
# SWMREC Cultivar Study 2017 & 2018

- 3 species:
  - Chinese (*Castanea mollissima*)
  - European x Japanese (*C. sativa* x *C. crenata*)
  - Korean/Japanese (*C. crenata*)
- 42 cultivars planted – often represented by a single tree
  - Many newly planted or grafted trees
- 7 cultivars with 2-5 mature trees were sampled

# Average (± SE) gall density (galls per meter) on shoots by cultivar



# Average (± SE) density of galls by location & cultivar at SWMREC



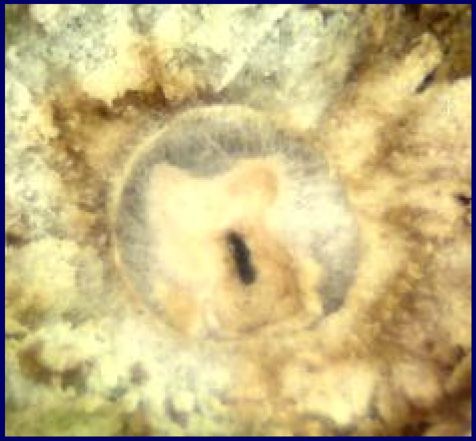
# Gall Dissections

- Randomly selected, measured & dissected galls from collected shoots; Total of 476 galls in 2017 & 395 in 2018
- Recorded gall contents:
  - ACGW life stage
  - Live or dead
  - Chamber condition

ACGW larva

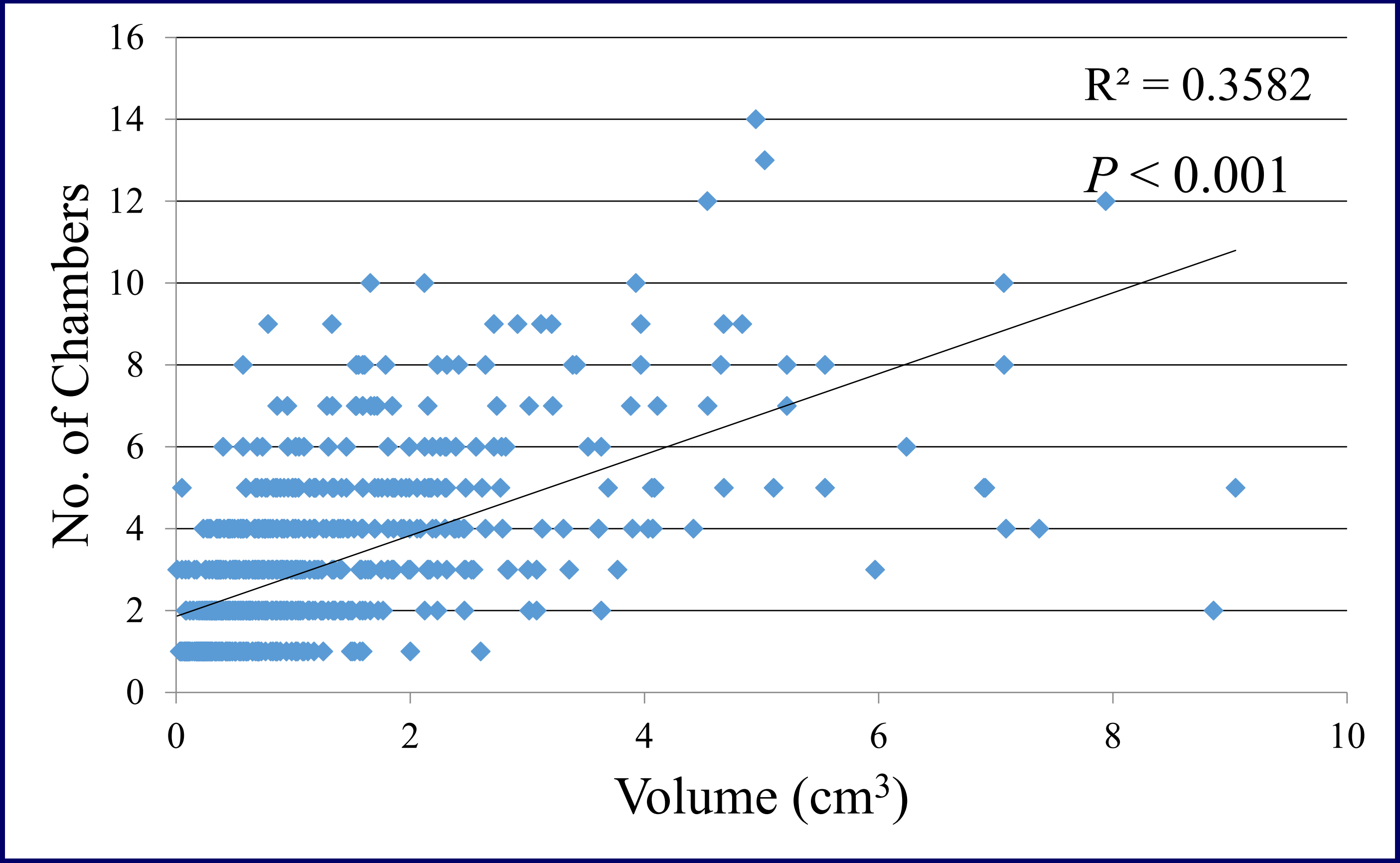
ACGW pupae

Chamber with fungus



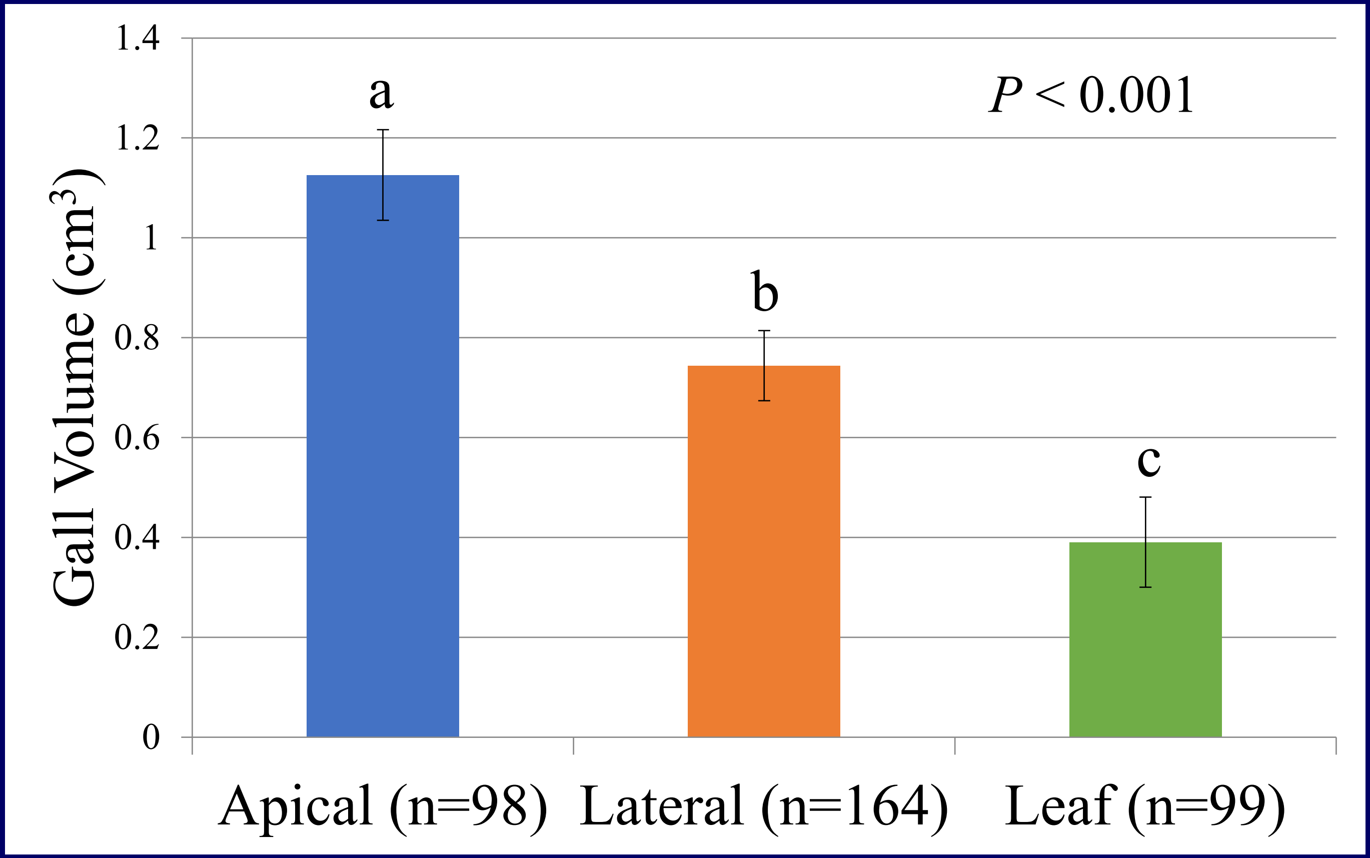
# Gall Volume & Number of Chambers

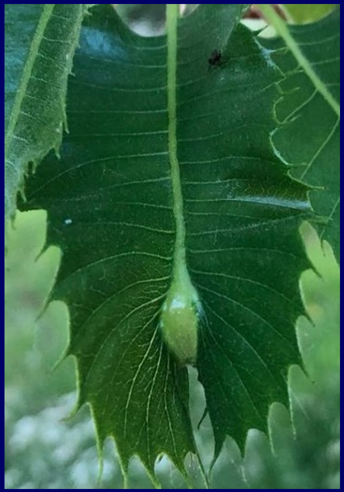
Galls were measured (834), volume calculated & chambers counted. Most (51%) galls had 1-2 chambers, 39% had 3-5 chambers & 10% of galls had > 5 chambers.



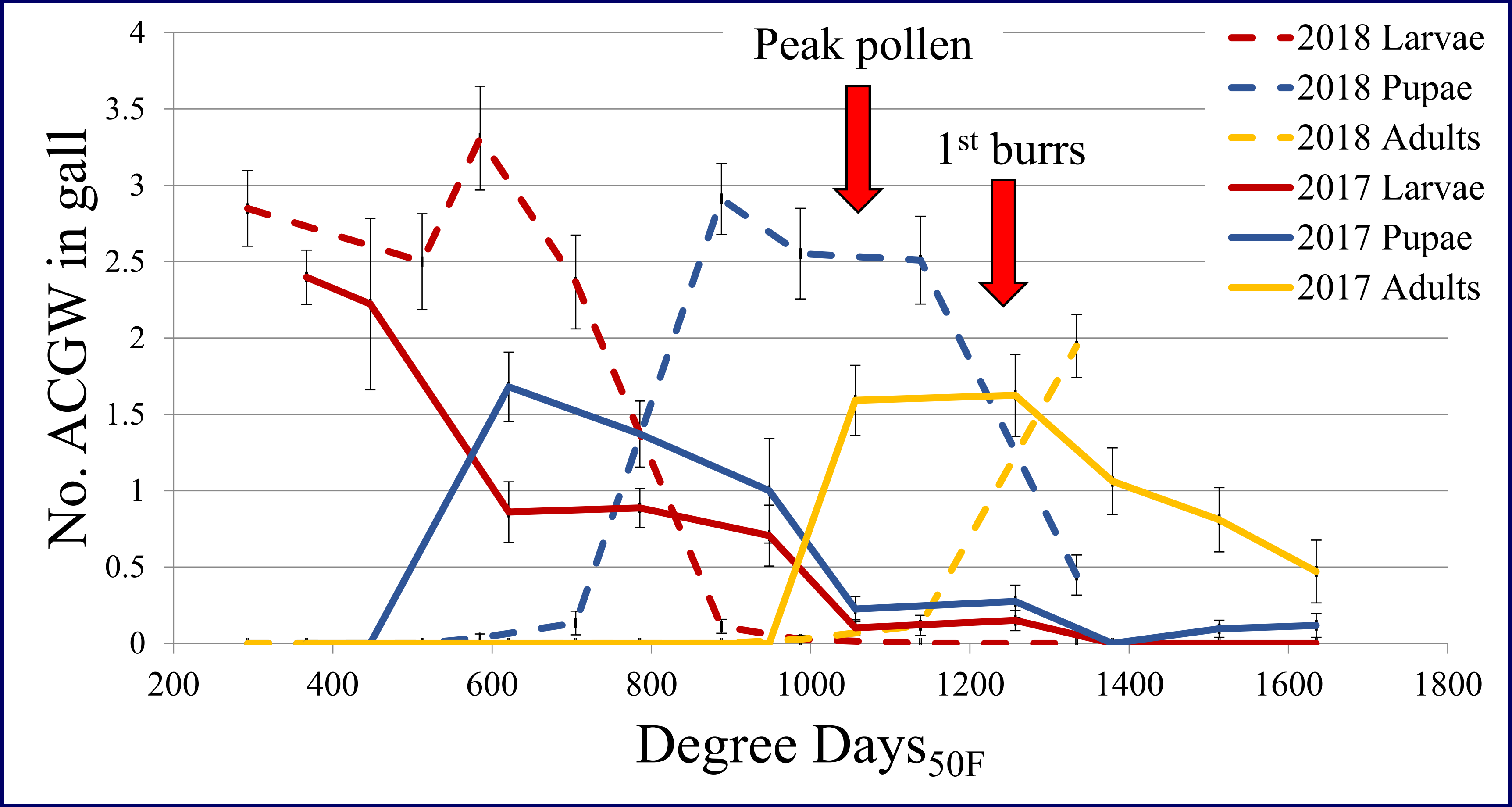

# Gall Volume & Gall Location

Location recorded & volume calculated for 361 galls. Volume ranged from 0.009 $cm^3$ to 8.86 $cm^3$. Only 19% of all the galls had volumes over 1.0 $cm^3$.



# Average (± SE) number of live ACGW in galls by life stage & cumulative degree days

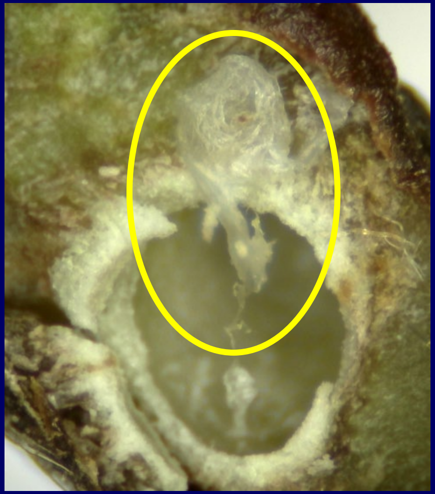



- Larvae: Mid May to early July
- Pupae: Early June to mid July
- Adults: Late June to late July

# ACGW mortality from unknown causes & fungus

| Site | 2017 Death | 2018 Death | 2017 Fungus | 2018 Fungus |
|---|---|---|---|---|
| 1 | 15.8% | 3.5% | 1.5% | 0% |
| 2 | 13.4% | 0% | 3.2% | 0% |
| 3 | 6.4% | 2.7% | 2.1% | 0.5% |
| 4 | 29.7% | | 5.5% | |
| 5 | 23.1% | 2.5% | 7.7% | 2.5% |
| 6 | | 3.5% | | 0% |
| 7 | | 4.1% | | 2.5% |
| 8 | | 2.6% | | 0% |


Dead pupa


Dead larva

# Potential Relevance

- Gall dissections provide information about ACGW seasonal development in relation to calendar date & cumulative degree days.
- Assess differences in development among cultivars
- Quantify mortality rates by life stage.

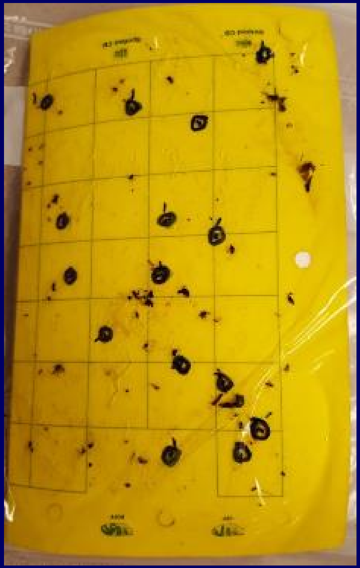


# ACGW Adult Trapping - Methods

Yellow sticky traps were used to capture adult ACGW

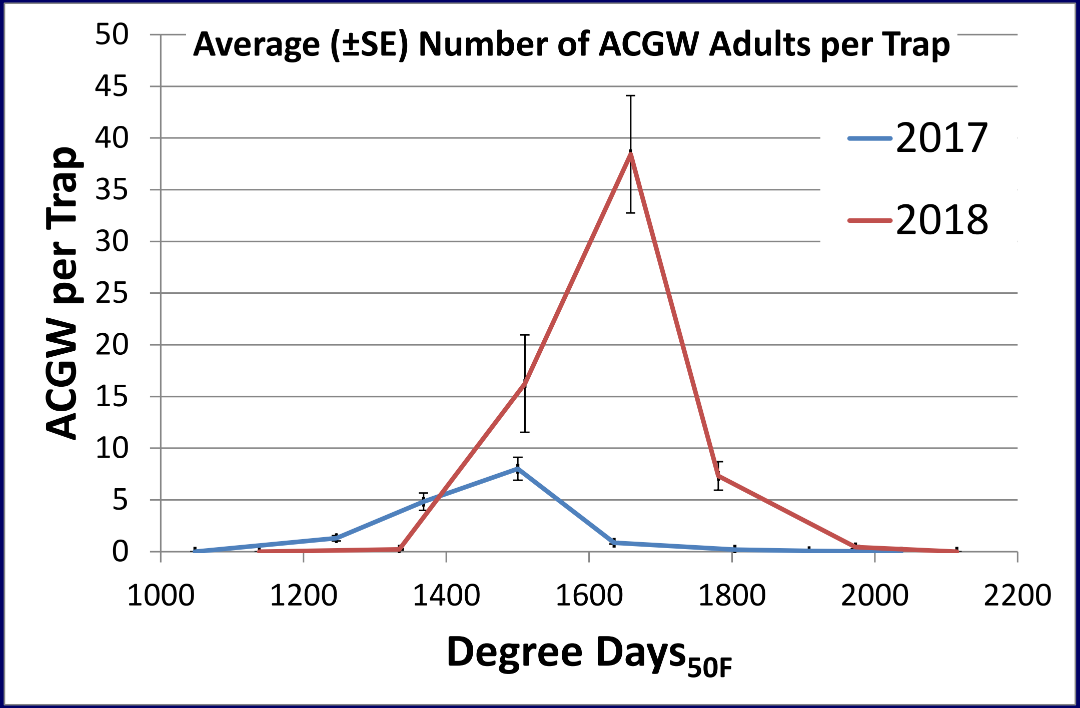
| | 2017 | 2018 |
|---|---|---|
| Sticky traps deployed | 21 June to 15 Aug | 2 July to 8 Aug |
| Trapped at… | 11 sites | 15 sites |
| Traps collected | Weekly | Weekly at 7 sites<br>Bi-weekly at 8 sites |



# ACGW Adult Trapping

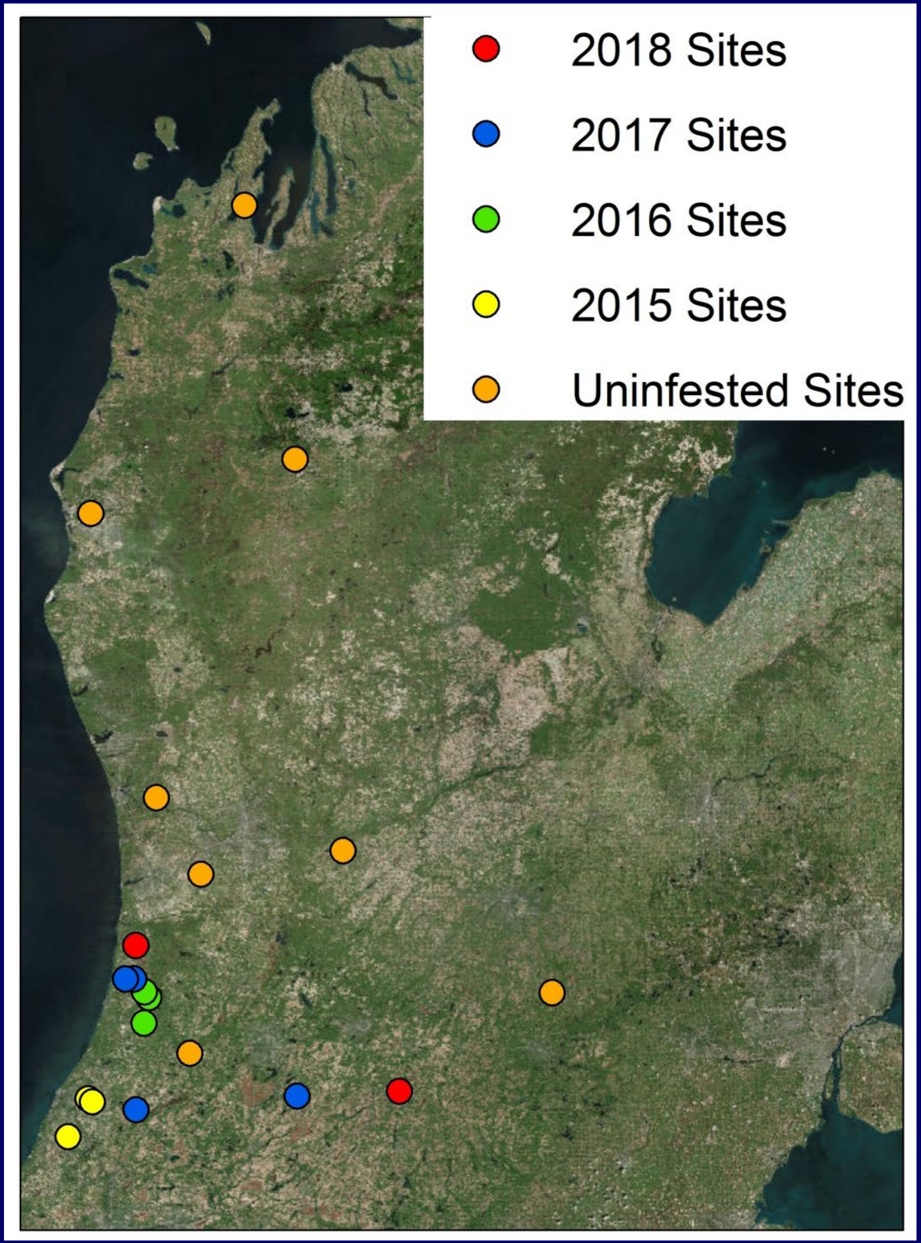
- Peak emergence in 2017: 19 July
  - 53% between 13 July and 19 July
- Peak emergence in 2018: 24 July
  - 68% between 18 July and 24 July
- Overall more adults captured in 2018
  - Trapped at more fields with multiple years of ACGW



# Potential Relevance

- If control is needed, insecticide cover sprays would be applied when ACGW adults are active.
- 2017: Adult ACGW active from 1250-1900 $DD_{50F}$, corresponding to 6 July to 8 August.
- 2018: Adult ACGW active from 1140-1980 $DD_{50F}$, corresponding to 3 July to 9 August.

# ACGW Annual Spread




- In 2015 and 2016, infested sites were located by observing galls
- In 2017 and 2018, infested sites were located by trapping for adult ACGW

| Year to Year | Max Spread (miles) |
|---|---|
| 2015 – 2016 | 26 |
| 2016 – 2017 | 39 |
| 2017 – 2018 | 23 |

# Local abundance & distribution of galls

- Systematically evaluated one site invaded in 2014 & one site invaded in 2015 for 2 years.
- Qualitatively assessed gall abundance on each tree; Rated gall abundance on 0-5 scale.

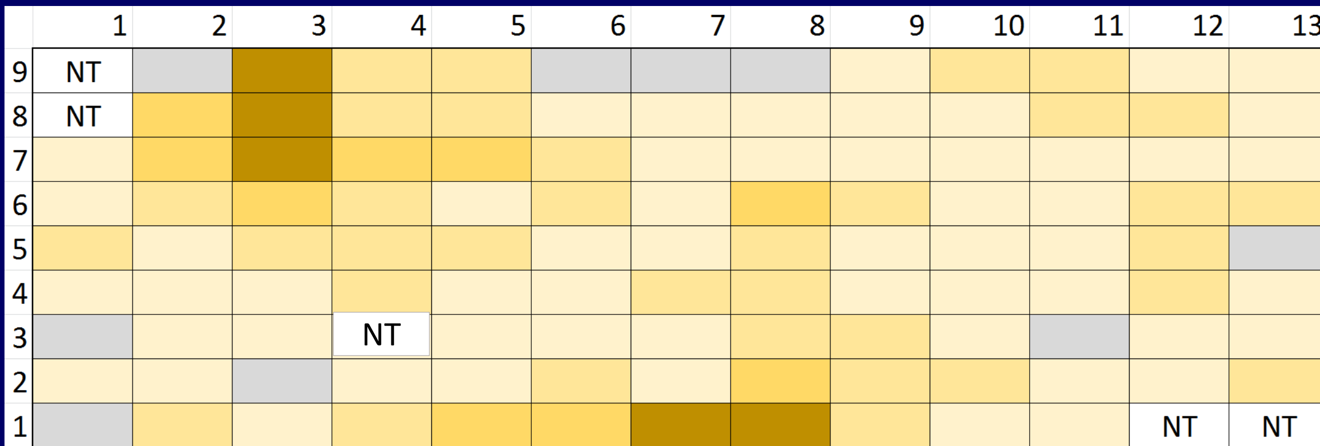
| Rank | Relative gall abundance |
|---|---|
| 0 | Absent |
| 1 | ≤ 10 visible |
| 2 | > 10 but scattered |
| 3 | A few clusters of abundant galls |
| 4 | Galls abundant in some parts of canopy |
| 5 | Galls abundant throughout canopy |

# Spatial Analysis – Semivariogram

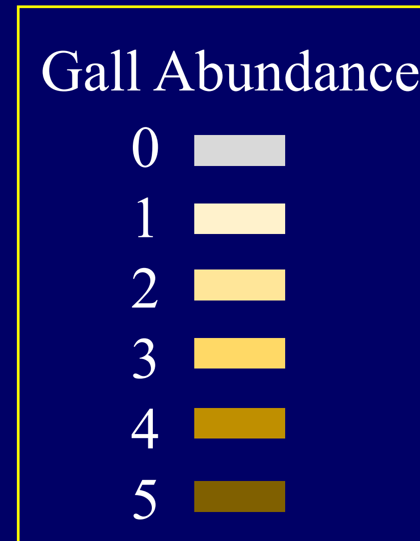
- Spatial autocorrelation: index of whether nearby trees influence infestation of a selected tree; can be + or -
- Semivariance: the strength of the relationship
- Semivariogram: how semivariance changes with distance

# Within-field abundance & distribution of trees with galls: Site invaded in 2015

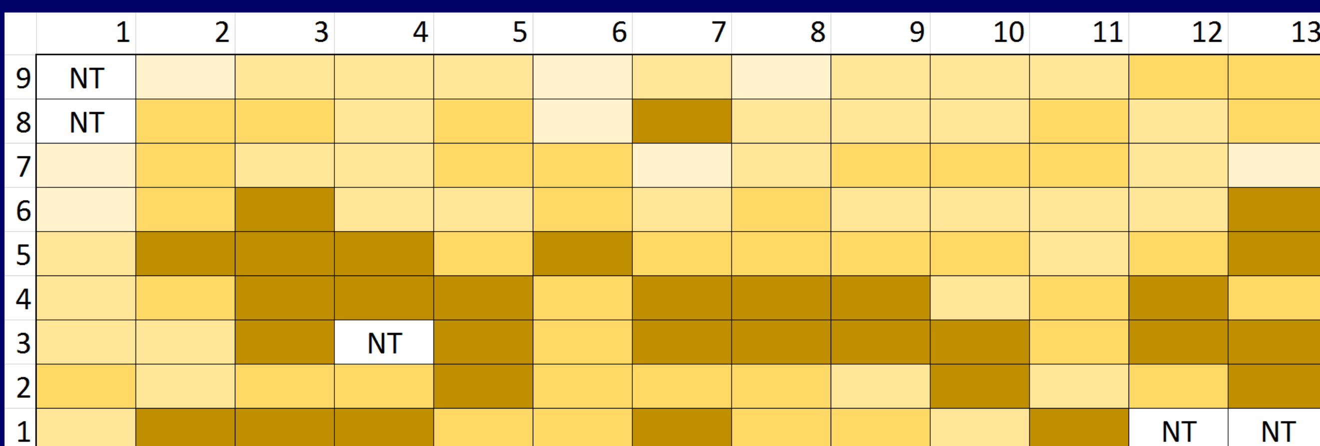
## Site 5 – **2017** evaluation




4% of trees rated as 4 or 5

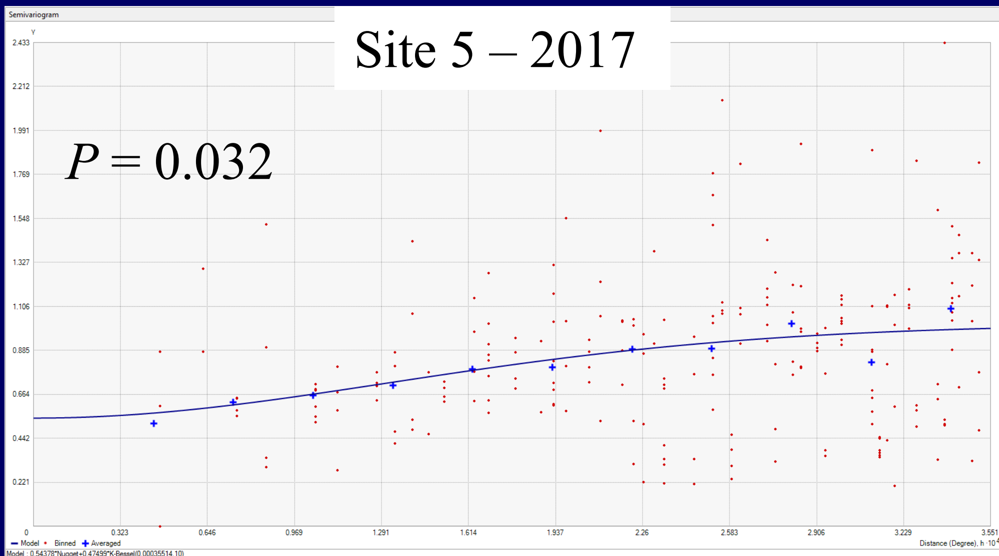


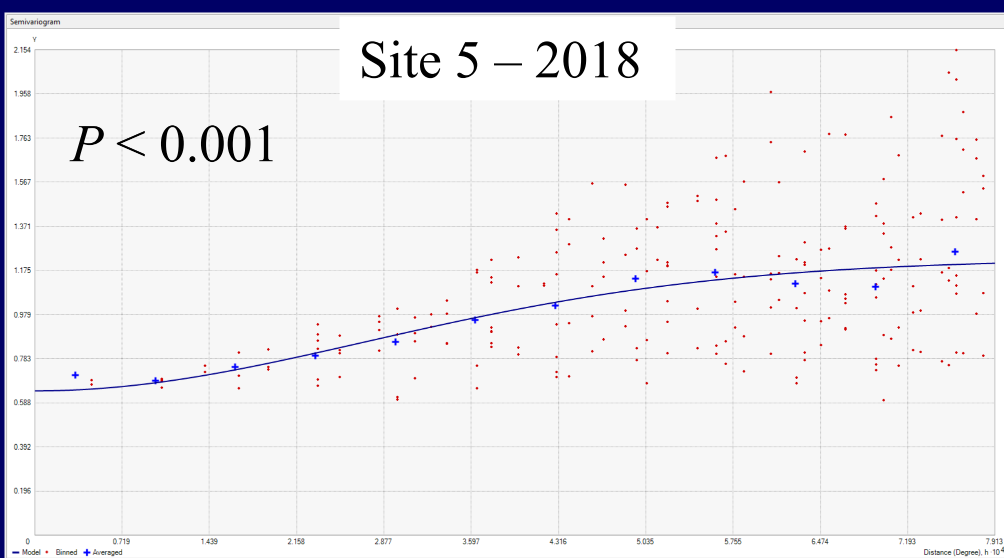

## Site 5 – **2018** evaluation




28% of trees rated as 4 or 5

# Semivariograms of Site 5 – 2107 & 2018

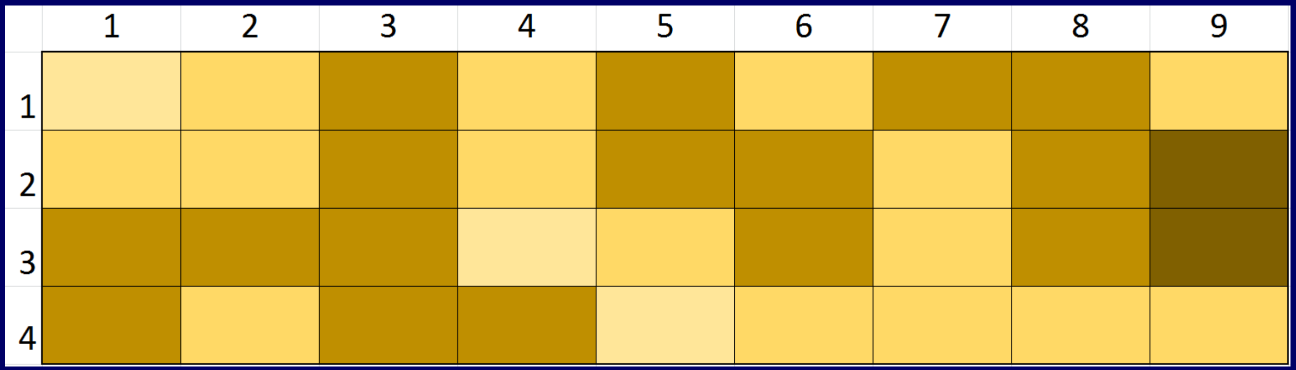


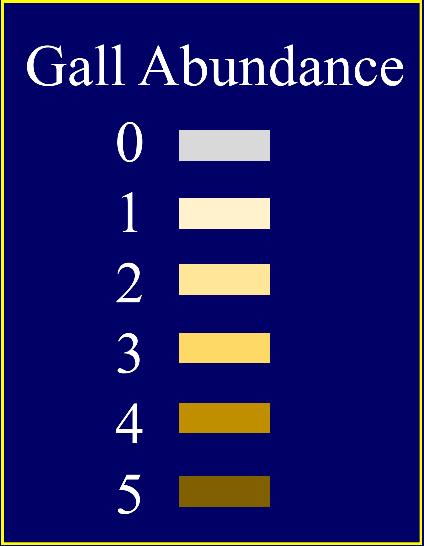

- Semivariance increases as distance increases
- Indicates strong spatial dependence
- Trees near infested trees are more likely to be infested & have higher gall densities than trees further away.

# Within-field abundance & distribution of trees with galls: Site invaded in 2014

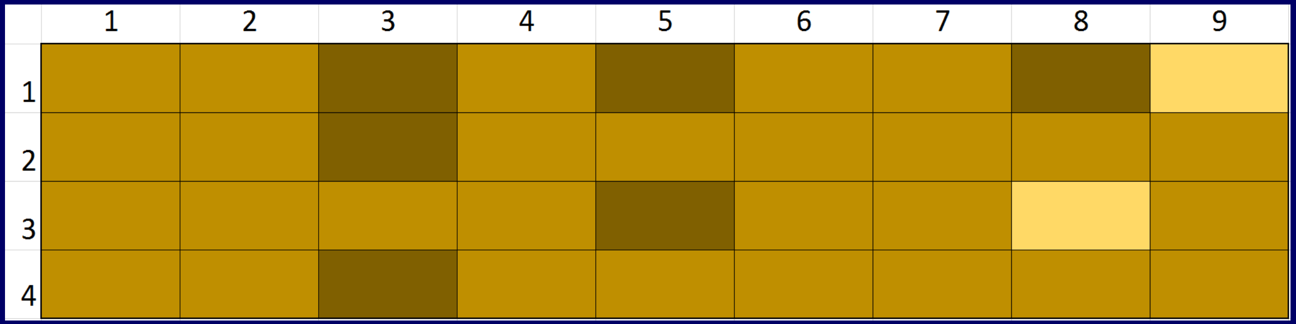
## Site 2 – **2017** evaluation




50% of trees rated as 4 or 5

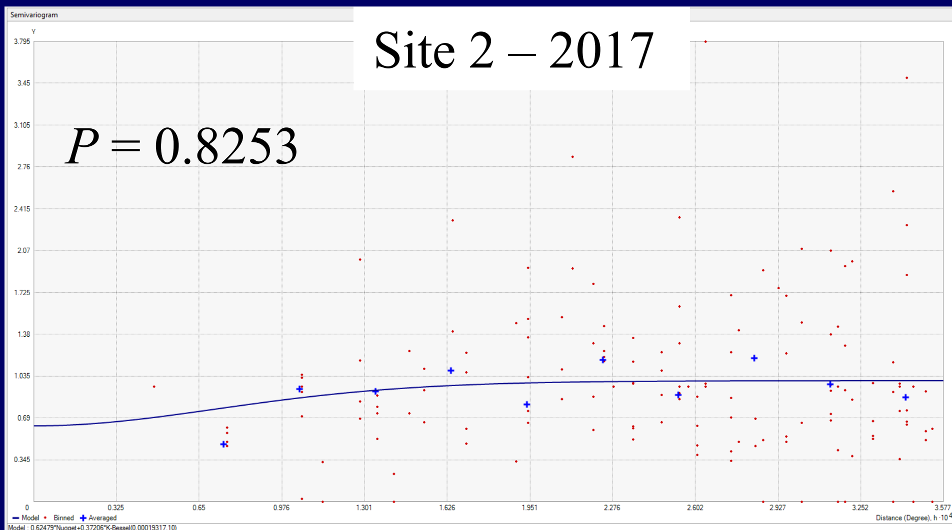


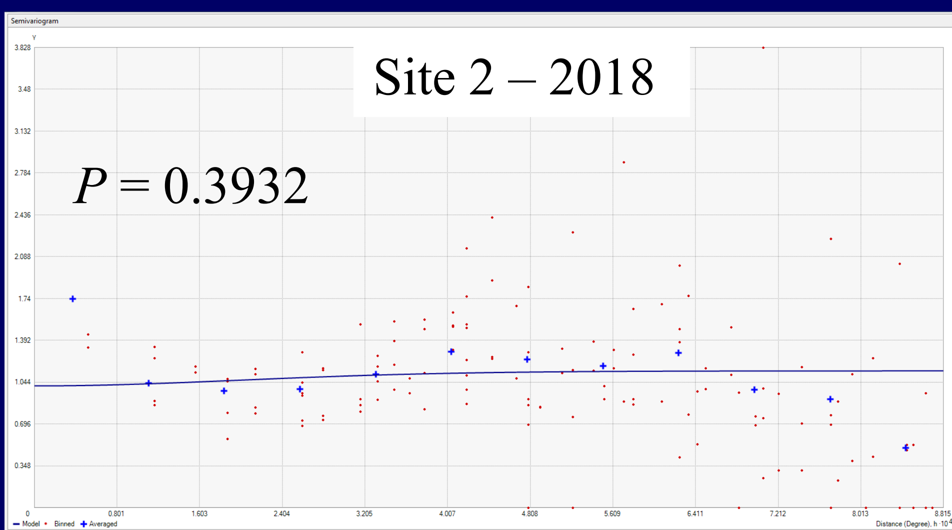

## Site 2 – **2018** evaluation




94% of trees rated as 4 or 5

# Semivariograms of Site 2 – 2017 & 2108



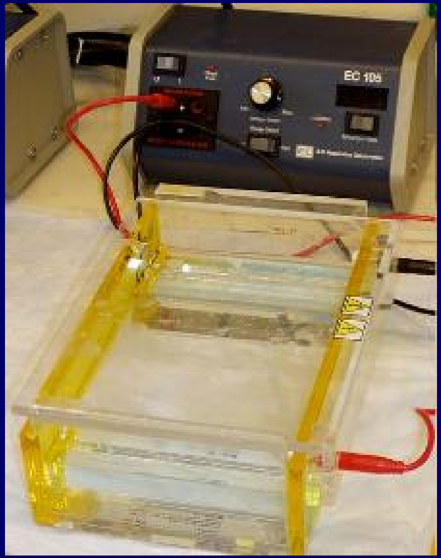

- Weak relationship between semivariance and distance indicates little or no spatial dependence
- This field has a longer infestation history & is smaller than Site 5. All trees have become infested & most have high gall densities. Location of infested & uninfested trees is no longer relevant.

# Potential Relevance

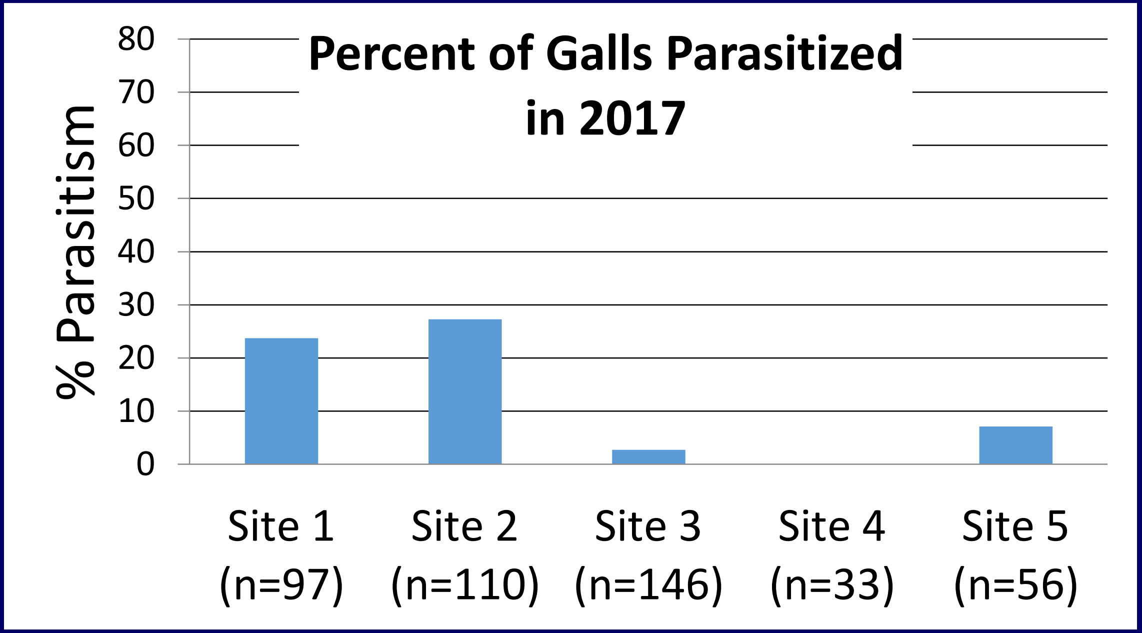
- Monitoring gall abundance & distribution provides information on ACGW dynamics & local spread.
- Compare newly invaded fields & fields with a longer history of ACGW
- Project ACGW dispersal & population increase within individual orchards.

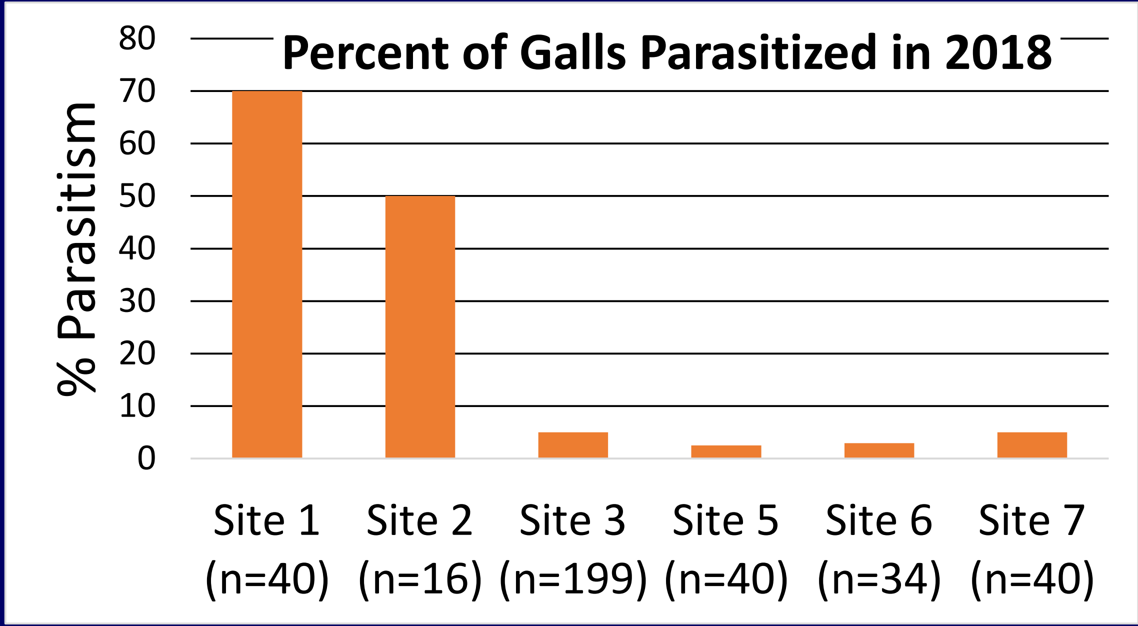
# *Torymus sinensis* parasitism

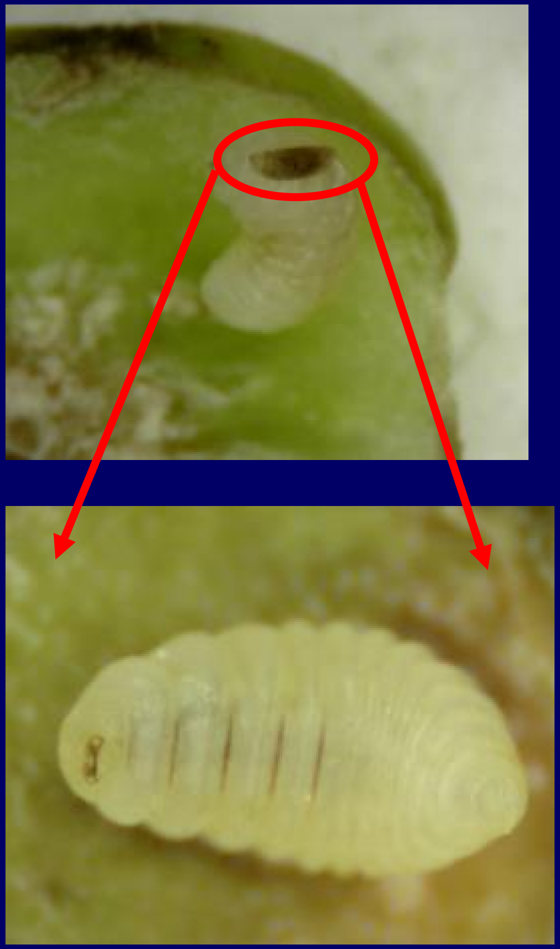
- *T. sinensis* was **<u>not</u>** intentionally introduced into Michigan.
- Non-ACGW larvae we suspected to be parasitoids were set aside during gall dissections.
- Extracted DNA from presumed parasitoid larvae; Used PCR to identify species, in cooperation with Dr. Medina Mora.



# Biocontrol of ACGW – Parasitism by Site



# Potential Relevance

- *Torymus sinensis* is established in at least 6 southwest Michigan orchards.
- Overall, an average (± SE) of 9 ± 3.6 % of larvae were killed by this parasitoid; range was 1 to 39% of larvae.
- Parasitoid is spreading; galls with parasitoid larvae were collected 38 miles from sites infested in 2015.
- Mortality from *T. sinensis* may slow ACGW population growth & gall abundance.

# Systemic Insecticide

- Trunk Injections
  - Fall 2017: Imidacloprid
  - Spring 2018: Imidacloprid & Ememectin Benzoate
  - Fall 2018: Imidacloprid & Ememectin Benzoate

- Tissue Samples (2018)
  - Leaves
  - Galls
  - Pollen
  - Nuts

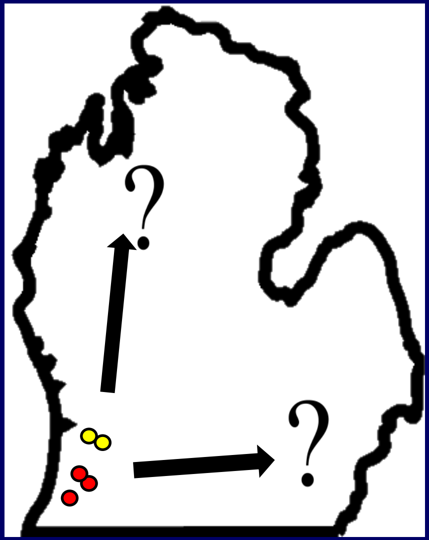



# Potential Relevance

- Will trunk injected insecticide control ACGW?
- Translocation & persistence of systemic insecticide in selected tissues of chestnut?
- Broader interest in systemic insecticides & physiology of nut-bearing trees.

# Ongoing work

- Evaluate systemic insecticides as ACGW control method
  - Assess translocation, persistence and residues
  - Imidacloprid and emamectin benzoate
- Spatial analysis
  - Macro and micro spread data
  - 2019 within-field gall abundance evaluation
  - 2019 ACGW adult trapping
- Develop an integrated management strategy for ACGW

# Acknowledgments


Undergraduate Research Assistants – MSU

Special thanks to the growers who allowed us to access their orchards & sample their trees!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Questions?