

TITLE: BROWN MARMORATED STINK BUG RISK AND IMPACTS IN WESTERN VINEYARDS

**Principal Investigator (PI)**

Vaughn Walton, Associate Professor,  
Horticultural Entomologist,  
Department of Horticulture, Oregon  
State University, 4017 Ag. & Life  
Science Bldg., Corvallis, OR.  
97331,vaughn.walton@oregonstate.edu

**Co-Principal Investigator:**

Nik Wiman, Assistant Professor,  
Department of Horticulture,  
Oregon State University, 4017 Ag.  
& Life Science Bldg., Corvallis,  
OR. 97331,  
nik.wiman@oregonstate.edu

**Co-Principal Investigator:**

Kent Daane  
Dept. ESPM  
University of California  
Berkeley, CA 94720-3114  
kdaane@ucanr.edu

**Co-Principal Investigator:**

Frank Zalom, PhD, Professor, Dept. of  
Entomology and Nematology, Univ. of  
California, Davis, CA 95616, Tel:  
(530) 752-3687, fgzalom@ucdavis.edu

**Co-Principal Investigator:**

Monica Cooper  
UC Cooperative Extension  
1710 Soscol Ave, Suite 4  
Napa, CA 94559  
mlycooper@ucanr.edu

**Co-Principal Investigator:**

Lucia Varela  
UC Cooperative Extension  
133 Aviation Boulevard Suite  
109. Santa Rosa, CA 95403-2894  
lgvarela@ucanr.edu

**TIME PERIOD COVERED BY REPORT**

The results reported here are from work conducted July 2015 to June 2017.

**ABSTRACT AND LAYPERSON SUMMARY OF PROJECT ACCOMPLISHMENTS**

Brown Marmorated Stink Bug (BMSB) was found in increasing numbers in vineyards in Oregon from 2014-2016. In California, BMSB was found in areas closely bordering vineyards, and the first recordings were found in California vineyards during 2016. Clear population trends were found in Oregon vineyards during all seasons. Population estimations from both Oregon and California using daily weather data showed higher population levels in California compared to Oregon. Temperatures above and below feeding thresholds (Low=6°C, High =26°C) resulted in cessation of feeding. Older life stages such as adults were found to result in a significant increase in feeding damage on winegrape berries. The feeding activity in relation to berry quality parameters is given for 2015. Increased feeding activity resulted in a significant increase in stylet sheaths per berry. There was a numerical reduction in berry weight and diameter with increasing feeding levels. The number of stylet sheaths in relation to degree-days (DD) per day was used to create a feeding factor for BMSB. This feeding factor was significantly correlated with the number of stylet sheaths per berry. Feeding data collected during 2015 and 2016 in Oregon, combined with weather data collected from California were used to create a BMSB risk index in relation to feeding. It is clear from these results that BMSB does not result in direct impacts of grape quality. BMSB adults are found for longer periods in California environments. This life stage population level and temperatures indicate that California vineyards are at higher risk from BMSB damage.

**INTRODUCTION**

Brown Marmorated Stink Bug, *Halyomorpha halys* (Stål) (BMSB, Hemiptera: Pentatomidae) is becoming increasingly prevalent in California and Oregon and is rapidly becoming an economic concern for western vineyards (Oregon Department of Agriculture 2011, Wiman et al. 2014a). This pest can feed on vegetative tissues, grapes, and can potentially cause contamination of the crop, leading to wine quality losses. Studies funded by a USDA-SCRI CAP grant confirmed spread and increased population levels of *H. halys* in important viticulture regions of Oregon (VMW et al. unpub.). *H. halys* was first found on the west coast in 2004 in Portland (Oregon Department of Agriculture 2011), and the pest is now common in urban and natural areas. Found on high-value specialty crops and non-economic alternate host plants alike, BMSB is increasingly causing agricultural issues for growers (Fig. 1). Since 2012, BMSB has increasingly been encountered by growers and can be found in wine grape vineyards of the Willamette Valley during the harvest period (Wiman et al. 2014a). Winemakers recently reported finding dead BMSB in fermenting wines and infestation of winery buildings by BMSB.

Immature and adult *H. halys* feed on reproductive plant structures such as fruits, and they may also feed on vegetative tissues, such as leaves and stems, sometimes piercing through bark (Martinson et al. 2013). Second instar nymphs and subsequent life stages of BMSB feed on tissues of a wide range of host plants (Nielsen et al

2008). During feeding, *H. halys* deposits saliva within the plant tissues, causing necrosis and scarring (Pfeiffer and Felton, 2014; Wiman et al., 2015). Feeding damage can cause economic damage, though economic action thresholds have only been determined in apple (Short et al. 2017). In addition, *H. halys* has high dispersal and reproductive capabilities, ovipositing an average of 240 eggs a season per female and flying up to 45 miles in a day (Lee et al., 2013; Nielsen et al., 2008; Wiman et al., 2014b). These factors, along with photoperiod, temperature fluctuations, overwintering refuges, and high population reservoirs are major factors contributing to the economic impact and rapid invasion and establishment of BMSB (Nielsen et al., 2016; Niva and Takeda, 2003; Rice et al. 2014, Wallner et al 2014). Fruit feeding by adult BMSB may cause direct crop loss due to berry necrosis. Berry feeding may also result in secondary pathogen infection and provide entry points for spoilage bacteria. Vectoring and facilitation of pathogen proliferation by BMSB is not unrealistic because true bugs (Heteroptera) such as BMSB share feeding behaviors with homopterans implicated as disease vectors in vineyards (Cilia et al 2012, Daugherty 1967, Mitchell 2004, Wiman et al 2014a). BMSB itself is a demonstrated vector of at least one phytoplasma disease (Hiruki 1999, Weintraub and Beanland 2006), while leaf-footed bugs (Heteroptera: Coreidae) and other pentatomids have also been implicated in transmission of pistachio stigmatomycosis (Michailides et al 1998). The impact of temperature on the development, fecundity, survival, and mortality of an exotic insect pest such as BMSB can be used to determine its invasive potential (Nielsen et al., 2008) and seasonal risk (Nielsen et al., 2016; Haye et al., 2014). Nielsen et al. (2008) detailed *H. halys* egg and nymph developmental periods, survival rates and temperature (DD) requirements as a first step to better understand the invasive characteristics of *H. halys*. These studies illustrated that temperatures below 15°C and above 35°C do not allow *H. halys* to complete its life cycle and reproduce.

Temperature is an important environmental factor influencing survival and reproduction (Fand et al., 2015; Nielsen et al., 2008). These age-specific fecundity and survival data related to temperature are vital components of population and risk models (Kiritani et al., 1963). The survival and reproduction rates of *H. halys* over a range of constant temperatures, together with earlier-generated life table data can be used to estimate seasonal population amplitude and structure. Population estimates using laboratory-generated parameters can be correlated with seasonal population trends of *H. halys* using pheromone-baited traps. Brown marmorated stink bug can develop on a wide range of host crops, meaning that it can find refuge or reproduce on non-crop hosts and then spread to cultivated crops such as wine grapes (Nielsen et al. 2008, Nielsen and Hamilton 2009, Leskey et al. 2012a, 2012b, Pfeiffer et al. 2012). However, unlike other pentatomids, BMSB are also capable of completing development on crop plants. As a result, crop damage from nymphs is more common than it is for other stinkbugs. In the Willamette Valley, wine grapes are among the last crops to be harvested and this may increase the potential for late-season infestation and damage in winegrape by BMSB. Contamination of grape clusters by BMSB at harvest is a major concern. Adult BMSB have been observed to lodge themselves between the grapes during harvest. Other researchers are evaluating physical removal of BMSB from clusters, as well as removal by chemical cleanup sprays, blowers and electronic sorters. However, some BMSB may remain in grape clusters and release defensive compounds during processing, causing taint in finished wine (E. Tomasino pers comm.). These taints are persistent, and may result in major market losses. Work conducted on Pinot noir has shown that trans-2-decenal, a defense compound produced by BMSB, is a contaminant present in wine that is processed with BMSB.

As in Oregon, many important wine grape growing regions of California are in close proximity to major urban centers where BMSB populations tend to increase and become sources for further spread. Oregon research has documented rapid colonization and significant increases in populations between seasons, In Oregon, BMSB has dispersed from Portland to northern Willamette Valley vineyards within a short period. It is important to survey the wine grape growing regions of Napa, Sonoma, and Lodi because these regions are geographically close to San Francisco and Sacramento, both areas with known BMSB infestation.

Feeding intensity of different life stages of BMSB in vineyards has not been determined. To date, most studies have focused on adults, even though nymphs are potentially more damaging. When BMSB egg masses are laid in vineyards, the nymphs are more confined to feed on the vines than the adults, which may fly back and forth between vineyards and borders. Thus, the feeding damage from nymphs may be more concentrated as the nymphs disperse from egg masses to feed on the host plant. This study will help determine the potential for BMSB to cause direct damage to wine grape crops. Controlled damage studies to assess direct feeding damage by BMSB have been conducted in Oregon on blueberry (Oregon State University, and Rutgers). These studies showed an increasing number of stylet sheaths in grape berries as the numbers of BMSB test populations increased. Increased numbers of stylet sheaths were associated with decreases of berry counts, premature raisening, and increased berry necrosis but this work focused on adult feeding and was conducted for one-week periods only.

## OBJECTIVES

1. Survey key Oregon and California viticulture areas for BMSB presence.
2. Determine BMSB temperature-related field feeding intensity, impact and regional risk index.
3. Provide Extension for identification, distribution, and importance of Brown Marmorated Stink Bug in western vineyards.

## RESULTS AND DISCUSSION

### 1. Survey key Oregon and California viticulture areas for BMSB presence.

Methods. Surveys in California focused on high-risk regions containing vineyards and wineries in close proximity to high traffic areas such as highways, urban centers, throughways and railroad lines. Beat sheet sampling were conducted in Mendocino (6 sites), Napa (7 sites) and Sonoma counties (7 sites), Lodi-Woodbridge (3 sites) wine grape region, and San Joaquin Valley (Fresno County, 5 sites) every 2-4 weeks starting in August (2015) and May (2016, 2017) to the conclusion of harvest. Pheromone-baited pyramid traps (Khrimian et al. 2014) were used in conjunction with monitoring using beat sheets during the same time frame. BMSB pheromone traps were placed in the center of each row selected for beat sheet sampling.

The goal of California sampling was to identify the first BMSB in vineyards before it spread unnoticed in a range of important production regions. The UC Berkeley lab (Daane Lab) and UC Davis (Zalom Lab) started monitoring in October 2015, in both farms and gardens. BMSB were consistently captured in the cities of Sacramento, Davis (Yolo county) and Stockton (San Joaquin county) since Fall 2015, and in Modesto (Stanislaus county) since Fall, 2016). Six species of stink bugs were collected from these locations including *Euchistus conspersus*, *Thyanta pallidovirens*, *Chlorochroa uhleri*, *Chlorochroa ligata*, *Murgantia histrionica*, and *Nezara viridula*. BMSB was found in community gardens in Sacramento where it was also observed feeding on grapes.

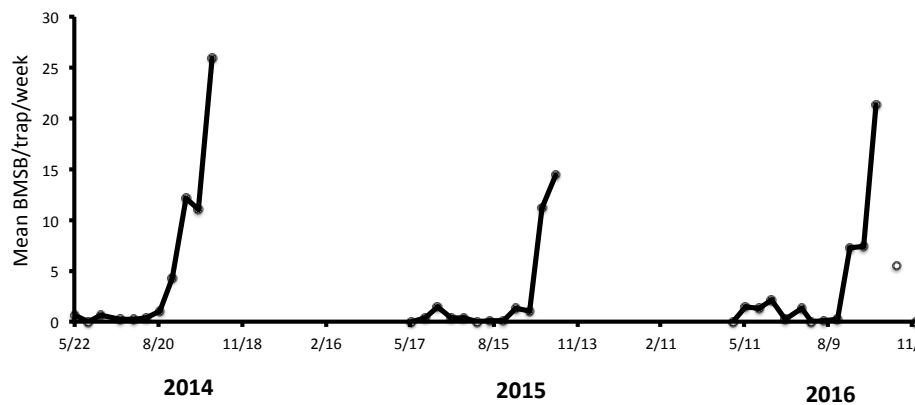
The first finds of BMSB were found in Napa county at St. Helena on three occasions in three different locations using a double-sided sticky traps baited with Trécé BMSB (*Halyomorpha halys*) pheromone dual lure i.e.

May 8, 2017 - 2 Male BMSB (Business/Residential).

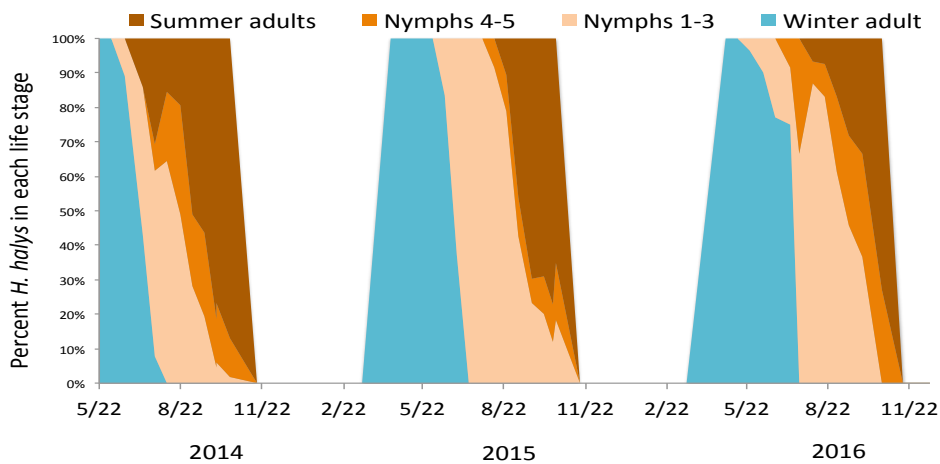
June 20, 2017 - 1 Male BMSB, 1 nymph - Napa Valley Reserve (Vineyard). There were 5 additional live nymphs (2nd instar) found at the base of the trap.

June 21, 2017 - 1 Male BMSB - V. Sattui Vineyard (Vineyard). Sampling in Oregon included seven vineyards in the northern Willamette Valley. Data from all vineyards were pooled for the respective seasons. The population size (Figure 1), and structure (Figure 2) per pyramid trap showed clear trends as the season unfolded.

The first BMSB finds in the Lodi area were at Clarksburg on June 15 and 22, 2016 – 2 males and 1 male, respectively, using Agbio pyramid traps and lures.



**Figure 1.** Number of BMSB per trap (7 traps) per week in the northern Willamette Valley, Oregon during 2014-2016.



**Figure 2.** Seasonal *Halyomorpha halys* population structure based on pheromone baited trap counts in grapevine and hazelnut in the Willamette Valley of Oregon during 2014-2016.

These data were compared with population estimates for BMSB to determine the suitability of climates and relative BMSB risk for different production regions. For population estimates, we used daily minimum and maximum temperatures collected from the Oregon and California sampled vineyards. For the purposes of this study, we used Willamette Valley daily minimum and maximum temperatures obtained from the Aurora Agrimet (<https://www.usbr.gov/pn/agrimet/>) and UC Davis (<http://ipm.ucanr.edu/WEATHER/#DEGREEDAYS>) weather station to estimate *H. halys* populations. For environmental conditions, daily DD accumulation was used to estimate survival and reproduction of cohorts of *H. halys* (Nielsen et al 2009, Walton et al Unpublished). For the purposes of this study, the daily DD accumulation was fitted to BMSB population survival (Gompertz) and reproduction (Cauchy) curves. Fitting of these curves allowed estimation of age-specific survival ( $L_x$ ), gross maternity ( $M_x$ ), and net maternity ( $L_x M_x$ ) (Carey, 1993). Daily DD accumulation was used to estimate the variable-rate survival and reproduction on a daily basis. For each DD increment, the population size for each cohort and the whole population was estimated by using net maternity ( $L_x M_x$ ). Data outputs were presented using fractions of *H. halys* life stages through the calendar year (Figure 3), as well as relative population size (Figure 4) taking the above parameters into consideration.

#### *Seasonal BMSB trapping and population size and structure estimates*

**Results – BMSB trapping in Oregon.** In all of the seven locations, BMSB was found in low numbers during the early part of summer in Oregon. The number of BMSB per trap increased to above 15 BMSB per trap per week during September through October in all seasons. The seasonal numbers of *H. halys* in Oregon pyramid traps showed similar trends in terms of population level and structure during 2014-2016 (Figures 1-4).

The *H. halys* trap counts over the three years were low during the late dormant period, i.e. early in the growing season. Increasing *H. halys* counts were found on 22 May, 2 June and 12 May during 2014, 2015 and 2016, respectively (Figure 1). The peak trap catches were 25.88, 14.37 and 21.38 individuals on 16 October 2014, 20 October 2015 and 29 September 2016 respectively. During 2014, the first adults were caught in traps on 22 May (Figure 2). The first nymphs in stages 2-3 were collected on 19 June and counts of this life stage continued to 16 October. Stage 4-5 nymphs were collected from 24 July to 20 October. Summer adults were collected from 10 July to 16 October during 2014. During 2015, the first adults were caught in traps on 2 June. During 2015, the first nymphs in stages 2-3 were collected on 16 June and counts of this life stage continued to 20 October. Stage 4-5 nymphs were collected from 11 August to 20 October. Summer adults were collected later in 2015 compared to 2014 – from 25 August to 21 October. During 2016, the first adults were caught in traps on 12 May. The first nymphs in stages 2-3 were collected on 25 May and counts of these life stages continued until 29 September. Stage 4-5 nymphs were collected from 11 July to 21 October. Summer adults were collected from 4 August to 21 October during this season.

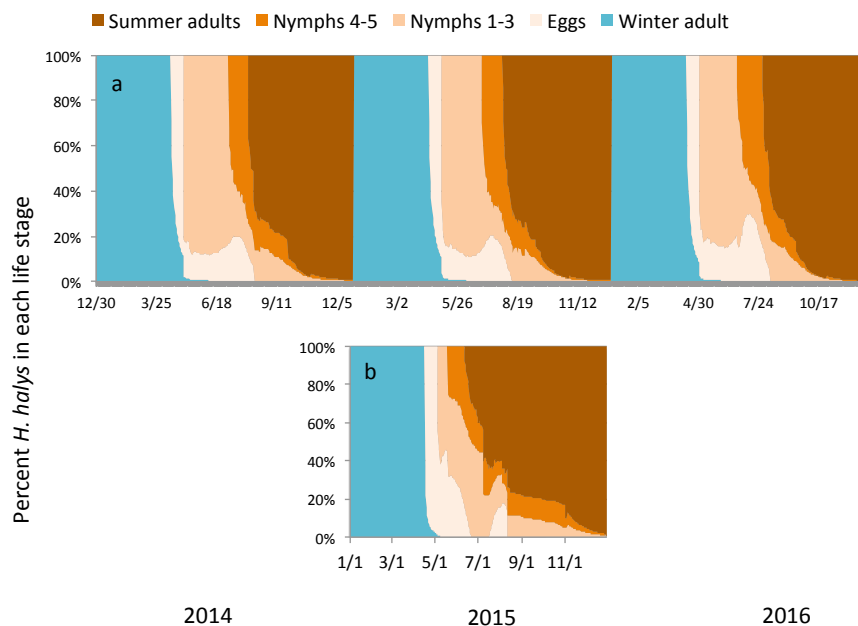
The population size estimates of *H. halys* showed significantly lower levels in winter compared to those of summer (Figure 3). Egg-laying is estimated to precede population increase in all seasons.

Population structure estimations during the season using year-specific weather data were similar to those found in the pheromone-baited traps for Oregon. During 2014, the percentage of winter adults significantly decreased during late May as the egg life stage started to increase. Winter adults persisted throughout the growing season at low levels. Egg-laying started on 15 April, peaked on 24 July and ceased on 11 August. The first nymphs in stages 1-3 were estimated to appear on 5 May and counts of this life stage peaked on 7 July and declining to low levels of less than 5% of the population by 15 September. Stage 4-5 nymphs were estimated to start on 7 July and peaked on 8 August, declining to less than 5% of the population on 15 October. Summer adults were estimated to emerge starting on 5 August, peak on 18 September and persist as the only life stage through winter.

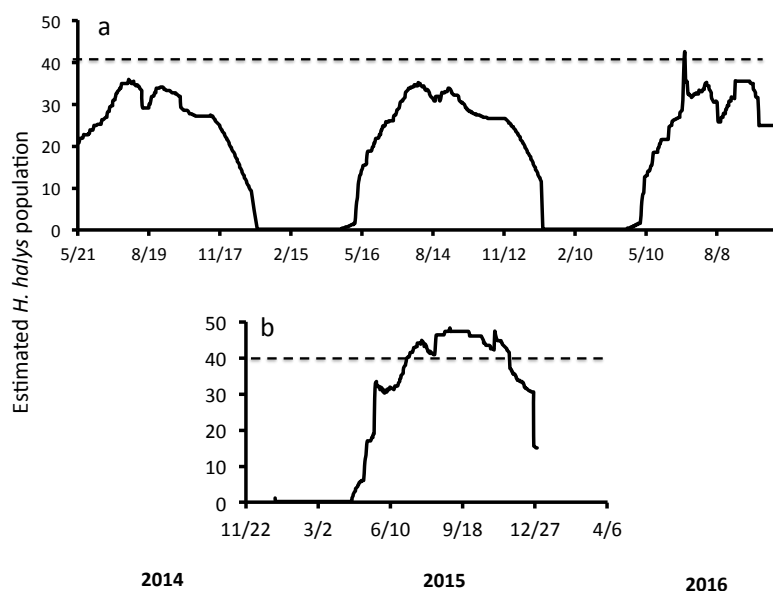
During 2015, the percent winter adults significantly decreased during late May as the egg life stage started to increase. Winter adults were estimated to persist in all production regions throughout the growing season at low levels. Egg-laying was estimated to start on 20 April, peaking on 19 July and stopping on 14 August. The first nymphs in stage 1-3 were estimated to emerge beginning on 8 May, peak on 3 July, and decline to levels of less than 5% of the population by 21 October. Stage 4-5 nymphs were estimated to emerge on 4 July and peak on 1 August, declining to less than 5% of the population on 16 November. Summer adults were estimated to emerge beginning on 2 August, peak on 6 September and persist as the only life stage through winter.

During 2016, the percent of winter adults significantly decreased during late May as the egg life stage start to increase. Winter adults were estimated to persist throughout the growing season at low levels. Egg-laying was estimated to start on 16 April, peak on 15 July and cease on 10 August. The first nymphs in stages 1-3 were estimated to start on 4 May, peak on 29 June and decline to levels of less than 5% of the population by 16 November. Stage 4-5 nymphs were estimated to start on 26 June, peak on 31 August and decline to less than 5% of the population by 13 November. Summer adults were estimated to start on 1 August, peak on 29 September and persist as the only life stage through winter. When comparing Oregon population structure (2015 season) with that of California, it is clear that egg laying and nymphal life stages can be found earlier in California compared to Oregon. BMSB nymphal life stages persist longer in California locations (Figure 3).

Population structure as recorded in *H. halys*-baited pyramid traps followed roughly similar trends during all three seasons in Oregon (Figure 3). The estimates of population size increase happened roughly during the same time period during all years in the Willamette Valley (Figure 4). Population increase of *H. halys* was estimated to start on 17 April 2014, 17 April 2015 and 13 April 2016 respectively. Peak population levels were estimated to occur on 11 July 2014, 14 July 2015 and 27 June 2016 respectively. The estimated population peak was roughly during the period when trap counts dropped, and is approximately one to two months before the populations again started to increase in the pheromone-baited traps. When comparing population size estimates between Oregon and California, it is clear that California population size are higher for longer periods (dotted line, Figure 4).



**Figure 3.** *Halyomorpha halys* population structure estimates for seven grapevine locations in the Willamette Valley (a) of Oregon climate during 2014-2016 and Davis, California (b) during 2015.

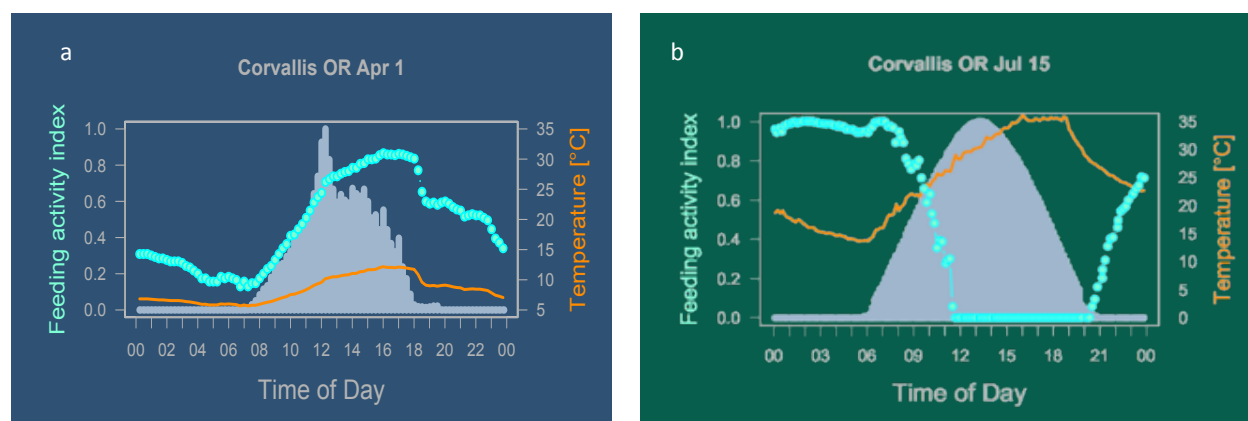


**Figure 4.** *Halyomorpha halys* population level estimates for grapevine environments in the Willamette Valley (a) of Oregon climate during 2014-2016, and Davis, California (b) during 2015.

## 2. Determine BMSB temperature-related field feeding intensity, impact and regional risk index.

**Methods. Feeding intensity.** In Oregon, we deployed portable electronic feeding monitors (Wiman et al. 2014b) during 2016 in order to determine in-vineyard feeding intensity. Portable feeding monitors consisting of an open circuit enclosed onto a section of the grape vine will be located within 20 meters of the pheromone traps. Four electronic feeding monitors were placed in each of the two rows in a partially shaded vineyard border, and a fully sun-exposed location within the center of each vineyard. Each feeding monitor was used to determine feeding frequency, duration and time. Each portable feeding monitor logged feeding for five individual BMSB. The insects were replaced once per week. The relative risk and intensity of BMSB feeding damage were determined by creating a feeding index of insect-days (Ruppel 1983) for each of the vineyard regions using standard methods as described by Wiman et al. (2014b). Additionally, these feeding patterns were verified by counting the number of stylet sheaths and plant damage within the monitored feeding area.

**Results.** Data from this work showed clear feeding activity patterns on a daily basis (Fig. 5 a, b) with a decrease in feeding at temperatures below and above 6 and 26°C respectively. These data support the estimated lower (3-6°C) and upper (26-29°C) threshold ranges of temperature-related feeding activity of BMSB (Wiman et al 2014).

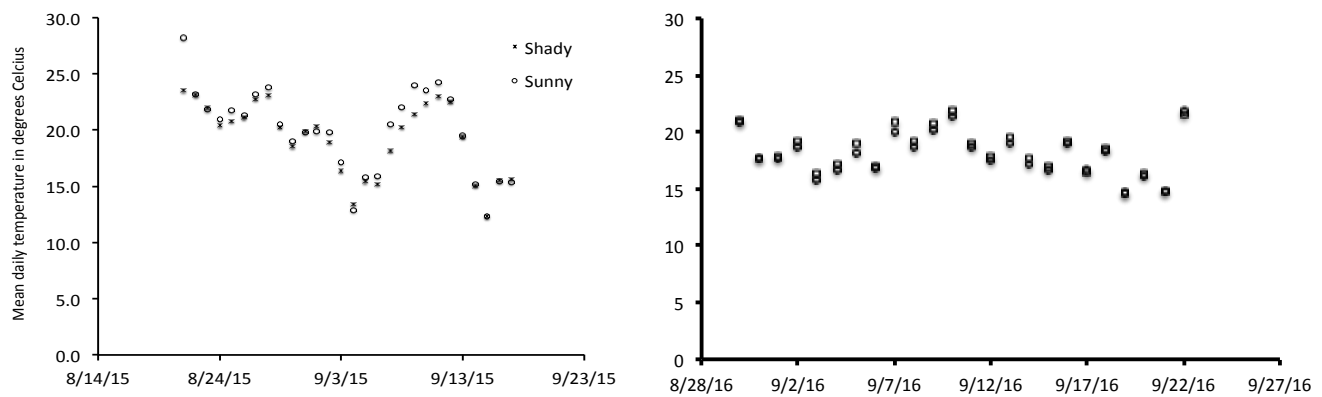


**Figure 5.** Adult daily *Halyomorpha halys* feeding activity on Pinot noir winegrapes during cool (a) and warm (b) days in Corvallis, Oregon during 2016 using electric feeding monitors (adapted from Wiman et al 2014b).

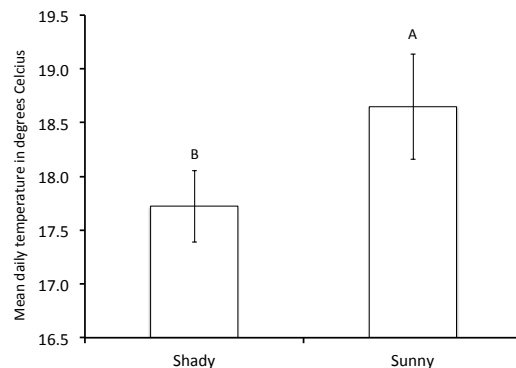
**Feeding impact.** Feeding exclusion sleeves (48.0 cm x 39.5 cm, Premier Paint Roller, Richmond Hill, NY, item 60597) were placed over wine grape clusters in a commercial vineyard with known BMSB infestation in the northern Willamette Valley. The trial was maintained for a four and three-week period respectively from August

21 to September 21, 2015, and August 22 to September 21, 2016. There were four treatments: 1) no BMSB; 2) a partial egg mass with 10 hatching eggs; 3) three BMSB nymphs; 4) three adult BMSB. All treatments were enclosed in a single sleeve. Ten replicates of each treatment were established in a randomized block design. Forty sleeves (ten of each treatment) were placed in a partially shaded vineyard border row, and forty sleeves were placed in a fully sun-exposed vineyard row in each vineyard (80 sleeves total). BMSB insects were exposed to clusters during the period when BMSB are typically found in vineyards in the Willamette Valley. Dead insects were replaced every week with BMSB of the same life stage during the exposure period. At the end of the experimental period, all clusters were removed and taken to the laboratory for further inspection. Feeding activity of BMSB was determined by counting the number of stylet sheaths per berry at the end of the exposure period. Additional key quality parameters were determined, including berry weight, pH, sugar, shriveling, cracking and presence or absence of spoilage bacteria such as botrytis using the slip-skin method (Crisosto et al. 2002). These data together with weather data (five dataloggers per vineyard location), feeding intensity and direct impact on crop can be used to develop a relative risk model for BMSB damage in different vineyard regions (Ruppel 1983, Froissart et al. 2010, Wiman et al. 2014a, 2014b).

Results. During 2015 there were significantly higher temperatures recorded in locations that received higher temperature exposure levels compared to 2016 (Fig. 6a, b). Mean temperatures ranged from 12.3-23.8°C during the experimental periods. Temperatures ranged from 23.5-28.2°C on days when there were full sun exposure to virtually indistinguishable on cloudy days. These trends were however not found during 2016 where the mean sunny (18.0°C) and shady (18.4°C) regimes were statistically similar ( $F_{2,53}=0.01, p=0.99$ ).

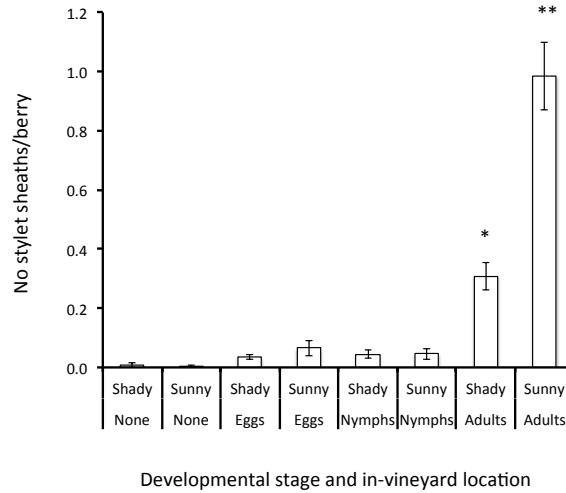


**Figure 6a.** Mean daily-recorded temperatures from each of shady and sun-exposed locations on Pinot noir preceding the harvest period on vines in Corvallis, Oregon during 2015 and 2016.



**Figure 6b.** Mean temperatures recorded in each of two sun-exposed locations on Pinot noir vines in Corvallis, Oregon during 2015 for a one-month period. Significantly different letters indicates different temperatures.

During 2015 there were significantly higher levels of stylet sheaths between sunny and shady locations in vines ( $F_{1,4074}=45.079, p<0.01$ ; Fig. 7), and there were higher levels of stylet sheaths in treatments with adults compared to immature BMSB life stages. Feeding activity of BMSB still needs to be determined for 2016, but the trends found during 2015 appeared consistent with those found during 2016.



**Figure 7.** Number of stylet sheaths per berry on Pinot noir in Corvallis, Oregon during 2015. Bars with no, one and two asterisks (\*) are significantly different from other bars.

In order to determine if there were differences in BMSB feeding days (Insect days, Ruppel 1983) between sunny and shaded locations during 2015, we determined the mortality rates over the four-week period of the feeding trial and there were however no clear differences in cumulative mortality rates between locations that BMSB were placed on vines. For 2015, the winegrape quality parameters (Table 1-2) showed statistically lower berry and cluster weights, lower berry diameter, less berries per cluster, and more stylet sheaths per berry (Table 1) between climate regimes. There was a numerical decrease in berry and cluster weights, lower berry diameter with increasing age of BMSB life stage, as well as warmer temperatures (Table 2).

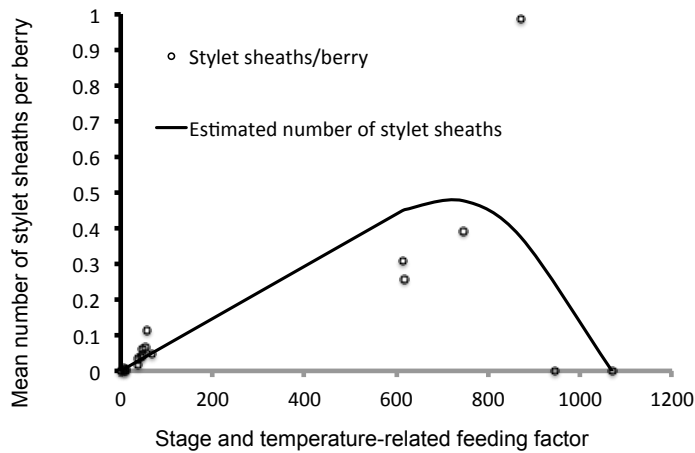
**Table 1.** Mean berry characteristics of Pinot noir grapes and *Halyomorpha halys* feeding activity ( $\pm$ SE) for temperature regimes (N = 40) and life stage treatments (N = 20) during 2015 in Corvallis, Oregon.

| Group   | Berry Weight (Grams) | Cluster Weight (Grams) | Berry Diameter (mm) | Berries/Cluster | Stylet Sheaths/Berry | °Brix            |
|---------|----------------------|------------------------|---------------------|-----------------|----------------------|------------------|
| Shady   | 1.3 $\pm$ 0.03a      | 90.0 $\pm$ 4.9a        | 12.1 $\pm$ 0.1a     | 72.4 $\pm$ 3.9a | 6.8 $\pm$ 3.0b       | 21.6 $\pm$ 0.04a |
| Sunny   | 1.1 $\pm$ 0.03b      | 56.7 $\pm$ 4.9b        | 11.6 $\pm$ 0.1b     | 50.2 $\pm$ 3.9b | 12.8 $\pm$ 3.0a      | 22.0 $\pm$ 0.04a |
| Control | 1.2 $\pm$ 0.005a     | 75.9 $\pm$ 5.8a        | -                   | -               | 0.009 $\pm$ 0.006b   | 21.5 $\pm$ 0.3a  |
| Eggs    | 1.1 $\pm$ 0.002a     | 69.7 $\pm$ 6.5a        | -                   | -               | 0.047 $\pm$ 0.012b   | 22.0 $\pm$ 0.3a  |
| Nymphs  | 1.2 $\pm$ 0.003a     | 80.8 $\pm$ 9.2a        | -                   | -               | 0.060 $\pm$ 0.018b   | 21.6 $\pm$ 0.2a  |
| Adults  | 1.2 $\pm$ 0.013a     | 67.1 $\pm$ 9.4a        | -                   | -               | 0.781 $\pm$ 0.177a   | 22.1 $\pm$ 0.5a  |

**Table 2.** Mean grape berry characteristics of Pinot noir and *Halyomorpha halys* feeding activity ( $\pm$ SE) for temperature regimes and life stage treatments (N = 10) during 2015 in Corvallis, Oregon.

| Treatment     | Cluster Weight (Grams) | Stylet Sheaths/Berry | °Brix           |
|---------------|------------------------|----------------------|-----------------|
| Shady Control | 87.1 $\pm$ 5.2a        | 0.013 $\pm$ 0.013c   | 21.3 $\pm$ 0.4a |
| Shady Egg     | 89.0 $\pm$ 6.3a        | 0.028 $\pm$ 0.012c   | 22.2 $\pm$ 0.5a |
| Shady Nymph   | 94.0 $\pm$ 14.4a       | 0.072 $\pm$ 0.031c   | 21.9 $\pm$ 0.2a |
| Shady Adult   | 89.9 $\pm$ 14.6a       | 0.335 $\pm$ 0.092b   | 21.1 $\pm$ 0.6a |
| Sunny Control | 64.8 $\pm$ 9.4a        | 0.006 $\pm$ 0.004c   | 21.7 $\pm$ 0.5a |
| Sunny Egg     | 50.3 $\pm$ 7.4a        | 0.066 $\pm$ 0.200c   | 21.9 $\pm$ 0.5a |
| Sunny Nymph   | 67.6 $\pm$ 10.5a       | 0.047 $\pm$ 0.018c   | 21.3 $\pm$ 0.4a |
| Sunny Adult   | 44.3 $\pm$ 6.8a        | 1.226 $\pm$ 0.282a   | 23.0 $\pm$ 0.5a |





**Figure 8.** *Halyomorpha halys* (BMSB) stylet sheaths per berry over feeding factor. The feeding factor was estimated based on life stage, and number of Degree-Days/day (DD/day). *Halyomorpha halys* feeding activity was acquired using an electronic feeding monitor during 2016 and also on Pinot noir winegrape during 2015 and 2016 in Corvallis, Oregon.

**Table 3.** *Halyomorpha halys* (BMSB) feeding factor based on life stage, and number of Degree-Days/day (DD/day). *Halyomorpha halys* feeding activity was acquired using an electronic feeding monitor as well as over two seasons on Pinot noir during 2015 and 2016 in Corvallis, Oregon.

| BMSB life stage | Year            | Temperature regime | Numerical BMSB life stage factor | DD/day | Feeding factor |
|-----------------|-----------------|--------------------|----------------------------------|--------|----------------|
| None            | 2015            | Shady              | 1                                | 7.07   | 7.07           |
| None            | 2015            | Sunny              | 1                                | 10.03  | 10.03          |
| None            | 2016            | Shady              | 1                                | 7.115  | 7.115          |
| None            | 2016            | Sunny              | 1                                | 8.59   | 8.59           |
| Eggs            | 2015            | Shady              | 5.22                             | 7.07   | 36.9054        |
| Eggs            | 2015            | Sunny              | 5.22                             | 10.03  | 52.3566        |
| Eggs            | 2016            | Shady              | 5.22                             | 7.115  | 37.1403        |
| Eggs            | 2016            | Sunny              | 5.22                             | 8.59   | 44.8398        |
| Nymphs          | 2015            | Shady              | 6.67                             | 7.07   | 47.1569        |
| Nymphs          | 2015            | Sunny              | 6.67                             | 10.03  | 66.9001        |
| Nymphs          | 2016            | Shady              | 6.67                             | 7.115  | 47.45705       |
| Nymphs          | 2016            | Sunny              | 6.67                             | 8.59   | 57.2953        |
| Adults          | Feeding monitor | Cold               | 86.78                            | 0      | 0              |
| Adults          | 2015            | Shady              | 86.78                            | 7.07   | 613.5346       |
| Adults          | 2015            | Sunny              | 86.78                            | 10.03  | 870.4034       |
| Adults          | 2016            | Shady              | 86.78                            | 7.115  | 617.4397       |
| Adults          | 2016            | Sunny              | 86.78                            | 8.59   | 745.4402       |
| Adults          | Feeding Monitor | Hot 1              | 86.78                            | 10.88  | 944.1664       |
| Adults          | Feeding Monitor | Hot 2              | 86.78                            | 12.33  | 1069.9974      |

BMSB feeding was correlated based on BMSB life stage and temperature (Ruppel, 1983). For life stages, a factor of 1 was attributed to control treatments, 5.22 for eggs, 6.67 for nymphs and 86.78 for adults. These factors were obtained by dividing the number of stylet sheaths found for each life stage by the number of stylet sheaths found in the control treatments (0.009) over the two seasons. We assume, based on the electronic feeding monitors, that no stylet sheaths are found in situations where temperatures are below 6 and above 26°C respectively. These zero values of feeding were used in the fitting of a non-parametric curve in order to describe the lower and upper thresholds of BMSB feeding. The effect of temperature was determined by estimating the number of degree-days (DD) per day for each temperature regime. The DD/day were estimated using the lower and upper thresholds of 14 and 34°C (Nielsen et al., 2008), respectively. Based on the relative number of DD/day in each regime, the corresponding factor was attributed to each of the regimes. The life stage factor was multiplied by DD/day to create a feeding factor (Table 3). For the BMSB feeding correlation, the regression of stylet sheaths/berry on the feeding factor resulted in a significant fit using the function  $y = (0.0000089) * x * (x - 143.717) * ((1028.8) - x) * \exp(1 / (-0.12867))$  ( $R^2 = 0.71$ ;  $F = 6.33$ ;  $df = 1, 4$ ;  $p < 0.003$ , Fig. 8).

### **3. Provide Extension for identification, distribution, and importance of Brown Marmorated Stink Bug in western vineyards.**

**Methods.** Because BMSB may first be seen in small organic gardens and ornamental trees, we also began outreach or surveys of small organic farms (Napa and Sonoma counties) and Southeast Asian vegetable farms (Fresno County). In the north coast region, we have partnered with Master Gardener groups in Napa and Sonoma to gain access to home gardens in which we may find desirable host source plants. Additionally, contacts have been made, in partnership with the Napa Agricultural Commissioner, allowing us access to survey and sample small-diversified farms. No BMSB have yet to be found at these sites.

**Results.** In Oregon, we presented results of earlier and work for this grant to growers in five locations, McMinnville, Oregon (63 attendees), Milton Freewater, Oregon, (30 attendees), Roseburg, Oregon, (50 attendees), Medford, Oregon, (48 attendees) and Rickreal Oregon (211 attendees). Several extension meetings were held in the San Joaquin Valley and coastal winegrape regions as represented by the sampled regions mentioned above.

**Conclusions.** In California's north coast wine grape region, Lodi-Woodbridge wine grape region, and San Joaquin Valley (Fresno County), no BMSB were found in vineyards or small vegetable farms. While this is only the initial study, BMSB have been found in the Lodi Woodbridge region in ornamental trees and landscape plants, but none have yet been found in sampled vineyards in this region. During 2016, BMSB was found in Napa in a home garden, and at Clarksburg in the Lodi area on landscape plants. During 2017, the first finds of BMSB were in Napa county at St. Helena on three occasions in three different locations. In Oregon, BMSB were found in increasing numbers from 2014-2016 in each of the seven vineyards sampled. The risk tools developed in this study included estimations of BMSB population size and structure. An additional risk tool included assessment of risk based on life stage. These studies, together with the first finds in some California vineyards indicate that California climates are suitable for BMSB populations to establish, and can result in increased risk.

#### **LITERATURE CITED**

- Bergh, J.C., Morrison, W. R., Joseph S.V., and T. C. Leskey 2017. Characterizing spring emergence of adult *Halyomorpha halys* using experimental overwintering shelters and commercial pheromone traps. *Entomologia Experimentalis et Applicata*. DOI: 10.1111/eea.12539
- Brière, J. F., Pracros P., Le Roux, A. Y., and Pierre, J. S. (1999). A novel rate model of temperature-dependent development for arthropods. *Environmental Entomology*, 28, 22-29.
- Cilia, M., M. Bereman, T. Fish, M. J. MacCoss, and S. Gray. 2012. Homopteran Vector Biomarkers for Efficient Circulative Plant Virus Transmission are Conserved in Multiple Aphid Species and the Whitefly *Bemisia tabaci*. *Journal of Integrative Agriculture* 11: 249-262.
- Crisosto, C. H., Garner, D., & Crisosto, G. 2002. High carbon dioxide atmospheres affect stored 'Thompson seedless' table grapes. *HortScience* 37(7): 1074-1078.
- Daugherty, D. M. 1967. Pentatomidae as vectors of yeast-spot disease of soybeans. *Journal of Economic Entomology* 60(1): 147-152.
- DeLong, D. M. 1932. Some problems encountered in the estimation of insect populations by the sweeping method. *Ann. Entomol. Soc. Am.* 25: 13-17.
- Fand, B. B., Sul, N. T., Bal., S. K., & Minhas, P. S. (2015). Temperature impacts the developments and survival of common cutworm (*Spodoptera litura*): Simulation and visualization of potential population

- growth in India under warmer temperatures through life cycle modelling and spatial mapping. *PLoS ONE*, 10(4), e0124682.
- Froissart, R., Doumayrou, J., Vuillaume, F., Alizon, S., & Michalakakis, Y. 2010. The virulence–transmission trade-off in vector-borne plant viruses: a review of (non-) existing studies. *Philosophical Transactions of the Royal Society B: Biological Sciences* 365(1548): 1907-1918.
- Haye, T., Abdallah, S., Garipey, T., & Wyniger, D. (2014). Phenology, life table analysis, and temperature requirements of the invasive brown marmorated stink bug, *Halyomorpha halys*, in Europe. *Journal of Pest Science*, 87(3), 407-418.
- Hiruki, C. 1999. Paulownia witches'-broom disease important in East Asia. *Acta Hort.* 496: 63-68.
- Ingels, C. 2014. Update on brown marmorated stink bug characteristics, spread, and management. Accessed January 28, 2014. (<http://ucanr.edu/?facultyid=1084>).
- Jackson, C. and Jackson, M.C., 2016. Package 'flexsurv'. Jackson, C. H. (2015). flexsurv: A platform for parametric survival modelling in R. Retrieved January 26, 2017 from <https://github.com/chjackson/flexsurv-dev>
- Joseph, S. V., Stallings, J. W., Leskey, T. C., Krawczyk, G., Polk, D., Butler, B., & Bergh, J. C. 2014. Spatial distribution of brown marmorated stink bug (Hemiptera: Pentatomidae) injury at harvest in mid-Atlantic apple orchards. *Journal of Economic Entomology* 107(5): 1839-1848.
- Kawada, H., & Kitamura, C. (1983). The reproductive behavior of the brown marmorated stink bug, *Halyomorpha mista* Uhler (Heteroptera: Pentatomidae) I. Observation of mating behavior and multiple copulation. *Applied Entomological Zoology*, 18(2), 234-242.
- Khrimian, A., Zhang, A., Weber, D. C., Ho, H. Y., Aldrich, J. R., Vermillion, K. E., ... & Leskey, T. C. 2014. Discovery of the aggregation pheromone of the brown marmorated stink bug (*Halyomorpha halys*) through the creation of stereoisomeric libraries of 1-bisabolen-3-ols. *Journal of Natural Products* 77(7): 1708-1717.
- Kiritani, K., & Hôkyo, N. (1962). Studies on the life table of the southern green stink bug, *Nezara viridula*. *Japanese Journal of Applied Entomology*, 6(2), 124-140.
- Kiritani, K., Hôkyo, N., & Kimura, K. (1963). Survival rate and reproductivity of the adult southern green stink bug, *Nezara viridula*. *Japanese Journal of Applied Entomology*, 7(2), 113-124.
- Krenz, B., J. R. Thompson, M. Fuchs, and K. L. Perry. 2012. Complete Genome Sequence of a New Circular DNA Virus from Grapevine. *Journal of Virology* 86: 7715-7715.
- Lee D-H, Leskey TC. 2015. Flight behavior of foraging and overwintering brown marmorated stink bug, *Halyomorpha halys* (Hemiptera: Pentatomidae). *Bull. Entomol. Res.* 105:566-73
- Lee, D., Short, B. D., Joseph, S. V., Bergh, J. C., & Leskey, T. C. (2013). Review of the biology, ecology, and management of *Halyomorpha halys* (Hemiptera: Pentatomidae) in China, Japan, and the Republic of Korea. *Environmental Entomology*, 42(4), 627-641.
- Leskey, T. C., Hamilton, G. C., Nielsen, A. L., Polk, D. F., Rodriguez-Saona, C., Bergh, J. C., ... & Wright, S. E. 2012a. Pest status of the brown marmorated stink bug, *Halyomorpha halys* in the USA. *Outlooks on Pest Management* 23(5): 218-226.
- Leskey, T. C., Short, B. D., Butler, B. R., & Wright, S. E. 2012b. Impact of the invasive brown marmorated stink bug, *Halyomorpha halys* (Stål), in mid-Atlantic tree fruit orchards in the United States: case studies of commercial management. *Psyche: A Journal of Entomology*. Article ID 535062: 1-14.
- Martinson, H. M., Raupp, M. J., & Shrewsbury, P. M. 2013. Invasive stink bug wounds trees, liberates sugars, and facilitates native Hymenoptera. *Annals of the Entomological Society of America*, 106(1), 47-52.
- Medal, J., Smith, T., & Cruz, A. S. (2013). Biology of the brown marmorated stink bug *Halyomorpha halys* (Heteroptera: Pentatomidae) in the laboratory. *Florida Entomologist*, 96(3), 1209-1212.
- Michailides, T.J., D.P. Morgan & D. Felts. 1998. Spread of *Botryosphaeria dothidea* in central California pistachio orchards. *Acta Hort.* 470: 582-591.
- Mitchell, Paula L. 2004. Heteroptera as vectors of plant pathogens. *Neotropical Entomology* 33(5): 519-545.
- Nielsen, A. L., & Hamilton, G. C. 2009. Life history of the invasive species *Halyomorpha halys* (Hemiptera: Pentatomidae) in northeastern United States. *Annals of the Entomological Society of America* 102(4): 608-616.
- Nielsen, A. L., Chen, S., & Fleischer, S. J. (2016). Coupling developmental physiology, photoperiod, and temperature to model phenology and Dynamics of an Invasive Heteropteran, *Halyomorpha halys*. *Frontiers in Physiology*, 7(165), 1-12.
- Nielsen, A. L., Hamilton, G. C., & Matadha, D. 2008. Developmental rate estimation and life table analysis for *Halyomorpha halys* (Hemiptera: Pentatomidae). *Environmental Entomology* 37(2): 348-355.

- Niva, C. C., & Takeda, M. (2003). Effects of photoperiod, temperature and melatonin on nymphal development, polyphenism and reproduction in *Halyomorpha halys* (Heteroptera: Pentatomidae). *Zoological Science*, 20(8), 963-970.
- Pfeiffer, D. G., Leskey, T. C., & Burrack, H. J. 2012. Threatening the harvest: the threat from three invasive insects in late season vineyards. In *Arthropod Management in Vineyards*, pp. 449-474. Springer Netherlands.
- Pfeiffer, M., & Felton, G. W. (2014). Insights into the saliva of the brown marmorated stink bug *Halyomorpha halys* (Hemiptera: Pentatomidae). *PLoS One*, 9(2), e88483.
- Prakash, A., Rao, J. (1999). Age specific fecundity, life table and intrinsic rate of increase of rice stink bug, *Eysarcoris ventralis* Westw. *Journal of Applied Zoological Researches*, 10(1), 6-8.
- Price, P. W. (1997). *Insect ecology* (3rd ed.). New York: Wiley.
- Rice KB, Bergh CJ, Bergmann EJ, Biddinger DJ, Dieckhoff C, et al. 2014. Biology, Ecology, and Management of Brown Marmorated Stink Bug (Hemiptera: Pentatomidae). *Journal of Integrated Pest Management* 5:A1-A13
- Ruppel, R. F. 1983. Cumulative insect-days as an index of crop protection. *J. Econ. Entomol.* 76: 375–377.
- Silva, C. C. A., Laumann, R. A., Moraes, M. C. B., Aquino, M. F. S. de, & Borges, M. (2015). Comparative biology of two congeneric stinkbugs, *Chinavia impicticornis* and *C. ubica* (Hemiptera: Pentatomidae). *Pesquisa Agropecuaria Brasileria*, 50(5), 355-362.
- Smith, J. R., Heslerand, S. P., & Loeb, G. M. (2014). Potential impact of *Halyomorpha halys* (Hemiptera: Pentatomidae) on grape production in the Finger Lakes region of New York. *Journal of Entomological Science*, 49(3), 290-303.
- Wadill, V., & Shepard, M. (1974). Biology of a predaceous stinkbug, *Stiretrus anchorago* (Hemiptera: Pentatomidae). *The Florida Entomologist*, 57(3), 249-253.
- Wallner AM, Hamilton GC, Nielsen AL, Hahn N, Green EJ, Rodriguez-Saona CR. 2014. Landscape Factors Facilitating the Invasive Dynamics and Distribution of the Brown Marmorated Stink Bug, *Halyomorpha halys* (Hemiptera: Pentatomidae), after Arrival in the United States. *PLoS ONE* 9:e95691
- Watanabe, M. (1979). Ecology and extermination of *Halyomorpha halys*. 4. The relationship between day length and ovarian development. *Ann. Rep. Toyama*
- Weintraub, P. G., & Beanland, L. 2006. Insect vectors of phytoplasmas. *Annu. Rev. Entomol.* 51: 91-111.
- Wermelinger, B., Wyniger, D., & Forster, B. (2008). First records of an invasive bug in Europe: *Halyomorpha halys* Stål (Heteroptera: Pentatomidae), a new pest on woody ornamentals and fruit trees? *Mitteilungen der Schweizerischen Entomologischen Gesellschaft* 81, 1-8.
- Wiman N.G., Walton V.M., Shearer P.W., Rondon S.I. 2014b. Electronically monitored labial dabbling and stylet ‘probing’ behaviors of brown marmorated stink bug, *Halyomorpha halys*, in simulated environments. *PLoS ONE* 9(12): e113514 doi:10.1371/journal.pone.0113514.
- Wiman, N. G., Parker, J. E., Rodriguez-Saona, C., & Walton, V. M. (2015). Characterizing damage of brown marmorated stink bug (Hemiptera: Pentatomidae) in blueberries. *Journal of Economic Entomology*, 108(3), 1148-1155.
- Wiman, N. G., Walton, V. M., Shearer, P. W., Rondon, S. I., & Lee, J. C. (2014b). Factors affecting flight capacity of brown marmorated stink bug, *Halyomorpha halys* (Hemiptera: Pentatomidae). *Journal of Pest Science*, 88(1), 37-47.
- Wiman, N., Shearer, P., Walton, V., Rondon, S., Tomasino, E., Brunner, J., & Murray, T. (2014a). Brown marmorated stink bug: Biology and crop damage. Retrieved April 7, 2016 from <http://nwhortscs.com/wp-content/uploads/2014/01/Organic-Day-Wiman1.pdf>
- Zalom, F. G., Goodell, P. B., Wilson, L. T., Barnett, W. W., & Bentley, W. J. (1983). Degree-Days\_the\_Calculation\_and\_Use\_of\_Heat\_Units\_in\_Pest\_Management\_University\_of\_California\_Division\_of\_Agriculture\_and\_Natural\_Resources\_Leaflet\_21373

#### FUNDING AGENCIES.

Funding for this research was provided by the California Department of Food and Agriculture, Pierce’s Disease/Glassy Winged Sharpshooter Board