Trapping for early detection of the brown marmorated stink bug, *Halyomorpha halys*, in New Zealand

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Abstract The brown marmorated stink bug (BMSB) would have wide-ranging and likely devastating, effects on New Zealand's horticultural industries if it were to establish here. This insect has spread rapidly around the world, becoming pestiferous only a few years after detection; therefore, there will be limited time to develop management strategies to prevent damage if viable BMSB populations were to establish in New Zealand. Lures containing BMSB pheromone paired with 92 sticky panels were deployed near transitional facilities and other potentially high-risk entry points in the Auckland, Hawke's Bay and Nelson regions. Traps were monitored fortnightly from November 2018 to April 2019 and all pentatomid species identified and enumerated. No BMSB were captured, but seven other pentatomid species were caught. Numbers and species varied among site, region and date. The phenology of the pentatomids captured supports reports of one to two generations occurring in pipfruit-production regions depending on growing-degree days. The phenologies of the pentatomid species caught suggest that any control measures for prevention of fruit damage by BMSB would be limited to late summer. A number of recommendations for a BMSB monitoring programme are provided.

Keywords Invasive species, apples, integrated fruit production, biosecurity, pentatomid

INTRODUCTION

The brown marmorated stink bug (BMSB), *Halyomorpha halys* Stål (Hemiptera: Pentatomidae) is native to the Northern Hemisphere countries of China, Japan, Korea and Taiwan but concerns about its potential establishment in New Zealand have increased in recent years (Zhu et al. 2012; Haye et al. 2015; Anon. 2017a; Fraser et al. 2017). New Zealand's primary production industries are susceptible to invasive insect pests and repeated border interceptions of BMSB over the last few years (Anon. 2019) have elevated this concern substantially. The high volume of imports into New Zealand from countries where BMSB already occurs (e.g. China, Japan, United States, Italy) suggests a high risk of introduction in the future, particularly since there are multiple potential origins and pathways (container traffic, international travellers and post) for entry (Valentin et al. 2017). Reproductive diapause and over-wintering behaviour were thought to limit BMSB range expansion across the equator but its recent establishment in Chile (Faúndez & Rider 2017) has demonstrated that opposite seasonality will not prevent Northern Hemisphere propagules from establishing in New Zealand.

Temperature and photoperiod significantly affect BMSB seasonality and population potential (Nielsen et al. 2016), but the minimum requirements (i.e. suitable climate) for BMSB populations are met in the majority of horticultural production regions in New Zealand (Zhu et al. 2012; Haye et al. 2015; Kriticos et al. 2017; Fraser et al. 2017). However, variations in potential host plants play an important role in pentatomid development (Panizzi 1997) and, together with climate, will likely influence the extent of damage that may be caused in different regional production systems. In New Zealand, for example, a considerably different approach to management may be needed if BMSB is limited by these factors to one generation per year versus multiple generations per year.

The value of New Zealand's horticultural sector is expected to reach $10 billion/year by 2020 (Anon. 2017b). In the United States, protecting fruit from damage by BMSB relies largely on frequent broad-spectrum chemical insecticide applications that maximise fresh residue on fruit and leaf surfaces (Leskey & Nielsen 2018). Over the past three decades, New Zealand's pipfruit industry has shifted away from insecticide spray regimens of this nature (Walker et al. 2017) and such control measures would be severely detrimental to the Integrated Fruit Production (IFP) system in New Zealand that generates fruit with low, or non-detectable insecticide residues. Broad-spectrum insecticides can destroy the community of natural enemies in pipfruit (Lo et al. 2015, Rogers et al. 2015), this can stimulate secondary pest outbreaks (Dutcher 2007) and have other unintended consequences for growers.

In New Zealand, signatories to the Government Industry Agreement (GIA) agree that any incursion of BMSB will require a robust response that incorporates a variety of tools such as mass trapping, detector dogs, public awareness, biological control, and applications of broad-spectrum insecticides all targeting eradication. Early detection and a rapid response in a small geographical area is highly preferable to a response that encompasses numerous production sites.

Post-border monitoring for the presence of invasive pests prior to their establishment in New Zealand has been conducted for numerous insect pests (Cowley 1990; Stephenson et al. 2003). The New Zealand Ministry for Primary Industries has intercepted BMSB at New Zealand's borders since 2005 and the number of BMSB intercepted each year since then is shown in Figure 1. The number of at-border interceptions has increased dramatically since 2013 when BMSB was added to the border monitoring survey list. This increase, along with an increase in post-border interceptions (Anon. 2019), has led to the establishment in 2018 of a monitoring system pilot for the early detection of BMSB. This system involves the use of pheromone traps in some high-risk locations around New Zealand such as transitional import facilities in Auckland and Christchurch. A concurrent monitoring trial was conducted in the important horticultural regions of Hawke's Bay and Nelson. Traps developed for BMSB are based on aggregation pheromones (Khrimian et al. 2014), which also attract a range of other pentatomids, and can help to elucidate the presence and phenologies of stink bugs already present in New Zealand.

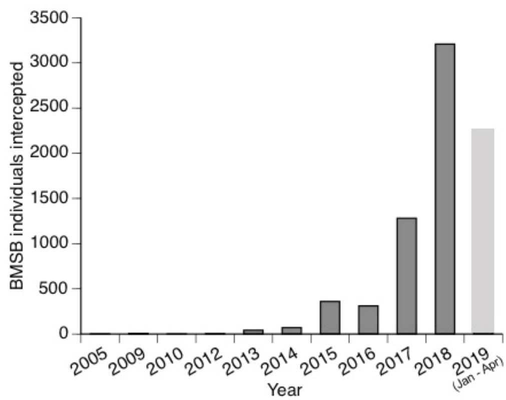

Figure 1 Total number of brown marmorated stink bug (BMSB) individuals intercepted at the New Zealand border by the New Zealand Ministry for Primary Industries by calendar year from 2005 – April 2019.

The work reported here involved identifying and quantifying the range of pentatomid species by-catch in traps established to collect BMSB.

MATERIALS AND METHODS

Statistical Analysis

The relatively small number of non-zero trap counts collected in this study did not support robust analyses allowing for statistical differences between regions to be determined. Thus, simple count data, daily mean and total counts are used for reporting.

Climate information

Growing degree days (GDD) were accumulated from 1 July 2018 and were calculated using the formula

$$GDD = \max\left(\frac{(T_{max}+T_{min})}{2} - T_{threshold}, 0\right)$$

Where T_{max} = maximum daily temperature, T_{min} = minimum daily temperature, and $T_{threshold}$ = species-specific minimum development temperature. The threshold temperature used here was 14.17°C, adopted from Nielsen et al. (2016) as the minimum development temperature for BMSB. Daily temperature data were exported from Plant and Food Research weather stations at Mount Albert in Auckland, and Havelock North in Hawke's Bay. Nelson weather data were exported from the Tasman weather station operated by HortPlus.

Hawke's Bay and Nelson monitoring

Traps and lures were imported from the United States and consisted of 150-mm x 300-mm clear, sticky panels to be hung below pheromone lures. The Pherocon® BMSB High Load lure (Trécé Inc.) was chosen to facilitate data sharing with other monitoring groups, with the expectation that these traps would be used in future monitoring efforts. These lures contain two aggregation pheromones (murgantiol and methyl 2,4,6 decatrienoate) that attract BMSB and other stink bugs to the sticky panels. These traps are considered as effective as other current lure/trap combinations (Acebes-Doria et al. 2018).

Traps were placed at 20 sites (12 in Hawke's Bay, eight in Nelson) deemed to be high-risk locations for BMSB entry into those regions. These were primarily located proximal to transitional facilities, but also included ports, airports, and postal centres. At most locations, traps were deployed in an array comprised of three traps placed 10 metres apart and hung 1.0–2.0 m above the ground in or next to vegetation (horticultural crops or other trees). At each location where an array could not be formed (the Napier Port and Napier Airport), three traps were hung distances of >100 m apart. *Paulownia* sp., a preferred native host of BMSB in its native range, were sought out for trap placement. Apple orchards, organic maize fields, and vegetable fields near transitional facilities were also included.

Traps were deployed in the first week of November 2018 and monitored fortnightly until the end of April 2019. At each visit, traps and the surrounding vegetation within a 5-m radius were visually inspected for any stink bug nymphs or adults, which were then collected and placed in individual vials and labelled. Specimens were identified the same day with the aid of microscope. Sticky panels were replaced every six weeks and lures were replaced every three months following the manufacturer's recommendation.

Auckland and Christchurch monitoring

Pherocon BMSB High Load lures and sticky panels were placed at 16 locations around transitional facilities in Auckland, and nine locations in Christchurch. Pentatomid catches from Christchurch monitoring were low and are not reported here. At each location, two traps consisting of a sticky panel and lure were placed approximately 125 m apart. Traps were affixed to trees or wooden stakes 1.3–2.0 m above the ground. Traps were deployed in late October 2018 and monitored fortnightly until early April 2019 for stink bug egg masses, nymphs and adults (egg counts not reported here). At each site visit, traps and surrounding vegetation within a 5-m radius were inspected and vegetation was sampled with beating sheets by agitating foliage with a long stick to dislodge any bugs present onto a sheet placed underneath. Stink bugs at each location found outside the 5-m radius were also recorded and identified, but are not presented here.

RESULTS

No BMSB were recorded over the course of this study. Adults and nymphs of seven other species of stink bug were captured, with the most predominant being the native Australasian green shield bug (*Glaucias amyoti*), and adventive green vegetable bug (*Nezara viridula*), which together accounted for over 80% of the individuals found (Fig. 2). Five other species were found in lower densities: the native brown soldier bug (*Cermatulus nasalis*); the adventive brown shield bug (*Dictyotus caenosus*); the adventive green potato bug (*Cuspicona simplex*); the adventive Pittosporum shield bug (*Monteithiella humeralis*); and, the native Schellenberg's soldier bug (*Oechalia schellenbergii*).

All regions displayed similar stink bug phenology, with populations generally low or non-detectable until early February (Fig. 3) although low densities of two species were detected earlier in Auckland. Two peaks of *N. viridula* are identifiable in Hawke's Bay,

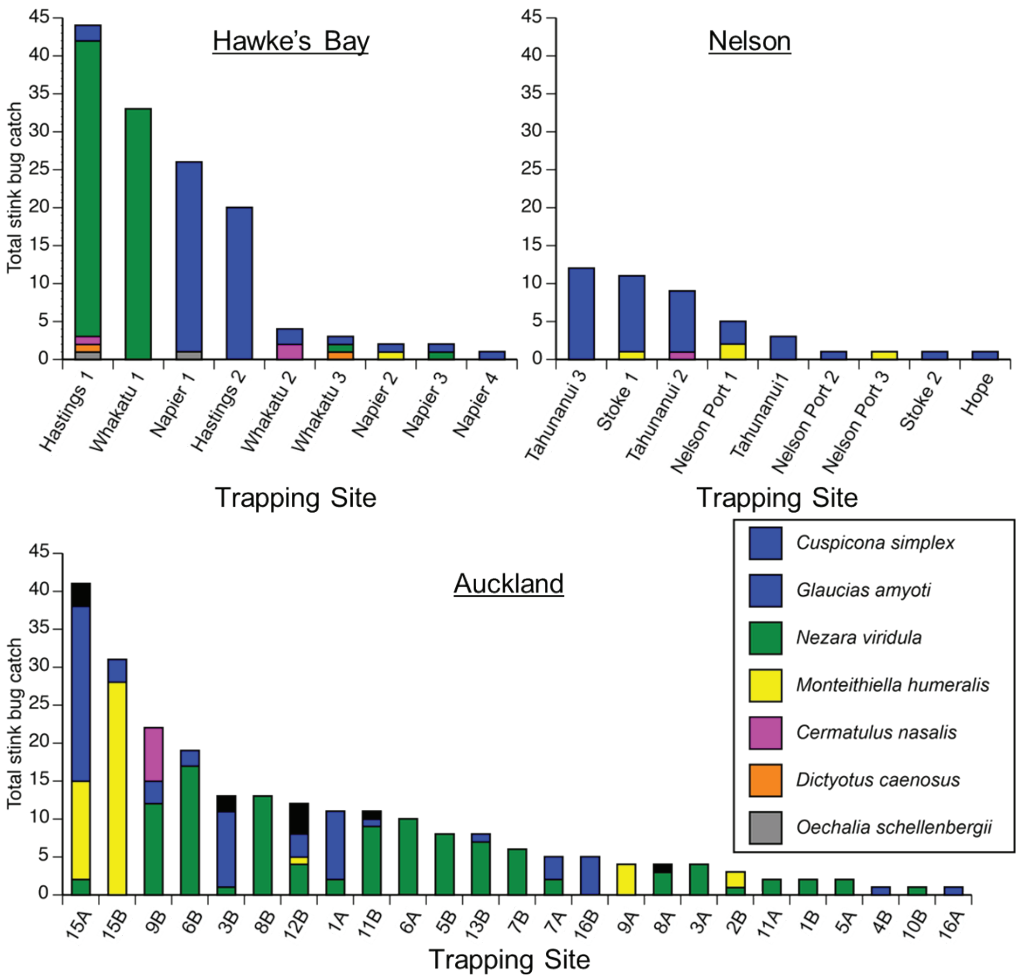

Figure 2 Total pentatomid catch and species composition at trapping sites where stink bugs were captured for Hawke's Bay, Nelson and Auckland from November 2018 to April 2019.

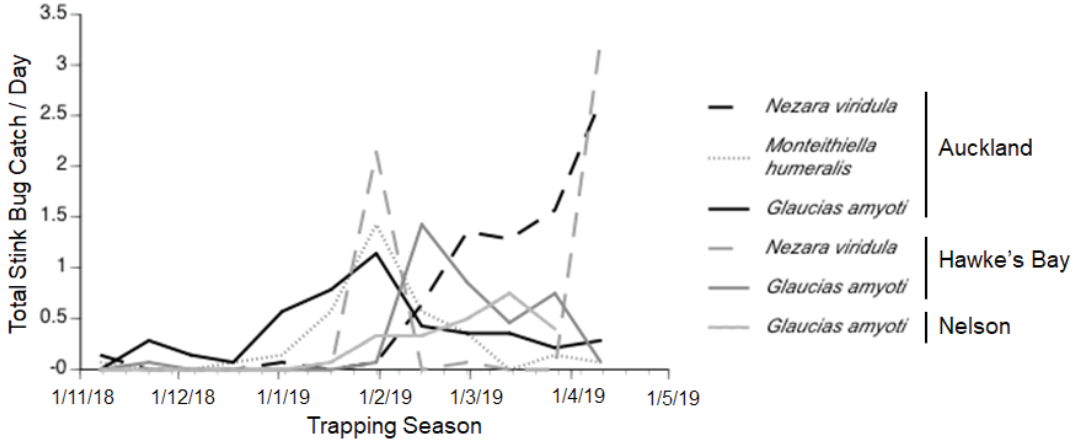

Figure 3 Total stink bug catch per day for the three most commonly observed pentatomid species (*Nezara viridula, Monteithiella humeralis,* and *Glaucias amyoti*) in each New Zealand region monitored fortnightly from 4 November 2018 to 11 April 2019.

however this was limited to two sample locations and sampling dates. In Auckland, *N. viridula* populations continued to increase from February on through April. In all three regions, *G. amyoti* numbers peaked and began to decline in a two-month period between 31 January and 28 March.

Both *N. viridula* and *G. amyoti* were more abundant than all other stink bug species with the exception of *M. humeralis* in Auckland (Figs. 2 & 3). Either *N. viridula* or *G. amyoti* were found at almost every trapping location, while *M. humeralis* was isolated to a few locations, possibly influenced in part by vegetation in the vicinity. In Auckland, 89% of stink bugs caught were found in the surrounding vegetation and 11% stuck on traps, while 58% of stink bugs caught in Hawke's Bay were found in the surrounding vegetation with 42% on traps. Contrast these findings with 98% being caught on traps in the Nelson region. These differences are probably influenced by the robustness of vegetation monitoring carried out in each region.

Stink bug abundance and diversity ranged from one to five species per trap site. As many as 44 stink bugs were detected at one trapping site in Hawke's Bay over the season, while three trapping sites caught none. In Auckland, one trapping site caught a maximum of 41 stink bugs, while seven trapping sites in Auckland remained empty. In Nelson, the maximum detection at one site was eight individual stink bugs, while four sites caught one.

The number of stink bugs collected per day were plotted against the modelled number of GDD (Fig. 4). The timing of peak bug numbers for the New Zealand sites based on GDD was very similar to those reported internationally (Nielsen

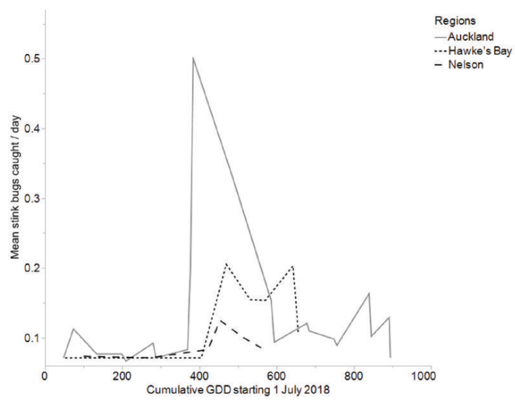

Figure 4 Daily pentatomid counts for Hawke's Bay, Auckland and Nelson using traps baited with brown marmorated stink bug (BMSB) pheromone in relation to accumulated growing degree days (GDD) from 1 July 2018 using the GDD model generated by Nielsen et al. (2016).

et al. 2016), which suggests that endemic stink bug phenologies are partly temperature driven. From 1 July 2018 to 15 April 2019, the Auckland weather station recorded an accumulation of 895.9 GDD, the Hawke's Bay site recorded 636.9 GDD and the Nelson site recorded 562.3 GDD (Table 1).

DISCUSSION

The results presented suggest populations of the most abundant stink bug species observed grow and peak between February and April, near the time most pipfruit growers are harvesting. If the phenology of BMSB in the New Zealand climate were similar to those expressed internationally, insecticide maximum residue limits (MRLs) would limit growers to few, if any, chemical options for stink bug control in pipfruit orchards late in season and strategies beyond chemical control would be required to limit crop damage. The highly mobile nature of BMSB suggests that limiting crop damage in late-harvested crops (e.g. apples, kiwifruit) might depend on effective control in earlier-season crops, coupled with deterrence *in situ*. In this study, *N. viridula* in Hawke's Bay appeared to display more than one generation over the season, in accordance with other reports (Martin 2018). It is unclear if BMSB would exhibit the same number of generations in Hawke's Bay as *N. viridula*. The data presented by Nielsen et al. (2008) on the minimum growing degree days represent a worst-case scenario and suggest a second generation is plausible based on the 2018-19 data presented here. The difference between one and two generations per year will affect the range, timing and severity of crops attacked and will likely have substantial impacts on growers' management tactics. Work should be continued to clarify this possible outcome.

The effect of trapping locations is clearly an important factor that may restrict interpretations of stink bug phenology. To address this, research that monitors endemic stink bug populations in and around production systems (rather than invasive species around transitional facilities) will help to validate the findings presented here. Trap placement within the canopy significantly affects BMSB catch (Quinn et al. 2019) and other placement factors (e.g. in orchard versus in hedgerows, or within native versus non-native hosts) may be similarly important. Additionally, the lures used in this study attracted a broad range of stink bugs, but are unlikely to attract each species evenly (Tillman et al. 2010). While

Table 1 Mean growing degree days (GDD) and associated calendar dates for Hawke's Bay, Auckland, and Nelson regions where BMSB traps were located.

GDD 1 July 2018 start	Auckland Region		Hawke's Bay Region		Nelson Region	
	Date reached	# weeks after 1 July 2018	Date reached	# weeks after 1 July 2018	Date reached	# weeks after 1 July 2018
100	29/11/18	22	09/12/18	23	20/12/18	25
200	19/12/18	24	31/12/18	26	09/01/19	27
300	06/01/19	27	17/01/19	29	28/01/19	30
400	19/01/19	29	01/02/19	31	14/02/19	33
500	02/02/19	31	22/02/19	34	16/03/19	37
600	15/02/19	33	24/03/19	38		
700	04/03/19	35				
800	21/03/19	38				
900	20/04/19	42				

the two species *N. viridula* and *G. amyoti* are the most abundant stink bugs captured, it is feasible that they are not necessarily more abundant than other species, but were more readily attracted to the lures in use. This could be addressed with no-choice laboratory trials to clarify future research.

The risk of BMSB to New Zealand, including Māori taonga (Teulon et al. 2019), is evident and monitoring areas of likely introduction is integral to early detection that informs eradication efforts. A high-level IPM framework would effectively manage multiple pests in multiple production systems (Kogan 1998) and will undoubtedly be the goal for BMSB control in all of New Zealand's major production regions should BMSB become established. A landscape-level approach that addresses BMSB populations throughout an entire region would need to be informed by pest biology, climate and effective control tactics, before a management strategy could be constructed.

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REFERENCES

Acebes-Doria AL, Morrison WR, Short BD, Rice KB, Bush HG, Kuhar TP, Duthie C, Leskey TC 2018. Monitoring and biosurveillance tools for the brown marmorated stink bug, *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae). Insects 9(3), e 82.

Anonymous 2017a. Brown marmorated stink bug. https://www.biosecurity.govt.nz/protection-and-response/responding/alerts/brown-marmorated-stink-bug/ (accessed 29 April 2019).

Anonymous 2017b. Fresh Facts. http://www.freshfacts.co.nz/files/freshfacts-2017.pdf (accessed 29 April 2019).

Anonymous 2019. KVH Information sheet BMSB risk update March 2019. https://www.kvh.org.nz/vdb/document/104792 (accessed 29 April 2019).

Cowley JM 1990. A new system of fruit fly surveillance trapping in New Zealand. New Zealand Entomologist 13: 81–84.

Dutcher JD 2007. A review of resurgence and replacement causing pest outbreaks in IPM. In: Ciancio A, Mukerji KG (eds) General Concepts in Integrated Pest and Disease Management. Integrated Management of Plants Pests and Diseases, vol 1. Springer, Dordrecht.

Faúndez EI, Rider DA 2017. The brown marmorated stink bug *Halyomorpha halys* (Stål, 1855) (Heteroptera: Pentatomidae) in Chile. Arquivos Entomoloxicos 17: 305–307.

Fraser D, Kumar S, Aguilar G 2017. Mapping the potential global range of the brown marmorated stink bug, *Halyomorpha halys*, with particular reference to New Zealand. Climate 5(3): 75–89.

Haye T, Gariepy T, Hoelmer K, Rossi J-P, Streito J-C, Tassus X, Desneux N 2015. Range expansion of the invasive brown marmorated stinkbug, *Halyomorpha halys*: and increasing threat to field, fruit and vegetable crops worldwide. Journal of Pest Science 88: 665–673.

Khrimian A, Zhang A, Weber DC, Ho HY, Aldrich JR, Vermillion KE, Siegler MA, Shirali S, Guzman F, Leskey TC 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.

Kogan M 1998. Integrated Pest Management: Historical perspectives and contemporary developments. Annual Review of Entomology 43: 243–270.

Kriticos DJ, Kean JM, Phillips CB, Senay SD, Acosta A, Haye T 2017. The potential global distribution of the brown marmorated stink bug, *Halyomorpha halys*, a critical threat to plant biosecurity. Journal of Pest Science 90: 1033–1043.

Leskey TC, Nielsen AL 2018. Impact of the invasive brown marmorated stink bug in North America and Europe: History, biology, ecology, and management. Annual Review of Entomology 63: 599–618.

Lo PL, Walker JTS, Rogers DJ 2015. Risks to pest management in New Zealand's pipfruit Integrated Fruit Production programme. New Zealand Plant Protection 68: 306–312.

Martin NA. 2016, revised 2018. Green vegetable bug - *Nezara viridula*. Interesting insects and other invertebrates. New Zealand Arthropod Factsheet Series Number 47. https://nzacfactsheets.landcareresearch.co.nz/factsheet/InterestingInsects/Green-vegetable-bug---Nezara-viridula.html (accessed 29 April 2019).

Nielsen AL, Hamilton GC, Matadha, D 2008. Developmental rate estimation and life table analysis for *Halyomorpha halys* (Hemiptera: Pentatomidae). Environmental Entomology 37: 348–355.

Nielsen AL, Chen S, Fleischer SJ 2016. Coupling developmental physiology, photoperiod, and temperature to model phenology, and dynamics of an invasive Heteropteran, *Halyomorpha halys*. Frontiers in Physiology 7, e165.

Panizzi AR 1997. Wild hosts of pentatomids: ecological significance and role in their pest status on crops. Annual Review of Entomology 42: 99–122.

Quinn NF, Talamas EJ, Acebes-Doria AL, Leskey TC, Bergh JC 2019. Vertical sampling in tree canopies for *Halyomorpha halys* (Hemiptera: Pentatomidae) life stages and its egg parasitoid, *Trissolcus japonicus* (Hymenoptera: Scelionidae). Environmental Entomology 48: 173–180.

Rogers DJ, Lo PL, Walker JTS 2015. Vulnerability of pest management in New Zealand apples: pesticide toxicity to *Aphelinus mali* (Hymenoptera: Encyrtidae). New Zealand Plant Protection 68: 299–305.

Stephenson BP, Gill GSC, Randall JL, Wilson JA 2003. Biosecurity approaches to surveillance and response for new plant pest species. New Zealand Plant Protection 56: 5–9.

Teulon DAJ, Puketapu A, Ropata HT, Bicknell R 2019. Establishing a base for understanding the threat of the brown marmorated stink bug to plants of value to Māori. E whakarite ana he tūāpapa e mārama ai i ngā kino o te ngārara pīhau parauri ki ngā tipu e whai hua ki te Māori. New Zealand Plant Protection 72: 44-58.

Tillman PG, Aldrich JR, Khrimian A, Cottrell TE 2010. Pheromone attraction and cross-attraction of *Nezara, Acrosternum*, and *Euschistus* spp. stink bugs (Heteroptera: Pentatomidae) in the field. Environmental Entomology 39(2): 610–617.

Valentin RE, Nielsen AL, Wiman NG, Lee DH, Fonseca DM 2017. Global invasion network of the brown marmorated stink bug, *Halyomorpha halys*. Scientific Reports 7(1), e9866.

Walker JTS, Suckling DM, Wearing CH 2017. Past, present, and future of integrated control of apple pests: The New Zealand experience. Annual Review of Entomology 62: 231–248.

Zhu G, Bu W, Gao Y, Liu G 2012. Potential geographic distribution of brown marmorated stink bug invasion (*Halyomorpha halys*). PLoS ONE 7(2): e31246.