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

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Abstract The brown marmorated stink bug (BMSB) *Halyomorpha halys* (Heteroptera: Pentatomidae) is an invasive pest in North America and Europe that damages many plant species and invades human dwellings. It is regularly intercepted at Aotearoa/New Zealand's borders but is not yet known to have established. Māori are partners in New Zealand's biosecurity community and an understanding of the potential impact of any invasive alien species to their interests is essential. The known impacts of BMSB in published literature were reviewed with a focus on Māori plant taonga (valued or treasured plant species) in: (1) Māori commercial enterprises; (2) māra kai (food gardens); and (3) the natural estate. Many fruit and some vegetable species are likely to be affected by BMSB in commercial and non-commercial Māori horticulture but the impact of BMSB on indigenous/native and other taonga plant species in māra kai and the native estate is difficult to evaluate. BMSB poses a serious economic threat to some crop species of commercial value to Māori, as well as threat to some native taonga species. A kaupapa Māori approach examining unpublished mātauranga (knowledge) would considerably broaden this understanding.

Te Tuarongo He ngārara raupatu kaha nei i te tini o ngā tipu, te urutomo noa i te hunga tangata te ngārara nei. Ka kaha haukotingia te ngārara nei e te mana ārai o Aotearoa heoi anō, kāore anō kia whakawhenua i a ia. E mahi tahi ana a Māori rāua ko te hapori marukoiora, anō hoki e mārama ana i te mōrearea o ngā tipu tauiwi - e whai pānga kia rātou. Te Tukanga. I arotake i ngā tuhinga e hāngai ana ki ngā kopuratanga e mōhio nei - e Māori ai te titiro o roto: (1) ngā pākihi Māori (2) ngā māra kai (3) te taiao anō hoki. Te Whakautu. He maha hoki ngā huawhenua me ngā huarākau ka pāngia e te BMSB o roto i ngā pākihi, i ngā ahuone Māori heoi anō, te taea te whakatau i ngā pānga o te BMSB ki te iwi taketake me ōna taonga o roto i ngā māra kai. Te Whakakapinga. Kei tino raru ētahi tipu e whai pānga ki te Māori, ngā tipu taketake anō hoki i te BMSB. Mā te tirohanga Māori e whakawhānui i ngā mōhiotanga.

Keywords brown marmorated stink bug, *Halyomorpha halys*, Māori, taonga, plant border biosecurity, protection

INTRODUCTION

Estimates of economic damage to productive plant systems in Aotearoa/New Zealand from established invasive species are large (Goldson et al. 2015) but with environmental, social and cultural impacts mostly unmeasured (Brockerhoff et al. 2010). However, New Zealand continues to be at risk from a range of invasive alien species and their undesirable impact on valued plant species in both the productive sector and the natural estate (Edney-Browne et al. 2018; Sikes et al. 2018).

To mitigate the impacts of invasive alien species, New Zealand's biosecurity system has a range of measures that include pre-border, at-border and post-border activities (Ministry for Primary Industries (MPI) 2016). Increasingly, it is understood that an effective biosecurity system requires a collective effort from the wider community including government, industry and the general public (Hellstrom et al. 2008). Indeed, Biosecurity 2025 (Biosecurity NZ 2018) recognises the unique knowledge and perspective of New Zealand's indigenous people, and the need for them to actively participate at all levels of the system (MPI 2016). Such a role for Māori is increasingly recognised in biosecurity literature (Teulon et al. 2015, Allen et al 2018, Lambert et al. 2018, Black et al. 2019). Their increasing role is reflected in the activities of Te Tira Whakamātaki (The Māori Biosecurity Network) (Te Tira Whākamataki nd) and the Biological Heritage National Science Challenge (BHNSC nd).

The brown marmorated stink bug (BMSB) (*Halyomorpha halys* Stål) (Hemiptera: Pentatomidae) is an invasive alien species originating from East Asia. It is now established in North America and Europe (Leskey & Nielsen 2018) and has recently been found in Chile (Faúndez & Rider 2017). Throughout its distribution, BMSB is a serious pest of many agricultural and horticultural crops, as well as a significant nuisance pest because of its behaviour of overwintering inside dwellings in large numbers (Leskey & Nielsen 2018). BMSB has not established in New Zealand to date (Vandervoet et al. 2019) but is intercepted regularly at the border and is considered to pose a serious biosecurity threat to New Zealand plant systems (Duthie 2015; Haye et al. 2015; Ballingall & Pambudi 2017, MPI 2019). The potential impact of BMSB on a range of New Zealand plant crop and native plants has been documented (Duthie 2012; Ballingall & Pambudi 2017) but its specific potential impact on plant species of high value to Māori has not. Several Māori entities have recognised that BMSB poses a serious threat to plants in productive and natural systems (Te Tira Whākamataki 2017; Te Rūnanga o Ngāi Tahu 2018) but there is a need to further illustrate the basis for this conclusion.

Plants of cultural significance or value and considered taonga to Māori include many indigenous and introduced species (Waitangi Tribunal 2011). Taonga plants serve as important sources of food, fibre, medicine (rongoa), building and ritualistic materials for Māori (Department of Conservation DOC 2006; Roberts 2009; McGowan 2012). Taonga species may be part of a defined list (e.g. DOC 2006), or more generally any species of importance to Māori such as root crop plants (e.g. kūmara and taro), and animals such as kiore (rat) and wild pig (Roberts 2009).

The current study involved a review of published literature to generate a background document for future research into the wider topic adopting a kaupapa Māori focused approach including mātauranga (knowledge) sourced directly from hapu (subtribe) and iwi (tribe). The likely impacts of BMSB to valued plants in New Zealand are summarised and placed in the context of the potential threat of BMSB to Māori commercial interests, māra kai and other taonga species found in natural systems. This work

focused on the threats of BMSB to plants (i.e. damage) and not the potential broader effects that may be forthcoming, such as the disruption of the aiōpipi (calm) of the taiao (environment) (Te Tira Whākamataki 2017), which will require further consideration from a Te Ao Māori perspective.

METHODS

BMSB threat to plants

Information on the impact of BMSB to plant species was collated from key international BMSB literature reviews (Lee et al. 2013; Rice et al. 2014; Haye et al. 2015; Leskey & Nielsen 2018). In addition, publications obtained from regular alerts from Web of Science (Clarivate Analytics) over a period from May 2017 to April 2019 using the TOPIC option for keywords: *"Halyomorpha halys"* OR *"brown marmorated stink bug"* were reviewed for additional information published after the review articles. From these sources, a detailed list of BMSB host plants was established, in particular plant hosts that supported high densities of BMSB and/or those plant hosts that were reported to have significant damage caused by BMSB.

Māori horticulture and agriculture

Information on Māori agricultural and horticultural commercial interests, and māra kai (Māori community gardens) was sourced from an investigation of the Web of Science and 'grey' literature. Published literature concerning indigenous issues is often limited (Sanson-Fisher et al. 2006; McKerchar et al. 2014), including in the Māori agribusiness space (Hutchings et al. 2017) and there is a lack of ethnicity or ownership identifiers in national industry datasets (Kingi 2013). In particular, information was sourced from Google using a range of search terms (and their combinations) including Māori, (or Maori), iwi, māra (or mara), maara, kai, community, garden, pastoral, arable and horticulture, along with the names of the eight largest iwi (TDB Advisory Ltd 2019). Websites of these eight iwi were also inspected further for any relevant information (e.g. size and range of investments in agriculture and horticulture). Traditional kaupapa Māori research processes, which may identify information held within hapu and iwi, was not undertaken in this study as this paper is intended to serve as the basis for further research utilising these and other methods.

Natural estate

Based on the information collated for host plants of high BMSB abundance and high BMSB damage (see above, Appendix 1), notable New Zealand indigenous and native plant species were identified (Allan 1961) and grouped according to plant family in an attempt to identify New Zealand plant species from the natural estate that might be threatened by BMSB.

RESULTS

BMSB threat to plants

The threat from BMSB to a range of plant species is well documented in a series of review publications for Asia (Lee et al. 2013), North America (Rice et al. 2014; Leskey & Nielsen 2018) and Europe (Haye et al. 2015) and more recently including *Actinidia* spp. (Kiwifruit Vine Health 2017; Andreadis et al. 2018; Teulon & Xu 2018).

A summary of the plant species that host relatively large BMSB populations (largely from Rice et al. 2014, STOP BMSB 2015) and for which high BMSB damage has been reported (various sources) or both is provided in Appendix 1. As expected, this list is dominated by plants from the productive sector (i.e. fruit including grapes, vegetables, field crops, nut crops and ornamentals) in the northern hemisphere. For most plants, damage results from BMSB feeding on flowers and fruiting bodies leading to tissue damage and fruit deformities (Lee et al. 2013; Rice et al. 2014; Haye et al 2015; Leskey & Nielsen 2018). There are reports of losses of young flowers in North America but these are largely anecdotal observations (T. Leskey pers. comm.). Much of the damage associated with BMSB is cosmetic in nature (i.e. making the fruit less appealing to the consumer). Non-cosmetic damage, such as the putative loss of flowers, loss of fruiting bodies, plant wilting, and general statements regarding

'plant damage' have been reported (Appendix 1) but these are seldom qualified in terms of plant impact. Haye et al. (2015) stated that no direct, negative environmental impacts are known, such as damage to wild plants. An economic analysis of selected agricultural and horticultural industries estimated GDP losses of between $1.8 and $3.6 B could be accrued by 2038 if BMSB had become established in New Zealand in 2017 (Ballingall & Pambudi 2017). However, the report did not include any specific impacts to Māori.

Māori horticulture and agriculture

Māori own a range of assets in New Zealand's primary sectors including 50% of the fishing quota, 40% of forestry, 30% in lamb production, 30% in sheep and beef production, 10% in dairy production and 10% in kiwifruit production (Chapman Tripp 2017). Food and fibre account for approximately 47% of New Zealand's exports and 15% of these are linked to Māori resources (KPMG 2017). These assets contribute to the so-called, but perhaps poorly termed, Māori economy (Amoamo et al. 2018), which has been estimated to be worth $NZ50 B and which is reported to be growing faster than many other parts of the New Zealand economy (KPMG 2017).

Māori trusts and incorporations mostly engage in pastoral farming but some have diversified their interests to include geothermal energy, property, forestry, honey production, fisheries and horticulture (KPMG 2017) some of which could be affected by BMSB. Horticulture has been highlighted as an area for future investment and involvement within the Māori economy (KPMG 2017) and this expansion could also be adversely affected by BMSB. Several iwi were identified with significant interests in horticulture, wine and honey production (Table 1) but it was not possible to quantify the degree of Māori involvement in the 'other plant production' sectors that might suffer direct impact from BMSB apart from the kiwifruit sector (10% of total in kiwifruit production; Chapman Tripp 2017). Māori commercial entities grow kiwifruit, apple, sweet pepper, tomato and wine grape crops and all these could be at significant risk if BMSB became established in New Zealand based on the current literature (Appendix 1) although BMSB does not seem to be a problem on sweet pepper in greenhouses at least in North America (T Leskey pers. comm.). To date, no species from the Myrtaceae have been recorded as BMSB feeding or breeding hosts (Lee et al. 2015; CABI 2019; Bergmann et al. nd) so it is possible that BMSB would not be a direct threat to the mānuka honey industry.

There is no doubt that there are many smaller Māori entities producing fruit or vegetables that would be highly susceptible to BMSB attack such as those growers represented within Tāhuri Whenua Incorporated Society (Tāhuri Whenua 2019), Māori Kiwifruit Growers Inc. (Māori Kiwifruit Growers 2017) and Tuku–Māori Winemakers Collective (Tuku 2018). Tāhuri Whenua currently has 469 registered members with most (>90%) involved in marae or community gardens (R. Estrada pers. comm.). There is considerable (but non-quantified) Māori involvement in the horticulture industry, not necessarily as traditional producers (e.g. māra kai – see below), but as contributors to the New Zealand economy (Roskruge 2007).

Māori have significant investments in livestock and dairy (see above, Chapman Tripp 2017) and the indirect effects on these industries through BMSB feeding on fodder crops may be important but have not been studied. Field corn or maize has a high risk for BMSB damage (Appendix 1). How BMSB might impact the productivity and nutritional quality of maize silage for animal feed (its main use in New Zealand) is unclear. Similarly, the risk of BMSB to New Zealand's important brassica crops is not obvious. The greatest use (and value) of brassica crops in New Zealand is for animal feed and it is not known whether BMSB damage will be sufficient to affect this usage.

Māra kai (food gardens)

Horticulture is deeply rooted in Māori culture with ancestral links (whakapapa) going back to the origins of Māori genealogies (Roskruge 2007).

Table 1 A selection of Māori economic interests that might be impacted by the brown marmorated stink bug (BMSB) *Halyomorpha halys* (Heteroptera: Pentatomidae).

Iwi	Companies	Activity	References
Ngāti Awa, Te Arawa	Matai Pacific Iwi Collective (Ngāti Awa Group Holdings, Te Arawa Group Holdings & Rotoma No 1 Inc.)	98 ha kiwifruit	Anon 2018a
Ngāti Porou	Ngati Porou Miere Limited Partnership	Manuka honey production	Anon 2015a
Ngāi Tahu	Watson & Son	Manuka honey production	Anon 2019
	Ngāi Tahu Farming	Trialling apple, blueberry & stonefruit	Fulton 2018, Bristow 2019
Tūwharetoa	Tuaropiki Trust / Gourmet Mokai	11 ha glasshouses capsicums & tomatoes	Anon 2012
Te Tau Ihu: Ngāti Koata, Ngāti Rārua, Ngāti Tama, Te Ātiawa	KONO (Wakatū Incorporation) incl. Kono Wines, Tohu Wines & Aronui Wines	224 ha of apple, kiwifruit, pears & hops. Vineyards	Anon 2015b
Ngāi Te Rangi	Ngai Tukairangi Trust	125 ha kiwifruit	Landow 2018
	Mangatawa Papamoa Blocks Inc.	30 ha kiwifruit, 3.5 ha avocados	MPBI 2019

Traditionally, horticulture was part of the daily life for Māori providing food, medicine (rongoa) and utilities (e.g. clothing, rope) (Roskruge 2007). Since colonisation, the place and role of Māori horticulture has evolved over time in response to the importation of new plant species as well as other political (e.g. land confiscation and sale) and geo-demographic (e.g. urbanisation) issues (Roskruge 2007; McKerchar et al. 2014). Contemporary Māori horticulture in general, and māra kai in particular, has been discussed not just in the context of food production for whānau, marae or hapū, but is deeply embedded in food security, food sovereignty, community health, economic development and autonomy (McKerchar et al 2014; Hutchings et al. 2018). In this context, there has been a recent resurgence in food-gardening initiatives within Māori communities (McKerchar et al 2014) supported by both iwi (Te Rūnanga o Ngāi Tahu 2013; Anon 2018b) and government (Te Puni Kōkiri 2019).

Roskruge (2007) provided a detailed list and information of species grown historically in māra kai of which many (if not all) could be considered taonga. A BMSB threat status has been assigned to these species (Table 2) with only kānga (corn, *Zea mays*) at high risk based on international knowledge (Appendix 1), and poroporo (*Solanum aviculare*) and karaka (*Corynocarpus laevigatus*) at medium risk because of BMSB's propensity to attack fruit. A large number of species were classified as low-risk because they were either root/tuber crops or leafy vegetables, which are not considered at risk from BMSB (Kuhar et al. 2016). Many species (included various flaxes and ferns) could not be categorised due to lack of knowledge. A range of traditional foods such as kūmara (sweet potato), taro (arum), uwhi (yam), taewa (potato), kamokamo (squash), kānga (corn) and hue (bottle gourd) as

Table 2 Key plant species in Māori horticulture as found in Roskruge (2007) and their brown marmorated stink bug (BMSB) *Halyomorpha halys* (Heteroptera: Pentatomidae) damage profile.

Damage profile	Plant species	Reason and/or source material for justification of damage profile
At risk	kānga (Indian corn, maize) (*Zea mays*)	Rice at al. 2014
Medium risk	poroporo fruit (*Solanum aviculare*)	A pest of *Solanum lycopersicum* and *S. melongena* is a host plant (STOP BMSB 2015)
	karaka fruit (*Corynocarpus laevigatus*)	A preference for fruiting bodies (STOP BMSB 2015)
Low risk or no risk	kūmara (sweet potato) (*Ipomoea batatas*)	Tuber vegetables not at risk (STOP BMSB 2015, Kuhar et al. 2016)
	hue (bottle gourd) (*Lagenaria siceraria*)	Minor feeders on cucubits (Kuhar et al. 2016)
	uwhi/Uhi (yam) (*Dioscorea alata*)	Tuber vegetables not at risk (Kuhar et al. 2016)
	taewa/Peruperu/Riwai/Parareka (Maori potato) (*Solanum tuberosum*)	Tuber vegetables such as potato not at risk (STOP BMSB 2015, Kuhar et al. 2016)
	kamokamo (*Cucurbito pepo* cv Kamokamo)	Minor feeders on cucubits (Kuhar et al. 2016)
	hāria/paea/nīko/puka/rearea/nanī/pora (wild cabbage, Māori cabbage) (*Brassica oleracea*)	Leafy vegetables not at risk (Kuhar et al. 2016)
	aruhe/roi (fernroot) (*Pteridium esculentum, P. aquilinum, P. acquiline*)	Root and tuber vegetables not at risk (Kuhar et al. 2016)
	kōkihi/rengamutu (NZ spinach) (*Tetragonia tetragonoides*)	Leafy vegetables not at risk (Kuhar et al. 2016)
Unknown Risk	tii/kouka (cabbage tree) (*Cordyline* spp.)	No information found to support a risk profile
	rengarenga / māikaika (rock lily) (*Arthropodium cirratum*)	
	puha/rauriki/pororua (*Sonchus* spp.)	
	harakeke (NZ lowland or swamp flax) (*Phormium tenax*)	
	whaririki (NZ coastal or mountain flax) (*Phormium cookianum*)	
	pikopiko	
	mauku/mouku (hen & chicken fern) (*Asplenium bulbiferum)*	
	kiokio (palm leaf fern) (*Parablechnum novae-zelandiae*)	
	paretao/pānako (Shining spleenwort) (*Asplenium oblongifolium*)	
	pākau (gully fern) (*Pneumatopteris pennigera*)	
	shield ferns (*Polystichum richardii, P. vestitum*)	
	mamaku/korau (black tree fern) (*Cyathea medullaris*)	
	nīkau (*Rhopalostylis sapida*)	

The following plants were not profiled for various reasons: taro (*Colocasia esculenta*) – cultivation ceased by 1900 (Roskruge (2007), aute (maro) (*Broussonetia papyrifera*) (paper mulberry) – became extinct after 1844 (Roskruge (2007), and para (King fern or horseshoe fern) (*Ptisana salicina*) – cultivation for food ceased in the 1920s (Roskruge (2007)

well as other, more commonly grown, vegetables and fruit (EPA 2018) are grown in modern māra kai. Additionally, certain korare, or Maori green vegetables (Roskruge 2015), are likely to be at risk from BMSB. It is reasonable to assume that many of the vegetable and fruit species now grown in māra kai will have a similar BMSB risk status as those listed in Appendix 1.

Natural estate

BMSB is recognised as having a very broad host range (Lee et al. 2015; CABI 2019; Bergmann et al. nd) and many species have been reported to support relatively high BMSB populations or have high BMSB damage, or both (Appendix 1). Almost all records are from productive systems and urban and rural environments. There appear to be no studies examining the impact of BMSB in natural systems within its current invasive or original distribution. No host plants are recorded from what New Zealand would consider the natural estate, although there are numerous records of BMSB populations originating from woodland areas adjacent to crops early in the season (see Rice et al 2014). No records of BMSB collected from New Zealand indigenous or native plants were found. However, there are numerous New Zealand indigenous and native plants that are found within the families of plants that are hosts to BMSB, particularly from the Rosaceae and the Fabaceae (Appendix 1). In other cases, some known BMSB host plant families are not represented in the New Zealand indigenous/native flora (Appendix 1).

DISCUSSION

For Māori, the published discourse on biosecurity is wide-ranging covering constitutional, legal, political, social, cultural, ethical, economic, environmental and pragmatic issues reflecting the broader bi-cultural discussions within New Zealand (e.g. Waitangi Tribunal 2011; McKerchar et al. 2014; Allen et al. 2018; Hutchings et al. 2018; Lambert et al. 2018; Black et al. 2019). Here the discussion is restricted to the direct and tangible impact of BMSB to the plants of value to Māori and under the clear constraint of limited published information.

Māori have essential interests in horticultural and agricultural commercial enterprises, community gardens and the natural estate (Tables 1 & 2). Within these interests are many plants that are likely to have taonga status. Many fruit (and some vegetable) species in commercial and non-commercial Māori agriculture and horticulture, including māra kai, are likely to be affected by BMSB based on the known impact of BMSB in the northern hemisphere. However, it is not known if BMSB is a threat to many plant species (especially historical grown species) grown in māra kai.

It is difficult to determine the potential risk to New Zealand's indigenous/native flora, and non-cultivated taonga species since no published studies were found that examine the impact of BMSB on natural systems within its current invasive or original distribution. No direct, negative environmental impacts from BMSB have been recorded (Haye et al. 2015). BMSB is typically reported to cause cosmetic damage to fruit and vegetables and there are few reports of extensive BMSB damage threatening host plant viability (Appendix 1). Additionally, damaging outbreak populations are not universal across the current BMSB distribution and are associated with interactions between host plant and insect phenology, as well as host plant nutritional quality, landscape ecology (especially polycultures providing mixed diets and edge effects), photoperiod and possibly haplotype (Leskey & Nielsen 2018) – conditions that are difficult to predict for New Zealand systems.

Many New Zealand indigenous and native species are likely to be BMSB breeding and feeding hosts given the broad host range of BMSB (Appendix 1) but the extent of damage that BMSB will incur on these plants is unclear. In the northern hemisphere, several members of the Rosaceae family are reported as hosts, most of which are fruit tree species. In the native New Zealand flora, the Rosaceae is represented by scrambling vines (such as the bush lawyer (*Rubus* subg. *Micranthobatus*)) and by small herbaceous plants (like *Acaena* spp. and *Potentilla* spp.). Other

species of *Rubus* (blackberries) are recorded as hosts in North America although not noted to be strongly preferred by BMSB (Rice et al. 2014). The records of species in the Fabaceae family as BMSB hosts is of concern. This family includes the taonga species kowhai (*Sophora* spp.) and kaka beak (*Clianthus puniceus*), as well as a large number of native broom species. The pagoda tree (*Styphnolobium japonicum*) is reported to be a host of BMSB with high risk of damage (Appendix 1) and the genera *Styphnolobium* and *Sophora* are very closely related. The Solanaceae is a very large plant family that includes several crops (such as, tobacco, tomato and potato) and BMSB is known to feed on some of these plants. In the New Zealand flora, this family is represented by only two species of poroporo (*Solanum aviculare* and *S. lanciniatum*) and possibly also by a nightshade (*S. nodiflorum*), although the indigenous status of this plant is debated. The Malvaceae is a geographically widespread plant family which includes exotic trees such as hibiscus and the lindens, as well as herbaceous species such as field mallow. In New Zealand, the Malvaceae is represented by two closely related genera *Hoheria* and *Plagianthus* (houhere, ribbonwood or lacebark) which are trees of disturbed habitats, often colonising bush margins and river banks. The northern hemisphere maple belongs to the family Sapindaceae. In the New Zealand flora, the Sapindaceae is represented by the titoki (*Alectryon excelsus*) and by the akeake (*Dodonea viscosa*) both of which were widely used by pre-European Māori. The dogwood family (Cornaceae) is also of significance in the New Zealand flora represented by the native genera *Corokia* and *Griselinia*. The olive family (Oleaceae) is represented in New Zealand by the maire (*Olea apetala, O. cunninghamii, O. lanceolate* and *O. montana*), trees known for their very hard, durable wood. Most members of the Rubiaceae (the coffee family), form fleshy berries of the type favoured by BMSB. Native genera in the Rubiaceae include the genera *Coprosma* and *Nertera*, which are common throughout the country. Even New Zealand's unique and ancient conifer species may be potential hosts, as podocarp trees form seeds attached to a fleshy aral, which may support insect feeding.

It should be noted that the New Zealand native flora is unique and very different from the flora of most of the countries currently reporting BMSB colonisation. We suspect that there will be indigenous plant families that have not yet been encountered by BMSB, but that may prove to be suitable hosts in New Zealand. Thus, it appears likely that several indigenous/native plants will be suitable BMSB feeding and breeding hosts but it is unclear whether BMSB will have a significant damage on native plant species in the native estate.

This review provides a baseline for further research. For example, implementing a kaupapa Māori approach may reveal further insights not captured or accessible in conventional literature. Additionally, there are at least two other aspects that are likely to concern Māori if BMSB becomes established in New Zealand. Firstly, BMSB is a significant nuisance pest, with a habit of overwintering in man-made structures in very high densities (Leskey & Nielsen 2018). This has potential consequences for not only kainga (villages) but also for places like wharenui (meeting houses) and wharekai (dining halls) (Te Tira Whākamataki 2017). Secondly, BMSB has a unique habit of feeding through the bark causing copious sap flow at feeding sites where wasps have been reported to feed (Rice et al. 2014). This may contribute to increased impacts from invasive wasps (*Vespula* spp.) that are already a significant pest in New Zealand's natural systems.

ACKNOWLEDGEMENTS

We thank Nick Waipara (PFR), Glenn Greer (PFR), Anna Rathe (Hort NZ), Tracy Leskey (USDA) for very useful comments on an earlier draft. This research was funded by PFR as part of the Better Border Biosecurity research collaboration (*http://b3nz.org*). We are grateful to Manihera Te Hei for translating the title and abstract into Te Reo.

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APPENDIX 1

A summary of the plant species that host relatively large BMSB populations (largely from Bergmann et al. nd) and for which there is a moderate to high risk of BMSB damage (largely from STOP BMSB 2015). Definitions for 'high', and 'moderate' risk from BMSB were not defined. In many instances plant species for BMSB plant hosts were listed as common names so plant genera were inferred.

BMSB plant host	Plant family	High abundance	Damage	Reference	NZ native genera in same family
Actinidia spp. (kiwifriut)	Actinidiaceae		Feeding results in leaf yellowing & black/blue spots/scars on the fruit. Injured fruit becomes white & spongy & rots. Flower, bud or fruit drop may occur.	Teulon & Xu 2018	No representatives in NZ indigenous flora

Amaranthus caudatus	Amaranthaceae	+	No record of damage	Bergmann et al. nd	
Celosia argentea	Amaranthaceae		'damage'	Hoebeke and Carter 2003	*Alternanthera* (a Northland bog plant)
Beta (Swiss chard/ silverbeet)	Amaranthaceae		High risk of damage	STOP BMSB 2015	
Ilex aquifolium (English holly)	Aquifoliaceae	+	No record of damage	Bergmann et al. nd	No representatives in NZ indigenous flora
Asparagus officinalis (asparagus)	Asparagaceae		Moderate risk of damage	STOP BMSB 2015	No representatives in NZ indigenous flora
Helianthus spp. (sunflower)	Asteraceae Tribe Heliantheae	+	No record of damage	Bergmann et al. nd	*Bidens, Siegesbeckia* (herbaceous daisies)
Corylus sp. (hazelnut)	Betulaceae		High risk. Damages nuts throughout the entire period of kernel development	STOP BMSB 2015, Bosco et al. 2018	No representatives in NZ indigenous flora
Catalpa spp. (catalpa)	Bignoniaceae	+	No record of damage	Bergmann et al. nd	*Tecomanthe*
Brassica spp. (broccoli, cauliflower, collard) *Armoracia* sp. (horseradish)	Brassicaeae		Broccoli & cauliflower: Moderate risk Collard & horseradish: Moderate risk	STOP BMSB 2015	*Lepidium* (scurvy grass, nau), *Notothlapsi* (pen wiper), *Pachycladon, Cardamine, Cheesemania, Rorippa*
Cornus sp. (flowering dogwood)	Cornaceae		Moderate risk of damage	STOP BMSB 2015	*Corokia, Griselinia*
Cucurbita sp. (cucumber)	Cucurbitaceae		Moderate risk of damage	STOP BMSB 2015	*Sicyos* (mawhai)
Cupressus sp. (cyprus)	Cupressaceae		'is a pest'	Funayama 2005	*Libocedrus* (kawaka, pahautea)
Vaccinium sp. (blueberry)	Ericaceae		Moderate risk of damage	STOP BMSB 2015	*Gaultheria* (snowberry), *Pernettya*

Mimosa spp. (sensitive plant)	Fabaceae	+	No record of damage	Bergmann et al. nd	
Cercis canadensis (eastern redbud)	Fabaceae	+	High risk of damage	Bergmann et al. nd, STOP BMSB 2015	*Sophora* (kowhai), *Clianthus* (kaka beak), *Corallospartium*, *Notospartium, Chordospartium* (Marlborough brooms), *Swainsonia* (alpine)
Styphnolobium japonicum (Japanese pagoda tree)	Fabaceae		High risk of damage	STOP BMSB 2015	
Glycine max (soybean, edamame)	Fabaceae	+	High risk of damage. Shrivelled seeds & flattened pods	Bergmann et al. nd, STOP BMSB 2015, Rice et al. 2014	
Bean (green, pole, snap)	Fabaceae		High risk for green, pole & snap beans	STOP BMSB 2015	
lima bean	Fabaceae		Moderate damage for lima bean		
Magnolia grandifolia (southern magnolia)	Magnoliaceae	+	No record of damage	Bergmann et al. nd	No representatives in NZ indigenous flora
Hibiscus rosasinesis	Malvaceae		'damage'	Hoebeke and Carter 2003	*Plagianthis* (ribbonwood), *Hoheria* (houhere, lacebark)
Abelmoschus sp. (okra)	Malvaceae	+	High risk of damage	STOP BMSB 2015	
Tilia sp. (littleleaf linden)	Malvaceae		Moderate risk damage	STOP BMSB 2015	
Morus alba (white mulberry)	Moraceae	+	No record of damage	Bergmann et al. nd	*Paratrophis* (turepo)
Syringa pekinensis (Peking tree lilac)	Oleaceae		High risk of damage	STOP BMSB 2015	*Olea* (maire)
Phalaenopsis (moth orchid)	Orchidaceae Tribe Vandeae	+	No record of damage type	Bergmann et al. nd	*Drymoanthus* (twig orchid)
Paulownia tomentosa (princess tree)	Paulowniaceae	+	Severely affected. Paulownia witches broom (vectored by BMSB) can greatly reduce growth & vigour of trees	Bergmann et al. nd, Hoebeke and Carter 2003	No representatives in NZ indigenous flora
Cedrus sp. (cedar)	Pinaceae		'is a pest'	Funayama 2005	No representatives in NZ indigenous flora
Platanus occidentalis (plane tree)	Platanaceae	+	No record of damage	Rice et al. 2014	No representatives in NZ indigenous flora

Zea mays (corn, sweet corn)	Poaceae	+	High risk. Discoloured and shrink individual kernels. Some ear abortion?	Bergmann et al. nd, STOP BMSB 2015, Rice et al. 2014	*Festuca, Poa, Austrofestusca, Festuca, Puccinellia* (grasses)
Prunus spp. various (incl. peach, nectarine, apricot, cherry, flowering cherry)	Rosaceae	+	Peach/nectarine: High risk. Apricot & cherry: Moderate risk Stonefruit: Feeding causes depressed or sunken areas that may become cat-faced	Bergmann et al. nd, STOP BMSB 2015, Rice et al. 2014	
Pyrus spp. (pear, Asian pear)	Rosaceae	+	Apple, pear & Asian pear: High risk Pome fruit: Feeding results in indented depressions on the surface & corky spots in the fruit flesh. Feeding may cause fruiting structures to abort prematurely	Bergmann et al. nd, STOP BMSB 2015, Rice et al. 2014	*Rubus* (bush lawyer), *Acaena* (bidibid), *Potentilla, Geum* (alpines)
Malus (incl. apple & crab apple)	Rosaceae	+	Crab apple: wilting plants	Bergmann et al. nd, Leskey et al. 2012	
Crateagus sp. (hawthorne)	Rosaceae		Wilting plants	Leskey et al. 2012	
Amelanchier sp. (serviceberry)	Rosaceae		Moderate risk of damage Wilting plants	STOP BMSB 2015, Leskey et al. 2012	
Tetradium daniell (bee bee tree)	Rutaceae		High risk of damage	STOP BMSB 2015	*Phebalium* (mairehau), *Melicope* (wharangi)
Acer spp.	Sapindaceae	+	None described	Rice et al. 2014	*Alectryon* (titoki), *Dodonea* (akeake)
Ailanthus altissima (tree of heaven)	Simaroubaceae	+		Bergmann et al. nd	No representatives in NZ indigenous flora
Capsicim annuum (pepper)	Solanaceae	+	High risk of damage	Bergmann et al. nd, STOP BMSB 2015	
Solanum lycopersicum (tomato)	Solanaceae	+	High risk. Injury includes white spongy areas on the skin & internal tissue damage	Bergmann et al. nd, STOP BMSB 2015	*Solanum* (poroporo)
Solanum melongena (eggplant)	Solanaceae	+	High risk of damage	Bergmann et al. nd, STOP BMSB 2015	
Phasalis sp. (tomatillo)	Solanaceae		Moderate risk of damage	STOP BMSB 2015	
Ulmus sp.	Ulmaceae	+	No record of damage	Rice et al. 2014	No representatives in NZ indigenous flora