

Supplementary information for:

**Tritrophic analysis of the prospective biological control of brown marmorated stink bug,
Halymorpha halys, under extant weather and climate change**

Andrew Paul Gutierrez^{1,2}, Giuseppino Sabbatini Peverieri³, Luigi Ponti^{1,4}, Lucrezia Giovannini³,
Pio Federico Roversi³, Alberto Mele⁵, Alberto Pozzebon⁵, Davide Scaccini⁵ and Kim A Hoelmer⁶

¹Center for the Analysis of Sustainable Agricultural Systems (www.casasglobal.org), 37 Arlington Ave.,
Kensington, CA 94707-1035, USA; casas.global@berkeley.edu

²Division of Ecosystem Science, College of Natural Resources, University of California, Berkeley, CA
94720-3114, USA.

³CREA–Research Centre for Plant Protection and Certification, I-50125 Florence, Italy

⁴Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile (ENEA),
Centro Ricerche Casaccia, Via Anguillarese 301, 00123 Roma, Italy; luigi.ponti@enea.it

⁵Department of Agronomy, Food, Natural Resources, Animals and Environment, Università degli Studi di
Padova, Viale dell'Università 16, Legnaro (PD), Italy

⁶USDA-ARS – Beneficial Insects Introduction Research Unit, Newark, DE, USA

USA, Mexico, and Central America

Figure S1a maps the simulation results for 2000-2010 showing the prospective distribution and relative abundance of BMSB absent parasitism under field conditions, while Figure S1b maps the coefficient of variation (CV (%)) showing areas where the pest has been recorded but where sizeable field populations do not develop except near human structures where pest survival can be high during winter (dark red areas; Ciancio et al. 2021; see also Gutiérrez Illán et al. 2022). BMSB populations in southern areas are restricted by high temperature, and in arid regions by desiccation (see below).

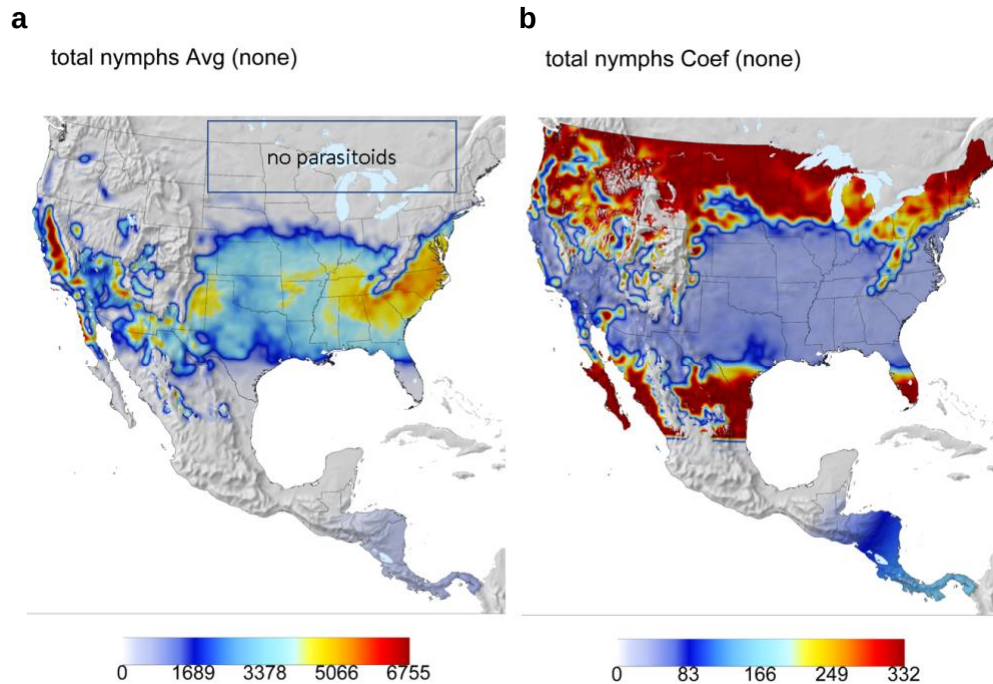


Figure S1. Temperature effects on average prospective annual BMSB field nymph densities absent parasitoids and the coefficient of variation (%) for the USA, Mexico, and Central America for 2000-2010.

Figure S2 shows the effects on BMSB nymphal densities of highly effective egg parasitoids and associated tachinid parasitism under 2000-2010 weather (Fig. S2a,b) and 2055-65 climate warming weather (Fig. S2c), and the number of BMSB eggs parasitized by *Trissolcus japonicus* (Fig. S2d) and *T. mitsukurii* (Fig. S2e), the number of eggs hyper parasitized by *Acroclisoides sinicus* (Fig. S2f), and the proportion hyper parasitized eggs (Fig. S2g) under 2000-2010 weather.

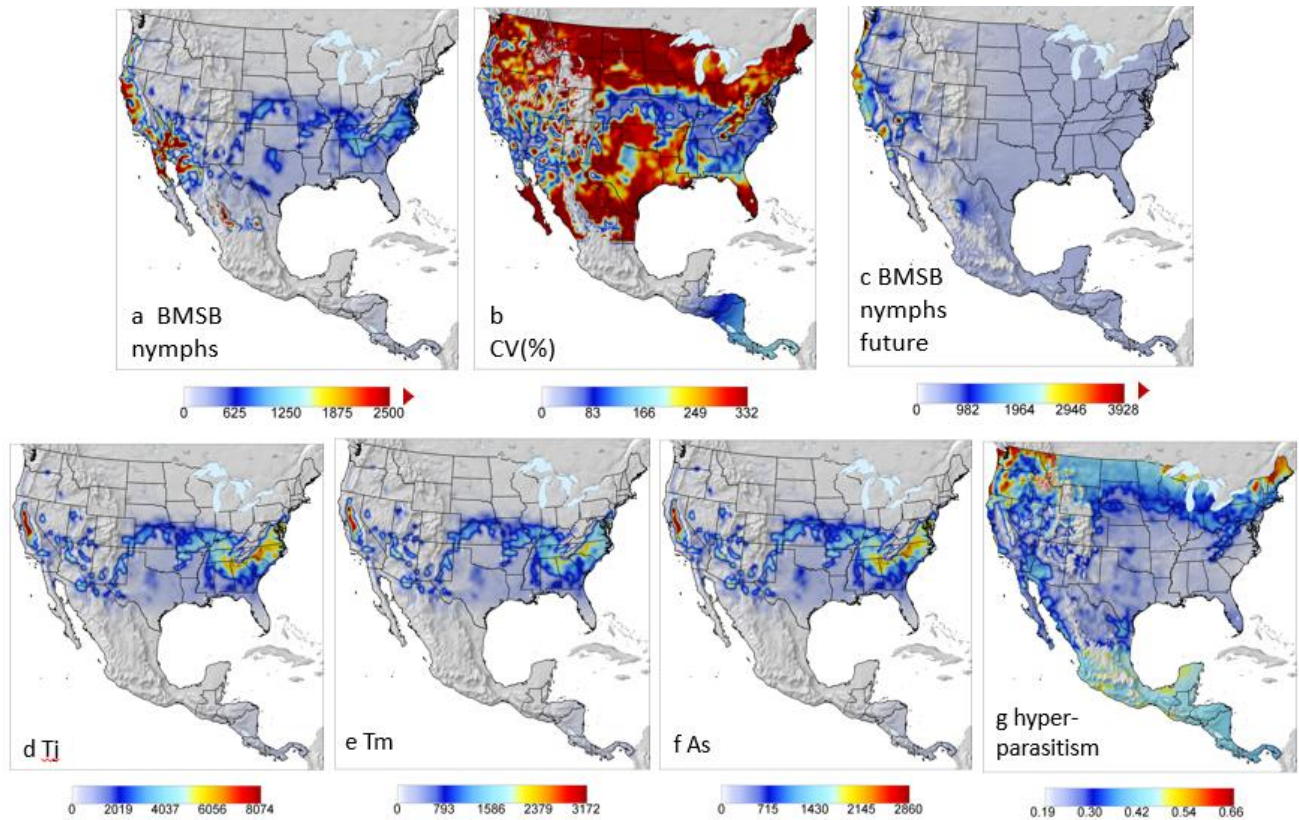


Figure S2. Prospective good biological control: average geographic distribution in the USA, Mexico, and Central America of annual *H. halys* nymph densities under 2000-2010 weather with equal egg parasitoid (*Trissolcus japonicus* and *T. mitsukurii*) preference for BMSB, equal hyperparasitoid *A. sinicus* preferences for the egg parasitoids ($^{As}\phi_{Tj}=1$ and $^{As}\phi_{Tm}=1$), and search parameters $Tj\alpha = Tm\alpha = 0.6$ and $^{As}\alpha = 0.1$ in all scenarios: (a) total nymphs truncated at 2500, (b) coefficient of variation (%) of Fig. S2a values, (c) nymph densities under 2055-2065 climate change weather, and from Fig. S2a, (d) the average number of *T. japonicus* parasitized eggs, (e) *T. mitsukurii* parasitized eggs, (f) the number of hyper parasitized eggs and (g) the proportion of primary parasitoid hosts hyper parasitized by *A. sinicus*. Inset figure 2Si shows that *T. mitsukurii* parasitized 34.4 % as many eggs as *T. japonicus*.

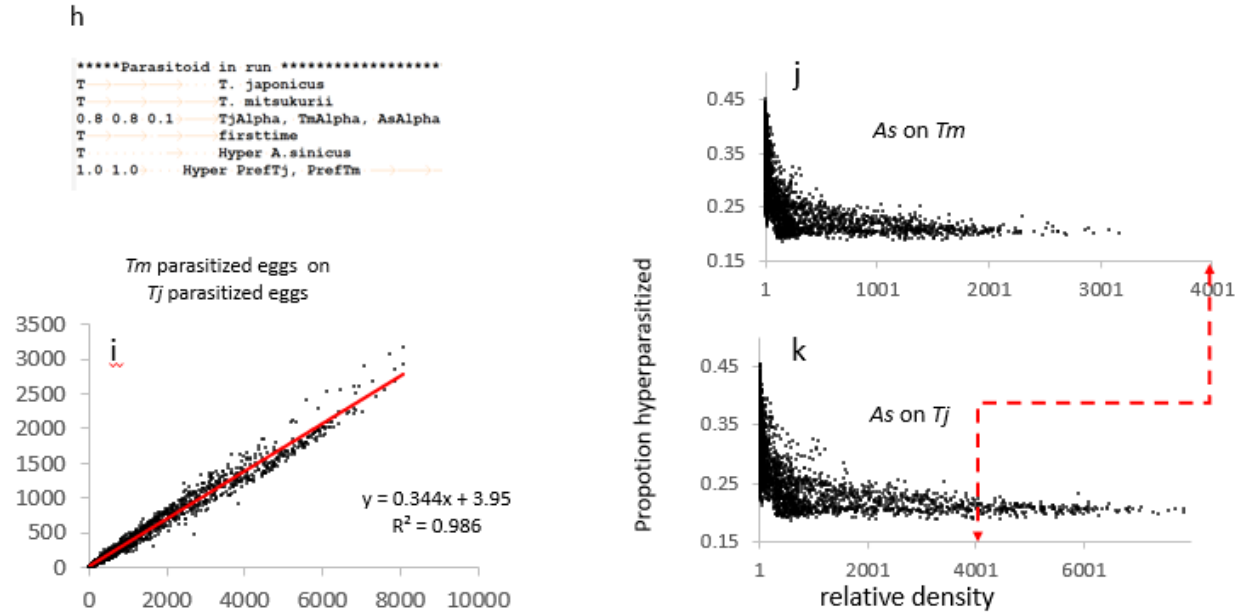


Figure 2 insets: (h) a sample run file, (i) the density of *T. mitsukurii* parasitized eggs to *T. japonicus* parasitized eggs, and (j, k) the proportions of *T. mitsukurii* and *T. japonicus* eggs hyper-parasitized by *A. sinicus* on density. The dotted red line points to equal values in j and k.

Effects of vapor pressure deficit

Host plants are affected by moisture stress on photosynthesis, and this stress can best be measured by vapor pressure deficit (VPD) which is a direct measure of the atmospheric desiccation strength (see Grossiord et al. 2020). Most plant hosts of BMSB are assumed to photosynthesize well in the range of $0.5 < \text{VPD} < 1.45$ (shaded area in Fig. 3a). Daily VPD is computed as follows:

$$\text{VPD} = \frac{610.7 \times 10^{(7.5T/237.3+T)}}{1000} \times (1 - RH / 100)$$

where T is the average daily temperature in °C and RH is the average daily % relative humidity. VPD is expressed in kPa (kilopascals).

Desiccation also affects BMSB development, survival, and reproduction (Grisafi et al. 2021), and for heuristic purposes, we assume the effects of VPD on reproduction are captured by a normalized VPD index (Fig. S3a)

$$0 \leq \phi_{\text{VPD}} = 4.24 \text{VPD} / (1 + 3.25^{\text{VPD}}) \leq 1$$

that is incorporated as a scalar function of the age (i , days at 25°C) specific reproduction profile ($f(i)$) (see main text eqn. 4) as follows:

$$f(i) = \frac{1.375i}{1 + 1.078^i}, R^2 = 0.97$$

and for $i = 1, \dots, {}^A K$

$$E(t) = sr \cdot \phi_{VPD}(T(t), RH(t)) \phi(T(t)) \sum_{i=1}^{{}^A K} f(i) {}^A N(i, t)$$

Khadka et al. (2020) showed that at near optimal temperature 25°C (see main text Fig. 3c) BMSB performance was highest at 55 RH which translates to VPD = 1.425 kPa. The concave oviposition data suggest RH limits of 15 to 95% RH (i.e., 2.69 and 0.16kPa). The demographic effect of our heuristic time-varying ϕ_{VPD} index (Fig. S3a) applied daily on BMSB (absent parasitoids) is seen by comparing Figures S1a and S3b. As expected, reduced population levels occur mainly in the arid western regions of the USA and Mexico, while other areas are marginally affected.

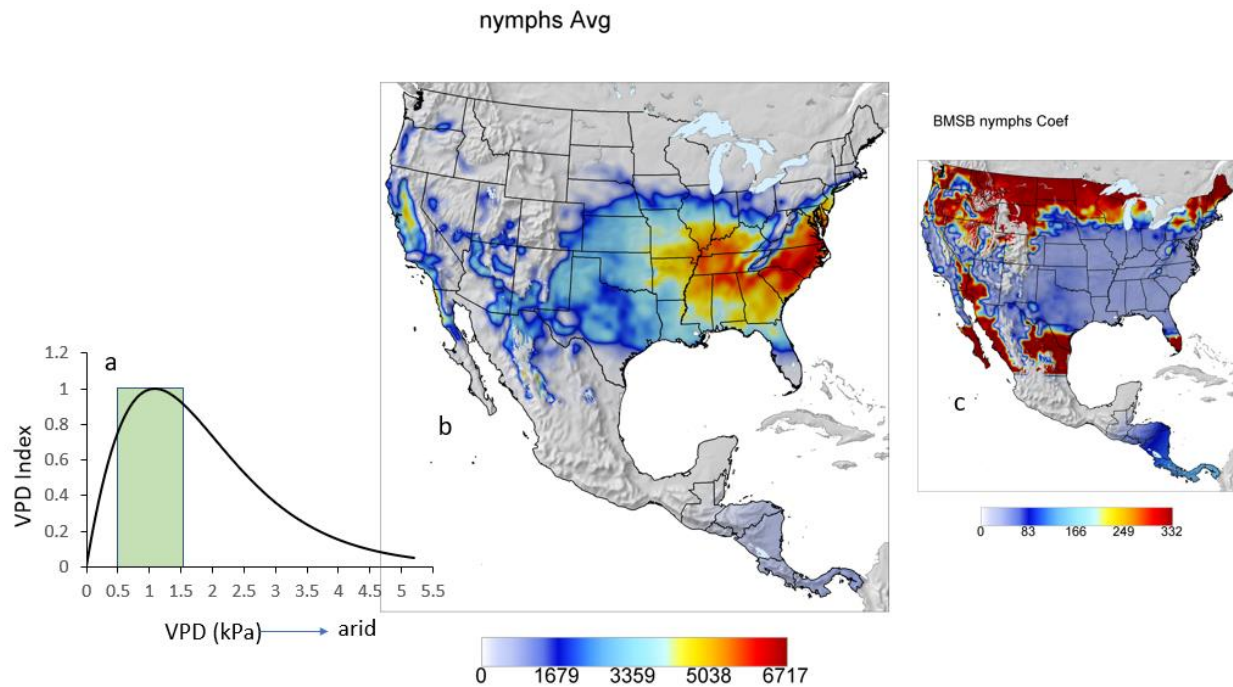


Figure S3. Heuristic desiccation effects on BMSB: (a) vapor pressure deficit index ($\phi_{VPD}(T(t), RH(t))$) on VPD, (b) average prospective annual BMSB field nymph densities absent parasitoids for the USA, Mexico, and Central America for 2000-2010 given the effects of

$\phi_{VPD}(T(t), RH(t))$, and (c) the coefficient of variation (%) for (b). The shaded area in S3a is the range of VPD where most plant host of BMSB are assumed to photosynthesize well.

References

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