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Modelling diapause termination and phenology of the Japanese beetle, *Popillia japonica*

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S1. Mathematical description of the model

Assuming the population of *P. japonica* being composed by three stages i, namely larvae ($i = 1$), pupae ($i = 2$), and adults ($i = 3$), the model is described by a system of partial differential equations

$$\frac{\partial \phi^i(t,x)}{\partial t} + \frac{\partial}{\partial x}\left[v^i\big(T(t)\big)\phi^i(t,x) - \sigma^i \frac{\partial \phi^i(t,x)}{\partial x}\right] = 0, \quad t > 0, \; x \in (0,1), \tag{1}$$

$$\left[v^i\big(T(t)\big)\phi^i(t,x) - \sigma^i \frac{\partial \phi^i(t,x)}{\partial x}\right]_{x=0} = F^i(t), \tag{2}$$

$$\left[-\sigma^i \frac{\partial \phi^i(t,x)}{\partial x}\right]_{x=1} = 0, \tag{3}$$

$$\phi^i(0,x) = \hat{\phi}^i(x), \tag{4}$$

The quantity $\phi^i(t,x)dx$ represents the number of individuals in stage i at time t with physiological age in $(x, x + dx)$. The term $v^i\big(T(t)\big)$ represents the stage-specific development rate function of stage i that depends on temperature T at time t. The functions $\hat{\phi}^i(x)$ represent the initial conditions of the model in terms of individual abundance within a stage. In all the simulations, the initial conditions are set to 100 diapausing larvae at the 1st of January, and to zero individuals for the other stages. All simulations end at the 31st of December of the same year. The term σ^i is a diffusion coefficient introduced to include the effects of stochasticity on the stage-specific development process. In this specific case $\sigma^i = 0$ for diapausing larvae and $\sigma^i = 10^{-3}$ for post overwintering larvae and pupae.

The flux of individuals from stage i to stage $i + 1$ is represented by the functions $F^{i+1}(t)$.

$$F^{i+1}(t) = v^i\big(T(t)\big)\,\phi^i(t,1), \qquad i = 1, 2.$$

The cumulative adult emergence is defined by the following non-decreasing function

$$Z^3(t) = Z^3(0) + \int_0^t F^3(s)\,ds$$

The adult stage is not simulated, as we are only interested in the time of emergence of the adults. Thus, the development rate of the adult stage ($i = 3$) is not defined.

S2. Model parameterisation process

Denoting by $Z_j^3\left(t_i,\ r^1,\ T_{inf}{}^1,\ T_{sup}{}^1, T_{La}\right)$ the simulated adult emergence at location j at time t_i, for parameters r^1, $T_{inf}{}^1$, $T_{sup}{}^1, T_{La}$ of post-overwintering larvae we define the functional

$$Q\left(r^1,\ T_{inf}{}^1,\ T_{sup}{}^1, T_{La}\right) = \sum_{j=1}^{12} \frac{1}{n_j} \sum_{i=1}^{n_j} \left| Z_j^3\left(t_i;\ r^1,\ T_{inf}{}^1,\ T_{sup}{}^1, T_{La}\right) - A^j(t_i) \right|^2$$

where $A^j(t_i)$ is the observed cumulative adult emergence at location j at time t_i and n_j is the number of available sampling points at location j. Then, we find the optimal parameters $\left(\hat{r}^1,\ \hat{T}_{inf}{}^1,\ \hat{T}_{sup}{}^1,\ \hat{T}_{La}\right)$ looking for the minimum of Q, namely

$$\left(\hat{r}^1,\ \hat{T}_{inf}{}^1,\ \hat{T}_{sup}{}^1, \hat{T}_{La}\right) = \min_{r^1, T_{inf}{}^1, T_{sup}{}^1.\ T_{La}} Q\left(r^1,\ T_{inf}{}^1,\ T_{sup}{}^1, T_{La}\right)$$

Table S1 Lower and upper bounds applied in the parameterisation process for estimating the parameters $\hat{r}^1$, $\hat{T}_{inf}{}^1$, $\hat{T}_{sup}{}^1$ of the development rate function of post-overwintering larvae and the temperature threshold triggering larval diapause termination T_{La}

	$\hat{r}^1$	$\hat{T}_{inf}{}^1$ (in °C)	$\hat{T}_{sup}{}^1$ (in °C)	$\hat{T}_{La}$ (in °C)
Lower bound	$3.00 \cdot 10^{-5}$	11	29	11
Upper bound	$7.00 \cdot 10^{-5}$	16	35	16

S3. Erlang distribution curve fitting on adult cumulative emergence data

Let us introduce the cumulative distribution function of the Erlang distribution

$$E(x) = \frac{\gamma(\alpha, \beta x)}{\Gamma(\alpha)}, \qquad \text{where} \quad \gamma(\alpha, x) = \int_0^x t^{\alpha-1} e^{-t}\, dt.$$

The parameters α and, β are computed by the `lsqcurvefit` function of MATLAB which finds the coefficients that best fits the function E to the data in the least-square sense.

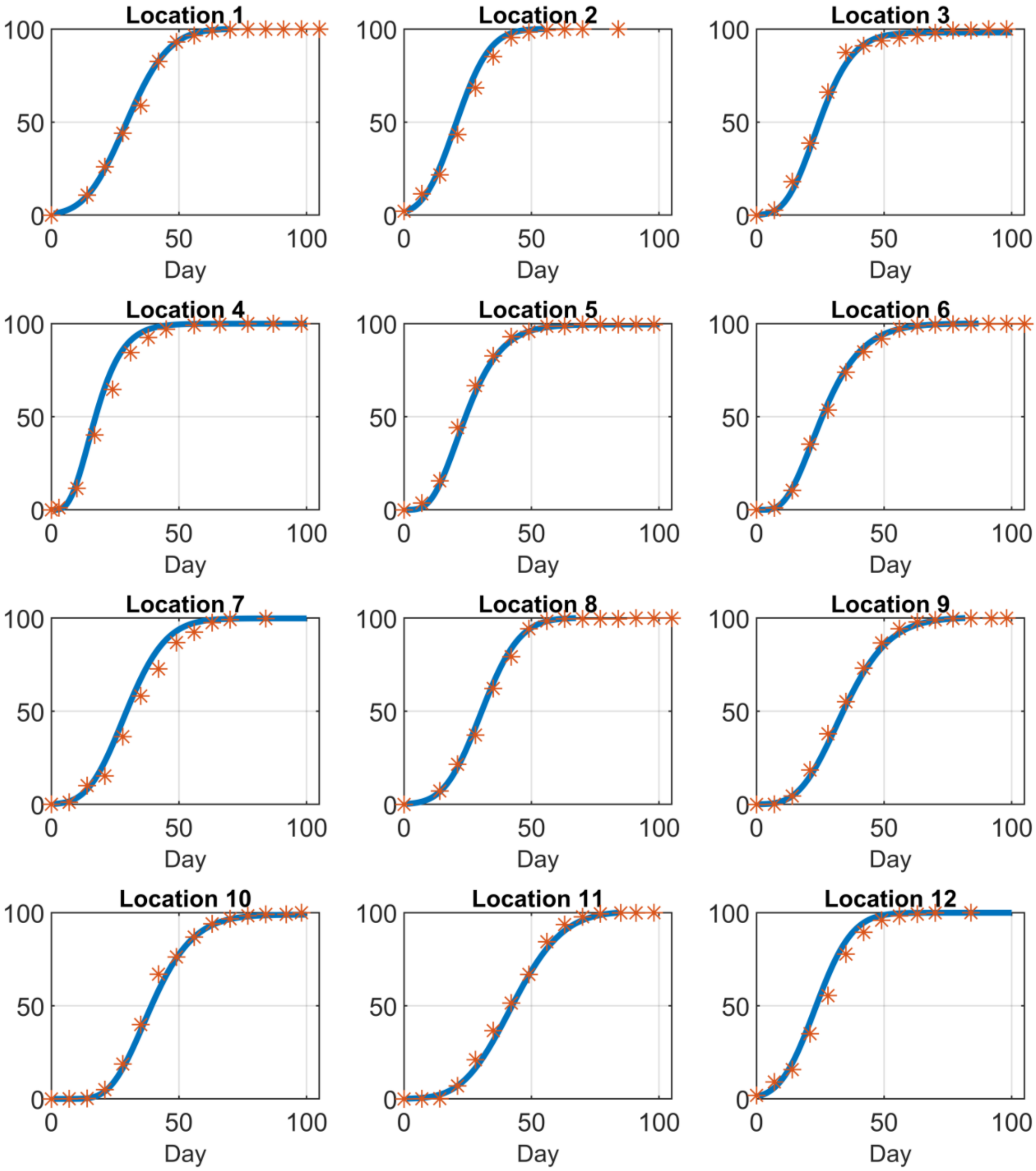

Fig. S1 Cumulative Erlang distribution functions fitted on adult emergence data of the 12 locations of the parameterisation dataset. In the ordinates are reported the percentage of adult emergence (from 0 to 100 %). Red asterisks represent observed adult cumulative emergence distribution starting from the first day of sampling and the continuous blue line represents the estimated function

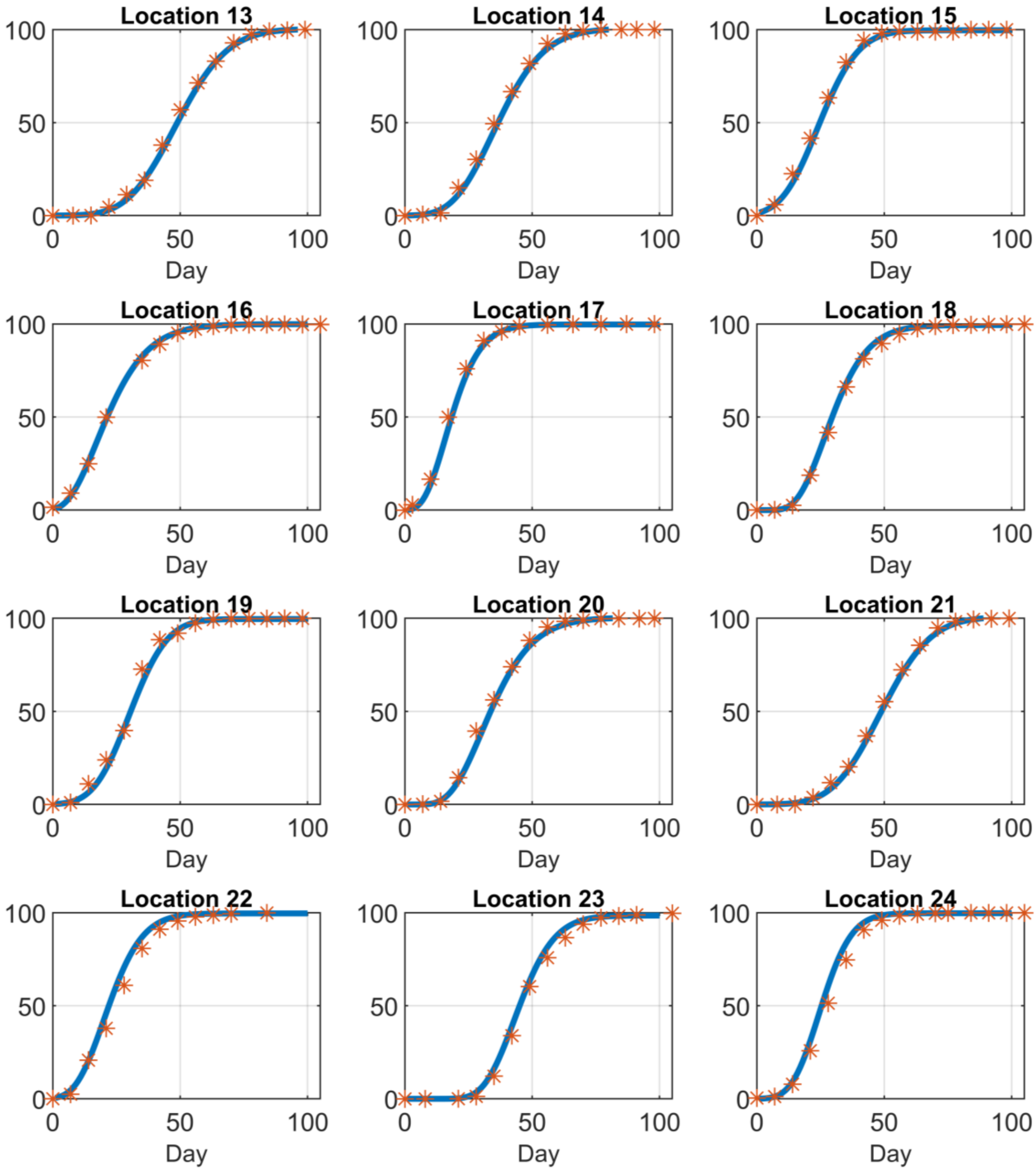

Fig. S2 Cumulative Erlang distribution functions fitted on adult emergence data of the 12 locations of the validation dataset. In the ordinates are reported the percentage of adult emergence (from 0 to 100 %). Red asterisks represent observed adult cumulative emergence distribution starting from the first day of sampling and the continuous blue line represents the estimated function

Table S2 Summary of the population dynamics data used in the present study. The table reports the Id location, the total amount of adult individuals per trap captured during the season, the adult emergence calculated at the 2nd, 5th, 10th and 99th percentile of adult emergence distribution, the day of peak of adults captured and the adult activity

		Adult emergence					
Id	**Total adult individuals/ trap**	**2nd percentile of total population**	**5th percentile of total population**	**10th percentile of total population**	**99th percentile of total population**	**Day of Peak**	**Adult flight period[a]**
1	23,351	156	160	165	212	193	56
2	24,340	171	175	178	216	198	45
3	1,942	165	168	171	235	186	70
4	6,457	171	173	175	211	183	40
5	929	182	184	187	238	195	56
6	9,816	169	171	173	225	181	56
7	12,943	178	182	185	233	205	55
8	11,833	159	163	167	209	186	50
9	9,087	161	165	168	222	178	61
10	1,112	169	172	175	234	192	66
11	53,417	163	169	174	228	206	65
12	29,128	172	176	180	221	205	49
13	36,224	169	174	179	235	192	67
14	50,067	162	166	170	223	185	61
15	8,527	160	164	168	215	186	55
16	589	170	173	175	230	195	60
17	4,633	171	173	175	213	183	43
18	6,785	172	175	178	229	195	57
19	15,847	167	171	175	219	193	53
20	9,177	164	167	170	221	178	57
21	30,259	169	174	179	232	199	63
22	4,725	174	177	180	224	198	50
23	4,340	175	178	181	240	198	65
24	7,520	171	174	176	213	188	43

[a] Calculated as the difference between the day of the 99th percentile of adult emergence and the day of the 2nd percentile of adult emergence

Table S3 Summary table showing the estimated parameters r^1, $T_{inf}{}^1$, $T_{sup}{}^1$ of the development rate function of post-overwintering larvae and the temperature threshold triggering larval diapause termination T_{La} obtained for the 12 Jackknife samples of the calibration dataset. The table reports, for each sample, the mean squared error (MSE) between observed and simulated phenological curves.

Jackknife sample	$\boldsymbol{r^1}$	$\boldsymbol{T_{inf}{}^1}$	$\boldsymbol{T_{sup}{}^1}$	$\boldsymbol{T_{La}}$	**MSE (days^2)**
1	$3.33 \cdot 10^{-5}$	12.5	32.6	12.5	15.95
2	$4.80 \cdot 10^{-5}$	13.4	29.1	13.4	21.54
3	$4.14 \cdot 10^{-5}$	13.0	29.9	13.0	22.14
4	$4.95 \cdot 10^{-5}$	13.4	29.0	13.4	19.26
5	$3.74 \cdot 10^{-5}$	12.5	29.9	12.5	21.65
6	$4.18 \cdot 10^{-5}$	12.9	29.7	12.9	22.04
7	$4.74 \cdot 10^{-5}$	13.6	29.6	13.6	17.57
8	$3.89 \cdot 10^{-5}$	12.5	29.8	12.5	19.12
9	$3.82 \cdot 10^{-5}$	12.5	29.9	12.5	22.42
10	$3.41 \cdot 10^{-5}$	12.3	30.8	12.3	18.09
11	$3.79 \cdot 10^{-5}$	12.4	29.8	12.4	22.32
12	$3.91 \cdot 10^{-5}$	12.5	29.4	12.5	22.66