**Table 1**

Dynamic equation for the present proposed models in this study

|  |  |
| --- | --- |
| Description | Equation |
| Food storages (*f*) |  |
| Brood population (*B*) |  |
| Hive bee numbers (*H*) |  |
| Forager numbers (*F*) |  |
| Brood survival function |  |
| Recruitments function |  |

**Table 2**

Summary for parameter values used in the present dynamic models

|  |  |
| --- | --- |
| Meaning and symble(unit) | Default value |
| Rate parameter |  |
| Maximum food collection rate, *c* (gram per forager per day) | 0.1a |
| Food consumption rate for adult bees, *γ*A (gram per forager per day) | 0.007 a,b |
| Food consumption rate for broods, *γ*B (gram per forager per day) | 0.018 a,b |
| Maximum egg laying rate, *l* (eggs per day) | 2000 a |
| Emergence rate, *ϕ* (per day) | 0.11 a |
| Minimum forager transition rate, *α*min (per day) | 0.25 a |
| Maximum forager transition rate, *α*max (per day) | 0.25 a |
| Social inhibition rate, *σ* (per day) | 0.75 a |
| Maximum forager natural death rate, *m* (per day) | 0.1 a,b |
| Imidacloprid-induced forager death rate, *m*d (per day) | ­–c |
| Control constant and time lag |  |
| Food impact constant, *b* (#) | 500 a |
| Hive bees impact constant, *v* (#) | 5000 a |
| Lag time of adult bees emerge from pupation, τ (day) | 12 a |

a Adopted form Khoury et al. (2013).

b Seasonal parameters used in this model.

c Imidacloprid dose-dependent parameter.

**Table 3**

Software versions and packages used in the model development and risk analysis

|  |  |  |
| --- | --- | --- |
| Tool | Description | Version |
| Software | |  |
| R | Statistical programing software by R language | 3.2.2 |
| RStudio | User interface for R | 0.98.1103 |
| Package | |  |
| desolve | General solvers for differential equation | 1.11-1 |
| devtools | Development tools to install rsconnect by github | 0.4.1.9 |
| ggplot2 | Graphing tool | 1.0.1 |
| mc2d | Two-Dimensional Monte-Carlo Simulations | 0.1-15 |
| rsconnect | Deploying shiny applications | 0.4.1.4 |
| shiny | Building interactive web applications | 0.12.2 |
| fitdistplus | Choosing and fitting of univariate distributions | 1.0-6 |

**Table 4**

Fitted model parameters for honeybees population dynamics

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Acute dose and mortality rate | Chronic dose and death rate | Rate ratio | | |
| Food collection (c) | Laying (l) | Death (m) |
| Equation | | | | | |
|  |  |  |  | | |
| Parameter | | | | | |
| a | 0.525 | 0.0007767 | 0.448 (0.0415)a | 0.588 (0.0356) | 0.584 (0.0274) |
| b | 3.605 | -4.487 | 0.090 (0.0598) | 0.149 (0.0513) | -0.139 (0.0395) |
| c | 0.982 |  | -0.386 (0.0576) | -0.422 (0.0494) | -0.248 (0.0381) |
| *r*2 | 0.99 | 0.99 | 0.65 | 0.77 | 0.69 |

a mean (s.e.).

**Figure Captions**

**Fig.1** Schematic representations of the dynamic model in present study.

**Fig. 2** Predicted the dose-response relationships of imidacloprid dose and bee mortality rate under (a) acute and (b) chronic conditions. Fitted the seasonal variation of parameter rate ratios with 95% CI for food collection, egg laying, and mortality.

**Fig.3** Dynamic simulations of imidacloprid-induced bee population stress and decline under the exposure dose of (a) 2000 (b)2300, and (c) 2500 μg L-1.

**Fig. 4** Predicted environmental exposure dose of imidacloprid in European countries.

**Fig. 5** Risk estimations of imidacloprid-induced extinction of honey bee population.

Figure 1

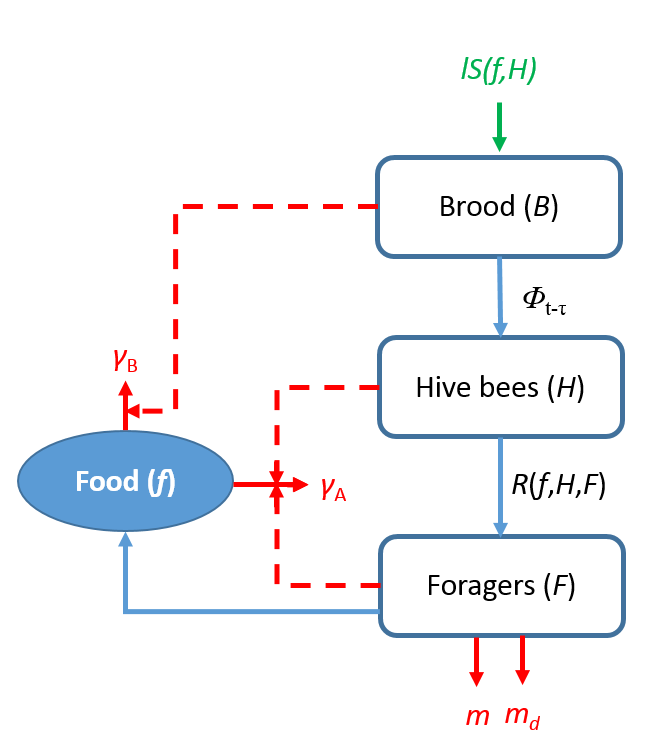
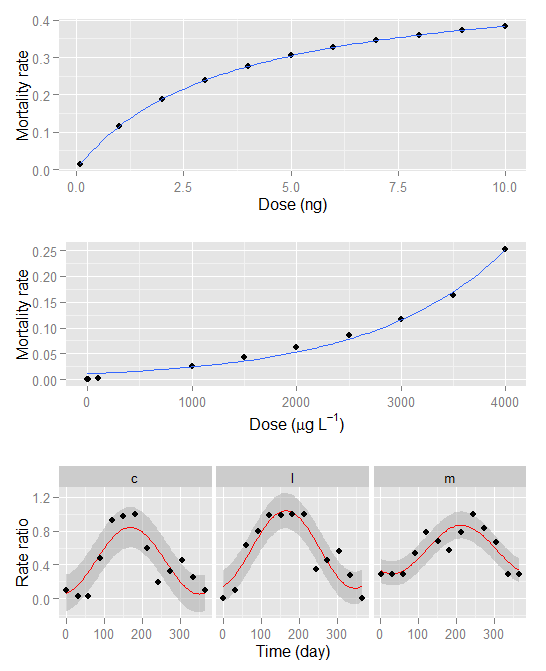
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Figure 2

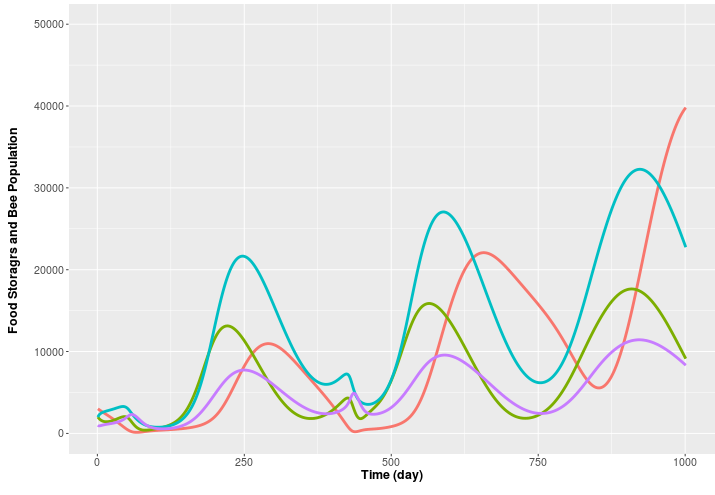
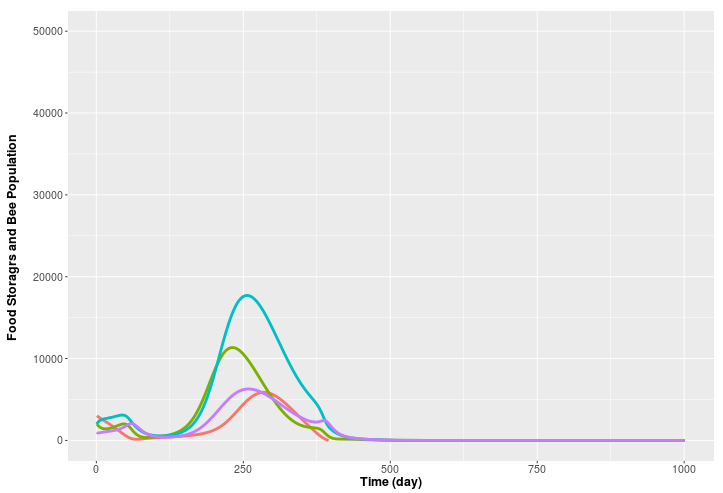
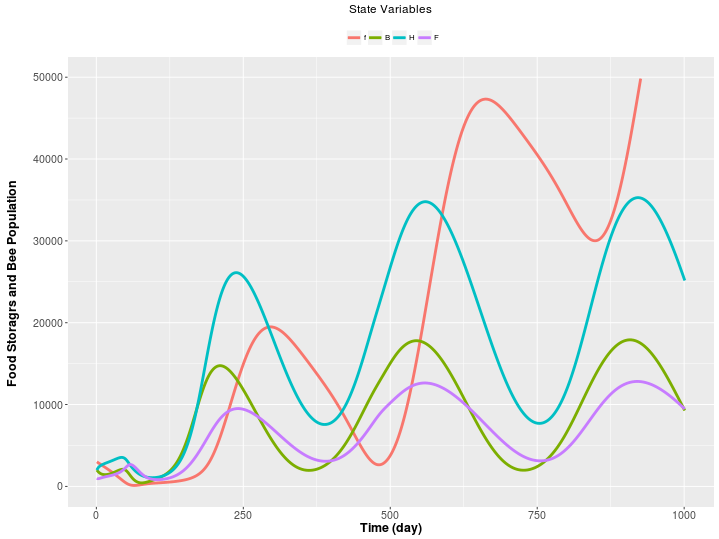
**a**



**c**

**b**

Figure 3



**a**

Imidacloprid = 2000 (μg L-1)

**c**

Imidacloprid = 2500 (μg L-1)

**b**

Imidacloprid = 2300 (μg L-1)

Figure 4

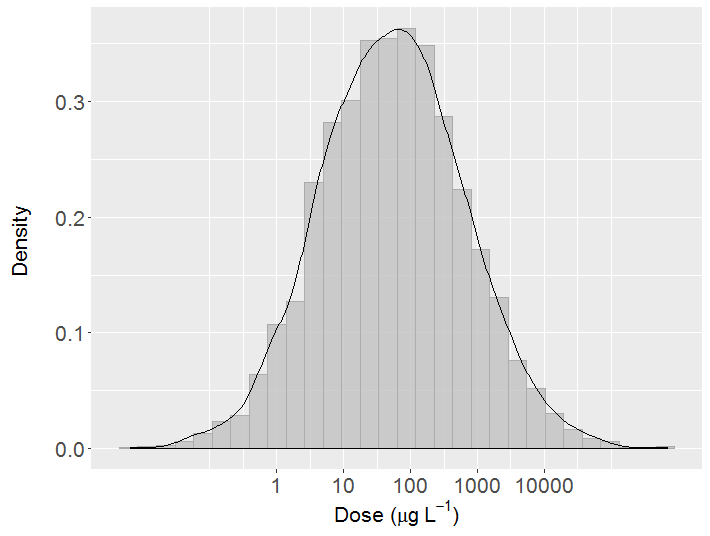


Fig. 5

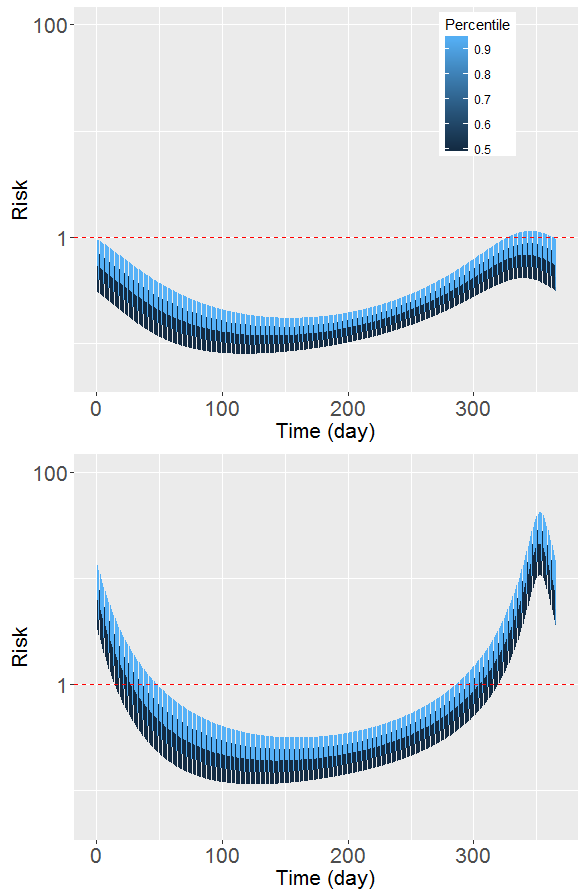


Fig. A1

