**Introduction**

* Importance of the mismatch between emergence of spruce budworm from hibernaculum and budburst of host trees
* The “time window of food quality”: the budworm can wait some time for the budburst, while the opposite is not true (if emergence occurs too late, food quality drops sharply, which affects survival and/or development and/or reproduction)
* Effects of temperatures on both processes
* Possible impacts of global warming

**Methods**

The model investigates the mismatch between spruce budworm emergence from hibernaculum and host tree budburst. Both processes are temperature-dependent. Two models are run independently. The first one represents spruce budworm development until emergence from hibernaculum. The second model represents host tree development until budburst. Then, we look at the mismatch between predicted emergence date and predict budburst date.

**1. Spruce budworm development**

Overwintering stage (*L2o*) spends several months in diapause within its hibernaculum. Daily temperature (*xt*) at any time (*t*) affects instantaneous development rate (*rt*) (Régnière et al., 2012).

|  |  |  |
| --- | --- | --- |
|  |  | (1) |

where

|  |  |  |
| --- | --- | --- |
|  |  | (2) |

Values for parameters *β1*,*β2*, *β3*, *β4*, *Tb*, and *Tm* can be found in table 1.

Development is integrated through time:

|  |  |  |
| --- | --- | --- |
|  |  | (3) |

where *R(t)* is cumulated development at time *t*. Accumulation starts at time *t0*, which is arbitrarily set at September 1st.

|  |  |  |
| --- | --- | --- |
|  |  | (4) |

Development is completed once:

|  |  |  |
| --- | --- | --- |
|  |  | (5) |

where *te* is time of emergence from hibernaculum.

**2. Host tree development**

We use a published model (Chuine, 2000). Tree accumulates forcing (heat) units *Rf(xt)* according to temperature (*xt*) at any time *t*:

|  |  |  |
| --- | --- | --- |
|  |  | (6) |

Forcing unit accumulation writes:

|  |  |  |
| --- | --- | --- |
|  |  | (7) |

Accumulation begins at a given time *t1*, which is arbitrarily set at January 24th (Desbiens, 2007):

|  |  |  |
| --- | --- | --- |
|  |  | (8) |

Budburst occurs when *Ft* reaches a threshold (*F\**):

|  |  |  |
| --- | --- | --- |
|  |  | (9) |

which determines time of budburst (*tb*). Values for parameters *bf*, *cf* and *F\** have been estimated for Balsam fir (Desbiens), and can be found in table 1.

The model computes the mismatch between the day of emergence from hibernaculum (*te*) and the day of budburst (*tb*):

|  |  |  |
| --- | --- | --- |
|  |  | (10) |

**3. Temperature data**

We collected temperature data from several places across Canada. These places are located across a gradient of latitude (see table 2). We used daily temperatures collected during a 20-years time interval (1999-2019) to predict the mismatch between emergence and budburst at each location and for each year.

We used predicted temperatures at the same locations for a 50-years time interval (2000-2050) according to three different scenarios for global warming (RCP2.6, RCP4.5 and RCP8.5). These temperatures were used to predict how the mismatch would evolve through time.

**4. Sensitivity analysis**

A sensitivity analysis was done on both models (budworm model and tree model) using Partial Rank Correlation Coefficient associated with Latin Hypercube Sampling (Wu et al., 2013).

**Upon success**

* We fitted parameters of the tree model for white spruce: a second important host for SBW
* Since the two hosts may react differently to climate change, so will do the mismatch between SBW and the two hosts

**Results**

* Both budburst and emergence vary with latitude (i.e., temperature regime), but in different ways
* Thus, the mismatch between budburst and emergence varies
* The “direction” of the mismatch (which event comes first: budburst or emergence) seems to vary with latitude, which is likely to have consequences on budworm survival
* Prediction through warming scenarios: an increase in temperature seems to increase the mismatch with Balsam fir, especially in Southern sites (budburst would occur two to three weeks after emergence)

**References**

Chuine, I., 2000. A united model for budburst of trees. J Theor Biol 207, 337–347. https://doi.org/10.1006/jtbi.2000.2178

Desbiens, M., 2007. Relation phénologique entre le débourrement des bourgeons chez le sapin baumier et l’émergence des larves de deuxième stade de la tordeuse des bourgeons de l’épinette, Choristoneura fumiferana (Lepidoptera: Tortricidae). ProQuest.

Régnière, J., St-Amant, R., Duval, P., 2012. Predicting insect distributions under climate change from physiological responses: spruce budworm as an example. Biol. Invasions 14, 1571–1586. https://doi.org/10.1007/s10530-010-9918-1

Wu, J., Dhingra, R., Gambhir, M., Remais, J. V., 2013. Sensitivity analysis of infectious disease models: methods, advances and their application. J. R. Soc. Interface 10, 20121018. https://doi.org/10.1098/rsif.2012.1018

**Table 1**: Parameters values

|  |  |  |
| --- | --- | --- |
| Parameter | Value | Reference |
| *β1* | 0.194 | Régnière et al., 2012 |
| *β2* | 3.0 | Régnière et al., 2012 |
| *β3* | 5.94 | Régnière et al., 2012 |
| *β4* | 0.034 | Régnière et al., 2012 |
| *Tb* | 2.5 | Régnière et al., 2012 |
| *Tm* | 35 | Régnière et al., 2012 |
| *bf* | -0.1789 | Desbiens, 2007 |
| *cf* | 14.63 | Desbiens, 2007 |
| *F\** | 10.86 | Desbiens, 2007 |

**Table 2**: Locations of temperature samplings

|  |  |  |
| --- | --- | --- |
| Location | Latitude | Longitude |
| Inuvik | 68.30 | -133.48 |
| High Level | 58.62 | -117.16 |
| Manic 5 | 50.65 | -68.73 |
| Lake Pikauba | 47.48 | -71.07 |
| Corner Brook | 48.95 | -57.95 |
| Sault Sainte Marie | 46.48 | -84.33 |
| Fredericton | 45.90 | -66.65 |
| Ottawa | 45.40 | -75.72 |