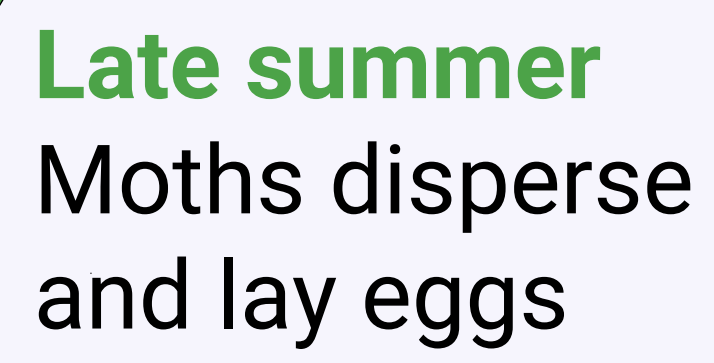
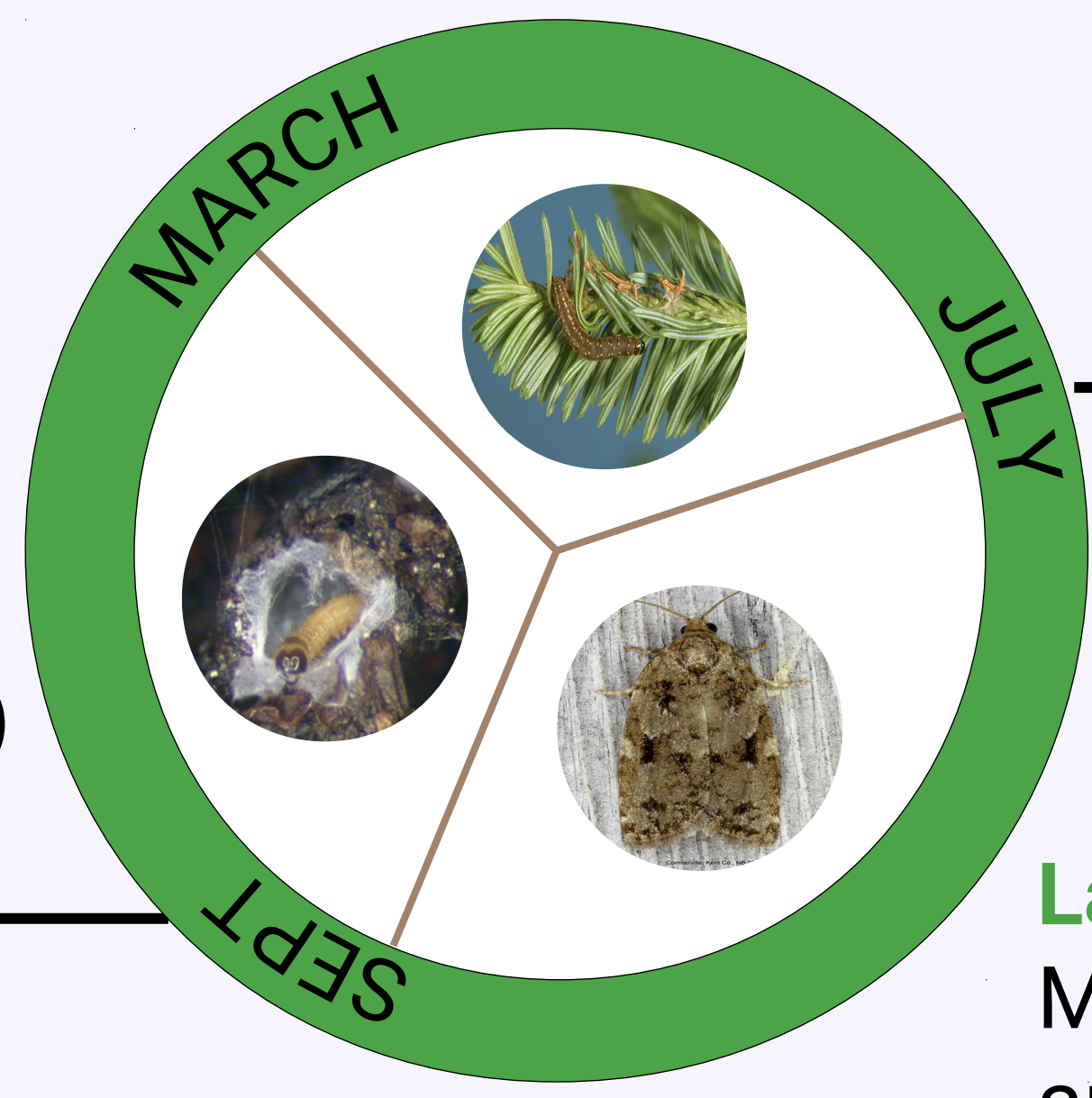
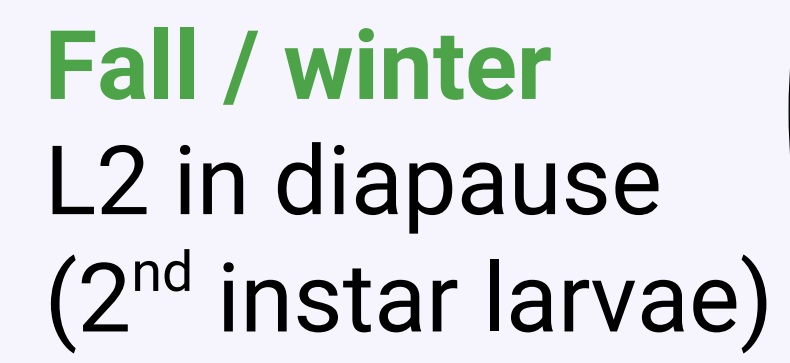
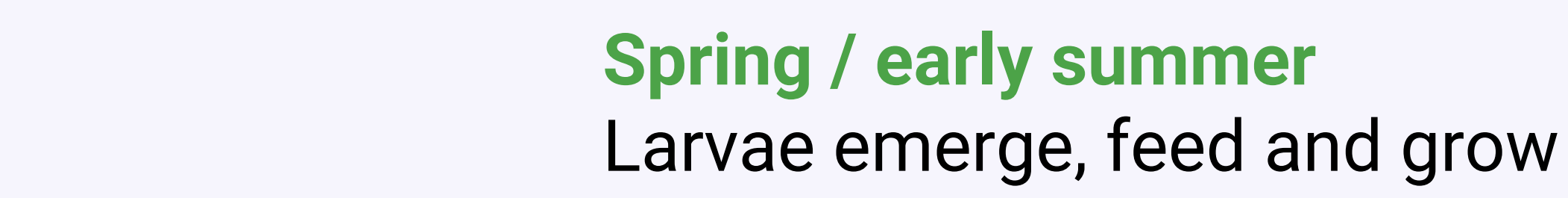


# Integrating deep and wide data sources with process-based model blocks for ecological forecasts: the case of spruce budworm outbreaks



Defoliation of balsam fir (primary host) and spruce species by spruce budworm larvae.

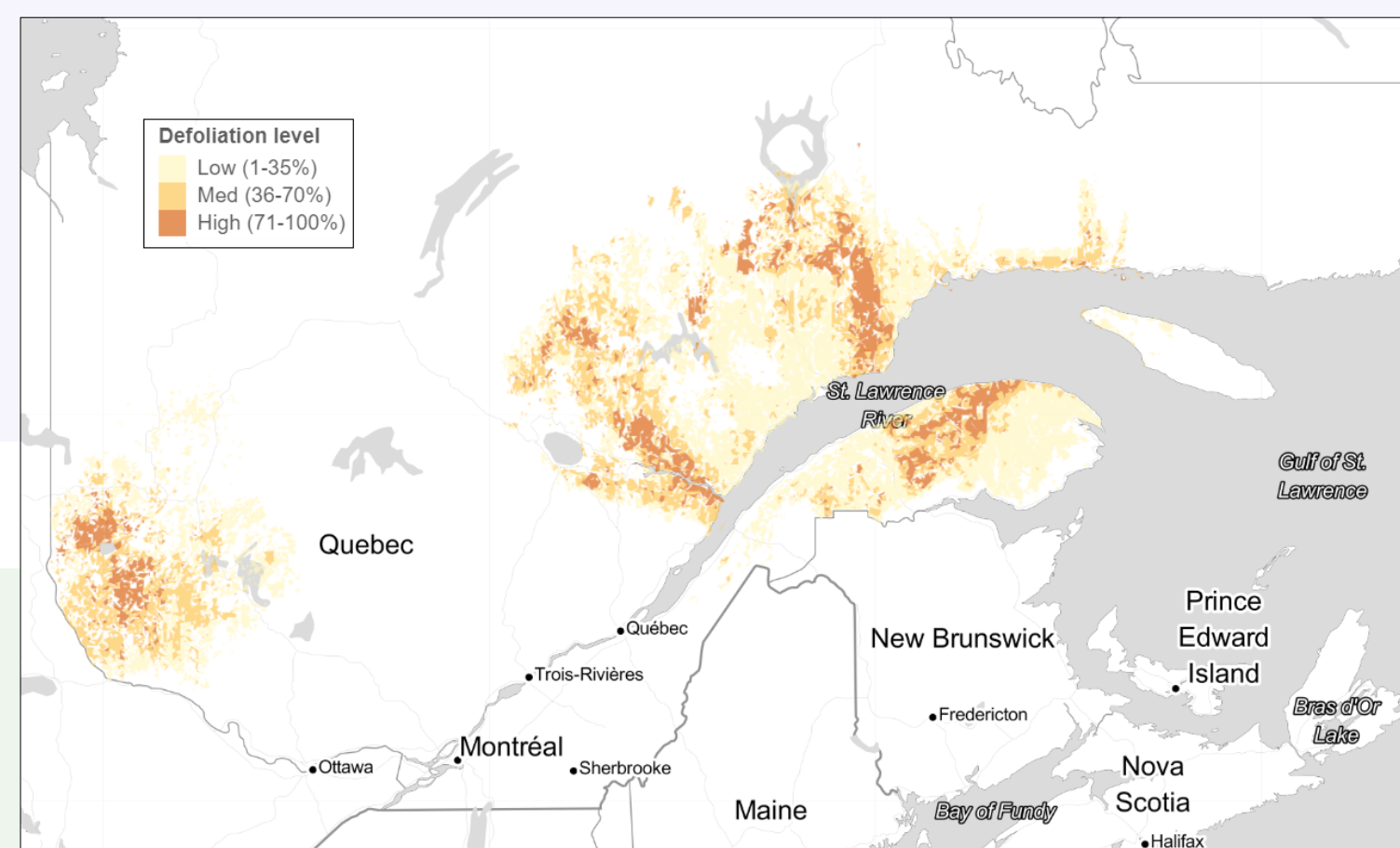
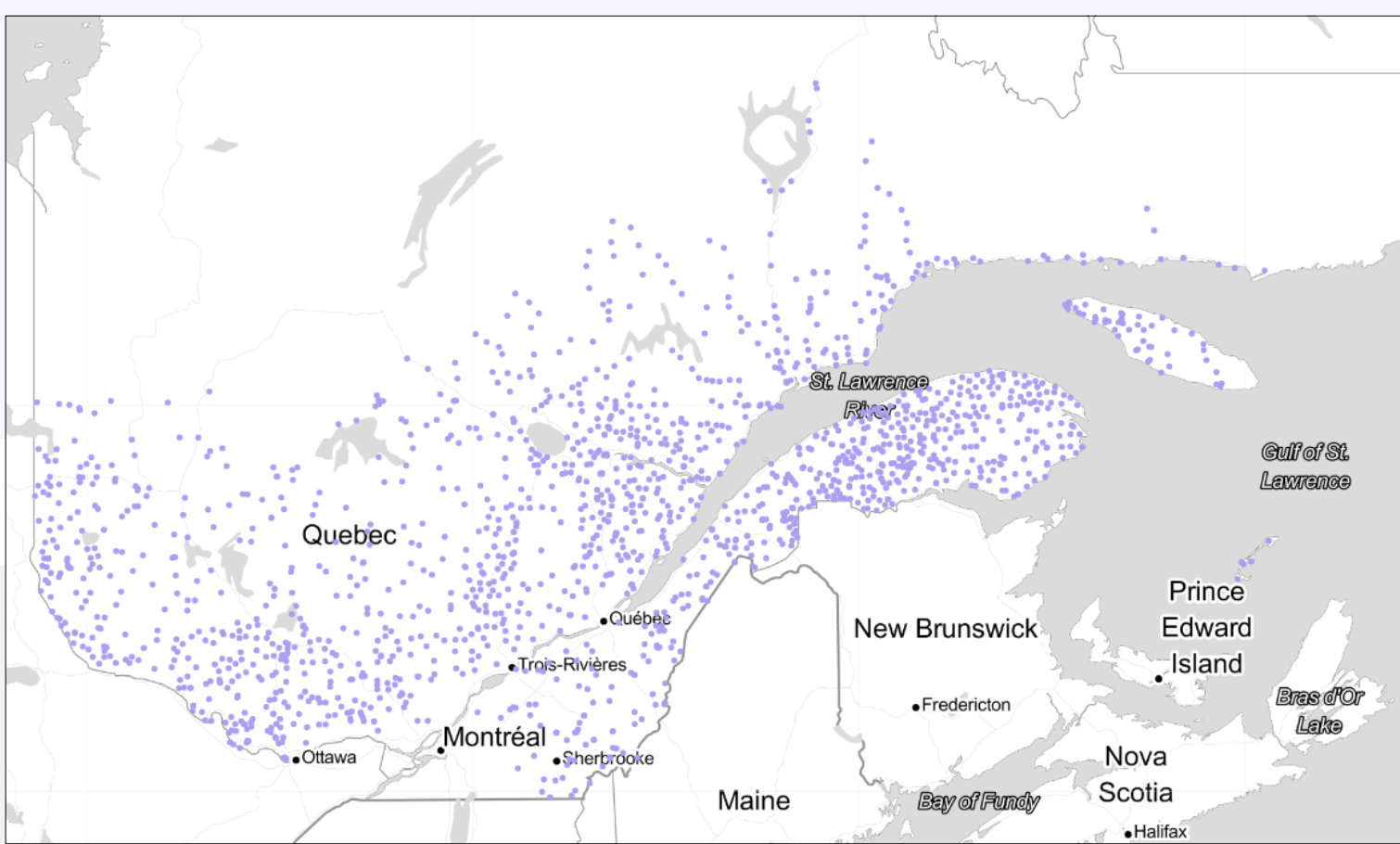
Peak of current outbreak (2020)  
**13 million ha** defoliated in  
 Québec, Canada.

Photos (above and to the left) by  
Natural Resources Canada

### Counting points for hibernating L2 (sample min. 3 branches by station)

### Aerial survey of defoliation (3-level semi-quantitative scale)

Used to forecast  
next year's  
defoliation



## Objective

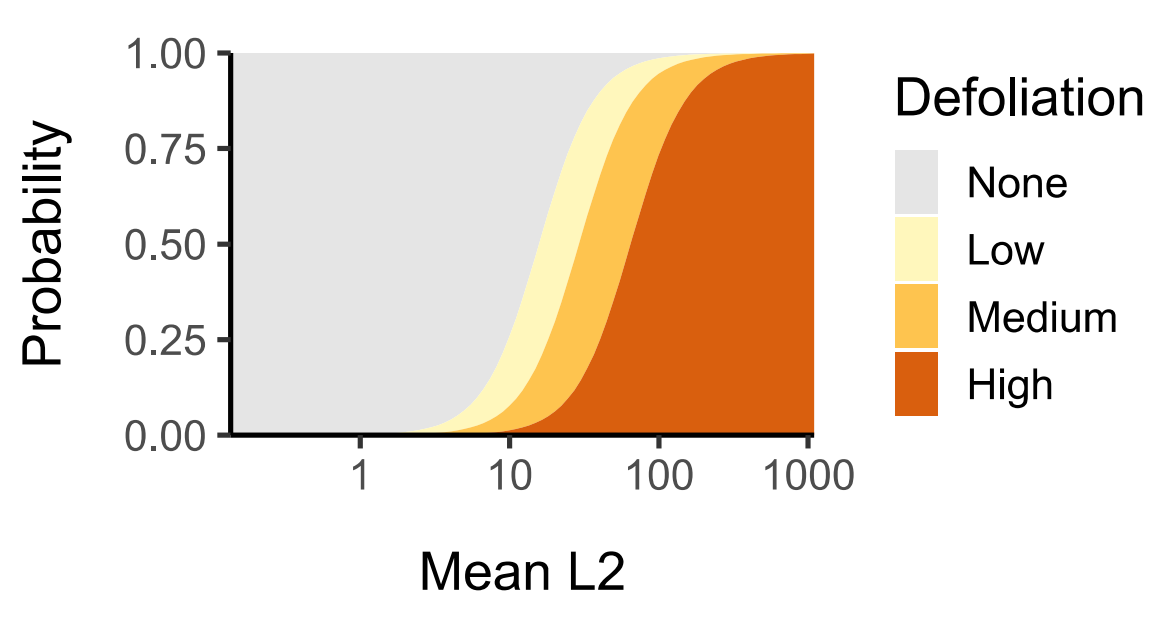
Fit a dynamic model of outbreaks to:

- Assign uncertainty to forecasts.
- Interpolate forecasts in space and extend beyond one year.

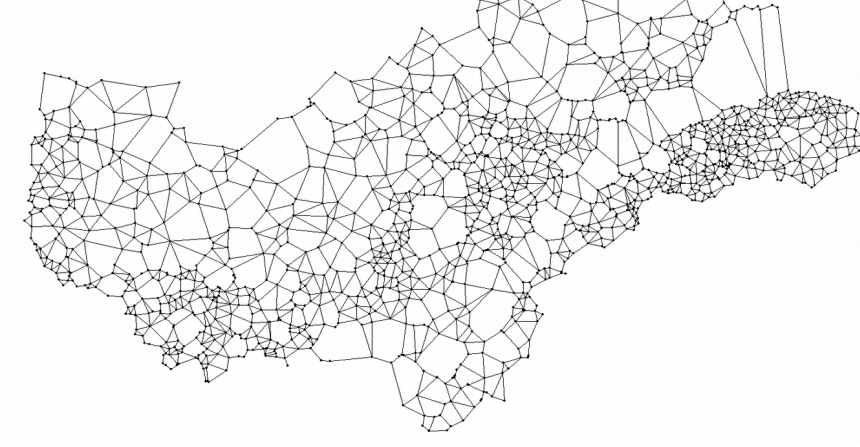
Count model  
(Zero-inflated negative binomial)

**Latent variable**  
Expected # of hibernating L2  
(by station-year)

## Ordinal logistic regression

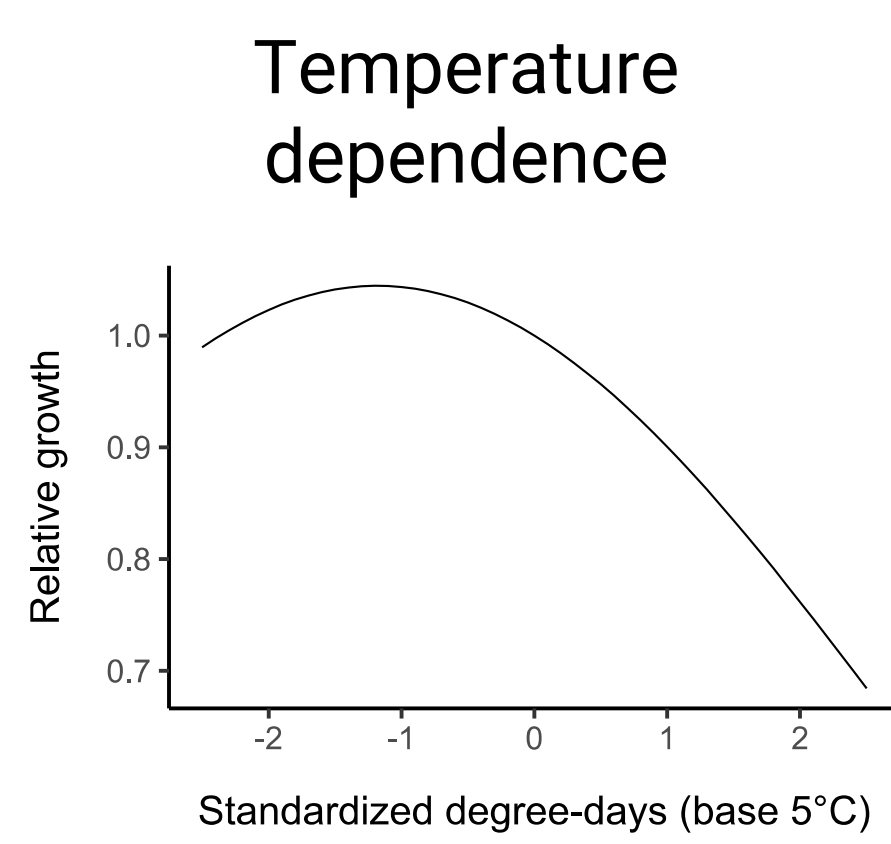
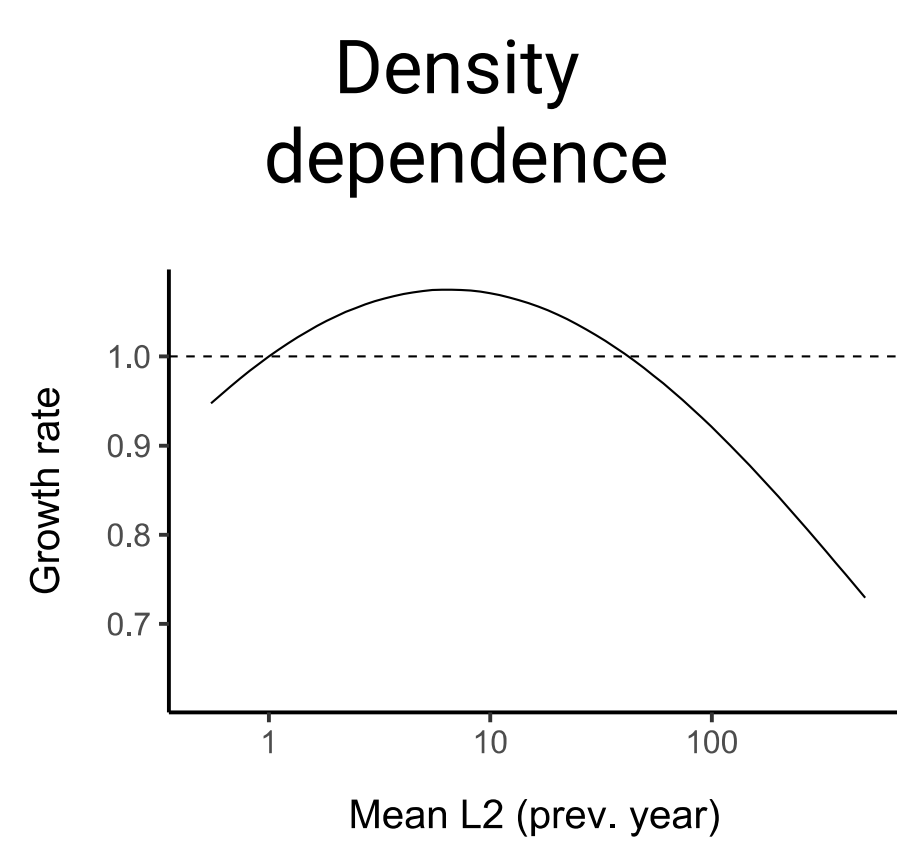


### Distance-weighted dispersal between neighbors



Pre-dispersal population

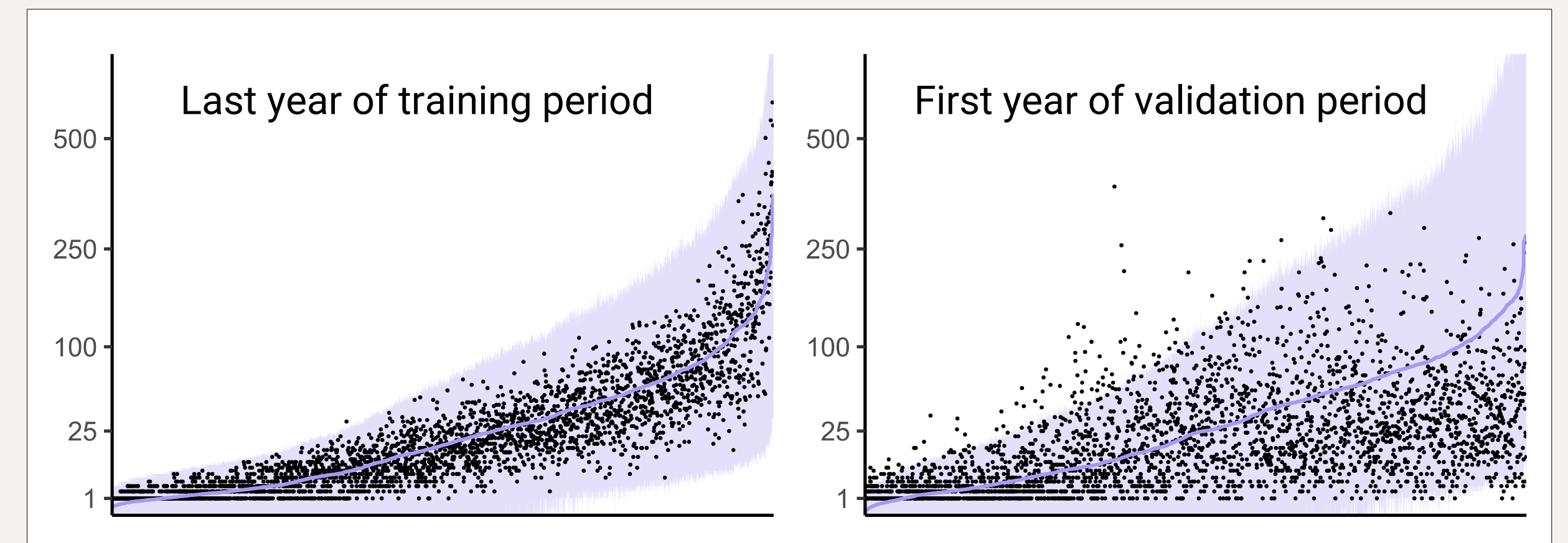
## Growth model



Also including

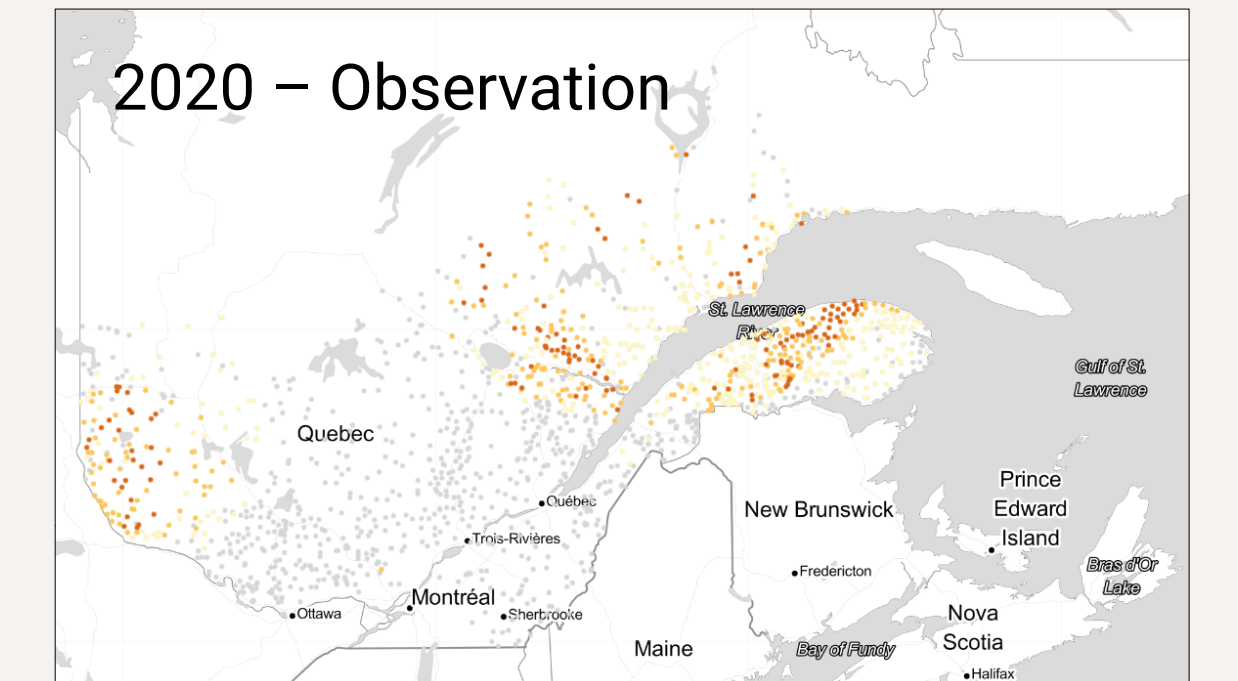
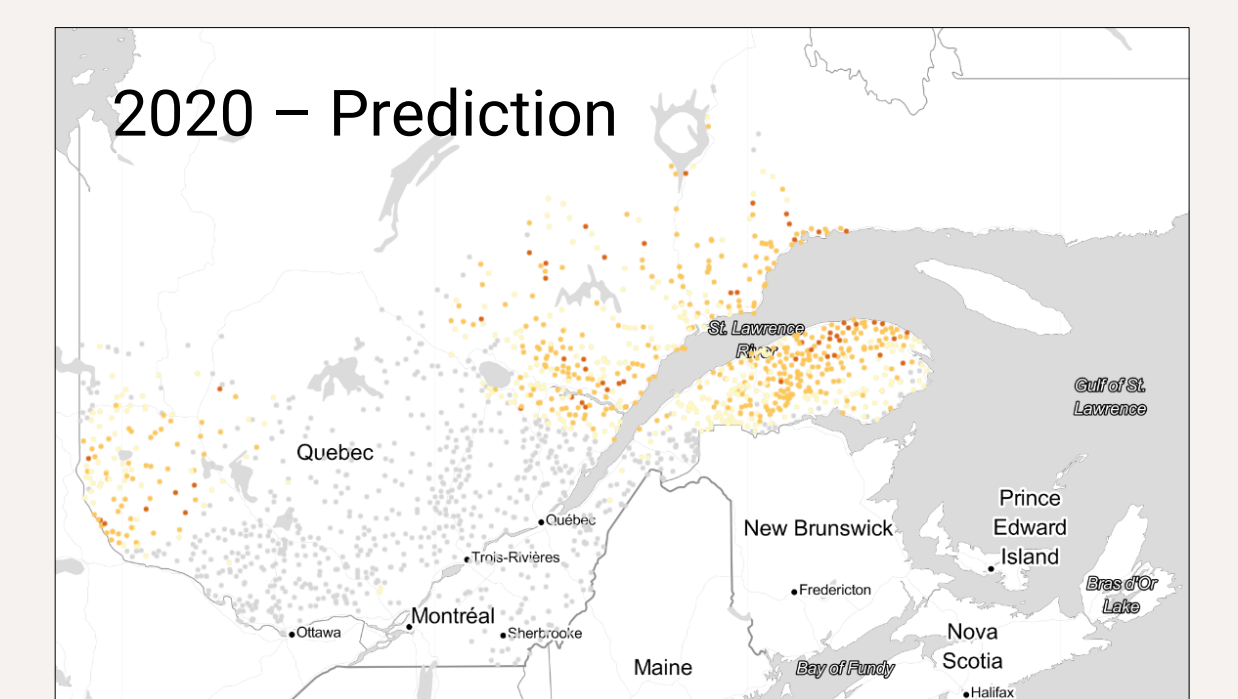
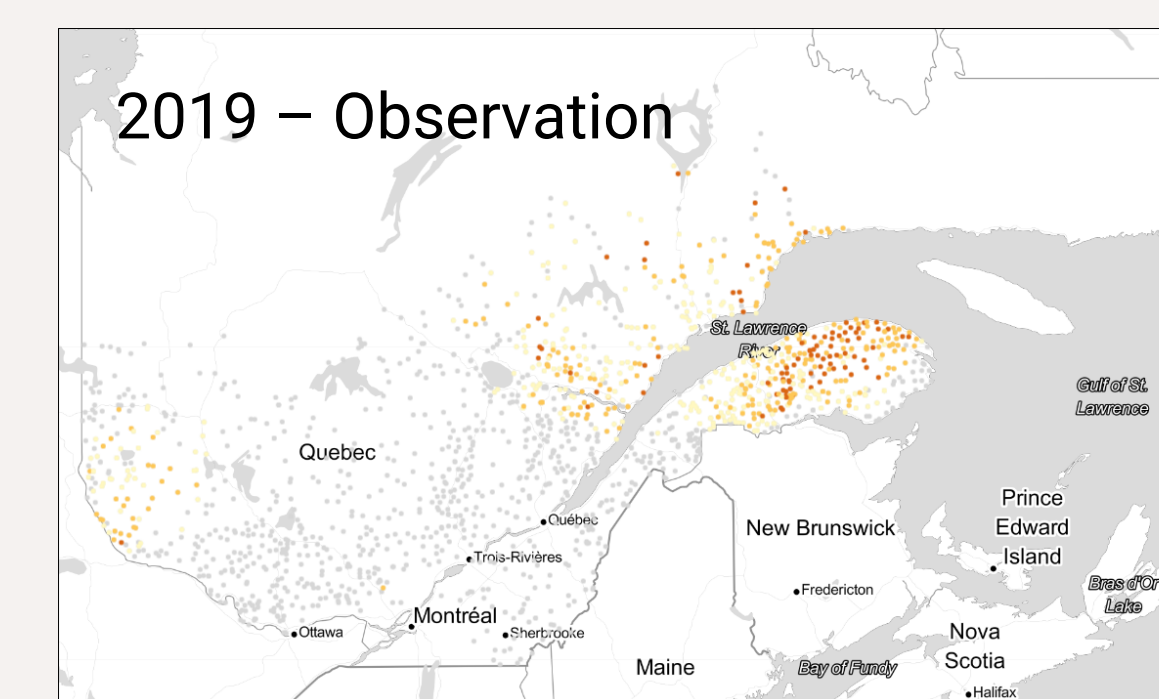
- Effect of stand age
- Effect of stand composition (fir, spruce, or non-host dominance)

## Prediction of L2 counts



Observations (points), mean (line) and 95% posterior predictive interval (shaded area)

## Defoliation forecast



| Event                                   | Model | 2020 |    |    |    | 2021 |    |    |    | Forecast year  |
|---|-------|------|----|----|----|------|----|----|----|--|
|   |       | Y    |    | N  |    | Y    |    | N  |    | L2 data in 2019?<br>(50% of sites)   |
| New defoliation<br>(8% of sites)        | STC   | 63   | 55 | 33 | 34 | 36   | 33 | 36 | 28 | <b>Recall (in %)</b><br>% of occurrences that were correctly predicted   |
|   | ST    | 63   | 54 | 33 | 34 | 34   | 31 | 33 | 26 |  |
|   | TC    | 63   | 55 | 20 | 30 | 37   | 32 | 20 | 23 |  |
|   | T     | 63   | 54 | 20 | 28 | 36   | 30 | 18 | 19 |  |
|   | 0     | 67   | 48 |    |    |      |    |    |    |  |
| Increased defoliation<br>(9% of sites)  | STC   | 63   | 40 | 44 | 35 | 46   | 16 | 48 | 15 | <b>Precision (in %)</b><br>% of predicted events that did occur  |
|   | ST    | 63   | 41 | 42 | 36 | 43   | 15 | 43 | 14 |  |
|   | TC    | 62   | 40 | 38 | 35 | 42   | 15 | 37 | 15 |  |
|   | T     | 63   | 41 | 36 | 35 | 40   | 15 | 34 | 14 |  |
|   | 0     | 63   | 40 |    |    |      |    |    |    |  |
| Decreased defoliation<br>(16% of sites) | STC   | 40   | 36 | 44 | 30 | 40   | 52 | 46 | 55 | <b>Model codes</b><br><br>S = spatial dynamics<br>T = temporal dynamics<br>C = covariates<br>(climate/forest)<br>0 = base model<br>(previous year L2 only) |
|   | ST    | 42   | 37 | 46 | 30 | 40   | 50 | 47 | 53 |  |
|   | TC    | 40   | 36 | 46 | 28 | 42   | 49 | 58 | 52 |  |
|   | T     | 43   | 37 | 48 | 28 | 42   | 48 | 60 | 51 |  |
|   | 0     | 44   | 35 |    |    |      |    |    |    |  |

## Assessment and next steps

- The spatiotemporal population dynamics model provides a greater forecasting range (new sites, two years ahead), but its accuracy could be improved (e.g. add non-isotropic and population density-dependent dispersal by emulating output of mechanistic models).
- Model on a grid covering whole study area, instead of point sites (long computation times in current implementation of hierarchical Bayesian model in Stan).

This study is part of the project: *"Forecasting spruce budworm activity in a climate change context"*.  
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 Students and postdocs: Max Debaly, Judicaël Osse, Anoj Subedi.

## Funding



## Forêts, Faune et Parcs



## RESULTS

## Model codes

S = spatial dynamics  
T = temporal dynamics  
C = covariates  
(climate/forest)  
0 = base model  
(previous year L2 only)