Spruce budworm (*Choristoneura fumiferana*) outbreaks: a story of population dynamics, environmental conditions, and defoliation

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Forest insect outbreaks: a global concern

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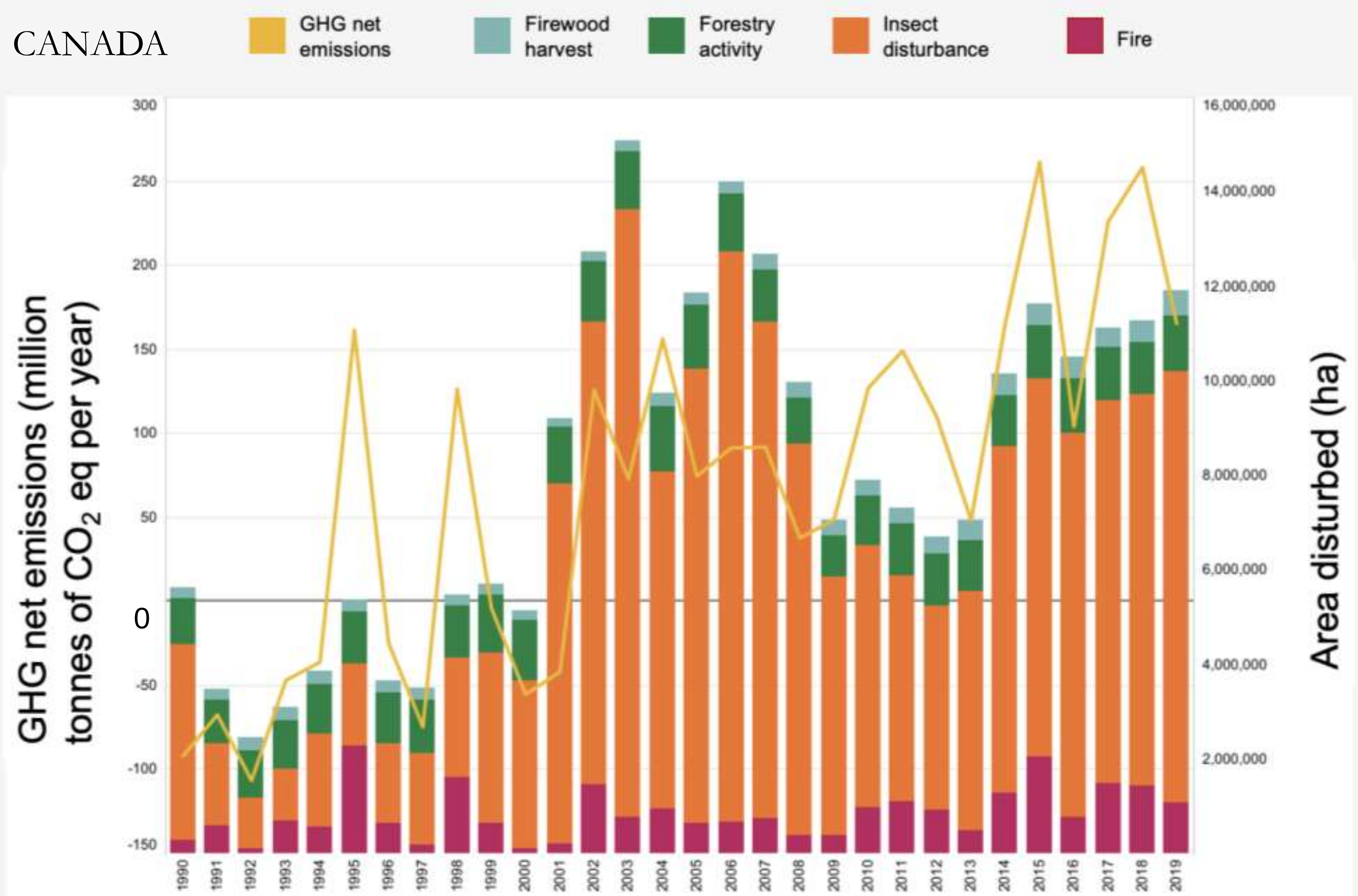
Damage economically important tree species

Carbon release

Influence fire risk



CANADA
GHG net emissions
Firewood harvest
Forestry activity
Insect disturbance
Fire
GHG net emissions (million tonnes of CO_2 eq per year)
Area disturbed (ha)
300
250
200
150
100
50
0
-50
-100
-150
16,000,000
14,000,000
12,000,000
10,000,000
8,000,000
6,000,000
4,000,000
2,000,000
1990
1991
1992
1993
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2013
2014
2015
2016
2017
2018
2019

nrcan.gc.ca

Spruce budworm
(*Choristoneura fumiferana)*

Moth native to eastern Canada and USA

Larvae feed on spruce and fir

Univoltine species (one brood per year)

Cyclical outbreaks every ~ 30-40 years

Jerald E. Dewey, USDA Forest Service, United States

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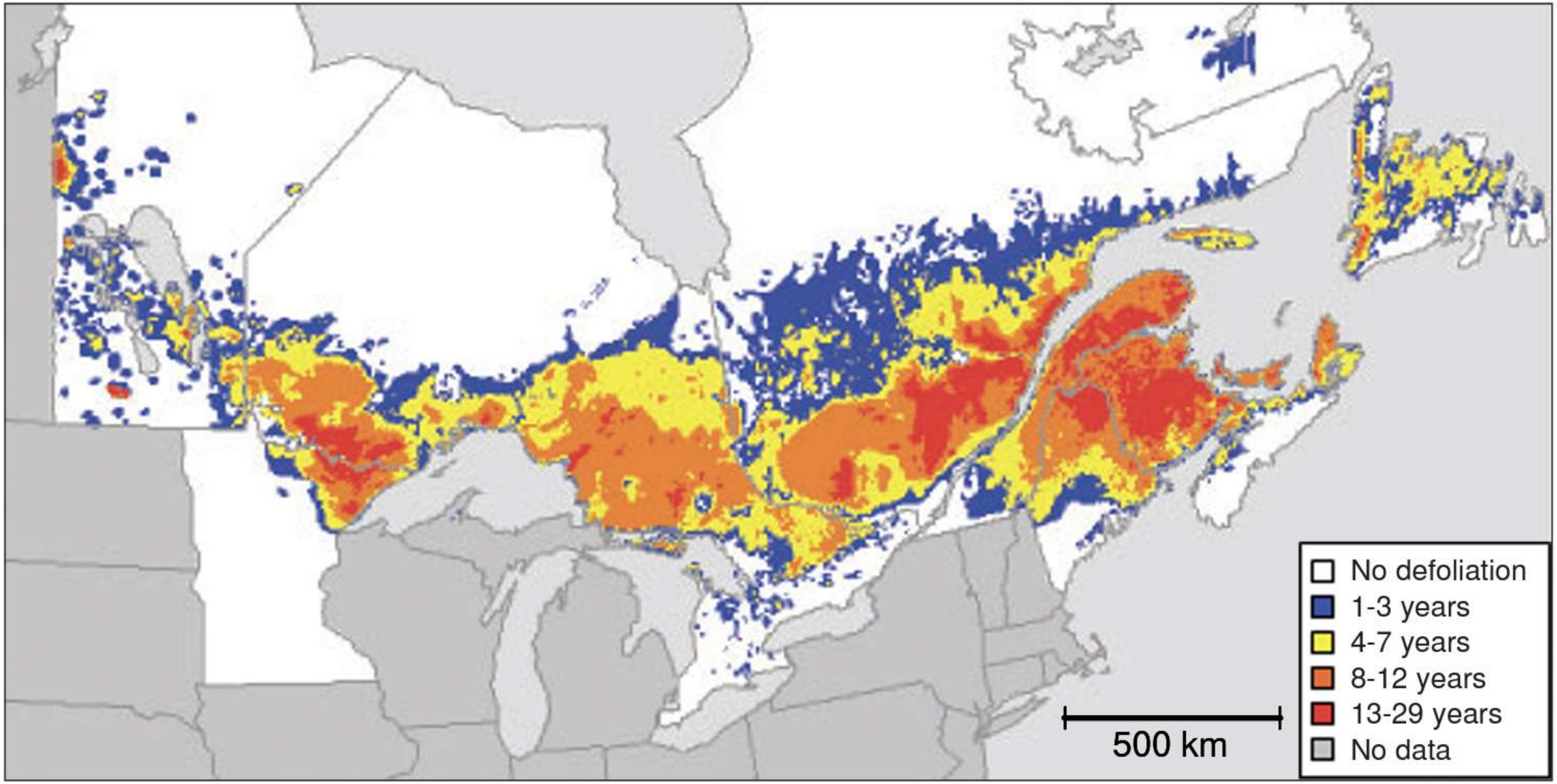
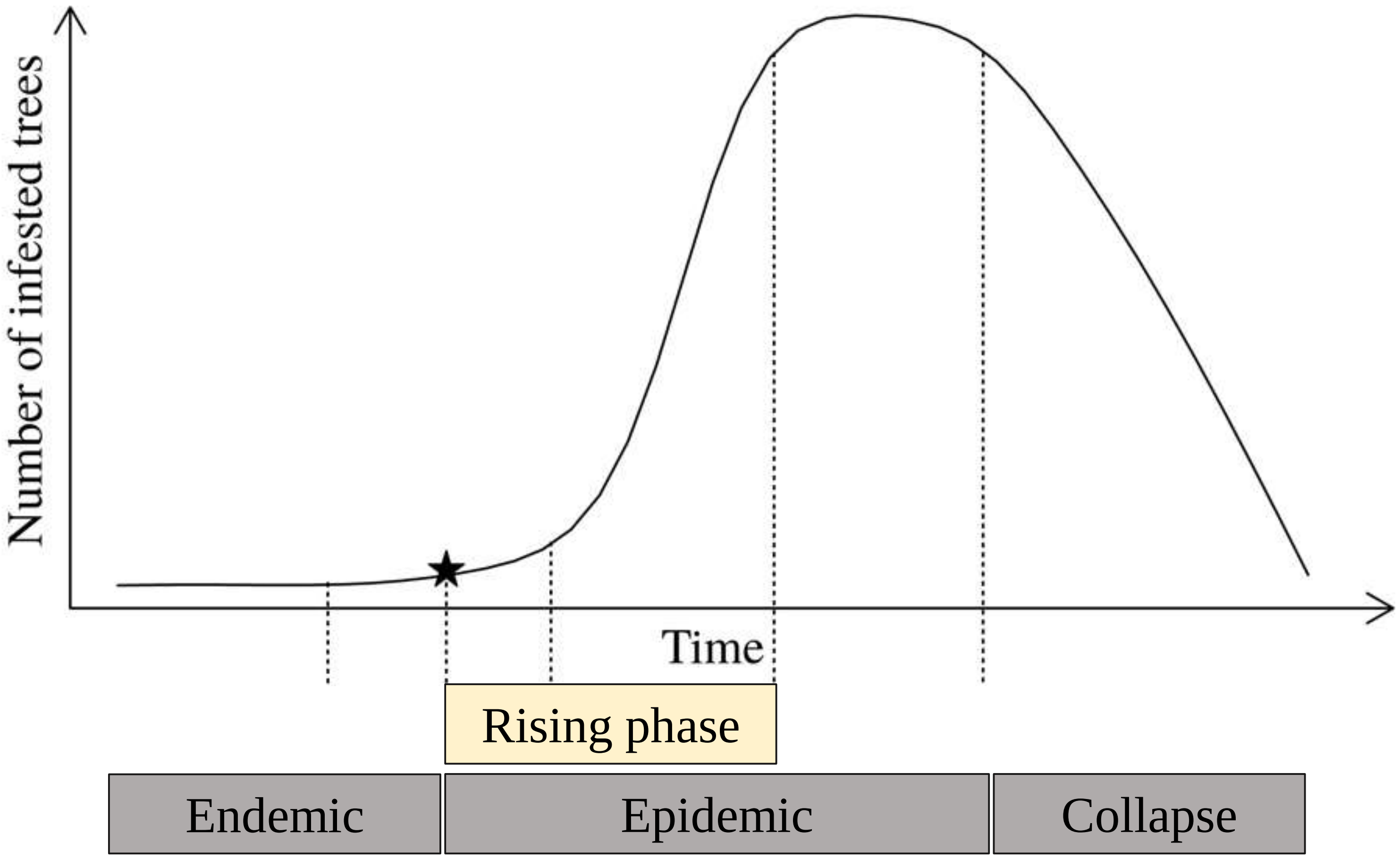


Frequency of defoliation by spruce budworm from 1954 to 1988. (Williams & Birdsey, 2003)

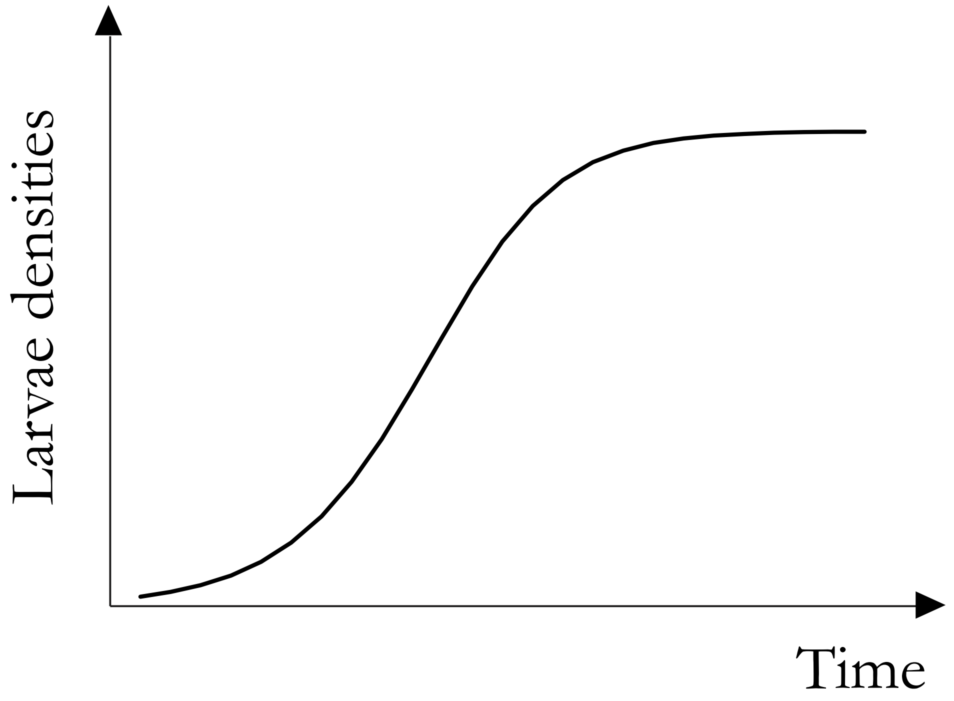
Outbreak Dynamics



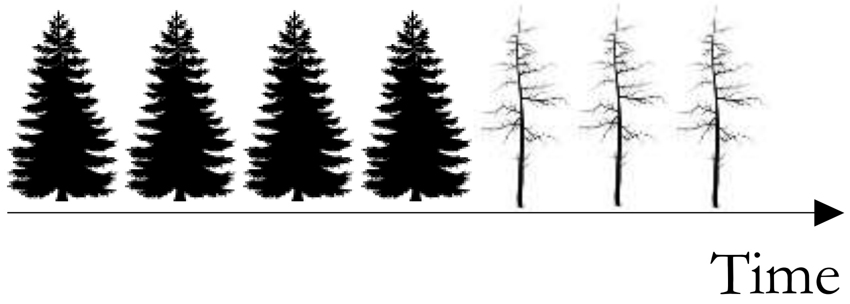
Adapted from Kunegel-Lion & Lewis, 2020

Outbreak at the local scale

Population dynamics



Defoliation



Outbreak at the local scale

Top-down drivers

Natural enemies

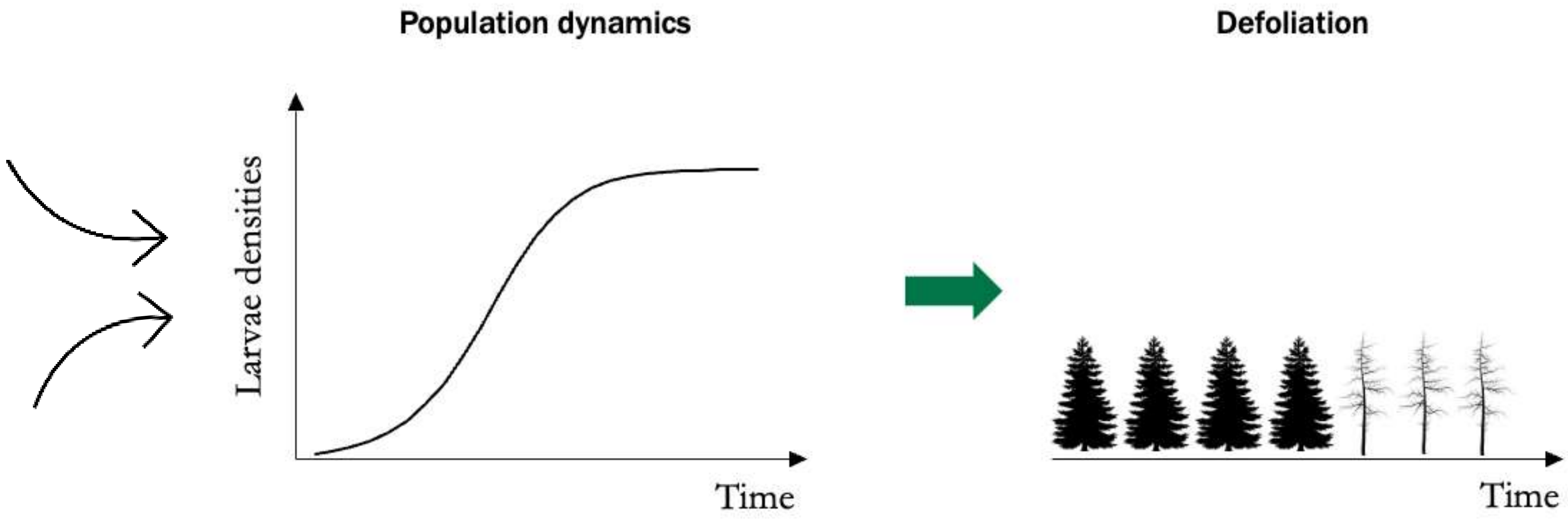
(Royama, 1984)

Bottom-up drivers

Forest structure

Host quality and availability

(Bouchard & Auger, 2014)



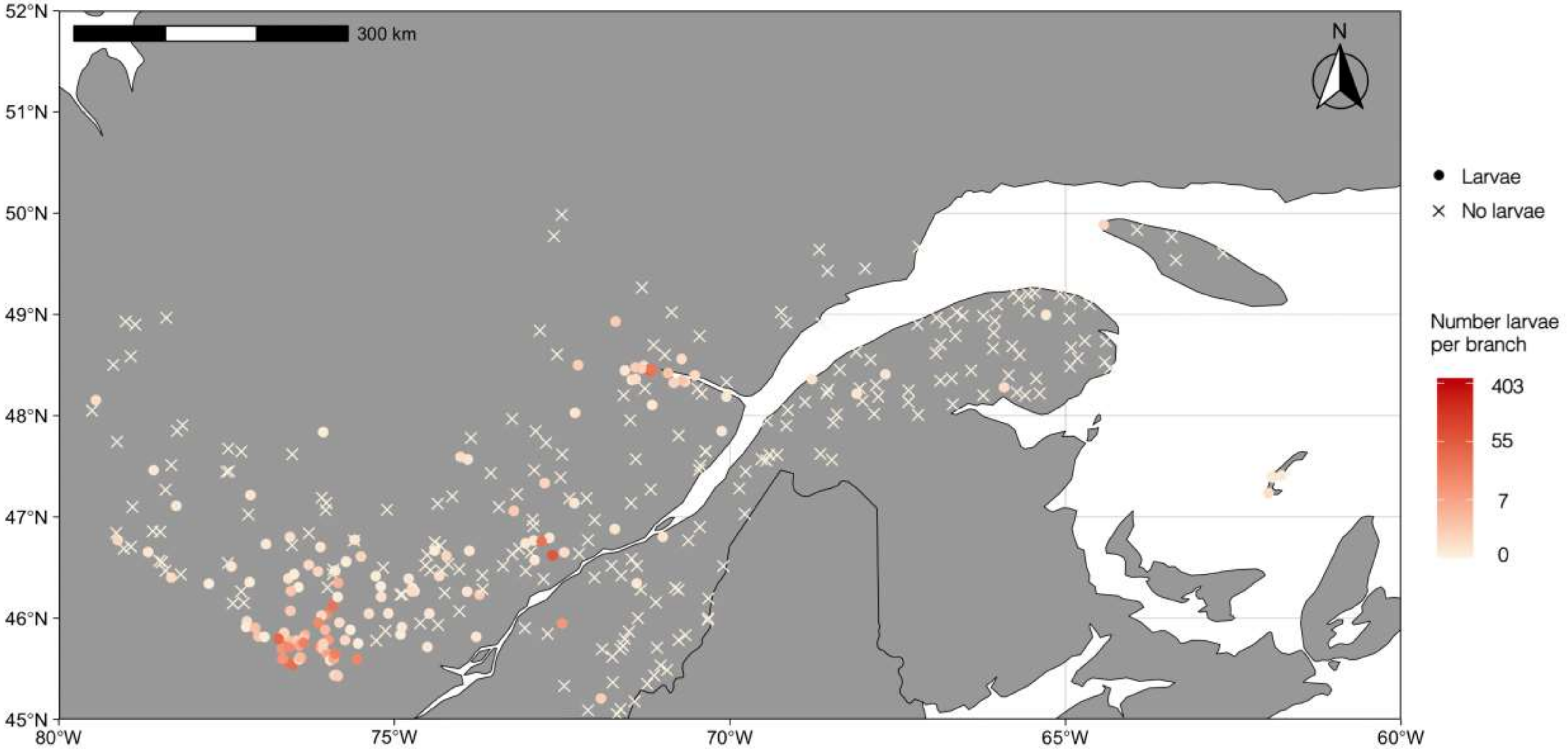
1

How do environmental conditions impact the development of an outbreak?

2

How do larvae densities and defoliation relate to one another?

2001



52°N
51°N
50°N
49°N
48°N
47°N
46°N
45°N
80°W
75°W
70°W
65°W
60°W
300 km
N
Larvae
No larvae
Number larvae per branch
403
55
7
0

1 How do environmental conditions impact the development of an outbreak?

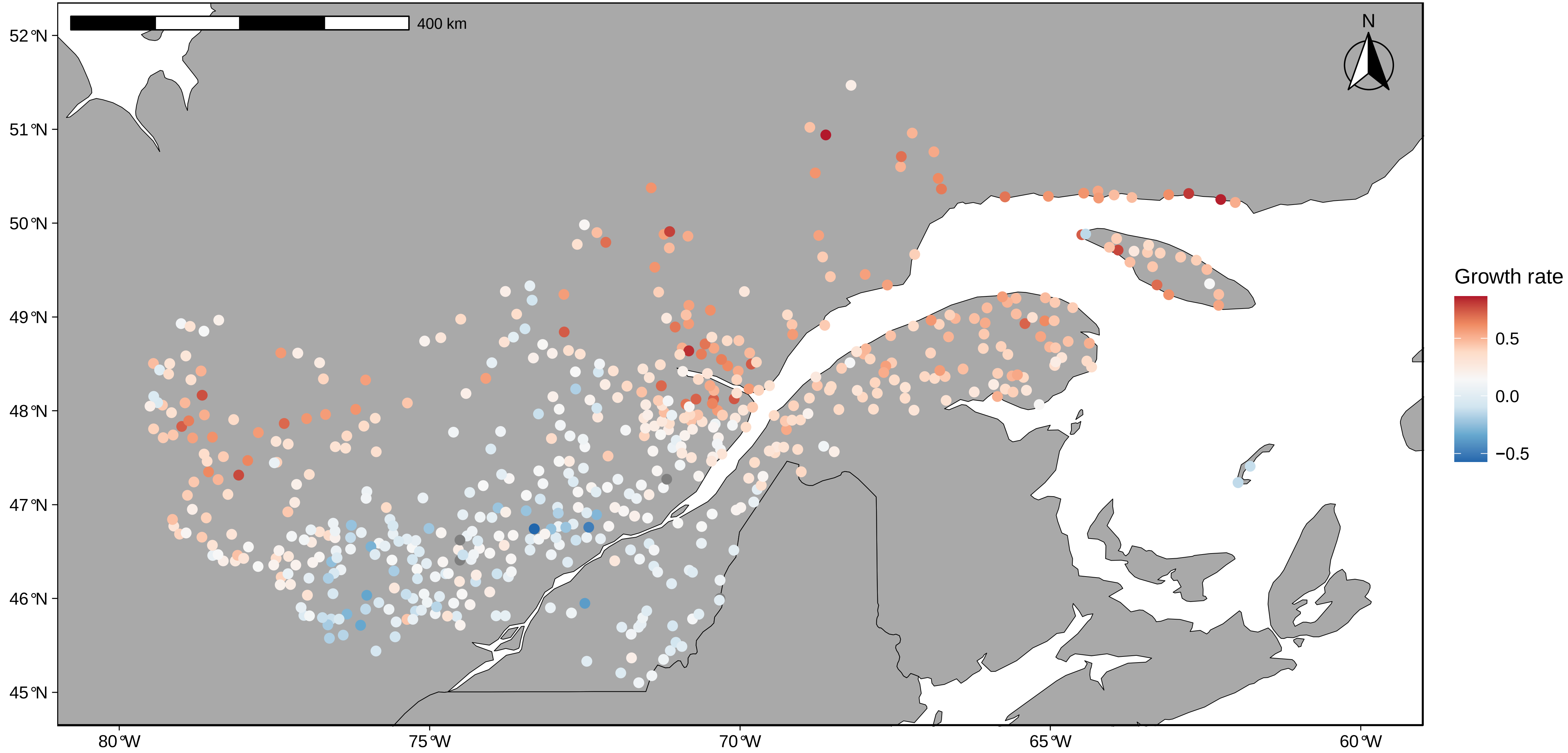
Estimate the growth rate of each time-series using a state-space model (Humbert et al., 2009)

Assess the impact of environmental predictors with multiple regression

Environmental predictors

- Topography (elevation, slope)
- Moisture regime (drainage)
- Tree proportion (balsam fir, white spruce, black spruce, and hardwood species)

1 Population growth rates

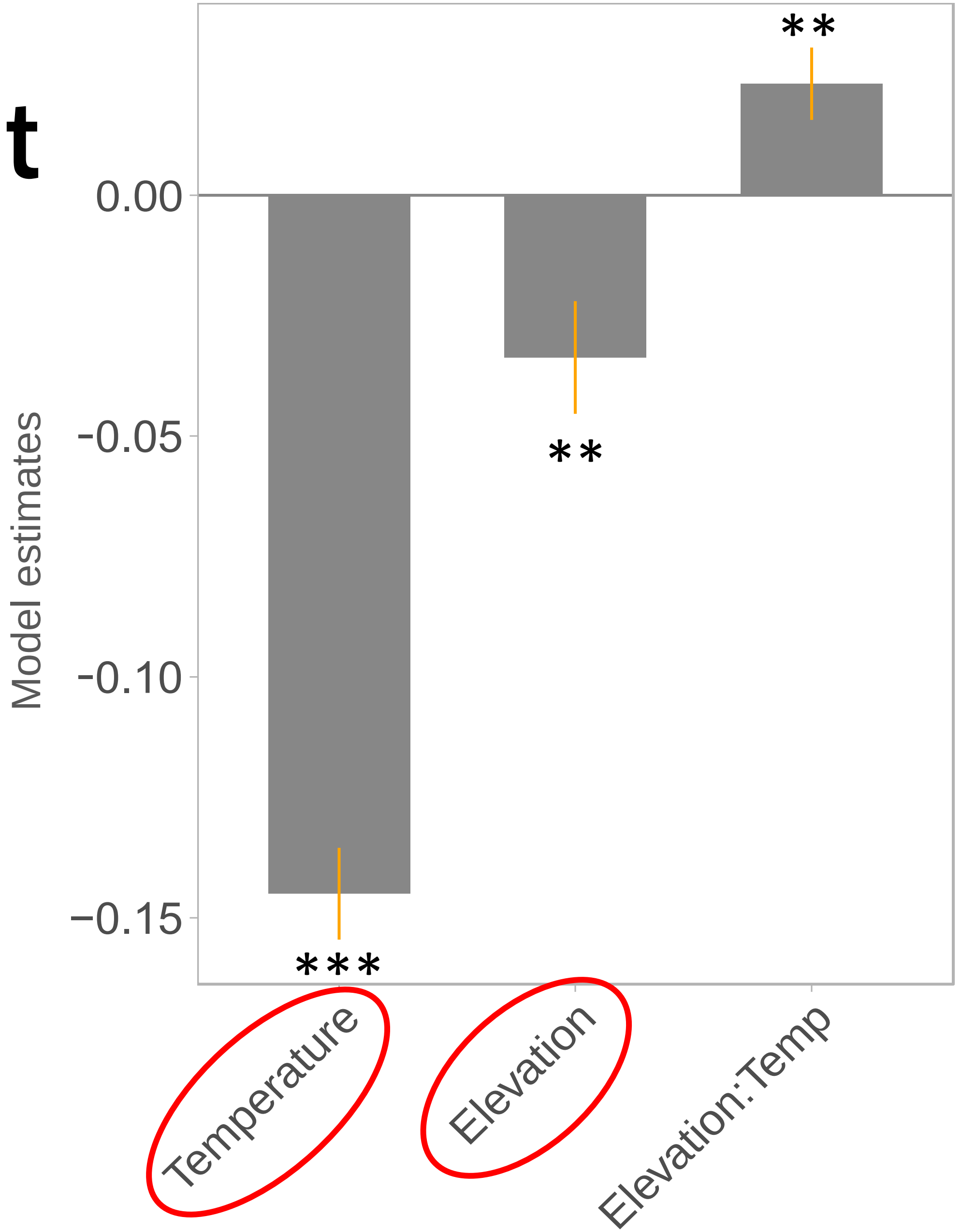


1 Influence of environment

Temperature has the largest impact on growth rate

Spatial structure not entirely explained

By adding "latitude" as a predictor, we increase R^2 by 10%



2

How do larvae densities and defoliation relate to one another?

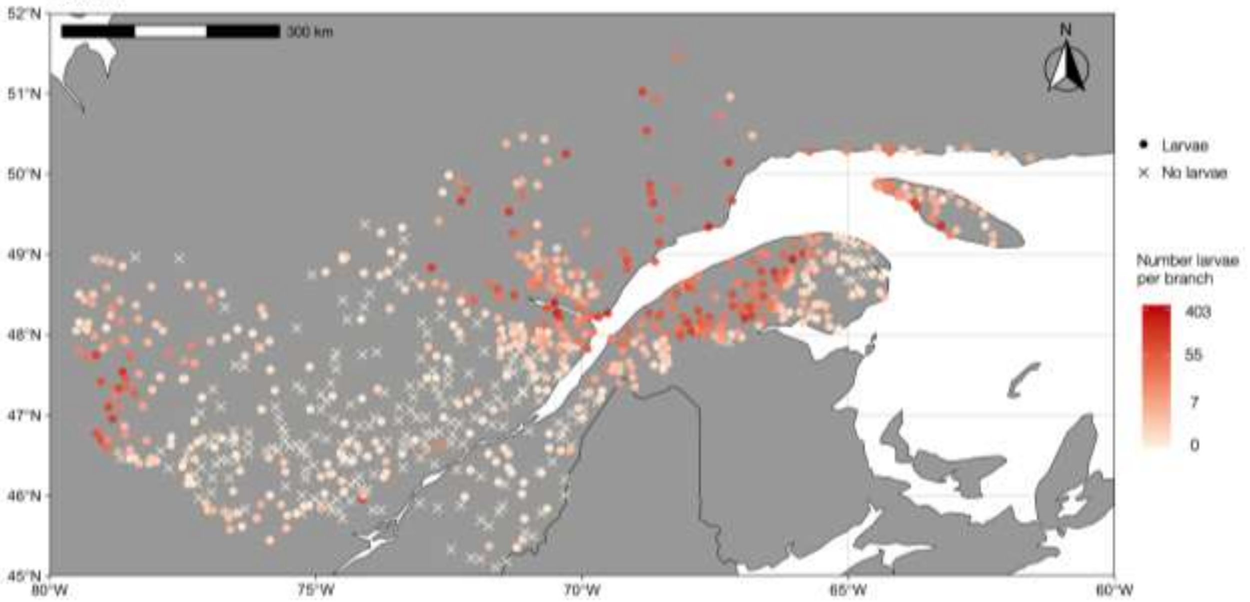
How do larvae densities and defoliation relate?

Aerial surveys of defoliation (SOPFIM)

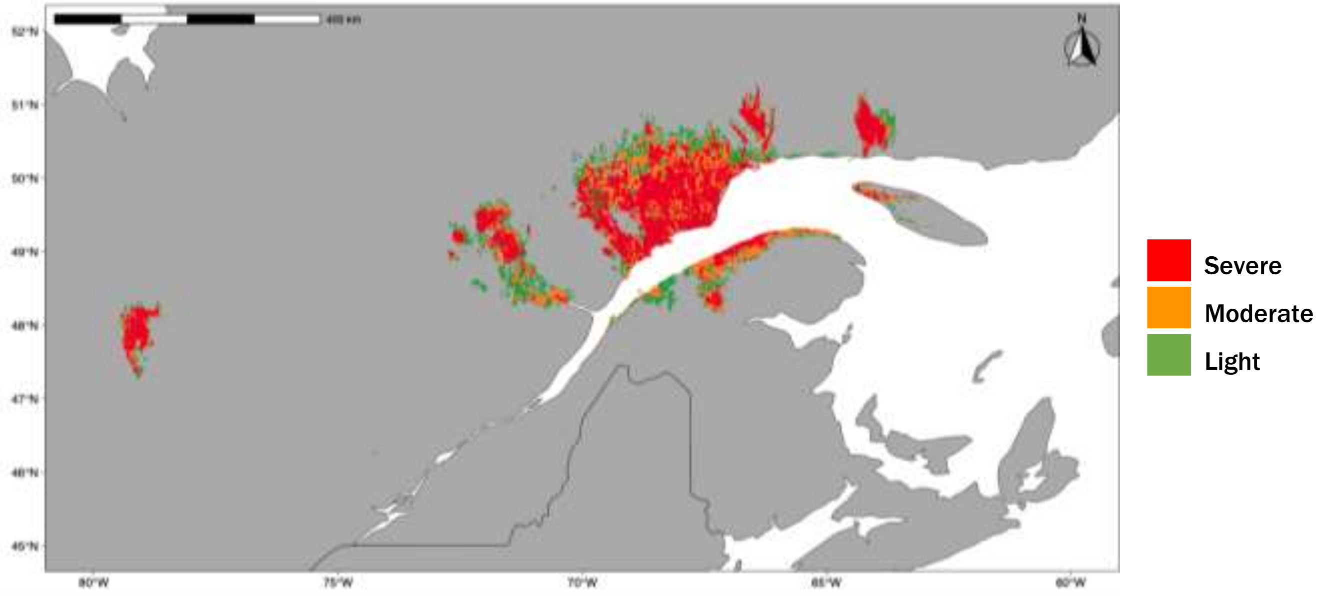
Optimize “best time-lag”

Effect of environmental conditions

2014 Larvae densities



2014 Defoliation level

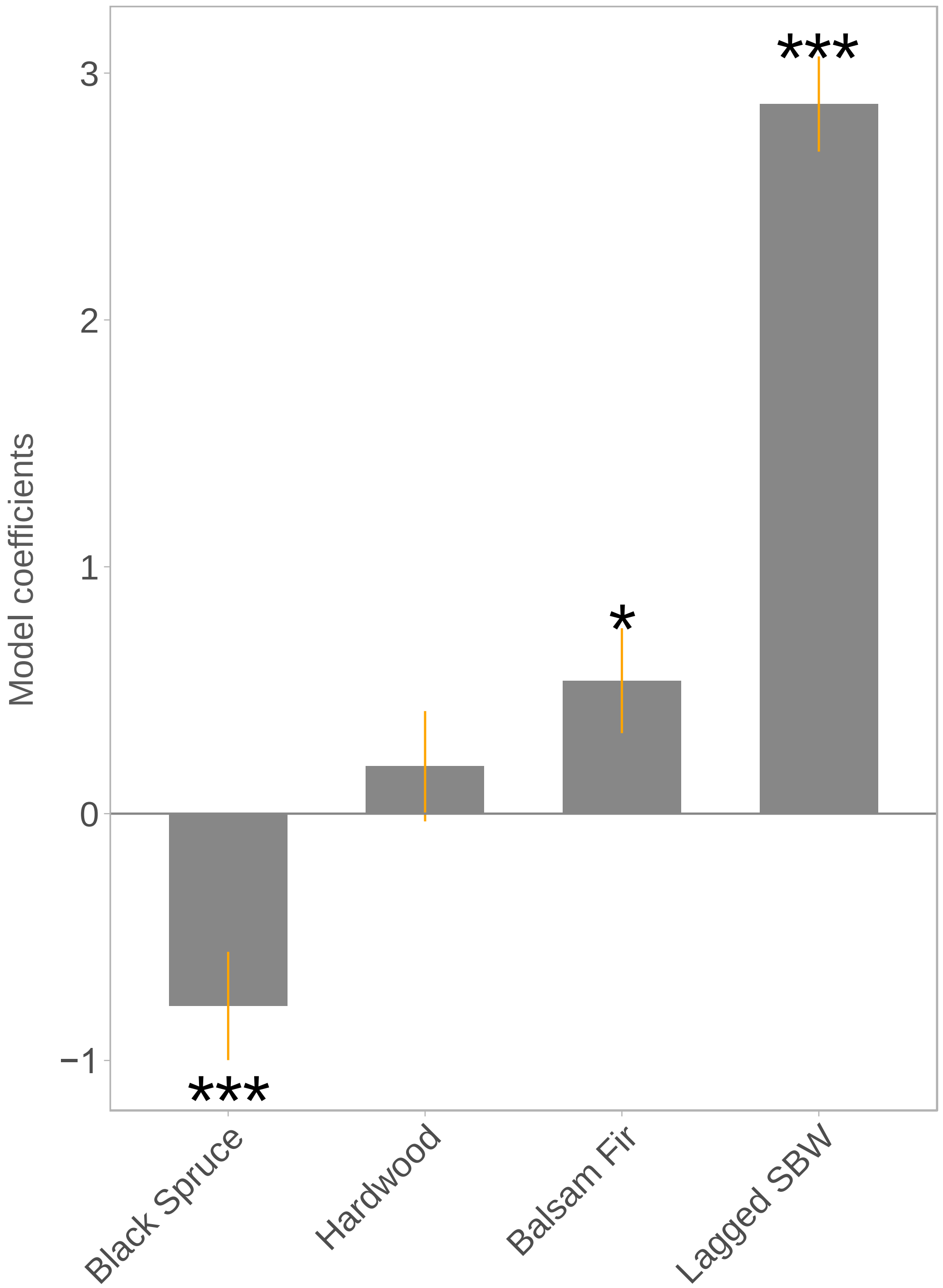


2 Influence of forest structure on defoliation

Best time-lag: cumulative densities <u>3 years</u> prior observed defoliation

Budworm densities explain most of the variance

Balsam fir and black spruce have opposite effects



Predicting probability of defoliation

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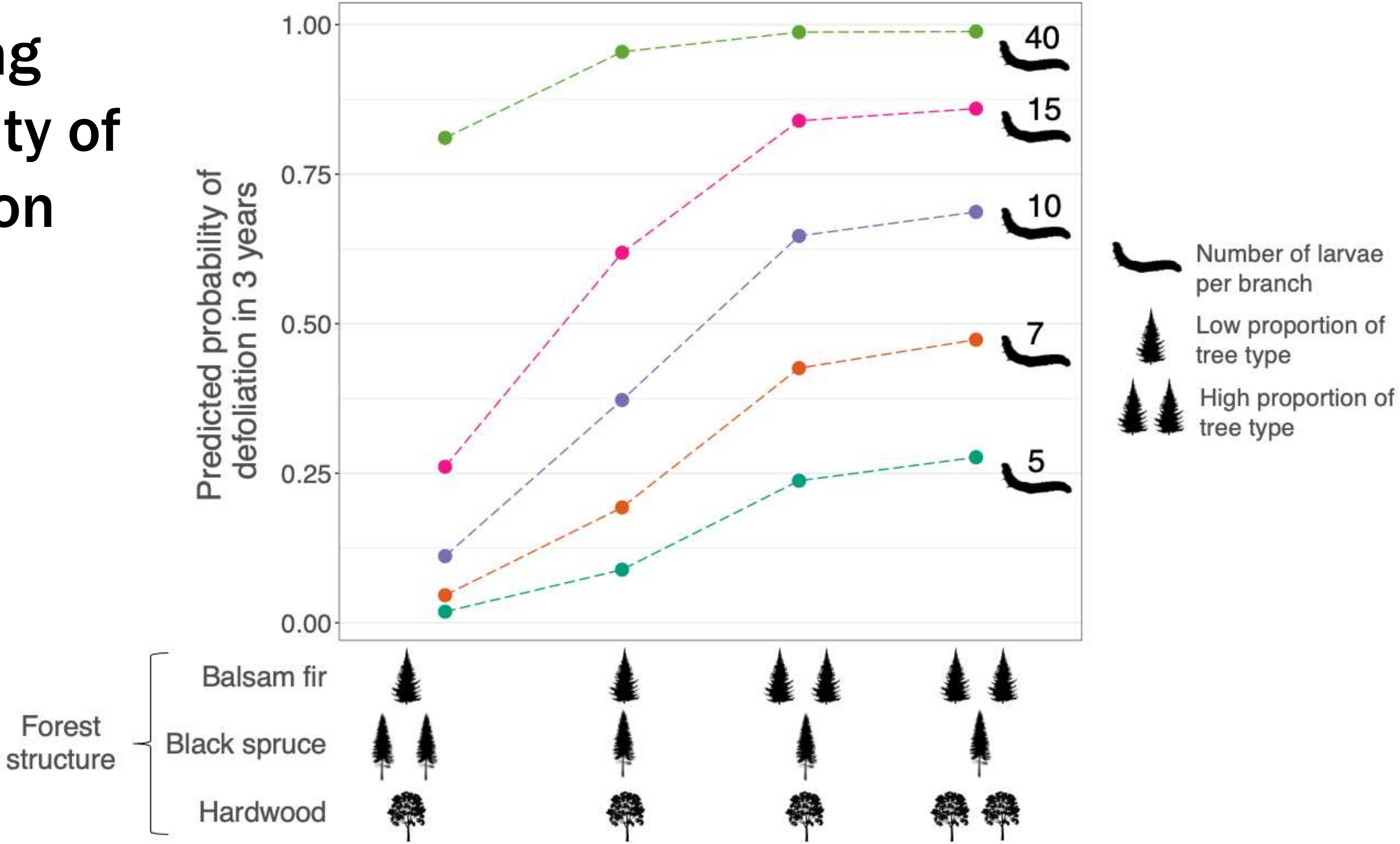
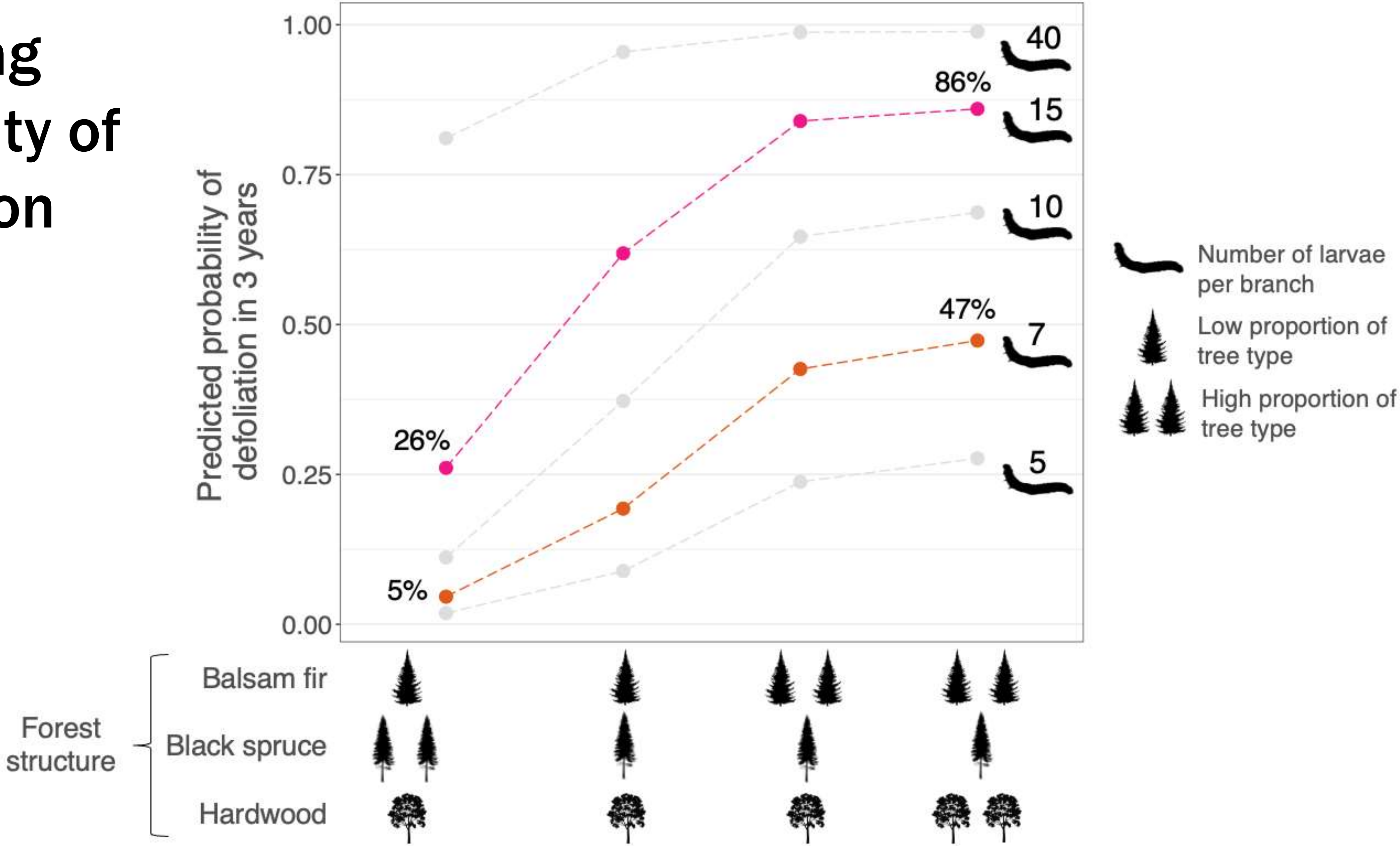


Predicting probability of defoliation



Take home messages

Larvae densities data contain very valuable information for making prediction

Spatial structure in growth rates

3 years time-lag

Importance of forest composition for defoliation risk

Next steps and potential application

Earlier forecast of defoliation

Uncertainty modelling

Inform management strategies

Thank you!

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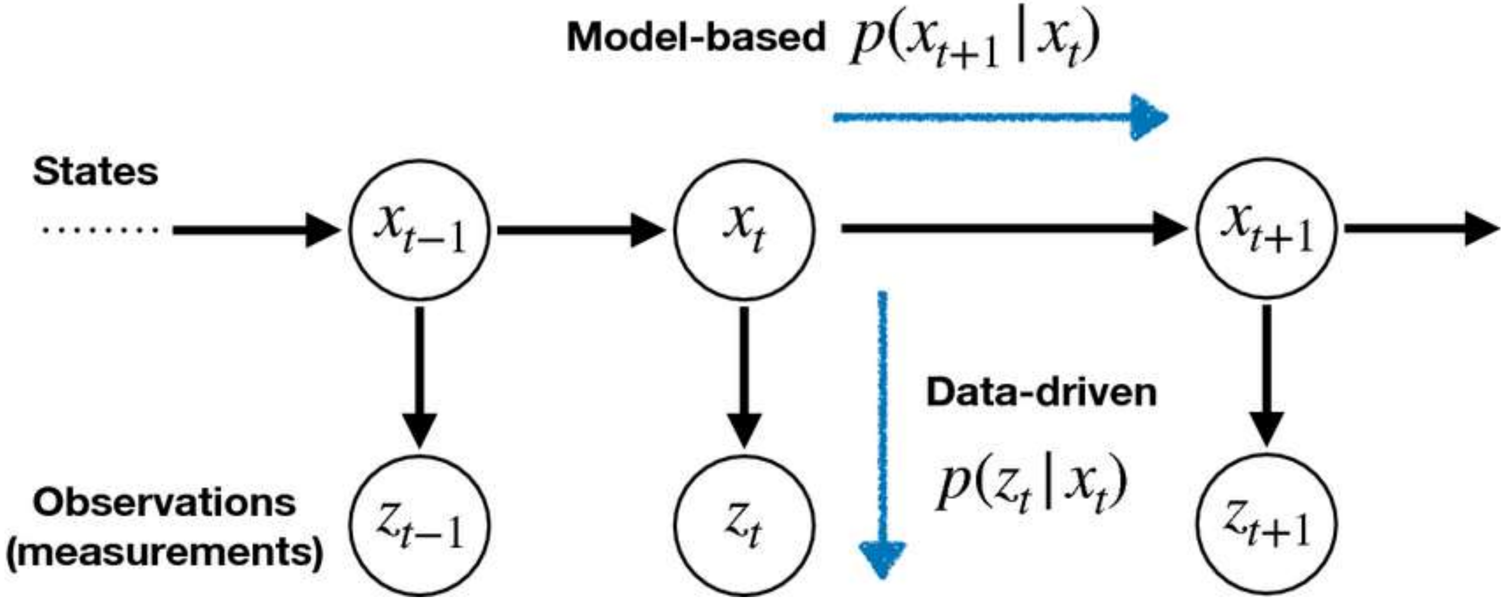
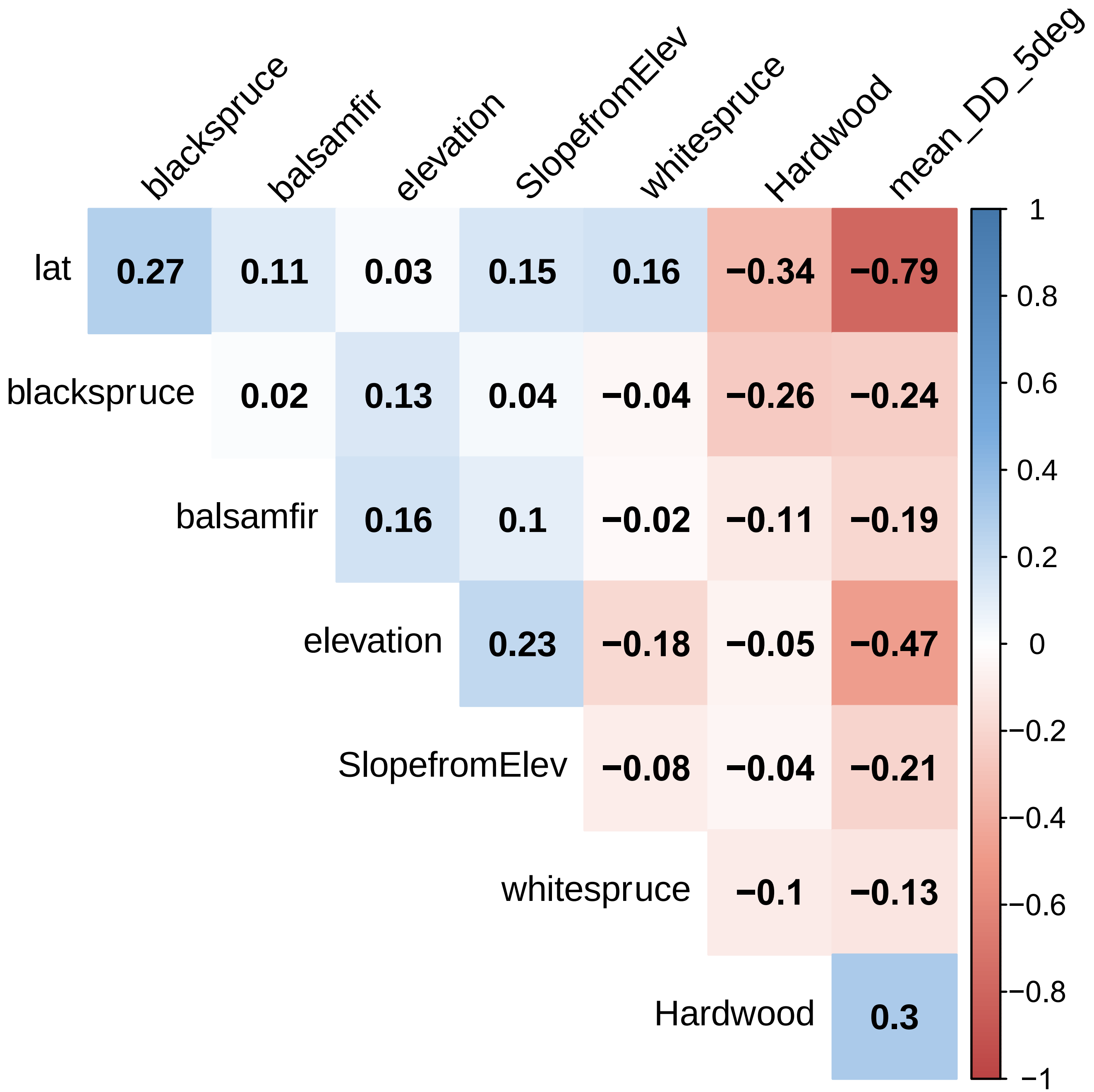
State-space modelling approach

Hierarchical model

Model natural variation in ecological processes separately from observation error.



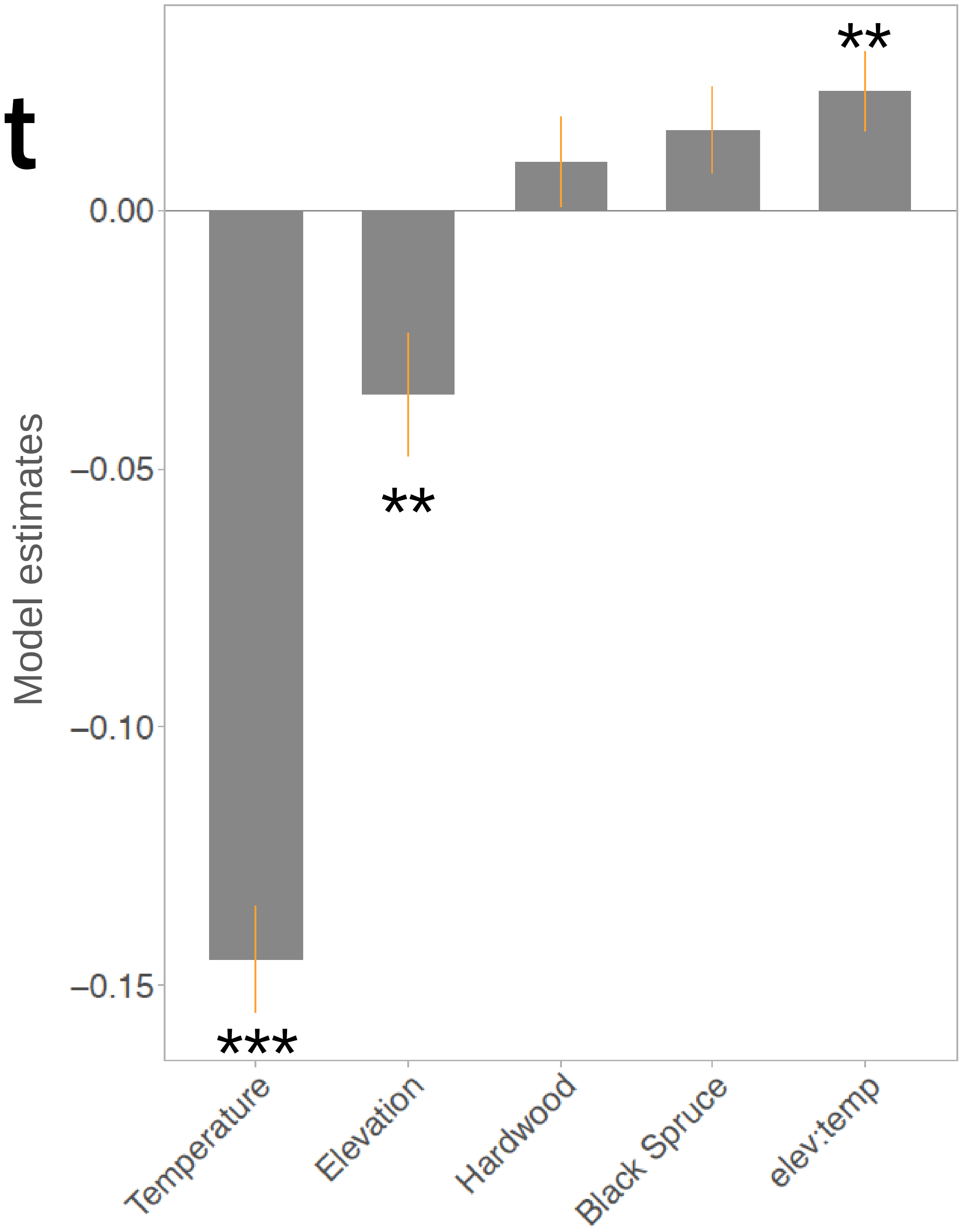
Correlation structure model 1



1 Influence of environment

Temperature has the largest impact on growth rate

Spatial structure not entirely explained (latitude was a better predictor)

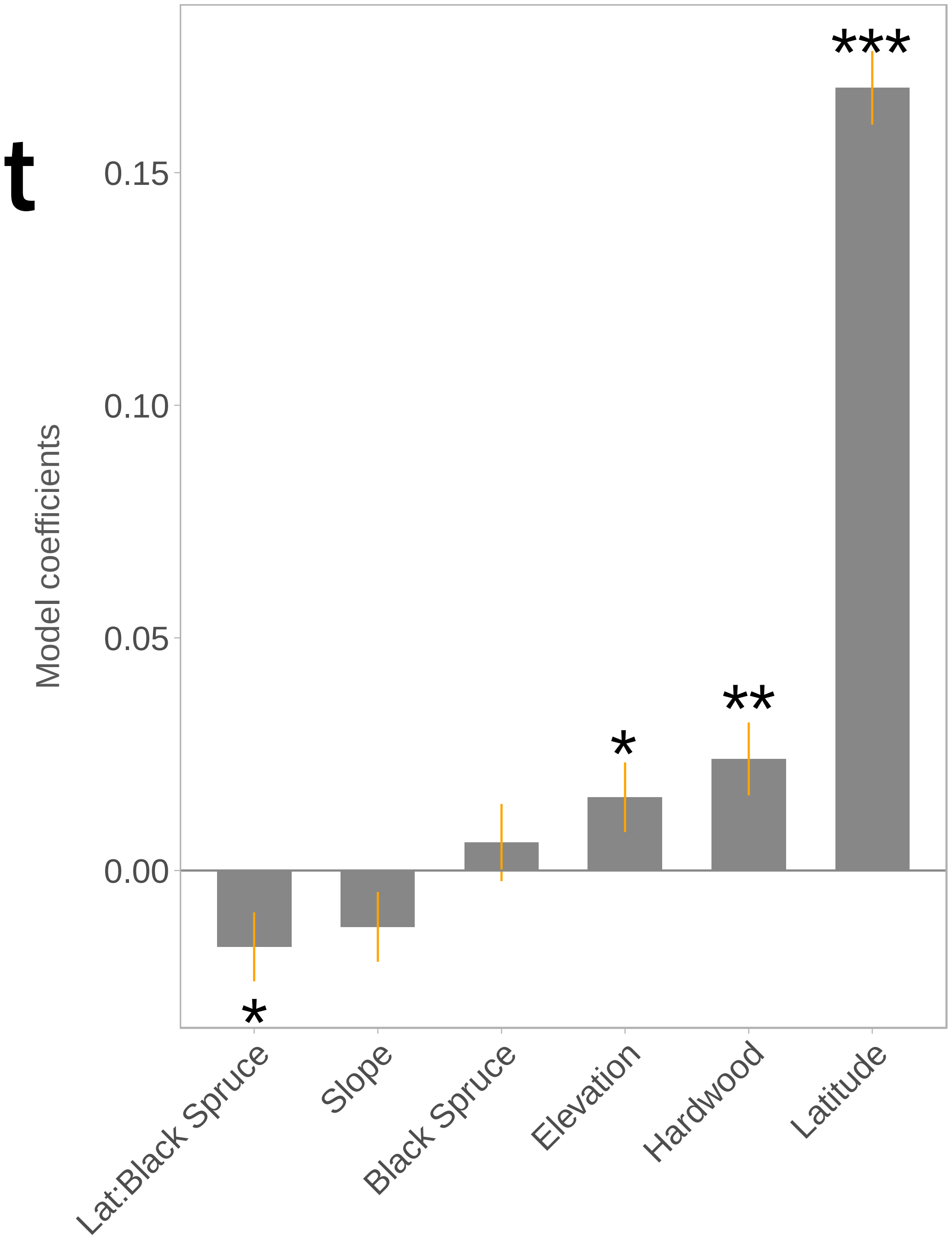


1 Influence of environment

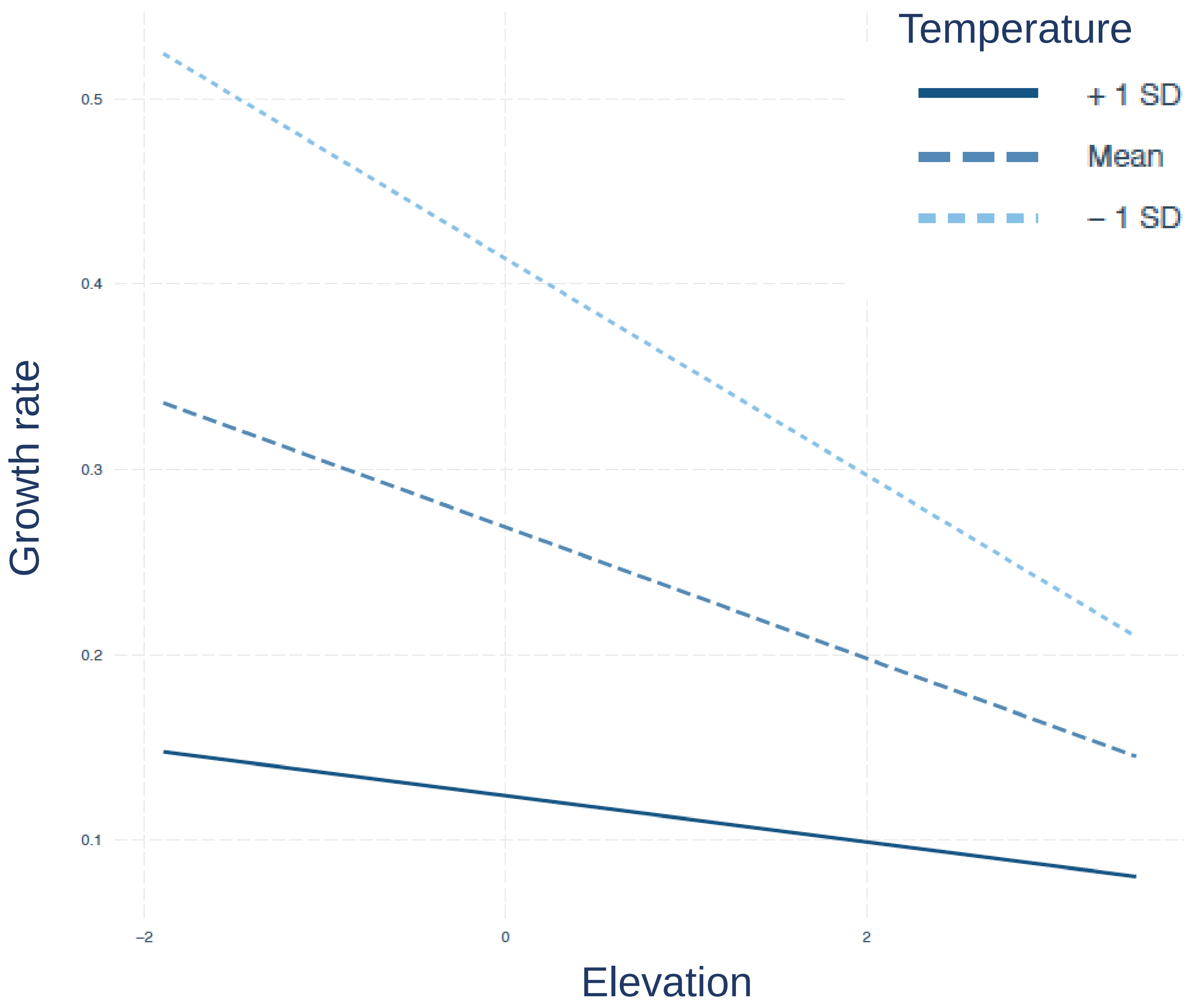
Latitude explains most of the variance

Latitude is a proxy for multiple environmental variables

Positive effect of hardwood proportion on growth rate (?)



Interaction model 1



Determination of the best lag

General model : defoliation ~ lagged L2

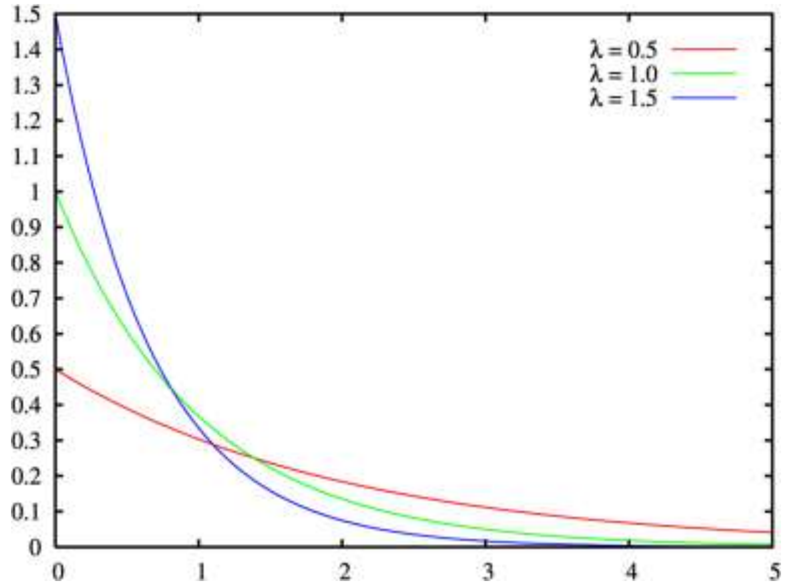
1. Discrete

2. Cumulative

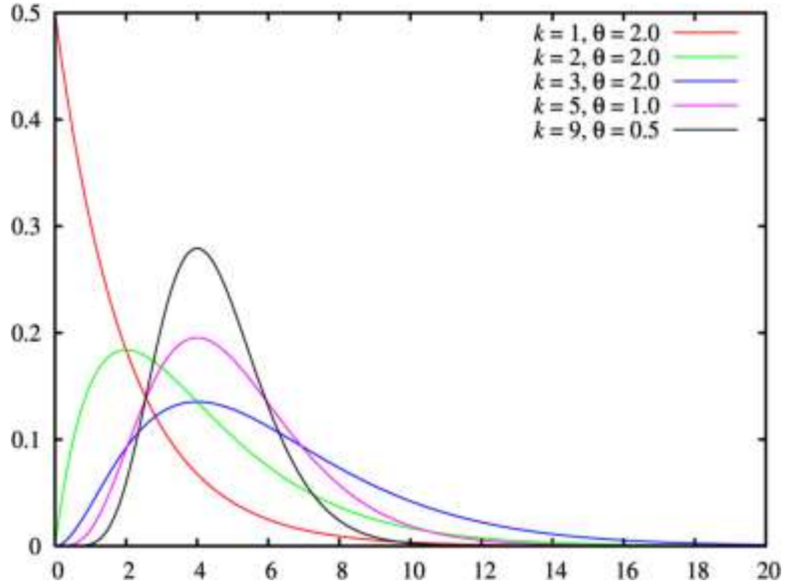
3. Weighting functions
   - Negative exponential
   - Gamma

Use "optim" in R to estimate the best parameters of each weighting functions.

Negative exponential - 1 parameter



Gamma - 2 parameters



Best lag

Cumulative: L2 densities 3 years prior to observed defoliation

Multiplicative: bigger impact if L2 densities stay high

Weighting function: factors derived from a gamma distribution of parameters shape = 9.0, scale = 0.2

↓

$$\text{Defoliation} \sim 0.26 * \log(L2_{t-1}) + 0.58 * \log(L2_{t-2}) + 0.13 * \log(L2_{t-3})$$