PHENOLOGY 2022

21 June 2022

Predicting the phenology of questing *Ixodes ricinus* nymphs in France with meteorological, bioclimatic, and land cover factors

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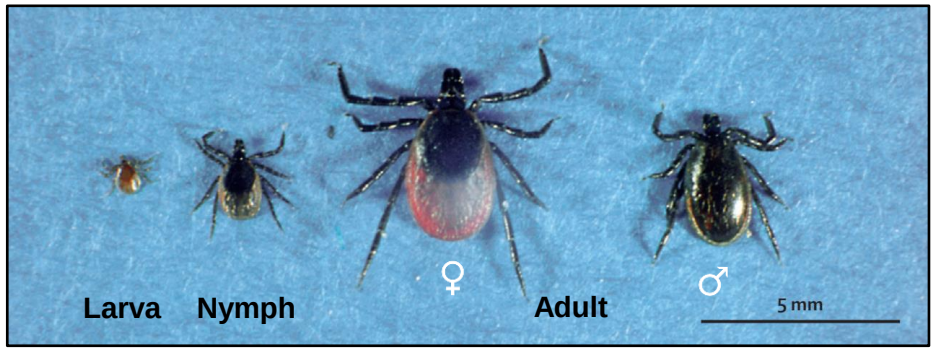
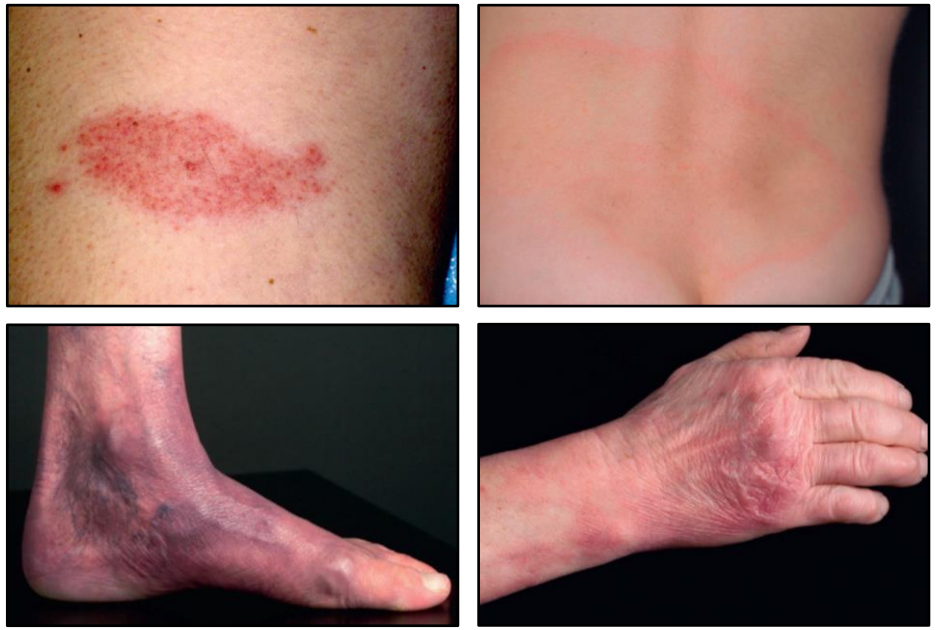
Ixodes ricinus

- **Hard tick** – Acari: Ixodidae
- **Three-host** life cycle
- Wide host range
- Transmits zoonotic diseases
  - **Lyme borreliosis**
  - Tick-borne encephalitis (rare in France)
- Spends > 95% of time off-host





(Stanek, 2012)

Impacts of abiotic conditions

- Key **ecological processes** of ticks are sensitive to the abiotic conditions…
  - Mortality rate
  - Development rate
  - Questing activity

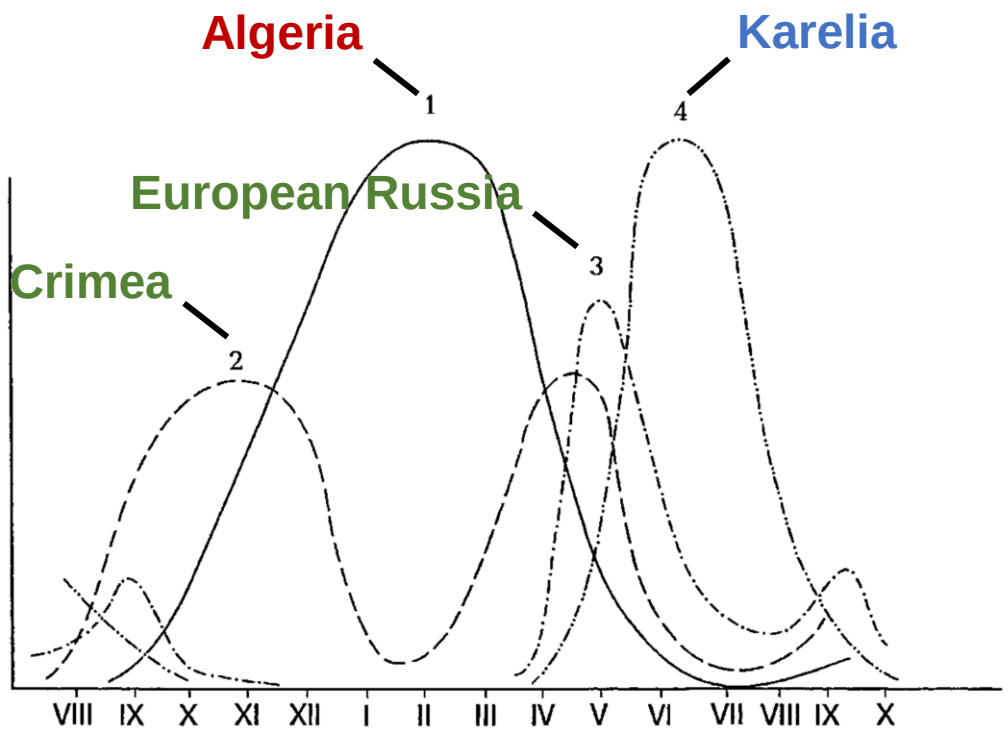
- Weather conditions influence…
  - Abundance
  - Phenology of questing ticks

  - Human-tick exposure risks
  - Tick-borne diseases

- How about climates…?

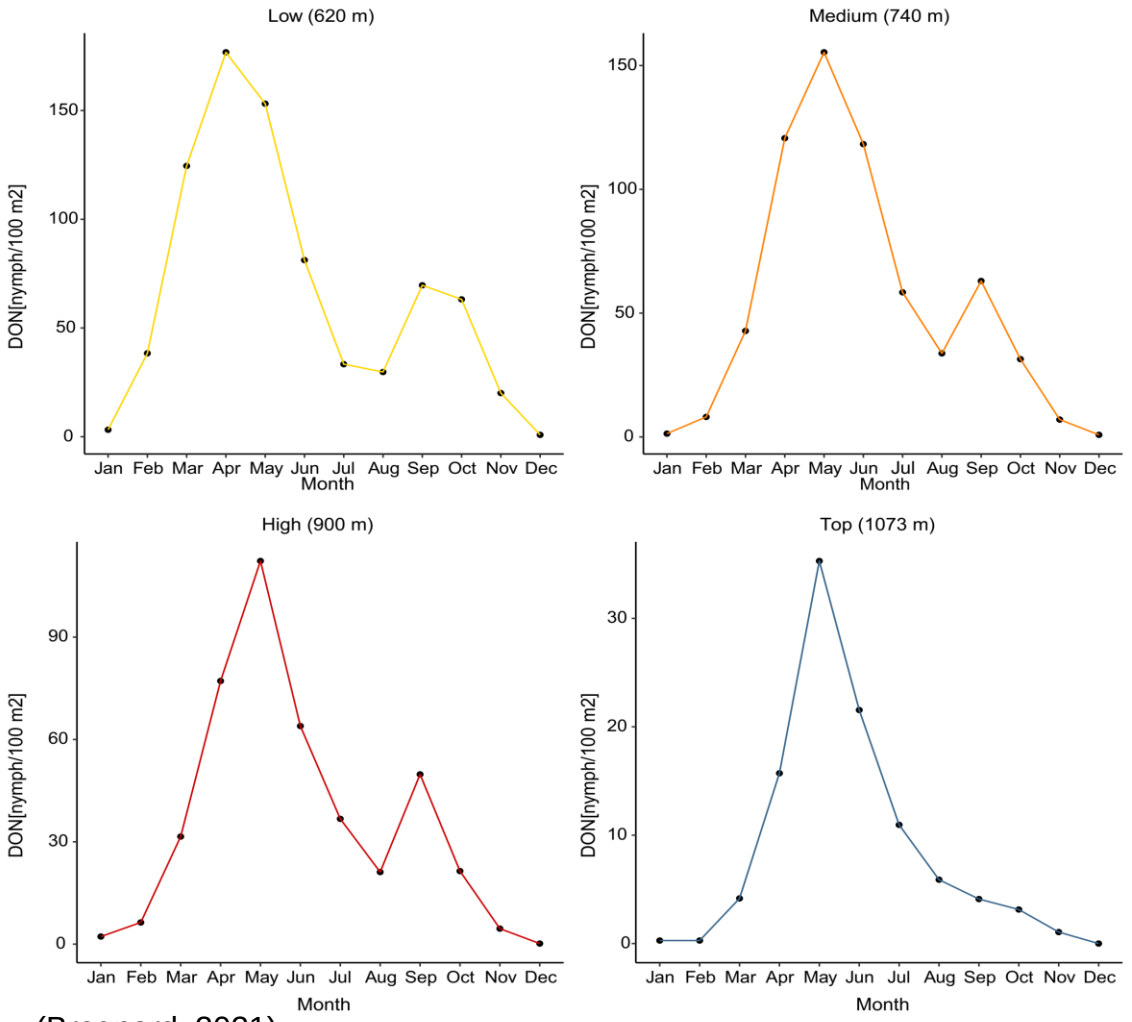
(European Centre for Disease Prevention and Control, 2014)

Phenology and climatic gradient



(Korenberg, 2000)

- **Cold climate**: Unimodal with spring/summer peak
- **Intermediate**: Bimodal with spring-autumn peaks
- **Warm climate**: Unimodal with winter peak



(Bregnard, 2021)

Switzerland (different elevations)

Previous studies in Europe

- Most of previous studies on *I. ricinus* nymphs were…
  - **Short-term** observations on **multiple sites**
    - Comparing abundance levels between sites
    - No seasonal/inter-annuals variations
  - **Long-term** observations on **a few sites**
    - Observed seasonal/inter-annuals variations
    - Unable to compare with other climatic types

- **Long-term studies on multiple sites** with various climatic types, using the same sampling protocol is needed

Objectives

- To investigate questing activity of *I. ricinus* nymphs, both **phenology** and **abundance**, across a wide range of climatic region types in France over a **long-term** observation period.

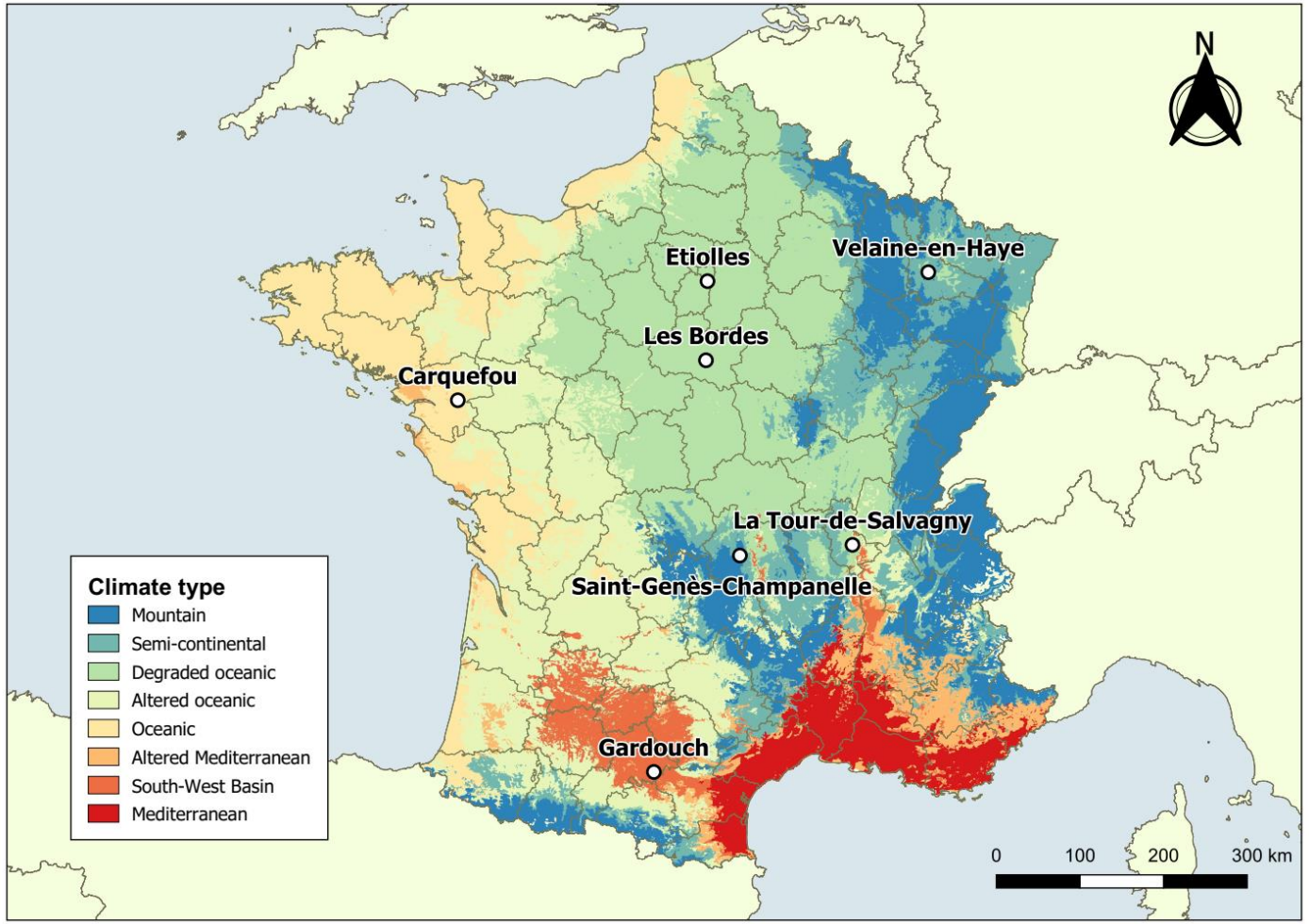
- To assess the **impacts of environmental factors**, such as meteorological, bioclimatic, and habitat characteristics on the variations of *I. ricinus* nymph questing activity

Sampling sites

- 11 Sites from 7 observatories
- 1 site/observatory, except…
  - La-tour-de Salvagny (A and B)
  - Gardouch (Internal and External)
  - Les Bordes (A, B, and C)
- From 2014 to 2021, except…
  - Les Bordes : 2018 to 2021

Climatick

Observatory stations of the CLIMATICK project

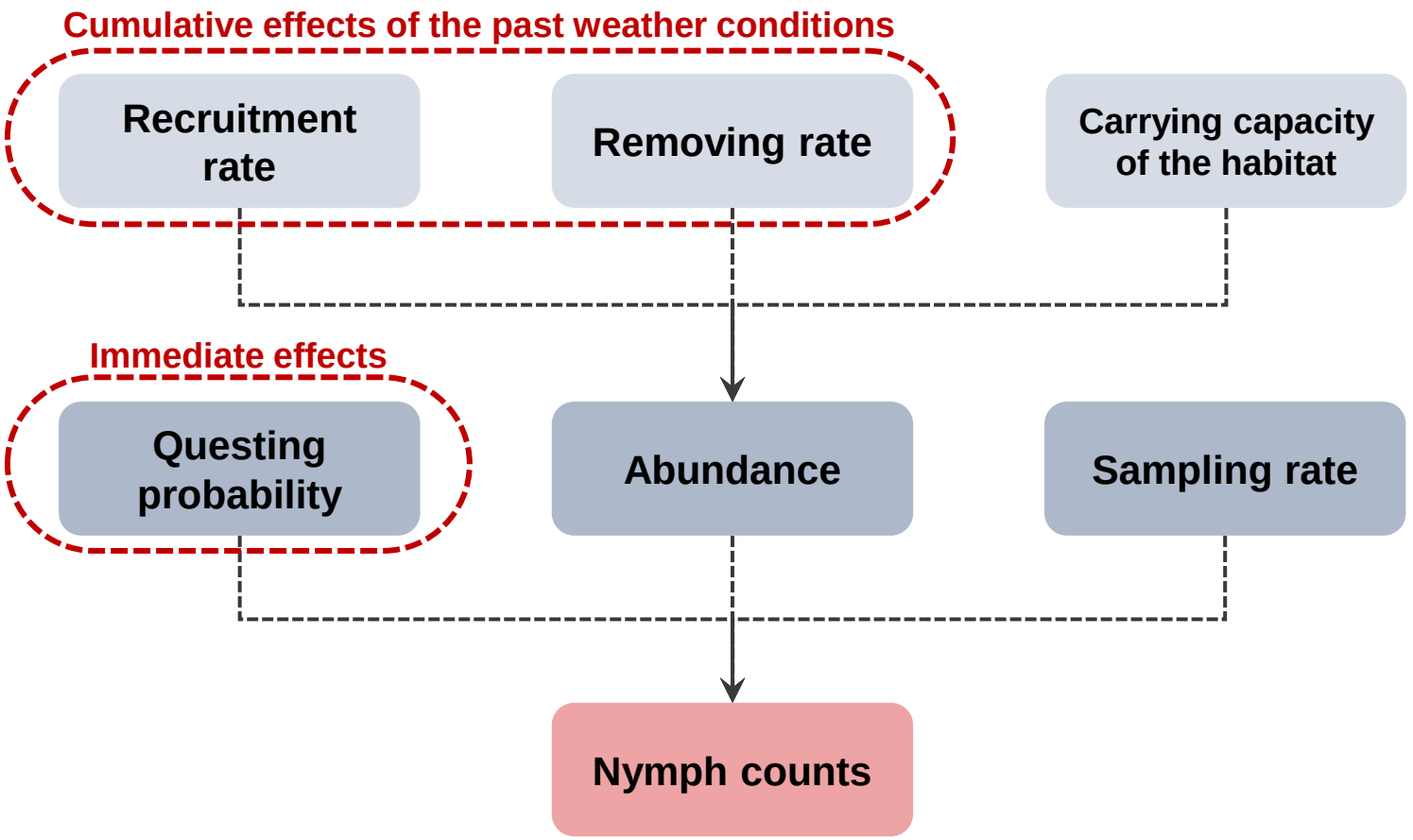


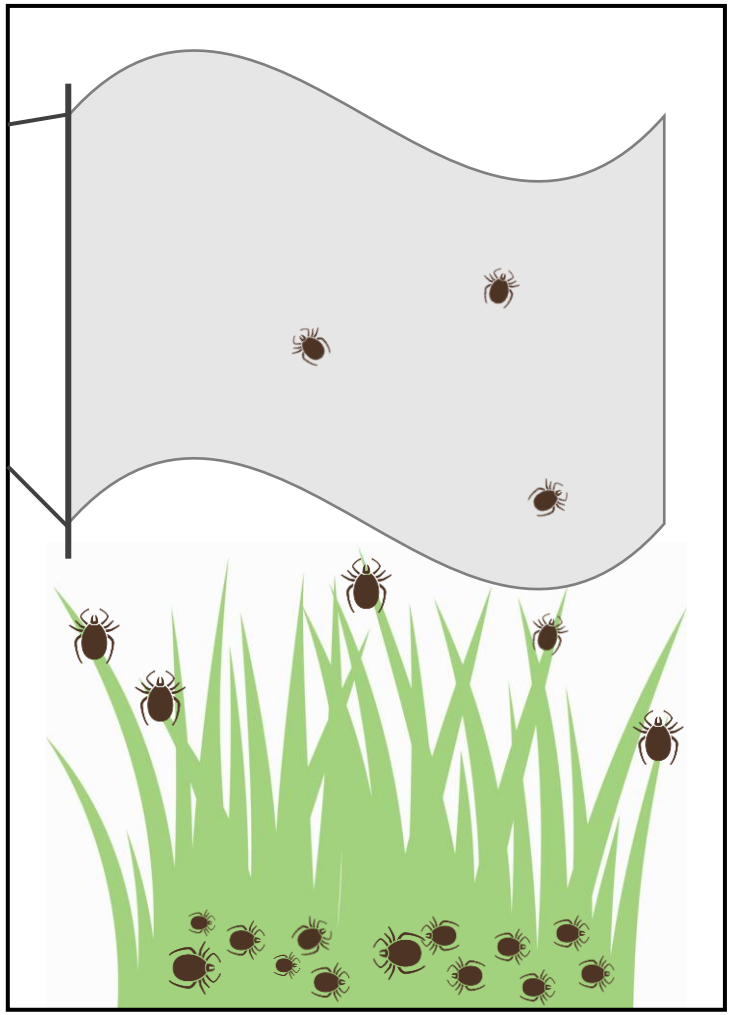
(Joly, D., 2010)

Sampling method

- Cloth-dragging technique
  - 1 m x 1 m white cloth
- Approximately 1-month intervals
- 10 transects/site (10 m/transect)
- **Same transects** throughout the study
- **Repeat 3 times** per transect
- Morphology identification at INRAE laboratory
- Nymph counts per 100 m^2

What do observed nymph counts mean?





Meteorological variables

Weather data

2-meter above ground

Hourly data
- Temperature; T
- Relative humidity; U

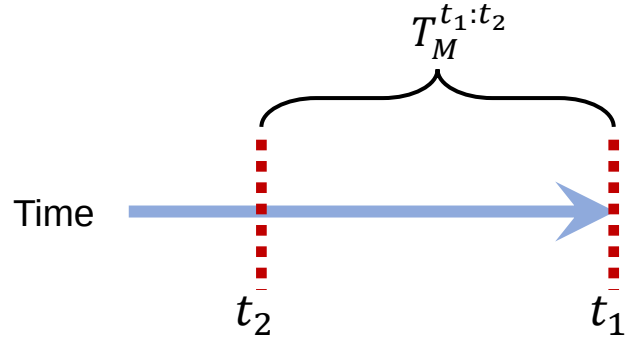
Daily data
- Maximum; T_X, U_X
- Average; T_M, U_M
- Minimum; T_N, U_N

Random forest

Imputed daily data → **Interval-averaged data**

External data
- MétéoFrance

Daytime data
- "*geosphere*" package
- Latitude



$T_M^{0:1}$: One-month moving average temperature

$T_M^{0:6}$: Six-month moving average temperature

$T_M^{0:12}$: Twelve-month moving average temperature

$T_M^{3:6}$: Previous three-to-six month moving average temperature

Bioclimate, topography, and land cover

Bioclimate

WorldClim data

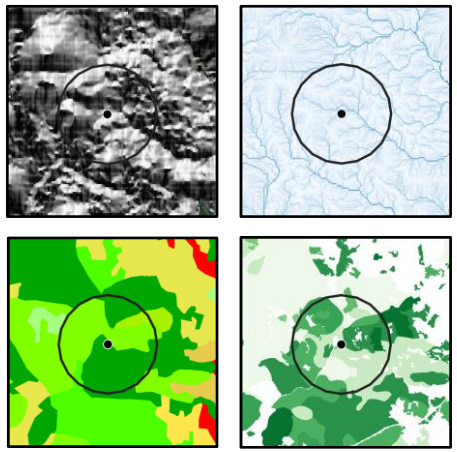
$BIO1_{temp}$: Annual mean temperature

$BIO2_{diur}$: Mean diurnal range

$BIO5_{maxTemp}$: Maximum temperature of the hottest month

$BIO12_{prec}$: Annual precipitation

QGIS



Topography

Digital elevation model

$mean_{elv}$: Mean elevation

sd_{elv} : Standard deviation of elevation

p_{flat} : Proportion of flat area

p_{north} : Proportion of area facing north

p_{east} : Proportion of area facing east

p_{west} : Proportion of area facing west

p_{south} : Proportion of area facing south

$Catchment$: Catchment area

Soil

European Soil Data Centre

pH_{soil} : Soil pH

Land cover

CORINE land cover data

H_{CLC1} : Shannon's index for level-1 CLC

H_{CLC2} : Shannon's index for level-2 CLC

BD Forêt data

H_{Forest} : Shannon's index for forest types

p_{Forest} : Proportion of forest cover

n_{Forest} : Number of forest patches

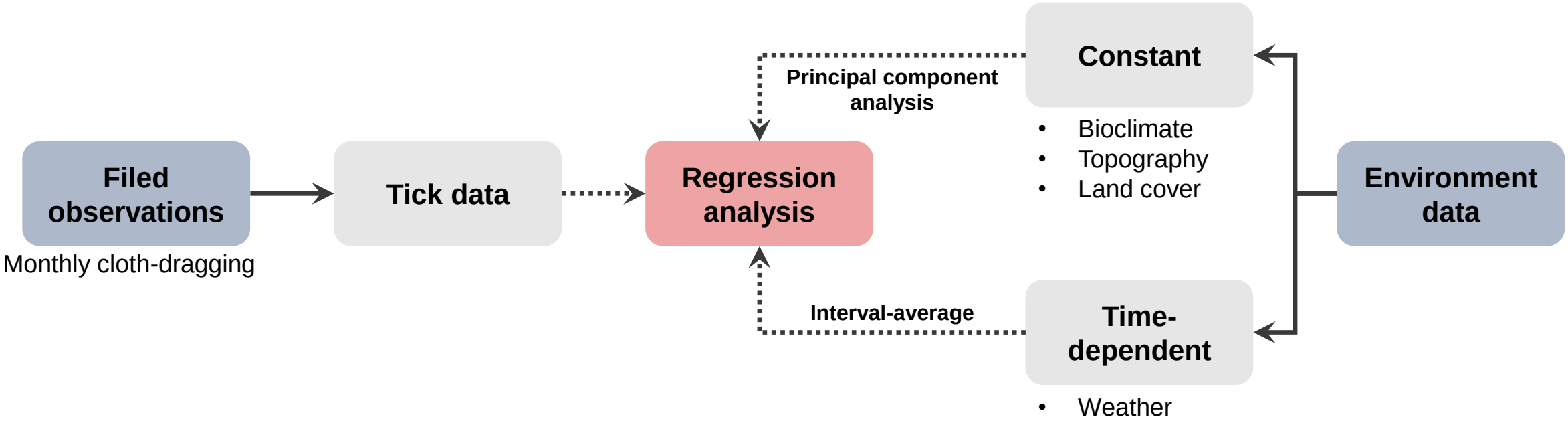
ED_{Forest} : Forest edge density

Shannon's index of diversity

$$H = \sum_{i=1}^{S} p_i \ln p_i$$

(Shannon, 1948)

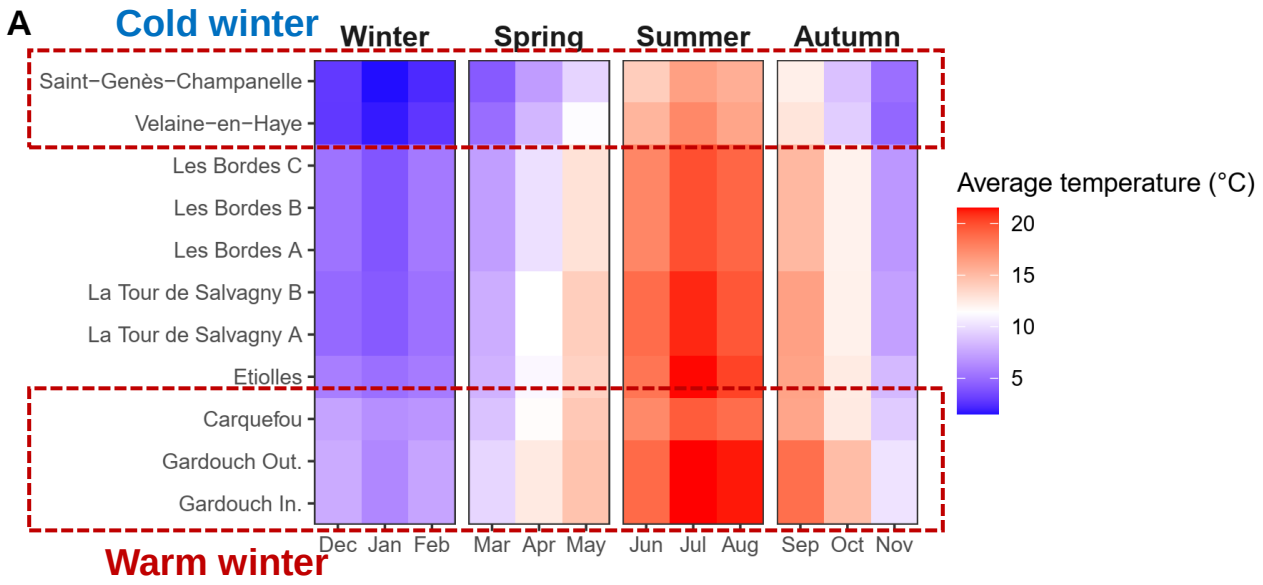
Overview of the analysis



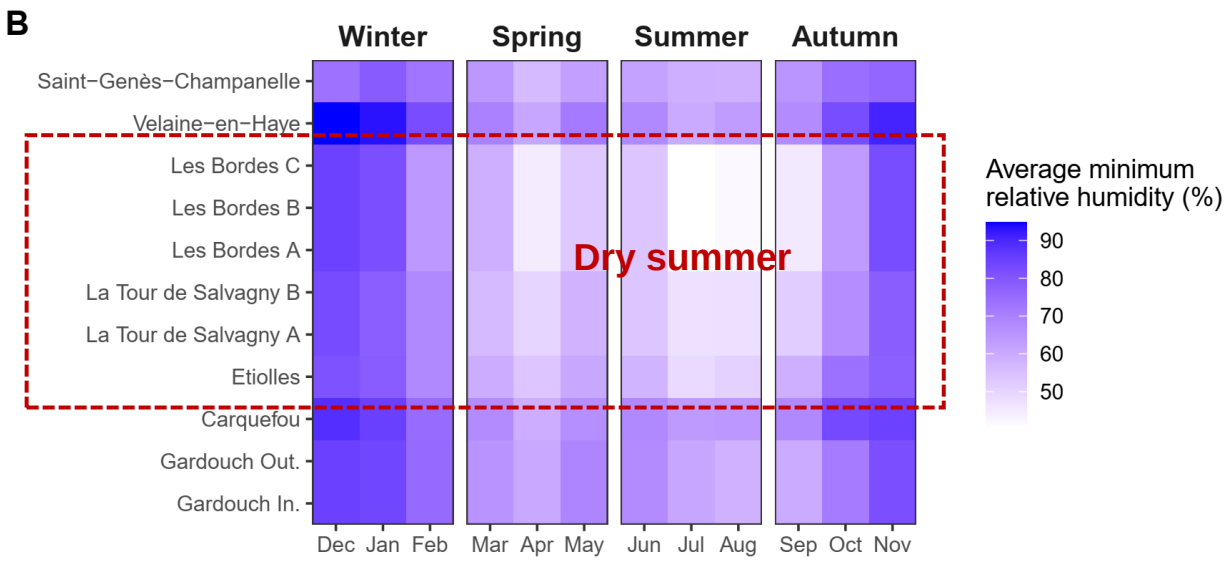
Multivariate mixed-effects negative binomial regression

Characteristics of sampling sites: Weather

Monthly average temperature

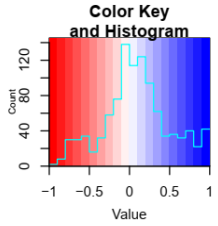


Monthly average minimum relative humidity

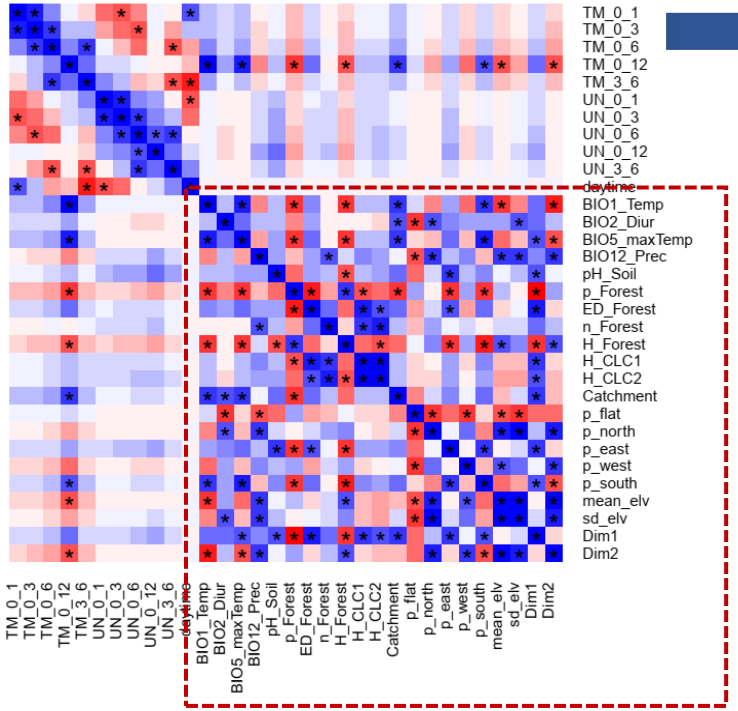


Characteristics of sampling sites: Climate and land cover

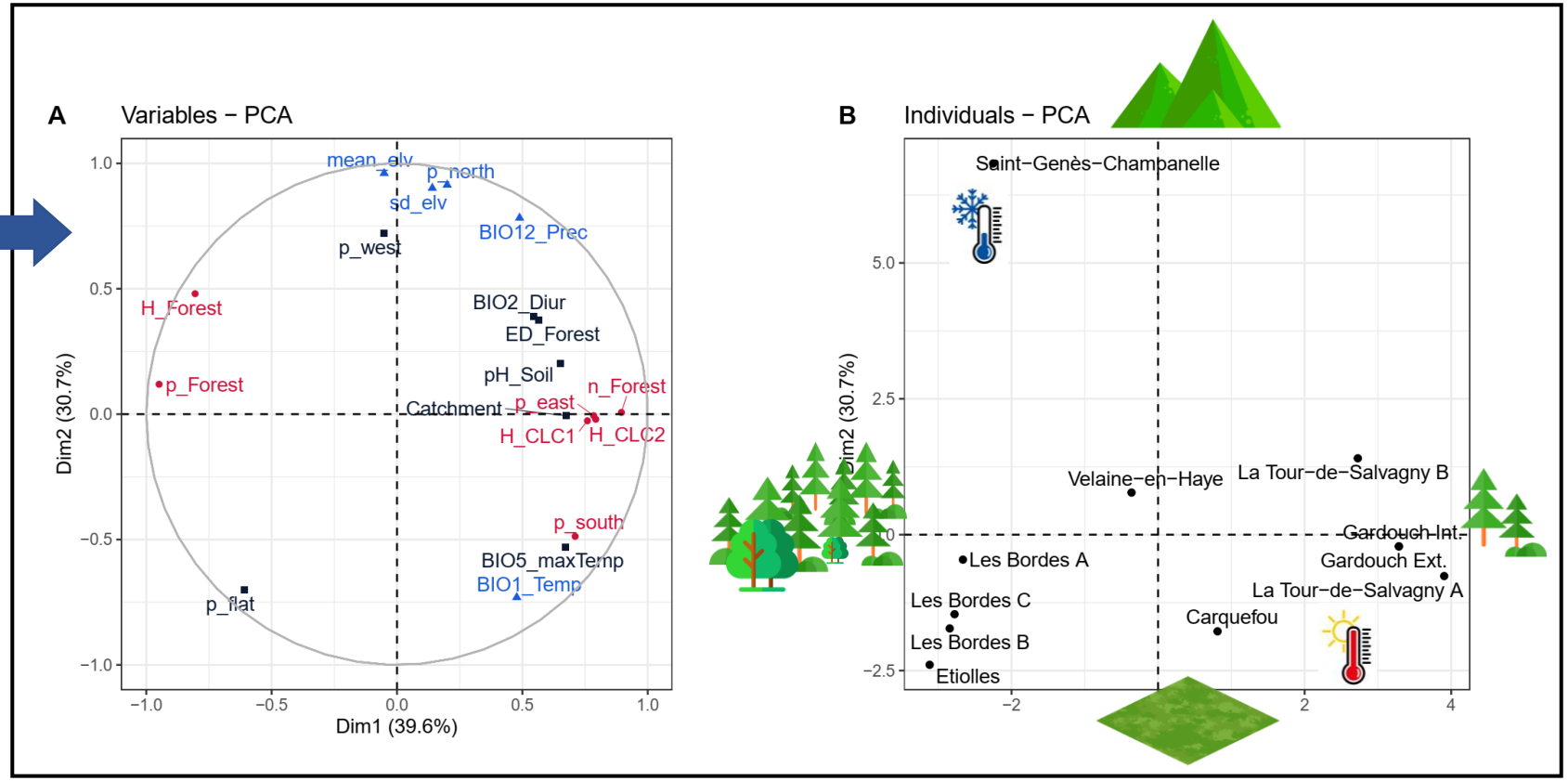
Constant variables are highly correlated…



Pearson's correlation coefficient

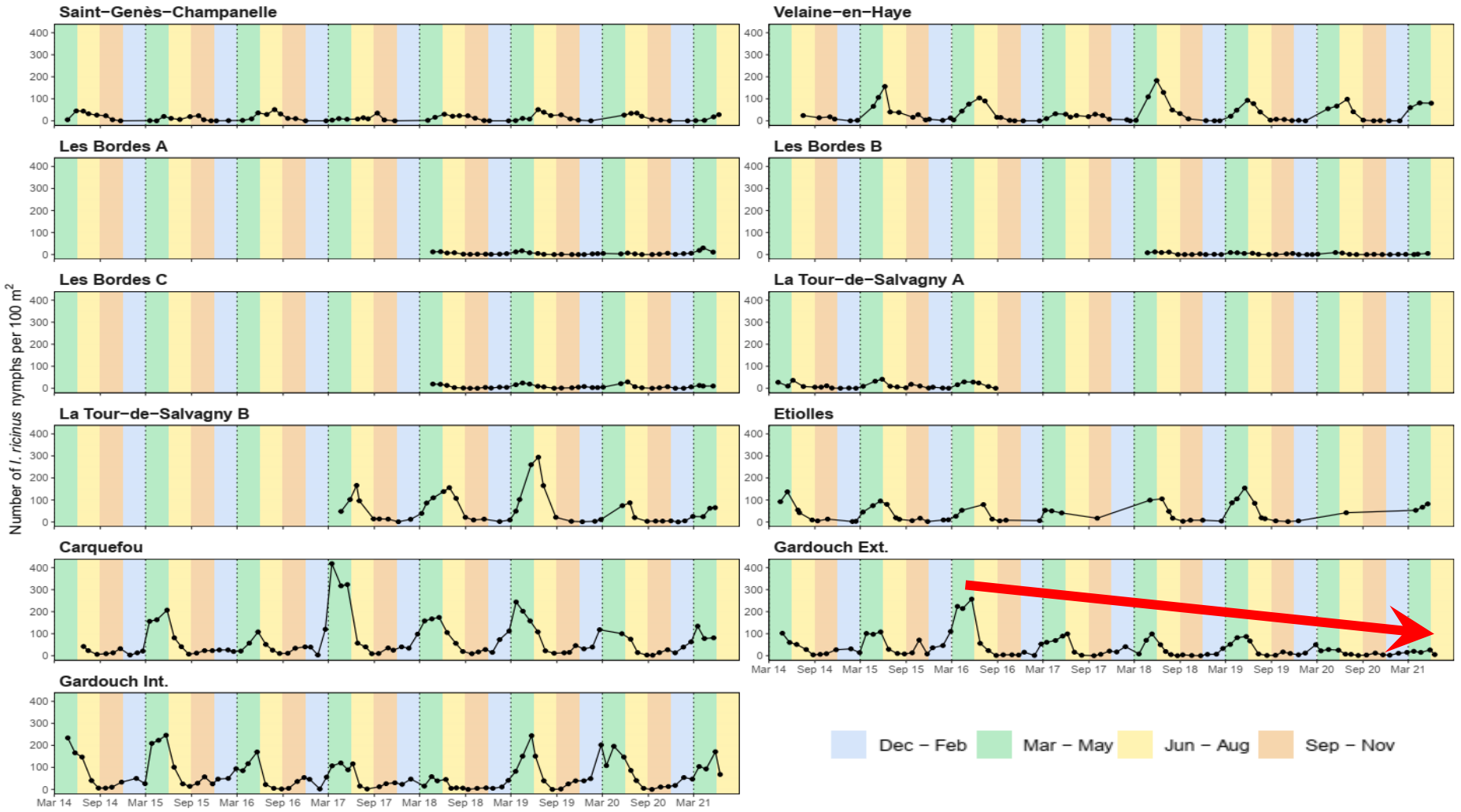


Principal component analysis

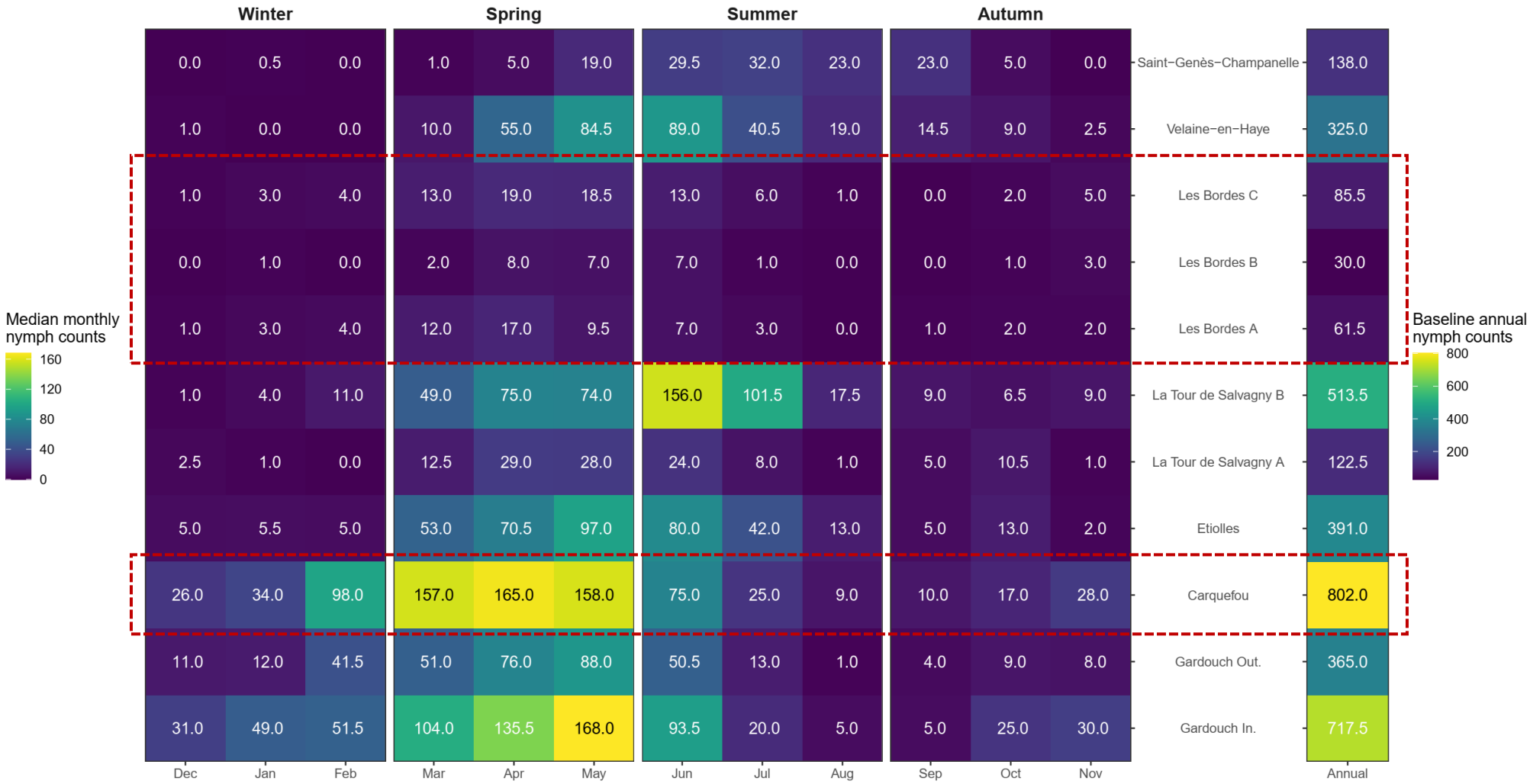


Coordinates on the PCA plot will be used in regression analysis

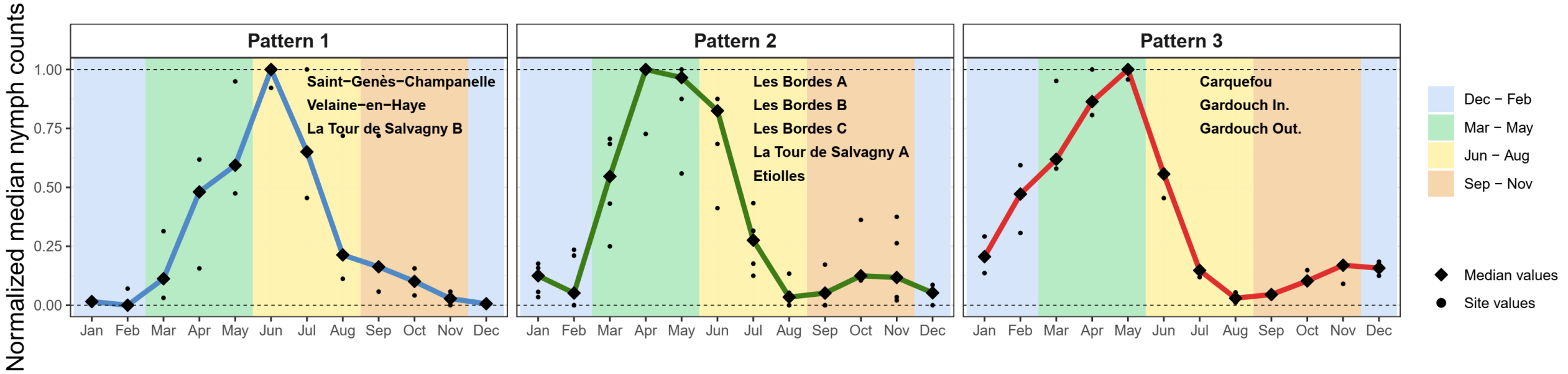
Observed nymph counts



Observed nymph counts



Phenological patterns



- **Cold climate**: Unimodal with spring/summer peak
- **Intermediate**: Bimodal with spring-autumn peaks
- **Warm climate**: Unimodal with winter peak

Multivariate mixed-effects negative binomial regression

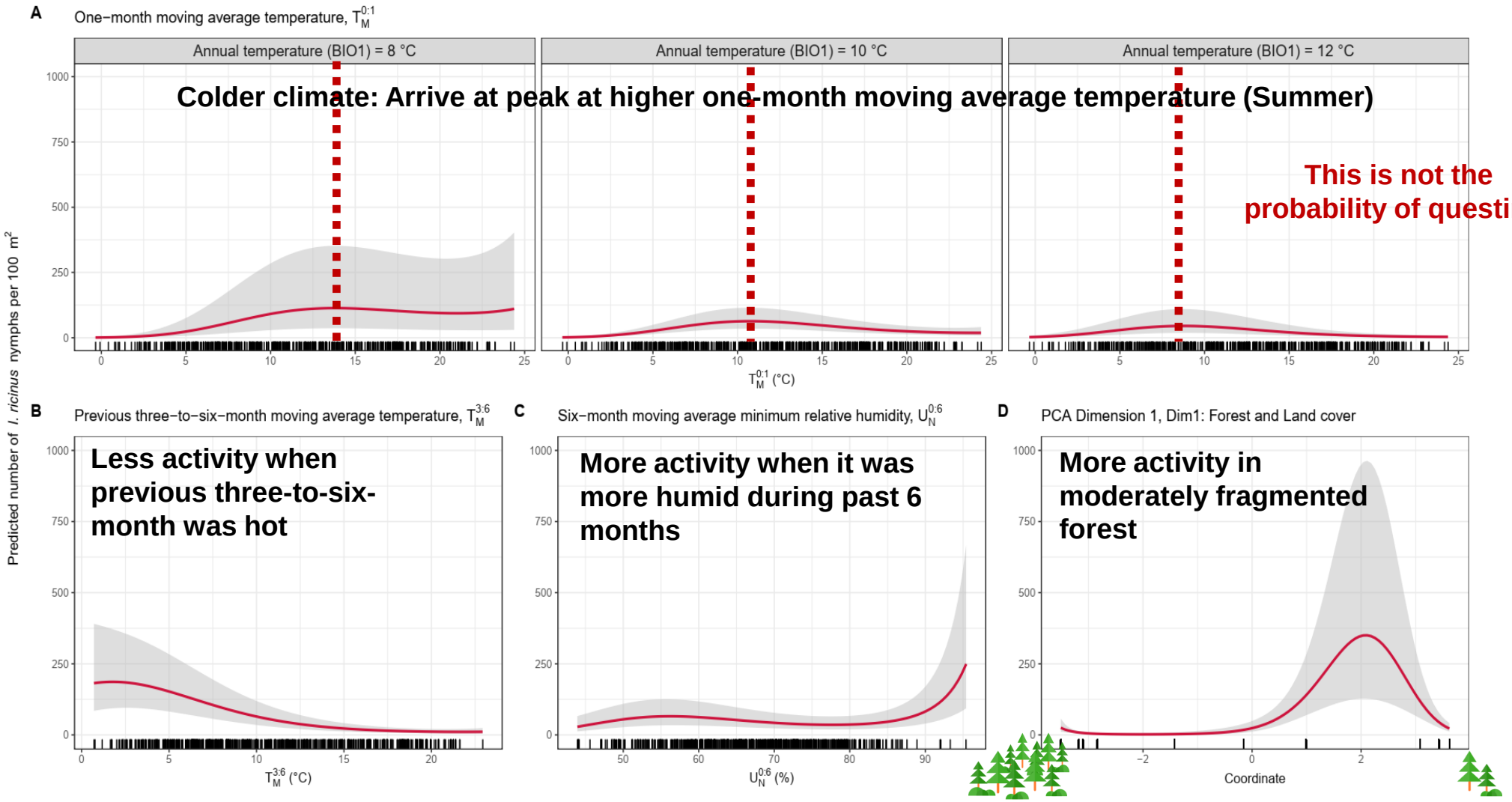
Random effects: Sampling sites

Model	Description	AIC	Dispersion parameter	Variance of intercepts	Pseudo-R^2
0	Null	5447.6	0.70449	1.0057	0.0000
1	$(T_M^{0:1})^3 + (T_M^{0:1})^2 + T_M^{0:1}$	5272.6	0.92771	1.0004	0.2495
2	$(T_M^{0:1})^3 + (T_M^{0:1})^2 + T_M^{0:1} * BIO1_{temp}$	5256.5	0.95624	0.9707	0.2729
3	$(T_M^{0:1})^3 + (T_M^{0:1})^2 + T_M^{0:1} * BIO1_{temp} + (T_M^{3:6})^3 + (T_M^{3:6})^2 + T_M^{3:6}$	4858.0	1.98588	0.9814	0.617
4	$(T_M^{0:1})^3 + (T_M^{0:1})^2 + T_M^{0:1} * BIO1_{temp} + (T_M^{3:6})^3 + (T_M^{3:6})^2 + T_M^{3:6} + (U_N^{0:6})^3 + (U_N^{0:6})^2 + U_N^{0:6}$	4823.9	2.13044	1.0004	0.6406
5	$(T_M^{0:1})^3 + (T_M^{0:1})^2 + T_M^{0:1} * BIO1_{temp} + (T_M^{3:6})^3 + (T_M^{3:6})^2 + T_M^{3:6} + (U_N^{0:6})^3 + (U_N^{0:6})^2 + U_N^{0:6} + (Dim1)^3 + (Dim1)^2 + Dim1$	4811.9	2.13050	0.4224	0.6507

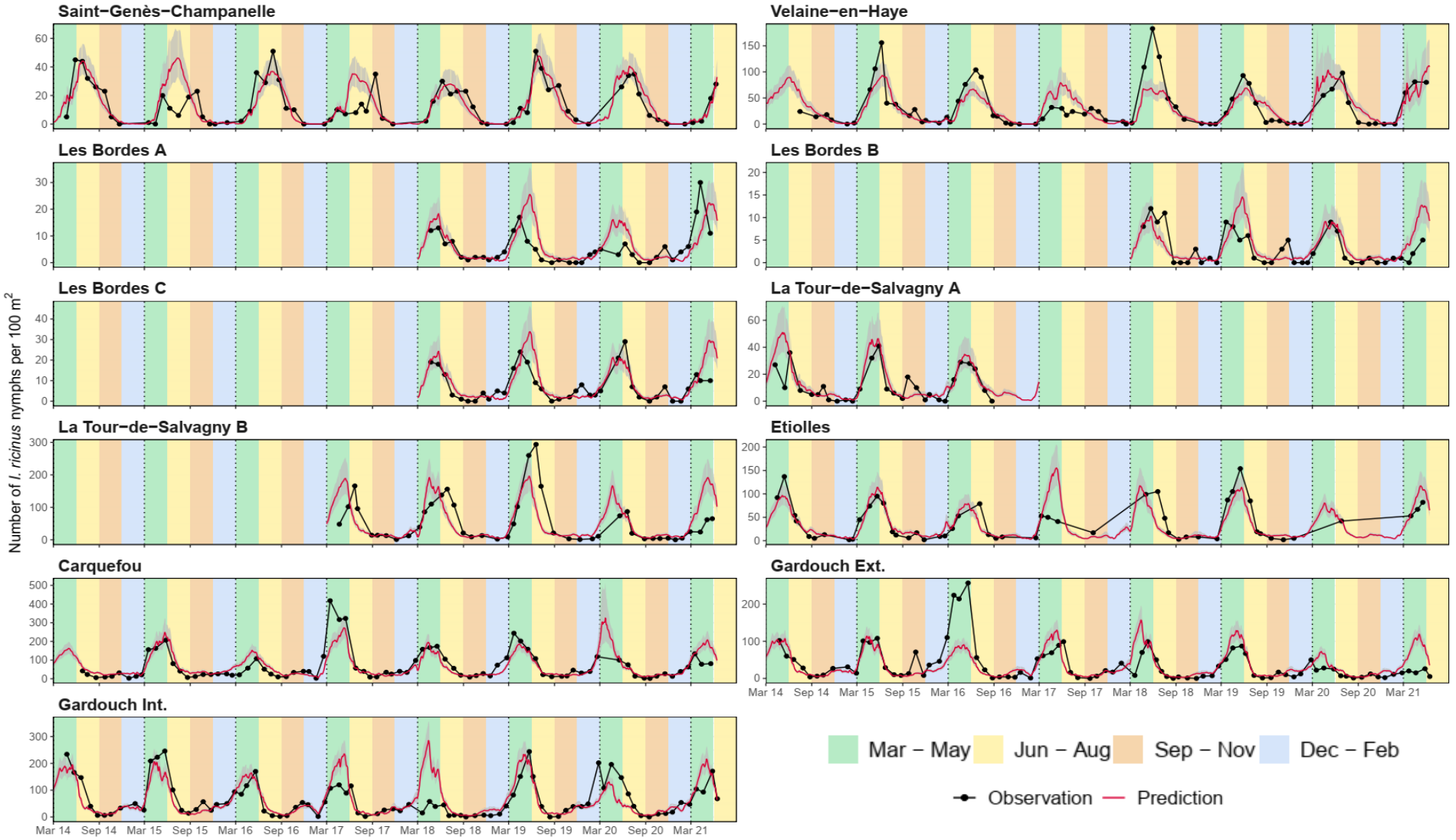
Interaction: Weather vs Climate

PCA Dimension-1: Forest characteristics

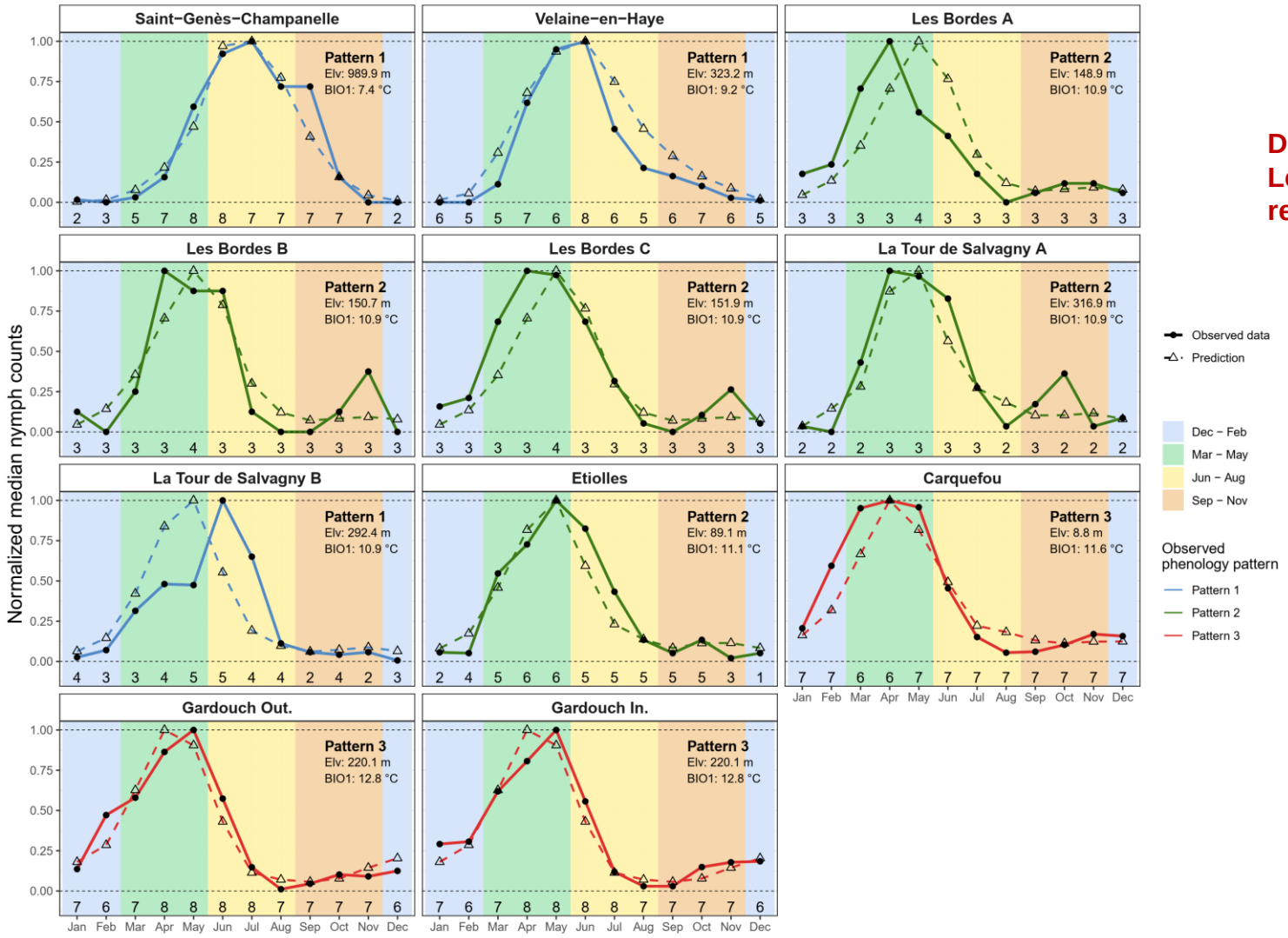
Predicted environmental effects



Observations vs Predictions



Observations vs Predictions



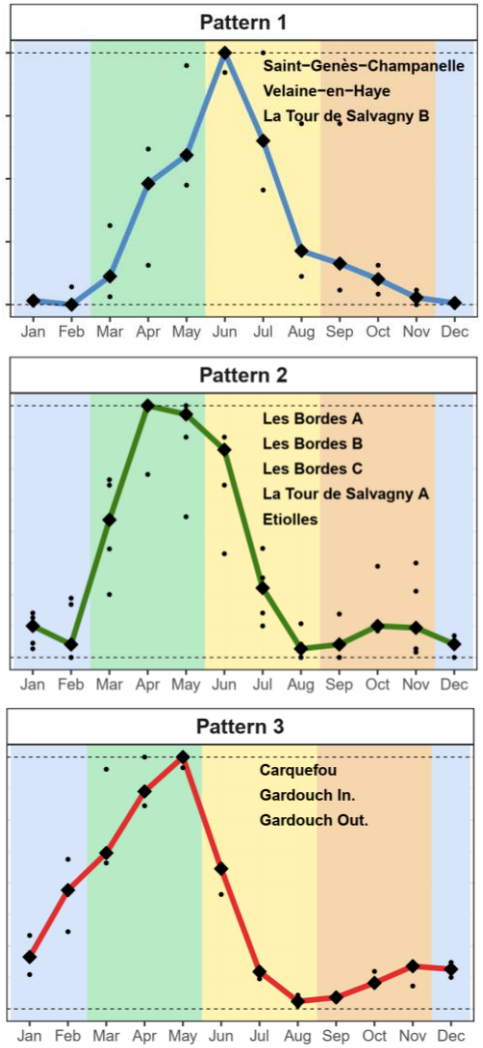
Did the Autumn peaks in Les Bordes/La Tour-de-Salvagny really exist?

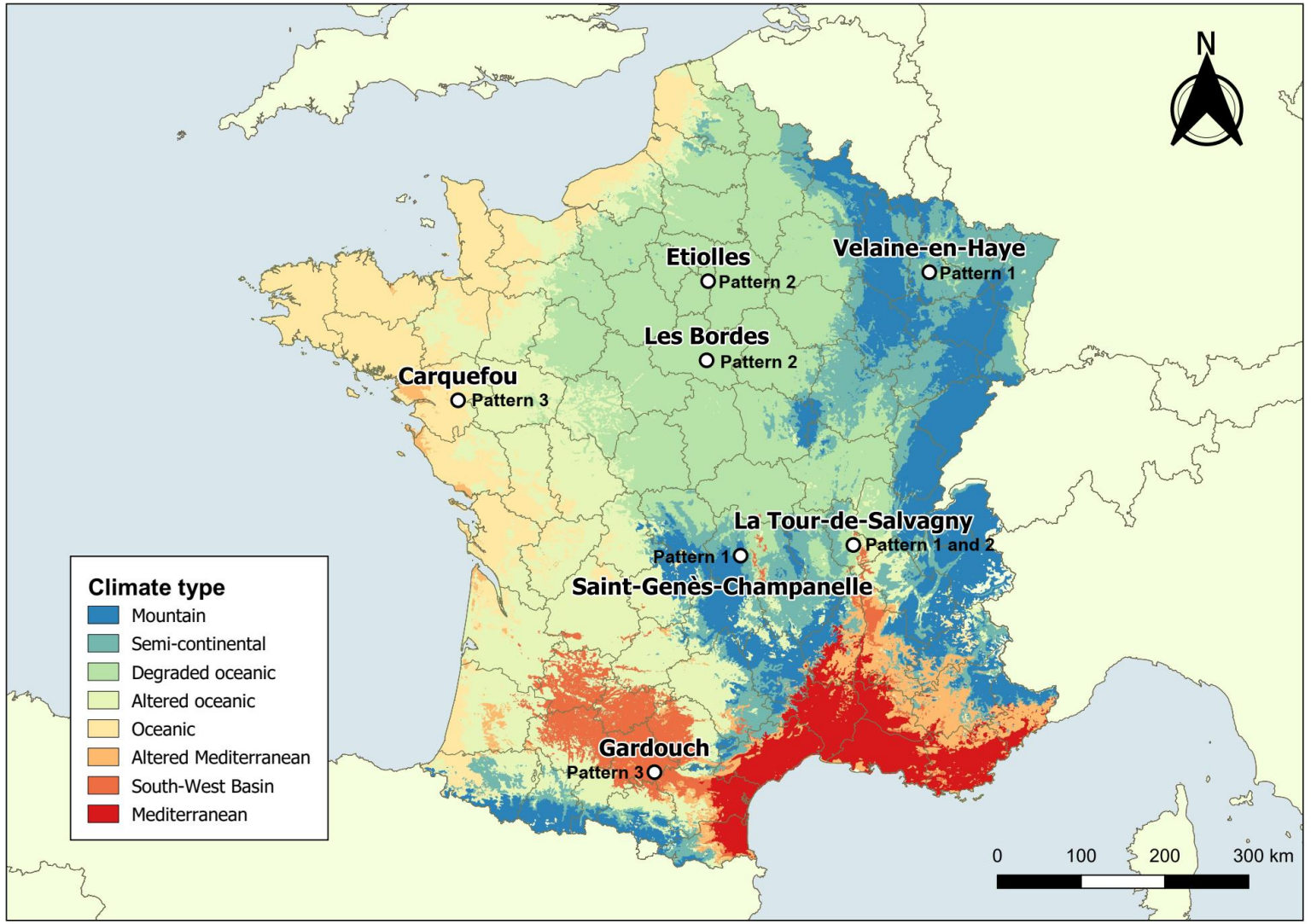
Summary

Cold climate

Intermediate (?)

Warm climate





Conclusions

- **Methodological:**
  - **Three repetitions** per sampling >>> Longitudinal observations across multiple sites in France
  - Principal component analysis + Interval-average variables
  - Modelling framework could be applied to make a risk map

- **Biological:**
  - Questing activity was explained by meteorological factors at **different lags**
  - **Moderately fragmented forest** support the highest baseline abundance
  - **Peaks** of questing activity tended to follow a **climatic gradient**

- **Limitations:**
  - Sub-daily variation was not capture by this design
  - Dynamics of hosts and habitats were not available

Thank You

For Your Attention