Effects of climatic warming on spring phenology in subtropical trees: process-based modelling with experiments designed for model development

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Abstract

We developed process-based tree phenology models for four subtropical tree species, and for the first time for these trees, we based the model development on explicit experimental work particularly designed to address the processes being modelled. For all the four species, a model of seedling leafout was developed, and for *Torreya grandis*, a model for female flowering in adult trees was additionally developed. The models generally showed reasonable accuracy when tested against two sources of independent data. In scenario simulations, the models projected an advanced spring phenology under climatic warming for 2020 – 2100. For the leafout of seedlings, the advancing rates varied between 4.7 and 5.9 days per one °C warming, with no major differences found between the climatic scenarios RCP4.5 and RCP8.5. For *Torreya* flowering, less advancing was projected, and the projected advancing per one °C warming was less for RCP8.5 (0.9 days / °C) than for RCP4.5 (2.3 days / °C). The low advancing rates of *Torreya* flowering were caused by reduced chilling under the warming climate and by the particular temperature responses found for *Torreya* flowering. These findings highlight the need to base the model development on explicit experiments particularly designed to address the process modelled.

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1

Air temperature

Rate of rest break
R_r

Potential rate of
ontogenetic development
$R_{o,pot}$

Eqn. 2

i = i + 1

State of rest break
S_r

Ontogenetic competence
C_o

Eqn. 6

Rate of
ontogenetic development
R_o

Eqn. 7

State of
ontogenetic development
S_o

No

Yes

Is $S_o \geq 100\ \%$?

Bud burst

End

Eqn. 8

2

a *Castanopsis* seedlings **b** *Phoebe* seedlings **c** *Pseudolarix* seedlings

d *Torreya* seedlings **e** *Torreya* trees

a *Castanopsis* seedlings **b** *Phoebe* seedlings **c** *Pseudolarix* seedlings

d *Torreya* seedlings **e** *Torreya* trees

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a   *Castanopsis* seedlings   **b**   *Phoebe* seedlings   **c**   *Pseudolarix* seedlings

d   *Torreya* seedlings   **e**   *Torreya* trees

Chilling treatment

- ■ 5°C
- ● 6°C
- ▲ 10°C
- ✳ 15°C

5

a *Castanopsis*

b *Phoebe*

c *Pseudolarix*

d *Torreya*

Predicted leafout / flowering (Day of year)

Observed leafout / flowering (Day of year)

RMSE=8.41
RMSE=8.44
RMSE=9.83
RMSE=5.35

Phenology records
Warming experiment

a *Castanopsis* seedlings

-0.8 Days/Decade -2.9 Days/Decade
-4.6 Days/°C   -4.8 Days/°C
$R^2 = 0.1$** $R^2 = 0.28$***

b *Phoebe* seedlings

-1.0 Days/Decade -3.5 Days/Decade
-5.7 Days/°C   -5.8 Days/°C
$R^2 = 0.13$*** $R^2 = 0.29$***

c *Pseudolarix* seedlings

-1.0 Days/Decade -2.9 Days/Decade
-5.9 Days/°C   -4.8 Days/°C
$R^2 = 0.09$** $R^2 = 0.34$***

d *Torreya* seedlings

-0.8 Days/Decade -2.8 Days/Decade
-4.8 Days/°C   -4.7 Days/°C
$R^2 = 0.16$*** $R^2 = 0.41$***

e *Torreya* trees

-0.4 Days/Decade -0.6 Days/Decade
-2.3 Days/°C   -0.9 Days/°C
$R^2 = 0.029$ $R^2 = 0.03$

RCP4.5: 1.4°C warming 2020-2100
RCP8.5: 4.8°C warming 2020-2100

DOY (days)