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Phenological reactions of Dutch tree species to climate change described by a simulation model of the annual cycle

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Introduction

The relationships between climate and both phenology and growth of Dutch tree species were studied to evaluate the potential impacts of climate change on trees and forests in the Netherlands. In order to make such assessments, insight is required on the mechanisms how climatic variables interact with plant processes. The topics addressed in this study are: (1) the modelling of phenology; (2) the consequences of climate change on spring frost damage; (3) the importance of phenotypic plasticity; and (4) the impacts of climate change on growth.

1. MODELLING PHENOLOGY

To evaluate the impacts of climate change on growth of temperate deciduous tree species, the onset and cessation of the growth must be accurately described. It was concluded that the timing of leaf unfolding could best be described by a model in which the effects of chilling temperatures (-5 to +10°C) and forcing temperatures (>0°C) operate sequentially in time, according to a triangular and logistic function, respectively (Kramer 1994a).

2. SPRING FROST DAMAGE

The effects of climatic warming to the probability of spring frost damage of *Larix decidua*, *Betula pubescens*, *Tilia platyphylla*, *Fagus sylvatica*, *Tilia cordata*, *Quercus rubra*, *Quercus robur*, *Fraxinus excelsior*, *Quercus petraea*, *Picea abies* and *Pinus sylvestris* in the Netherlands and in Germany were studied. It was concluded that for these species the probability of spring frost damage will decrease, provided the variability in temperature does not change (Figure 1, Kramer 1994b).

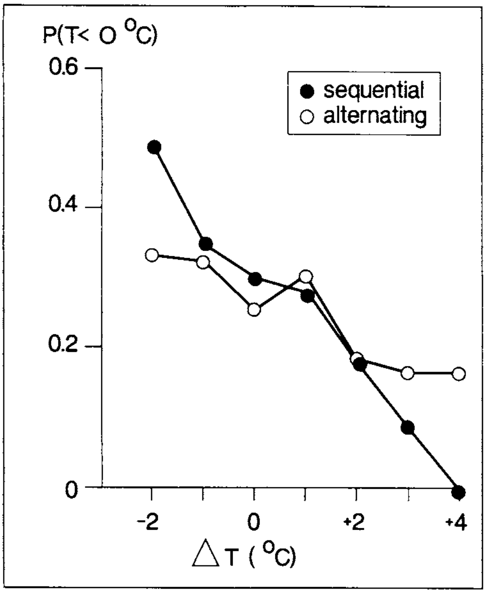

Figure 1. Shift of the probability of sub-zero temperatures around the date of leaf unfolding of *Fagus sylvatica* on uniform temperature increase according to the sequential and alternating model.

3. PLASTICITY

To evaluate the potential response of individual trees to climatic warming, phenological observations of clones of *Larix decidua*, *Betula pubescens*, *Tilia cordata*, *Populus canescens*, *Quercus robur*, *Fagus sylvatica* and *Picea abies* transferred over a large latitudinal range in Europe were analyzed (Figure 2). It was found that these tree species possess a considerable plasticity and are able to respond phenotypically to a major change in their local climate. For the clones of *Larix decidua* and *Quercus robur* the growing season may shorten with increasing temperature, because leaf fall is advanced more than leaf unfolding. In *Betula pubescens* and *Populus canescens*, leaf unfolding and leaf fall are advanced equally, whereas in *Tilia cordata* and *Fagus sylvatica* the date of leaf fall seems to be unaltered but leaf unfolding advances with increasing temperature (Table 1). These differences in the duration of the growing season in response to increasing temperature may alter the competitive balance between the species in mixed stands (Kramer, in press).

Table 1
Shift of leaf unfolding (U) on mean winter temperature (T_w) and leaf fall (F) on mean summer temperature (T_s)

	$\delta U/\delta T_w$	$\delta F/\delta T_s$
Larix decidua	-2.8	-8.5
Betula pubescens	-3.7	-3.0
Tilia cordata	-2.8	-1.4
Populus canescens	-3.0	-3.8
Quercus robur	-1.7	-5.6
Fagus sylvatica	-2.4	0.0
Picea abies	-3.5	

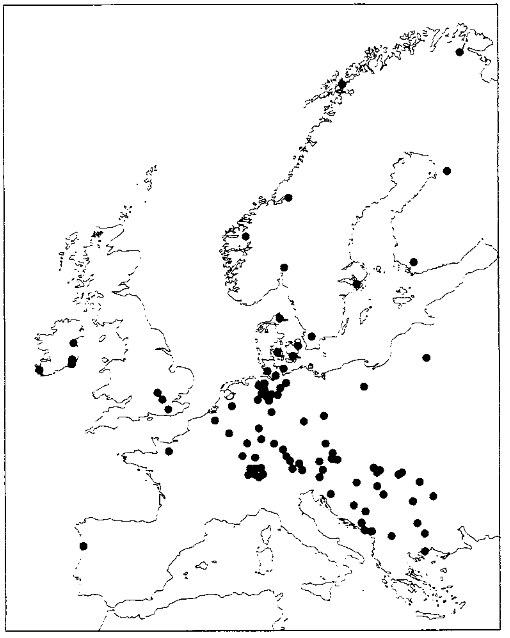

Figure 2. Location of the International Phenological Gardens.

4. GROWTH

The direct effects of increased atmospheric CO_2, together with indirect effects, *i.e.* water relations, on growth of *Picea abies* were quantified, using a process-based forest growth model (FORGRO). The results indicated an increased response on growth of *Picea abies* to increasing CO_2 under conditions of water shortage compared to the response in a potential growth situation. This effect is enhanced when the CO_2 increase is combined with a temperature rise possibly associated with the CO_2 induced climate change.

These results were qualitatively confirmed by a similar study on *Betula pubescens*, *Fagus sylvatica* and *Quercus robur*, using several mechanistic models of photosynthesis and allocation with different levels of detail, and four climate change scenarios. However, quantitatively large differences were found between both the species, the scenarios and the models.

The importance of phenology on the effects of climate change on growth of deciduous temperate-zone tree species was evaluated by a model comparison. The photosynthesis models used diverge in their response of annual gross photosynthesis the CO_2 concentration doubles, and the temperature increases by 2°C to 7°C, they agree of differences caused by phenology ranging from 5% if the temperature rises 2°C to 20% if it rises 7°C (Figure 3). The corresponding figures are 5% and 13% when a mechanistic model for allocation of assimilates over the plant organs is used.

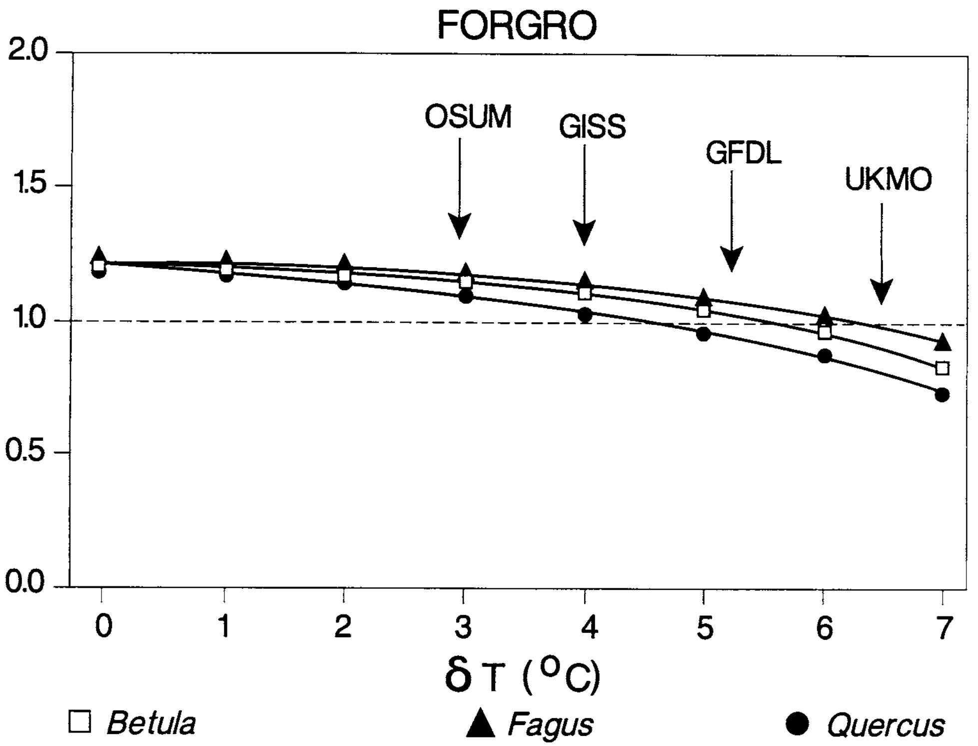

Figure 3. Change in NPP relative to the current climate, given a 2x [CO_2] and a range of temperature increases

5. REFERENCES

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