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Alder pollen in Finland ripens after a short exposure to warm days in early spring, showing biennial variation in the onset of pollen ripening

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ABSTRACT

We developed a temperature sum model to predict the daily pollen release of alder, based on pollen data collected with pollen traps at seven locations in Finland over the years 2000–2014. We estimated the model parameters by minimizing the sum of squared errors (SSE) of the model, with weights that put more weight on binary recognition of daily presence or absence of pollen. The model results suggest that alder pollen ripens after a couple of warm days in February, while the whole pollen release period typically takes up to 4 weeks. We tested the model residuals against air humidity, precipitation and wind speed, but adding these meteorological features did not improve the model prediction capacity.

Our model was able to predict the onset of pollen season with similar accuracy as models describing only the start of the pollen release period (average prediction error 8.3, median 5.0 days), while for the end of the pollen release period the accuracy of our predictions was not as good. We split the pollen data into odd and even years, and fitted our model separately to each half. Difference in the parameter values suggests a biennial behavior in the onset of pollen ripening, with almost two weeks of difference in the modeled starting date of the pollen development. Monte Carlo resampling of the observation data confirmed that the difference is not just a random anomaly in the data.

1. Introduction

In Finland, alder (*Alnus* sp.) is together with the far less common hazel (*Corylus* sp.) the starter of the allergenic pollen season. It belongs to the *Betulaceae* family including also birch (*Betula* sp.), which is the most important genus for pollen allergies in Finland. The major allergen of alder (Aln g 1) resembles the major allergen of birch (Bet v 1) both structurally and immunochemically (Matthiesen et al., 1991; Pehkonen and Rantio-Lehtimäki, 1995), and allergic cross reactivity is common. The temporal sequence of alder and birch flowering lengthens the period of allergenic exposure for those sensitive to *Betulaceae* pollen. Moreover, exposure to high alder pollen counts may increase the sensitiveness to pollen later on during the season (Emberlin et al., 1997). In their study concerning alder and birch, Jantunen et al. (2012) found a fair correlation between allergy symptoms and pollen counts, but further concluded that the risk of developing symptoms is influenced by the progression of the *Betulaceae* pollen season. Therefore, more accurate predictions of the onset of alder pollen release, by means of modeling, would help the allergy sufferers to manage their symptoms.

A number of phenological models have been produced to predict the onset of alder flowering. Some of these are simple temperature sum models, starting the temperature sum accumulation from a fixed day in spring (Linkosalo et al., 2000; Linkosalo et al., 2006). Also more complex models including a chilling submodel have been proposed (Andersen 1991; Jato et al., 2000; Rodriguez-Rajo et al., 2006; Rodriguez-Rajo et al., 2009; González-Parrado et al., 2006). However, Linkosalo et al. (2000) found that the temperature sum model without the chilling submodel performs better for predicting the start of alder flowering in Finland, and Linkosalo et al. (2008) showed that this applies at least to later-flowering species also when using independent data for model evaluation.

In a previous paper, Linkosalo et al. (2010) predicted the pollen release period of birch using temperature sum as the driving environmental variable. With the application to provide input for the long range transport model, they produced another version of the model, using also air humidity and wind speed as controls of the pollen release

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(Sofiev et al., 2013). The latter model is in use of a prediction system for birch long-range pollen transport events (Siljamo et al., 2013). For this study, we used similar model structures than in the two modeling papers mentioned above.

The aim of this study was to develop and test a pollen release model for alder. Our model uses only temperature sum as control of the pollen release period. Further we tested if additional environmental variables would improve the prediction potential of the model. We split the data to odd and even years and fitted the model separately to each half. Difference in optimal model parameter values revealed a biennial behaviour in the onset of pollen ripening. We utilised Monte Carlo resampling from a large matrix of parameter values combinations to enhance the calculation efficiency of the Monte Carlo resampling.

2. Materials and methods

There are two common species of alder in Finland, namely Black Alder (*Alnus glutinosa* (L.) Lam.) and Grey Alder (*Alnus incana* (L.) Moench.). Using historical time series of onset of flowering, Linkosalo (2000) found that in Finland Black Alder starts flowering on average 6 days before Grey Alder. However in the pollen trap data, it is not possible to distinguish between the pollen of the two species.

We used alder pollen data counts measured at seven pollen measurement sites (Table 1, Fig. 1). The sampling followed the Burkard-spore trap procedure described by Hirst (1952). In Turku, where the flowering starts first of all observations sites, the pollen data is collected throughout the year. On the other sites the collection is started once pollen is observed in the Turku site, and carried on until the pollen season has clearly ended.

The traps were located on open rooftops. The alder pollen grains were identified and counted on bi-hourly basis, taking 2 randomized samples per each strip representing a 2 h time period (Mäkinen 1981). The resulting variable was average pollen grain concentration/m^3. We studied the pollen counts on a daily basis, and daily data were summed up from the bi-hourly samples for each day.

The meteorological data were obtained from the Finnish Meteorological Institute (https://en.ilmatieteenlaitos.fi/open-data). The weather stations were located on average 8 kilometers from the corresponding pollen trap. Tri-hourly data from meteorological stations closest to the pollen traps were used and daily averages (or in the case of precipitation, daily sum) were calculated for the analyses.

Boreal wind-pollinated trees typically show quite large inter-annual variation in the amount of pollen release, and alder is no exception. There are some attempts to model the pollen amounts based on weather conditions and pollen intensity of previous years (Masaka and Maguchi, 2001; Ranta et al., 2008), but these models lack prediction power on independent data (Ranta et al., 2008). Therefore we decided to normalize the pollen amounts for each year, and focus our modeling on the timing of the pollen release only. For this purpose, the total accumulated pollen amount for each year and site was calculated, and daily pollen observations were divided with this annual total. Similarly, the pollen model predicts the daily pollen amounts as fractions of annual total. As the pollen count captures with Burkard traps is normalized, we used it as proxy for the released pollen, which was then predicted with the model.

Table 1
The sites, coordinates and years, where alder pollen was collected with Burkard-type pollen traps.

Site	Years	Latitude	Longitude
Kangasala	2000–2007	61°30′N	24°05′E
Kuopio	2000–2014	62°54′N	27°38′E
Oulu	2000–2012	65°04′N	25°31′E
Rovaniemi	2002–2014	66°33′N	25°44′E
Tampere	2008–2014	61°30′N	23°49′E
Turku	2000–2014	60°32′N	22°28′E
Vaasa	2000–2014	63°06′N	21°37′E

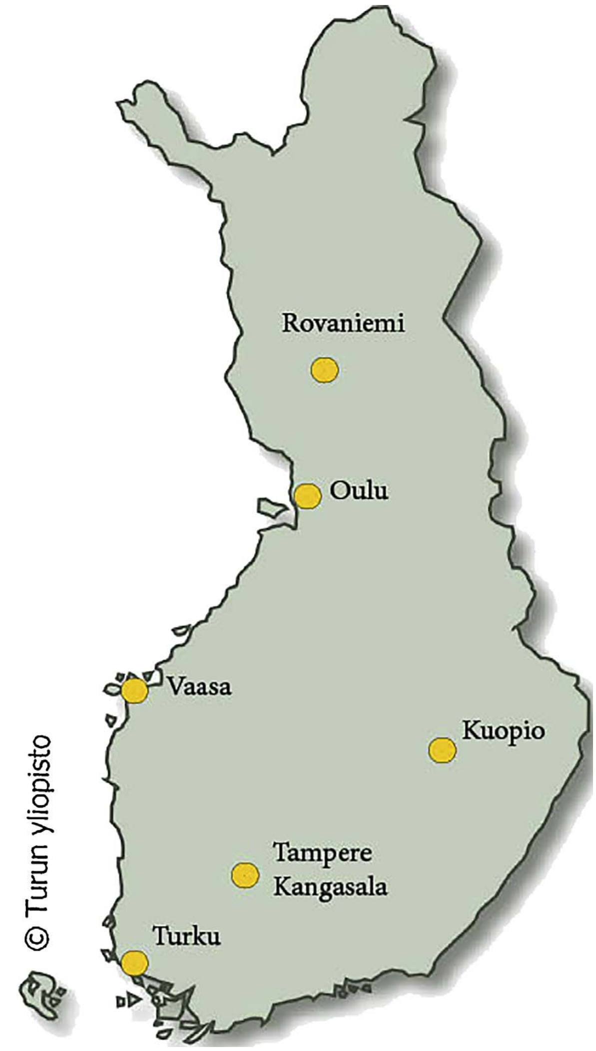

Fig. 1. The locations of the pollen measuring sites.

The pollen model predicts the ripening of the pollen to depend on a temperature sum, *TS*, accumulated from a fixed starting date, t_0, in spring. Temperature sum is accumulated from the fraction of daily temperature, *T*, above a critical temperature threshold, T_{Crit}. The cumulative amount of ripened pollen, *P*, is modeled to increase as a linear function between two temperature sum thresholds TS_{min} and TS_{max}, as was modeled for birch by Linkosalo et al. (2010).

$$TS(t) = \sum_{x=t_0}^{t} \max(T(x) - T_{Crit}, 0) \tag{1}$$

$$P(t) = \begin{cases} 0, & TS < TS_{min} \\ \frac{TS(t) - TS_{min}}{TS_{max} - TS_{min}}, & TS_{\min} \le TS(t) < TS_{max}, \\ 1, & TS \ge TS_{max} \end{cases} \tag{2}$$

Our model assumes that the pollen is released as it ripens. The model has 4 parameters, the starting date t_0, critical temperature threshold T_{Crit}, and the two temperature sum thresholds TS_{min} and TS_{max}.

We estimated the model parameters by minimizing the sum of squared errors (SSE) between the model predictions and measured data. To emphasize the model accuracy in predicting the start and end of the pollen season, we modified the calculation of SSE with a weight function *W*, that was 1 in the case both observed *(O)* and predicted *(P)*