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A statistical model for predicting the inter-annual variability of birch pollen abundance in Northern and North-Eastern Europe

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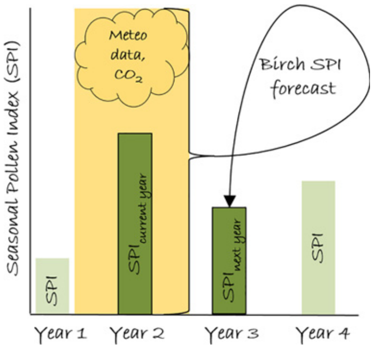
HIGHLIGHTS

- New model for predicting seasonal pollen index for large regions is developed.
- Procedure of cluster analysis-based region selection is proposed.
- A single universal equation describes the next year seasonal pollen index.
- Combination biological and meteorological factors shows the best predicting capacity.
- The model was tested for Russia and Belgium to identify the limits of the method.

GRAPHICAL ABSTRACT



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ABSTRACT

The paper suggests a methodology for predicting next-year seasonal pollen index (SPI, a sum of daily-mean pollen concentrations) over large regions and demonstrates its performance for birch in Northern and North-Eastern Europe. A statistical model is constructed using meteorological, geophysical and biological characteristics of the previous year). A cluster analysis of multi-annual data of European Aeroallergen Network (EAN) revealed several large regions in Europe, where the observed SPI exhibits similar patterns of the multi-annual variability. We built the model for the northern cluster of stations, which covers Finland, Sweden, Baltic States, part of Belarus, and, probably, Russia and Norway, where the lack of data did not allow for conclusive analysis. The constructed model was capable of predicting the SPI with correlation coefficient reaching up to 0.9 for some stations, odds ratio is infinitely high for 50% of sites inside the region and the fraction of prediction falling within factor of 2 from observations, stays within 40–70%. In particular, model successfully reproduced both the bi-annual cycle of the SPI and years when this cycle breaks down.

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1. Introduction

One of the most-important parameters quantifying the strength of an allergenic pollen season is a Seasonal Pollen Index, SPI, which is defined as a sum of all daily-mean pollen concentrations, i.e. a season-long integral of pollen concentrations. It was related to severity of human allergy (Bastl et al., 2016; D'Amato et al., 2007; Huynen et al., 2003), used as an indicator of the productivity of trees, such as olives (Galán et al., 2014; Myszkowska, 2013; Orlandi et al., 2005; Oteros et al., 2013; Prasad and Craufurd, 1999), as well as predictive parameter for the wine (Cunha and Ribeiro, 2015) or olives (Dhiab et al., 2016) production and as a bio indicator of plant reaction to the on-going climate change (Hatfield and Prueger, 2015; Hedhly et al., 2009; Storkey et al., 2014; Zhang et al., 2014). Apart from that, the SPI is used in numerous pollen forecasting models as a scaling factor determining the predicted pollen concentrations (Helbig et al., 2004; Prank et al., 2013; Puc, 2012; Ranta et al., 2008; Ritenberga et al., 2016; Siljamo et al., 2012; Sofiev et al., 2012; Stach et al., 2008; Toro et al., 1998; Veriankaitė et al., 2009; Zhang et al., 2013; Ziello et al., 2012).

The SPI is known to change substantially from year to year depending on combination of meteorological factors and physiology of the plant (Masaka, 2001; Ranta and Satri, 2007), see also a review of Dahl et al. (2013). Such variability, for some trees (e.g., birch), exhibits a quasi-bi-annual behaviour (a strong year is followed by a weak one and vice versa), which however, is broken in some years (Dahl and Strandhede, 1996; Detandt and Nolard, 2000; Grewling et al., 2012; Hättestrand et al., 2008; Jato et al., 2007; Latałowa et al., 2002). This behaviour was attributed by Dahl and Strandhede (1996) to a combination of meteorological and physiological factors, who suggested that neither meteorology nor the innate biannual behaviour is decisive, but rather a combination of both. Indeed, since catkin development is expensive, their abundance takes a large toll of carbohydrates from the annual shoot and impedes the expansion of leaves, thus limiting the amount of photosynthesis products available for development of the next year catkins. This cycle can be interrupted if weather is, for instance, strongly favourable allowing the smaller leaves to assimilate efficiently. Then flowering can be strong for two years in a row.

The same variability tends to occur synchronously in several plants, such as birch, alder and hazel, and over large regions (Ranta and Satri, 2007; Šaulienė et al., 2014). Such synchronization also suggests strong influence of meteorology as the only common factor for different plants distributed over large areas.

Apart from the strong inter-annual variability, several wind pollinated trees, such as birch, olives, oak, etc. have positive long-term trend of the SPI (Garcia-Mozo et al., 2014; Yli-Panula et al., 2009; Prank et al., 2013; Severova and Volkova, 2016; Spieksma et al., 2003, 1995). These trends were attributed to changing climatic conditions and/or to increasing abundance of the plants. Among measurable indicators of these factors, one can consider the growing level of CO_2 in the atmosphere and trends in the regional leaf area index. Thus, several studies showed that with higher level of CO_2, plants tend to produce more pollen (Ladeau and Clark, 2006; Zhang et al., 2015; Ziska et al., 2001; Ziska and Beggs, 2012).

Among the meteorological factors affecting the intensity of the trees flowering, temperature and precipitation amount of the preceding year are the most-commonly mentioned (Yli-Panula et al., 2009). One can therefore expect that the regional synchronization of the SPI behaviour takes place at least at synoptic scale, i.e. 10^2–10^3 km and this very scale should be considered when developing models for the SPI. However, most of studies consider it at shorter scales using one or few closely-located sites (Corden et al., 2002; Dahl and Strandhede, 1996; Grewling et al., 2012; Severova and Volkova, 2016).

Many of the above studies completed the analysis of the SPI inter-annual behaviour with statistical models aiming at predicting the next-year SPI using the previous-year SPI and meteorology. The procedure of constructing such models usually started from log- or square-root (sqrt-) transform of the SPI followed by multi-linear regression fitting. The input parameters usually included in the analysis are mean temperature of various time intervals (one study took heat sum over certain periods) and the previous-year SPI. However, no systematic pre-processing of the input parameters was performed, and all models were built for individual locations, even if the study was considering several sites.

The current study addresses the above-outlined omissions and aims at construction of a predictive model for birch SPI over large regions in Europe. We will propose a simple procedure for delineating such areas and build the model for the northern region.

2. The working hypotheses

We assume that the SPI is a regional parameter determined by the synoptic-scale meteorological processes, i.e. a few hundreds of kilometres. It should therefore be possible to identify the regions that react synchronously and demonstrate similar patterns of the SPI year-to-year variations. The corresponding temporal scale is from several days up to 1–2 weeks – this will be the maximum temporal resolution of the input data, i.e. we shall not be interested in individual meteorological events.

Secondly, absolute values of the SPI are of essentially no importance: they are decided by vegetation density in proximity to the station, which is a static parameter. Therefore, spatial and temporal variations inside these regions are separable.

With the above assumptions, it should be possible to construct a statistical model for the SPI variation over these regions taken as "boxes", i.e. not resolving individual stations but taking each region as a single entity with the normalised SPI averaged over the region.

3. Materials and methods

3.1. Study area

The study was focused over the region between the latitudes 50°N and 70°N and longitudes from 5°E to 40°E, Birch pollen data from 15 aerobiological sites were included in the analysis.

The analysed region has moderate maritime climate with cold winters and moderate summers. Birch fraction reaches up to 30% of the total forest coverage (see maps in (Ritenberga et al., 2016; Sofiev et al., 2006)).

3.2. Airborne pollen concentrations

Birch pollen data were extracted from the database of European Aeroallergen Network (EAN). Pollen sampling was performed using Burkard or Lanzoni 7-days volumetric trap (Hirst, 1954). Pollen was identified with optical microscopy, using country-specific (random, vertical, horizontal traverses) counting technique but generally following the aerobiological standards (Galán et al., 2014). For each year, the SPI was computed as an integral of concentrations over the whole observed period. The length of time series varied from station to station, reaching 40 years (1974–2015) for a few sites. The varying length of observations created evident challenges for processing and interpretation of the obtained results. However, under the assumption of internal homogeneity of the SPI variation within the region, verified in the next section, all stations are normalised and averaged into the regional mean, thus reducing the problem to a different sampling volume in different years. Additionally, all time series shorter than 11 years were filtered out (Table 1). No other thinning of the dataset was possible due to the limited number of sites (15, as shown in Table 1 and Fig. 1).