

A method to derive vegetation distribution maps for pollen dispersion models using birch as an example

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Received: 6 June 2011 / Revised: 24 August 2011 / Accepted: 6 September 2011 / Published online: 17 November 2011
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Abstract Detailed knowledge of the spatial distribution of sources is a crucial prerequisite for the application of pollen dispersion models such as, for example, COSMO-ART (Consortium for Small-scale MOdeling - Aerosols and Reactive Trace gases). However, this input is not available for the allergy-relevant species such as hazel, alder, birch, grass or ragweed. Hence, plant distribution datasets need to be derived from suitable sources. We present an approach to produce such a dataset from existing sources using birch as an example. The basic idea is to construct a birch dataset using a region with good data coverage for calibration and then to extrapolate this relationship to a larger area by using land use classes. We use the Swiss forest inventory (1 km resolution) in combination with a 74-category land use dataset that covers the non-forested areas of Switzerland as well (resolution 100 m). Then we assign birch density categories of 0%, 0.1%, 0.5% and 2.5% to each of the 74 land use categories. The combination of this derived dataset with the birch distribution from the forest inventory yields a fairly accurate birch distribution encompassing entire Switzerland. The land use categories of the Global Land Cover 2000 (GLC2000; Global Land Cover 2000 database, 2003, European Commission, Joint Research Centre; resolution

1 km) are then calibrated with the Swiss dataset in order to derive a Europe-wide birch distribution dataset and aggregated onto the 7 km COSMO-ART grid. This procedure thus assumes that a certain GLC2000 land use category has the same birch density wherever it may occur in Europe. In order to reduce the strict application of this crucial assumption, the birch density distribution as obtained from the previous steps is weighted using the mean Seasonal Pollen Index (SPI; yearly sums of daily pollen concentrations). For future improvement, region-specific birch densities for the GLC2000 categories could be integrated into the mapping procedure.

Keywords Vegetation distribution · Birch pollen · Land use data · Forest inventory · Seasonal Pollen Index

Introduction

Pollen dispersion models represent a helpful tool for pollen forecasters and allergy sufferers. They provide spatially and temporally highly resolved forecasts, which can be used by general practitioners to make diagnosis and to advise their patients. In addition, these forecasts provide useful information for allergy sufferers to reduce the symptoms.

In recent years, various pollen dispersion models have been developed (Hidalgo et al. 2002; Sofiev et al. 2006; Schueler and Schlünzen 2006; Helbig et al. 2004; Vogel et al. 2008). Some of these models have been operational now for some years such as the Finnish Emergency Dispersion Modelling System (SILAM; Sofiev et al. 2006). COSMO-ART (Consortium for Small-scale MOdeling - Aerosols and Reactive Trace gases; Vogel et al. 2009; Helbig et al. 2004) became pre-operational in 2010 in Germany and Switzerland and was used operationally in 2011.

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A major source of uncertainty in pollen dispersion models is related to the quality of the emission data (Skj  th et al. 2010; Sofiev et al. 2006). Generating emission data requires information on the distribution of the pollen producing plant. For tree species, this data is generally available for forested areas from National Forest Inventories as these datasets distinguish various species. Skj  th et al. (2008) brought all these national datasets together resulting in a Europe-wide inventory of all trees in broadleaved as well as conifer forests on a 50 km  50 km grid. K  ble and Seufert (2001) derived the forested area on a 1 km  1 km grid from the CORINE (Coordinate Information on the Environment) land-cover dataset (CEC 1994) and the Pan-European land Cover Mapping (PELCOM) project (M  cher 2000). The measurement network of the transnational survey of forest condition in Europe (UN-ECE 1998) served as the source for the species information. Sofiev et al. (2006) derived the birch distribution using a combination of the K  ble and Seufert (2001) dataset and a complementary dataset produced by the European Forest Institute (EFI). The latter dataset is a combination of National Oceanic and Atmospheric Administration – Advanced Very High Resolution Radiometer (NOAA-AHVR) data and forest inventory statistics (Schuck et al. 2002; P  ivinen et al. 2001).

A major shortcoming of all these datasets is the fact that they only rely on forested areas. However, depending on the tree species and region, there may be a substantial proportion of the trees outside the forests. For example, birch trees have been very popular in central European cities or gardens for decoration. These trees are allergologically very significant as they are located in densely populated places. Therefore, we propose a different approach to produce plant distribution maps from various data sources that also takes into account the trees located outside the forests. To illustrate this approach we use birch (*Betula pendula* and *Betula pubescens*) as an example.

The genus *Betula* is represented in Europe with several native species, but only two of them, *Betula pendula* and *Betula pubescens*, are widespread and are important pollen producers. Birch trees have a large ecological amplitude in soil fertility, moisture and climate conditions and therefore a wide natural distribution area on the Eurasian continent. Birch trees are pioneer species, which rapidly occupy open areas after forest fires and clear-cuttings due to their prolific seed production (Hynynen et al. 2010). The species are most abundant in northern Europe where the distribution is more or less continuous, either in mixed forests or in pure stands. In central Europe, the distribution is patchier and does not play an important role as economic tree species. Since birch trees are very shade-intolerant and have a low degree of within-stand competition, they disappear from the more nitrous forests stands. Towards the Mediterranean the frequency of birch trees decreases. Birch trees occur mainly

in the mountainous areas, for example, in northern Spain and are almost absent in Greece. Generally, downy birch (*B. pubescens*) occurs slightly more frequently in more northern, cool and humid areas than silver birch (*B. pendula*) and is almost absent in the Mediterranean.

In Switzerland *B. pendula* is much more frequent than *B. pubescens*. Considerable numbers of birch trees can be found in Southern Switzerland and in the Alps. Birch stands are mostly limited to specific locations such as steep slopes or pioneer stands (Br  ndli, 1998). In Southern Switzerland birch profits from the recent trend in land abandonments, less intense forest management and higher fire frequency. Birch is able to colonize these habitats very efficiently. The main source for birch pollen in Northern Switzerland is not birch trees in the natural vegetation but ornamentally planted trees in settled areas.

First, the data used for deriving a birch distribution map is described. In a further step the methodology is described in detail. The new birch distribution map is presented and discussed and final conclusions are drawn.

Data

Table 1 gives an overview of the datasets used for the generation of the birch distribution maps. The Swiss National Forest Inventory (Landesforstinventar LFI; WSL 2011) was produced using a systematic sample of 500 m² at every forested grid point of a regular 1.4-km grid covering the whole of Switzerland. The percentage of birch cover was determined manually (“ground truth”) by the staff of the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL). For the land use data we rely on the dataset Arealstatistik 1992/97 (AS97) by the Swiss Federal Office for Statistics (1997). This dataset contains no direct birch information. It uses a classification scheme of 74 land use categories that are determined using a systematic sample on a 0.1 km grid. For the Europe-wide birch distribution we use the Global Land Cover 2000 dataset (GLC2000; European Commission 2003) because the land use categories in the COSMO model are also based on this dataset regarding surface characteristics. For the final weighting, pollen data from 324 stations across Europe were used (source: European Aeroallergen Network Database, Vienna, Austria). In particular, the Seasonal Pollen Index (SPI) was employed, which is defined as the sum of daily pollen counts over an entire season at the respective location (Nilsson and Persson 1981; Mandrioli et al. 1998).

The interannual variation of the SPIs can amount to a factor of two. To ensure that no outliers are included in the study we employed only stations with at least 5 years of birch pollen data. However, most stations have 10–30 years of data providing robust SPIs.

Table 1 Overview of the datasets that were used to produce the birch distribution map. WSL stands for Swiss Federal Institute for Forest, Snow and Landscape Research (www.wsl.ch)

Datasets	Unit	Resolution	Spatial extent	Source
Swiss National Forest Inventory (LFI)	% birch cover of sample area	1.4 km	Forested areas in Switzerland	Brändli (2010); WSL (2011)
Arealstatistik (AS97; Land use dataset)	74 classes	0.1 km	Entire Switzerland	Swiss Federal Office for Statistics (1997)
Global Land Cover 2000 (GLC2000)	22 classes	1 km	Global	Global Land 2000 database (2003)
Mean Seasonal Pollen Index from 324 European pollen stations (SPI)	Mean yearly sum of daily pollen counts (SPI averaged over all available years)	Interpolated onto a 7 km grid (COSMO-7)	Europe	Data contributors to the European Aeroallergen Network Database (EAN)

Methods

The preset approach can be divided into two major steps. First, a National Forest Inventory and detailed land use data were combined in a region where data coverage is complete and data quality is high. In the present study, this yields a high-quality dataset for forested and non-forested areas (per land use category) in Switzerland. Second, a transfer procedure was applied using this dataset and a land use dataset that is available for a larger region. This results in an estimation of the plant distribution for a large region that is based on forest inventories and land use data. However, this approach alone does not take into account the fact that the same land use category may not imply the same plant distribution in other climate zones. To overcome this shortcoming, we use pollen count data from the European Aeroallergen Network (EAN) database as a weighting factor. As the plant distribution will finally be used in pollen dispersion models, the use of pollen data is especially suitable. A similar weighting procedure has been applied by Skjøth et al. (2010) for deriving pollen source inventories from *Ambrosia* pollen data.

We chose birch for three reasons. First, birch is an important allergen and state-of-the-art pollen dispersion models will quickly profit from new birch distribution maps. Second, in central Europe, birch is not only present in forests, but it is also abundant in cities, gardens, along roads or on extensively used arable lands. Hence, for this species a method is needed that also considers these birch stands. Third, as birch trees outside the forests are linked to human activities, their location can be related to land use data. We perform the calibration for Switzerland and derive a birch distribution map covering southern and central Europe.

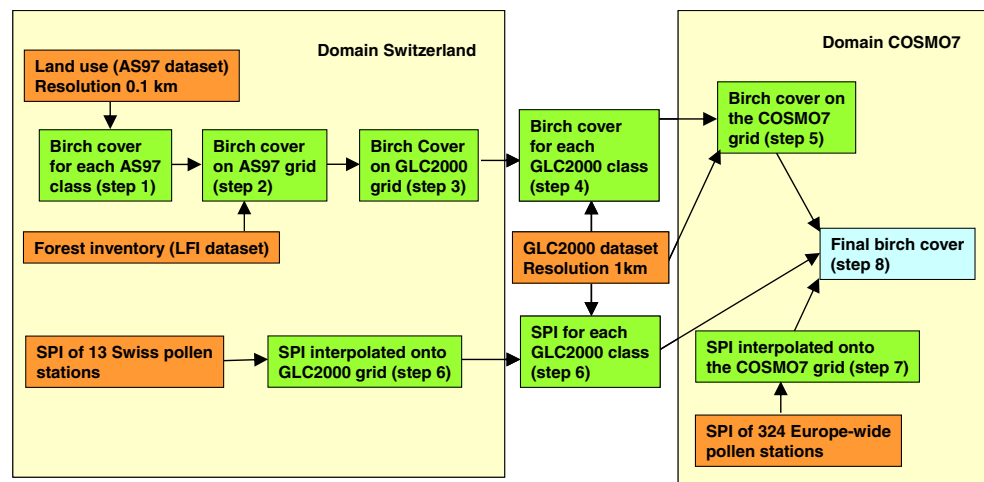
The procedure employed for the generation of the birch distribution suitable for input to pollen dispersion models can be divided into two major steps and eight minor steps. Figure 1 illustrates the procedure.

(A) Reference dataset in a limited region

1. Estimation of the birch cover for the AS97 land use classes outside the forests:

Subjective definition of four birch density classes (0%, 0.1%, 0.5% and 2.5%) based on ground truth surveys in the cities of Zurich and Lausanne (Switzerland) carried out in 2009 and assignment of one of these density classes to each of the AS97 categories outside the forests based on their description, photos and botanical knowledge of the plant distribution.

Fig. 1 The procedure outlined in steps 1 to 8. Red boxes denote original input datasets, green boxes denote derived datasets. The final result is highlighted by a blue box. Note the division into the Swiss and the COSMO7 domain



2. Assigning LFI data to the AS97 classes:

Determination of the closest AS97 grid point for each LFI (Swiss forest inventory) grid point. For these AS97 grid points the mean birch cover per AS97 forest category is calculated using the LFI data. These values are used for completing the birch cover dataset. Hence all data for forested areas stems from LFI data. As there are significantly more birch trees in the Ticino region (southern Switzerland), this procedure is performed for this region separately (see Fig. 2).

3. Aggregation to the GLC2000 grid:

Integration of the birch density from the AS97 (0.1 km resolution) to the GLC2000 grid (1 km

resolution). The resulting birch cover dataset (Fig. 3) encompasses entire Switzerland on the GLC2000 grid.

(B) Transfer to a larger domain

4. Attribution of birch density to GLC2000 land use classes and extension to Europe:

Determination of the median birch density for each GLC2000 category using all grid points within Switzerland (cf. Figs. 3 and 4). Based on this, the birch density dataset can be extended to a larger

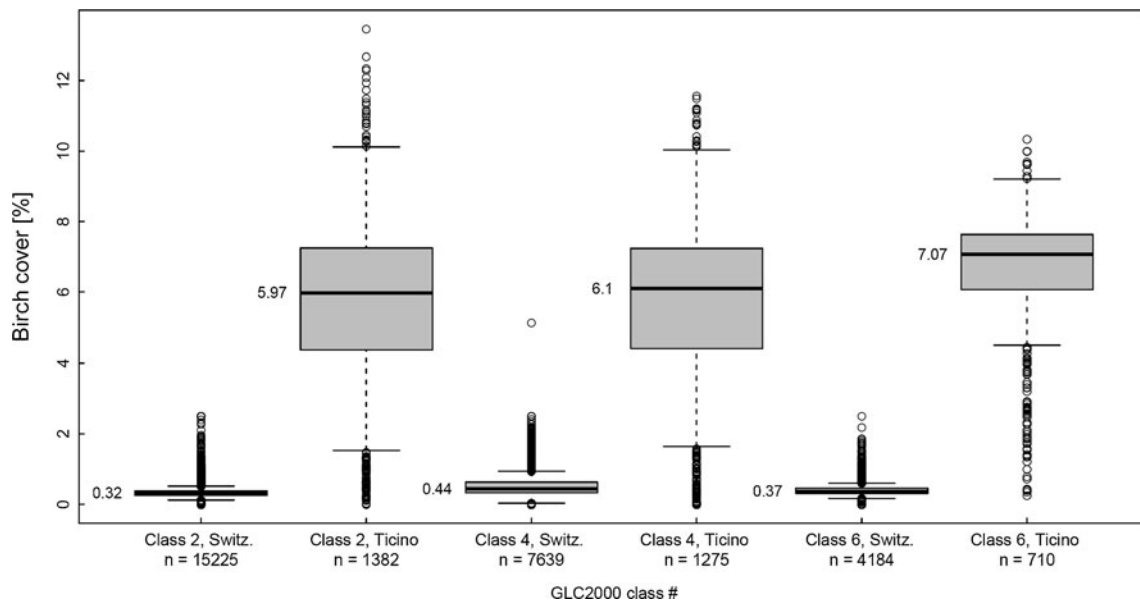
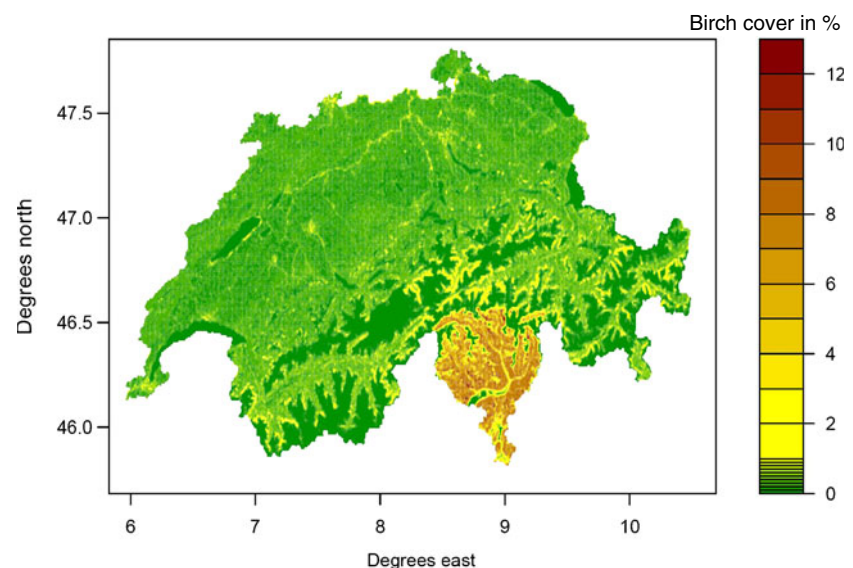


Fig. 2 Birch cover of GLC2000 forest classes derived from the Swiss National Forest Inventory. The Ticino region and the remainder of Switzerland are given separately. Note the big difference between the two regions. *n* denotes the number of GLC2000 grid points per class.

Class 2 is described as “Tree Cover, broadleaved, deciduous, closed”. Class 4 refers to “Tree Cover, needle-leaved, evergreen”. Class 6 encompasses “Tree Cover, mixed leaf type” (Global Land 2000 database 2003)

Fig. 3 Birch cover in percent in Switzerland on the GLC2000 grid (1 km resolution), derived from the National Forest Inventory and land use data. Note the compressed color key between 0 and 1



domain as the GLC2000 dataset is available for all of Europe. In this study, we use the COSMO-7 domain (colored area in Fig. 6). Note that 0.05% of the grid points cannot be classified as their GLC2000 classes do not occur in Switzerland. These grid points are mainly located in southern Spain and are interpolated using the values of the surrounding grid points.

5. Aggregation to the COSMO-7 grid:

Integration of the Europe-wide birch cover from the GLC2000 grid (1 km resolution) to the COSMO-7 grid (7 km resolution) using the birch cover values for the GLC2000 classes along with the fractions of the GLC2000 classes within each COSMO-7 grid point. For the Ticino region the separately calculated

values are applied (see step 2), while for the remainder of Switzerland the values without the Ticino data are used. For all other grid points in Europe the birch cover values for the GLC2000 classes are calculated using the mean of all grid points within Switzerland.

6. Calculation of the SPI for each GLC2000 land use class based on all Swiss grid points:

Interpolation of the SPIs of 13 Swiss pollen stations onto the GLC2000 grid covering the Swiss area using inverse distance weighting. Calculation of the mean pollen indices for each GLC2000 land use class within Switzerland. These SPI values of each GLC2000 land use class (resolution 1 km) are used for aggregation on the COSMO-7 grid (7 km resolution).

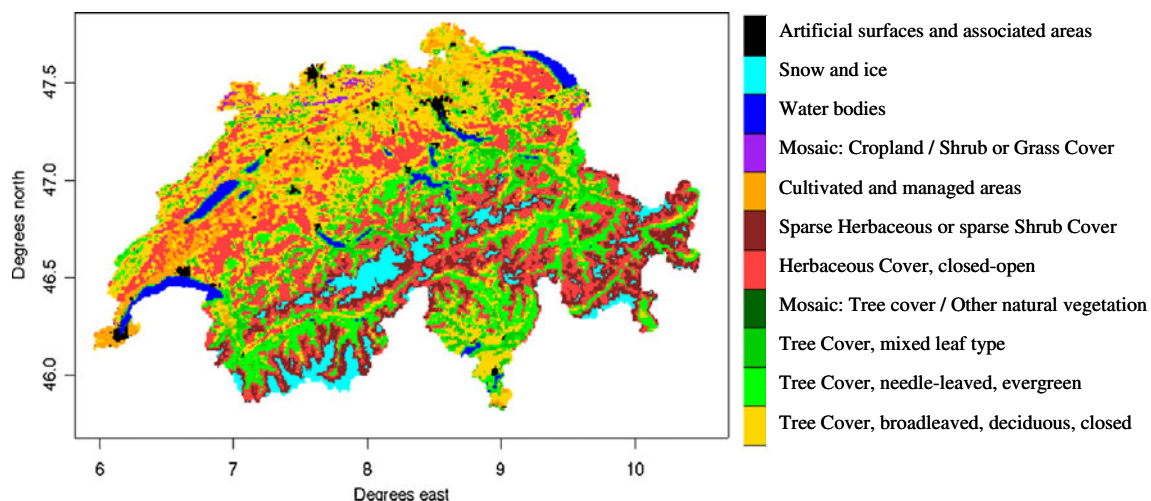


Fig. 4 GLC2000 classes in Switzerland (1 km resolution)

7. Calculation of the SPI field covering the COSMO-7 domain:

Interpolation of the SPIs from 324 Europe-wide pollen stations distributed over the whole COSMO-7 domain (Fig. 5). The minimum length requirement is 5 years of data. Squared inverse distance weighting is used as the interpolation method. The pollen data serve as a proxy for regional birch densities. For the interpolation the identification of the relevant stations per grid point is done the following way. Search for all stations within 2 degrees of distance. If more than 20 stations are identified, use only the closest 20. If less than two stations are found, increase the search radius to 3 degrees and repeat the procedure. If there are still less than two stations found repeat the procedure using 4 degrees. If still not satisfying the two-station-requirement, flag the grid point concerned as missing value. Using this procedure no missing values occur over European land areas.

8. Calculation of the final birch cover:

The following relation is used to determine the final birch density at each grid point

$$BC_{fin} = BC_{land} \times (SPI_{int}/SPI_{ref})$$

where

BC_{fin} =final (weighted) birch cover on the COSMO-7 grid

BC_{land} =birch cover from GLC2000 land use classes as estimated in step 5

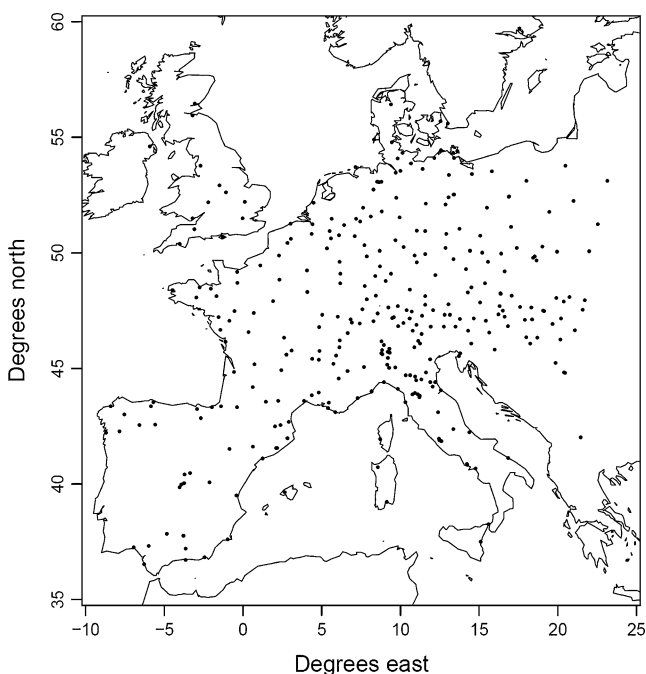


Fig. 5 The black dots denote the used pollen monitoring stations from the EAN database. The stations are selected based on the requirement of at least 5 years with birch pollen data during the period 1990–2009

SPI_{int} =interpolated SPI calculated in step 7

SPI_{ref} =Reference SPI values for each COSMO-7 grid point as estimated in step 6

Results

The boxplots in Fig. 2 depict the variability of birch cover in the Swiss forests. This is based on the National Forest Inventory aggregated onto the GLC2000 grid (step 2). The birch cover in Swiss forests, except the Ticino region, amounts to approximately 0.35%, with few grid points above 1%. The differences between the three GLC classes are small. Given the sample size of many thousand grid points, we consider this result as robust.

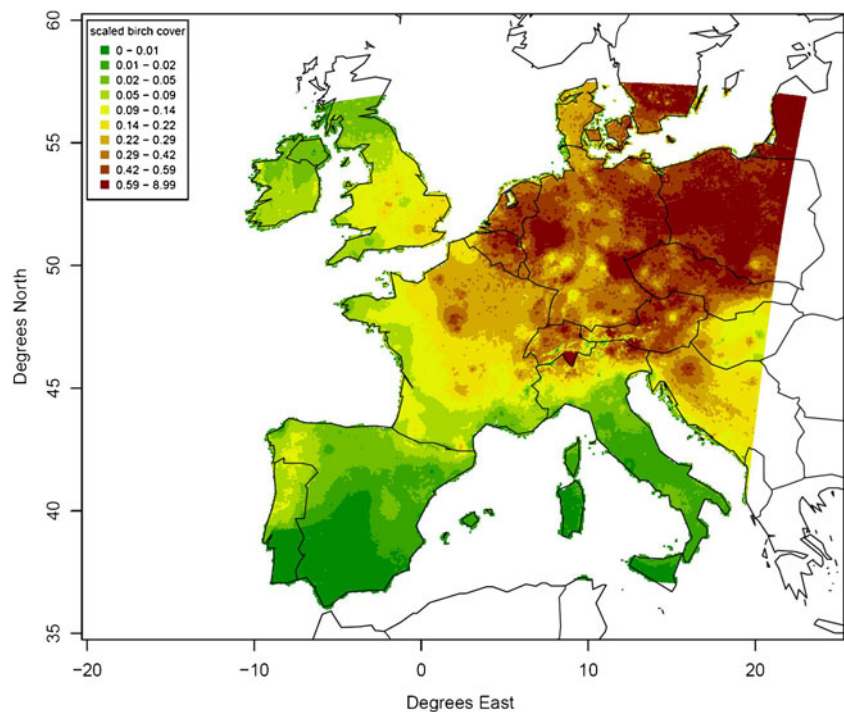
In the Ticino region the average birch cover amounts to around 6%, which is a magnitude higher than in all the other Swiss forests; in addition, the values range between 0% and 9%, displaying a higher variability. The sample size is considerably smaller, but still reaches around one thousand grid points per GLC2000 class.

The huge difference between the forests in the Ticino region and the rest of the country can be seen in Fig. 3 as well. This map is the result of step 4. Beside the National Forest Inventory, land use data is used to estimate the non-forested areas. The regions without any birch trees encompass mainly water bodies and the Alps, i.e. areas covered by snow and ice. These areas can be identified from Fig. 4. The areas with most birch trees (besides the Ticino region) include elevated forests, shores of rivers and cities (mainly yellow regions in Fig. 3). Cultivated managed areas and herbaceous cover appear to be sparsely covered by birch trees (cf. Figs. 3 and 4). The GLC2000 class “Sparse herbaceous and shrub cover” has even less birch trees, as these areas are mostly above timberline.

Figure 5 displays the distribution of the 324 pollen monitoring stations that are used for the interpolation of the SPIs onto the COSMO-7 grid. The stations are quite evenly distributed over the COSMO-7 domain thus facilitating the interpolation procedure. Poor data coverage occurs only in parts of the Iberian Peninsula, the British Isles and south-eastern Europe.

The final birch distribution (step 9) is shown in Fig. 6. Birch coverage is highest in north-eastern Europe with a general decrease towards the south-west. South of around 44° N birch is no common tree. In northern England and Ireland the birch densities are low as well. However, in south-eastern Europe, the dataset shows rather high birch values. Big cities such as London and Paris are visible because their land use class is assigned high birch coverage values. Similarly, the distribution of the pollen monitoring stations is portrayed as well (cf. Fig. 5). In Portugal there

Fig. 6 Final birch cover on the COSMO-7 grid (7 km resolution)



seem to be some birch trees, which is corroborated by surveys by the botanical garden of the University of Trás-os-Montes e Alto Douro, Portugal (<http://aguair.hvr.utad.pt>). However, the reason why there are birch trees in the dataset is because of the pollen monitoring stations located in north-eastern Spain that get a high weight in the interpolation procedure due to missing local stations.

It is worth noting the sharp gradient in derived birch density along the Swiss-North Italian border (Fig. 6). Figures 2 and 3 show that the birch densities in southern Switzerland are much higher than in the rest of the country. On the Swiss side of this sharp gradient the LFI data was used while on the Italian side the Swiss average was employed (cf. step 5 in the “Methods” section) which leads to this gradient. Including Italian LFI data would possibly make this gradient disappear.

Discussion and conclusions

We present a method to generate plant distribution maps based on forest inventories and land use datasets using birch as an example. These plant distribution maps are suitable as input to numerical pollen dispersion models. The procedure is based on calibration in a small region with good data coverage and extrapolation using a dataset that is available for a larger region. This method can be employed for many plant species and yields coherent datasets. It displays high data quality in the core (calibration) area with decreasing confidence towards the edge of the domain. The major advantage compared to existing datasets is the fact

that this method accounts for all possible locations of the respective plant and not only a part of it (e.g., forests).

In the course of the generation process, various assumptions have to be made which result in uncertainties on the resulting birch distribution map. The first relates to the definition of the four birch classes in step 1. Although some on-the-ground verification is available (cf. step 1), this remains a source of uncertainty because the choice also influences the estimation of the birch cover of the GLC2000 classes and thus the final result. Second, the assignment of the four birch classes to each of the 74 land use categories represents a source of uncertainty. The National Forest Inventory, however, is considered as rather accurate as birch data was directly gathered during this extensive and time-consuming survey (Brändli 2010). Another critical step is the calculation of the birch cover per GLC2000 class. This estimation is best for the region in question (Switzerland in our case). The extrapolation process onto the whole COSMO-7 domain remains a critical step as the assumption is made that a certain GLC2000 land use category has the same birch density wherever in Europe it may occur. This issue is addressed by the weighting using the interpolated SPIs.

The use of the interpolated SPIs as weighting factors assumes that most of the pollen captured in the traps are of local origin and not disturbed by long-range transport. Hoffmann et al. (2008) concluded from measurements and modeling results that *Zea mays* (maize) pollen are deposited within a few kilometers from the source. Similar results were obtained from modeling studies by Chamecki et al. (2009) for ragweed. Bricchi et al. (2000) found from

experiments that more than 88% of the pollen is deposited within a range of 2750 m from the source. However, other pollen species such as birch may be transported up to more than 1000 km depending on the meteorological conditions (Skj  th et al. 2007; Sofiev et al. 2006; Veriankaite et al. 2010). Given the sparse distribution of the pollen measuring stations in some regions such as the Iberian Peninsula (324 stations for whole Europe), the influence of some pollen stations may extend up to hundreds of kilometers. Hence, they serve not only as a proxy for local plants but also account for the long-range transport.

In step 8 the interpolated SPIs (SPI_{int} from step 7) are normalized by reference SPIs (SPI_{ref} from step 6). Table 2 shows that these reference SPIs are similar for all relevant GLC2000 classes. Hence no major difference compared to the use of an overall mean can be expected. Still, we decided to keep step 6 because the results could be improved if many more stations were available. The reason for these small differences is that most pollen stations are located in urban areas. Hence all interpolated SPIs are biased towards urban SPIs. The GLC2000 classes “snow and ice” and “water bodies” illustrate this most impressively. However, steps 1–3 make sure that birch is absent for these land use classes (Fig. 3).

The major improvement compared to the existing birch datasets is the inclusion of birch trees outside the forests. This is especially important in central Europe where birch is not a major forest species but is frequently planted in cities. This is different from the situation in Scandinavia and Russia where birch is a dominant species in the forests. Still, all available birch distributions (Skj  th et al. 2008; Sofiev et al. 2006; K  ble and Seufert 2001) show almost no birch trees in the Mediterranean region with increasing values to the north and east of Europe. The map by Skj  th et al. (2008) displays the density of *Betula sp.* in broad-

leaved forests derived from various National Forest Inventories; the proportion of broad-leaved forests is given separately. Class limits tend to coincide with the borders of countries, a feature that could be the consequence of the national nature of the raw data.

The birch cover map by Sofiev et al. (2006) is strikingly similar to the one presented in this study although it is derived from different sources using a completely different method. Features present in both datasets include low birch densities in the United Kingdom, some higher values in France, Germany and Poland and even higher values in southern Sweden and the Baltic countries. The similarity of both datasets is corroborated by experiments using the pollen dispersion models SILAM and COSMO-ART.

Vakkari (2009) produced a distribution map for silver birch in the framework of the European Forest Genetic Resources Programme. This map refers only to the range and not to the density of the birch cover. The southern limit coincides with the birch distribution presented in this study (Fig. 6). However, the birch distribution by Vakkari (2009) shows no birch trees in the North-Western part of the Iberian Peninsula. The presence of birch in that region is confirmed by both the birch cover map by Sofiev et al. (2006) and pollen traps at different locations that record amounts of pollen that are comparable to those captured in central Europe. Moreover, all datasets are consistent with the biological requirements of birch as outlined in the “Introduction”.

Clearly, the results from the present approach could be improved by using high-quality (reference) data from different regions of the domain—most ideally at least one dataset for each climatological region. This could help overcome the problem of region-specific birch densities that cannot be captured by a limited number of land use classes. Another way to overcome this problem is the adoption of a land use class dataset that employs a more detailed classification scheme than GLC2000. This would possibly allow distinguishing between region-specific land uses and forest biomes. When extending the model domain more to the east or north the calibration region should be changed because in north-eastern Europe birch is more common in forests than in Switzerland. Alternatively, forest inventories for the regions with dense birch forests could be used. Finally, this method could be further tested by using other plant species to derive large-scale distribution maps.

Table 2 Mean SPIs for the relevant GLC2000 land use classes based on all Swiss grid points (cf. step 6)

GLC2000 class	Mean SPI
Artificial surfaces and associated areas	4630
Snow and ice	4633
Water bodies	3933
Mosaic: cropland / shrub or grass cover	4532
Cultivated and managed areas	4025
Sparse herbaceous or sparse shrub cover	4127
Mosaic: tree cover / other natural vegetation	4648
Herbaceous cover, closed-open	4473
Tree cover, mixed leaf type	4575
Tree cover, needle-leaved, evergreen	4439
Tree cover, broadleaved, deciduous, closed	4560

Acknowledgements The authors would like to thank the following institutions for providing their pollen data to the European Aeroallergen Network (EAN):

The Austrian Pollen Information Service; The Scientific Institute of Public Health of Belgium; The German Pollen Information Service; The Spanish Aerobiological Network; the Danish Asthma-Allergy Association; The French Aerobiological Monitoring Network; The Italian Aerobiological Association; the Polish Allergen Research

Center; the Spanish Universities of León, the Balearic Islands, Barcelona, Málaga, Vigo, Santiago de Compostela, and Córdoba; the Basque department of Health, Spain; The Free University Berlin, Germany; The Leiden University Medical Center, Netherlands; the University of Gothenburg, Sweden; the University of Novi Sad, Serbia; the Serbian Environmental Protection Agency; The UK Met Office; The Pollen Research Unit in Worcester, UK; Queen's University Belfast, UK; The Scottish Crop Research Institute; the University of Wales Institute, Cardiff, UK; the Hungarian National Institute of Environmental Health; the Ministry of Health, Luxembourg; and The University of Cracow, Poland. Additionally, the authors wish to thank the Swiss Federal Institute for Forest, Snow and Landscape Research and the Swiss Federal Office for Statistics for access to their data.

Appendix 1

The following individuals contributed to this study by providing their pollen data to the European Aeroallergen Network (EAN) database:

Siegfried Jäger, Margit Cerny, Roland Schmidt, Sigmar Bortenschlager, Uschi Brosch, Helmut Zwander, Roland Schmidt, Manfred Bobek, Rudolf Litschauer, Hanna Schantl, Herta Koll, Margit Langanger, Monique Detandt, Ondrej Rybníček, Karl-Christian Bergmann, Petra Jankiewicz, Reinhard Wachter, Janne Sommer, Consuelo Díaz de la Guardia Guerrero, Francisca Alba Sánchez, Monserrat Gutiérrez Bustillo, Jordina Belmonte, Xabier Aguinagalde Aizpurua, Pilar Candau Fernández, Stella Moreno Grau, Belén Elvira Rendueles, Rosa Pérez Badía, Carmen Galán Soldevilla, M.A. Fernández Casado, H.S. Nava, F. Javier Suárez Pérez, Pablo Hidalgo Fernández, Luís Ruiz Valenzuela, D. Fernández González, Rosa M. Valencia Barrera, Ana M. Vega Maray, M. Jesus Aira, Javier Rodríguez-Rajo, M. Mar Trigo Pérez, Marzia Boi, Leonardo Llorens, Isabel Mateu Andrés, Begoña Tortajada, Daría Bermejo, Michel Thibaudon, Chris Hunt, Laura Watkeys, Yolanda Clewlow, Gavin Ramsay, Matt Smith, Ivana Hrga, Anna Páldy, Miklos Juhasz, Alessandro Travaglini, Edith Bucher, Paolo Mandrioli, Paola De Nuntiis, François Hentges, Snezana Milkovska, C.H.H. Schoenmakers, A.O. de Graaf, Letty de Weger, Piotr Rapiejko, Dorota Myszkowska, Agnieszka Lipiec, Barbara Majkowska-Wojciechow, Elzbieta Weryszko-Chmielewska, Malgorzata Puc, Mirjana Mitrovic Josipovic, Ana Dedier Ljubacic, Danijela Stamenkovic, Branko Sikoparija, Åslög Dahl, Andreja Kofol-Seliger, Karol Micieta.

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