Chapter 2
Pollen Sources

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Abstract This chapter reviews what is known about abundance and distribution of the 12 most important aeroallergenic pollens in Europe: *Ambrosia*, *Alnus*, *Artemisia*, *Betula*, Chenopodiaceae, *Corylus*, Cupressaceae/Taxaceae, *Olea*, *Platanus*, Poaceae, *Quercus* and *Urtica/Parietaria*. Abundance is based on 10 years of pollen records from 521 stations of the European Aeroallergen Network that were interpolated into 12 distribution maps covering most of Europe. The chapter compares the distribution maps with other types of distribution maps that are available for selected tree species and discuss two methods for making harmonized pollen source inventories: "bottom-up" and "top-down". Both methods have advantages and disadvantages, and both need to be explored and further developed. Remote sensing has shown to be a valuable method to improve the inventories, especially the use of satellites. The full potential as well as limitations of remote sensing in relation to pollen sources remains to be explored. The review suggests that the most probable way of obtaining inventories of all 12 pollen species is to use top-down methods that use an ecosystem-based approach that for each particular species connects ecological preference, pollen counts and remote sensing.

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2.1 Introduction

2.1.1 Gymnosperms and Angiosperms

Pollen is a biological structure functioning as a container, in which is housed male gametophyte generation of the angiosperms and gymnosperms (Moore and Webb 1983). Such a container is an evolutionary adaptation for life out of water because it protects male gametes from adverse atmospheric influence while transferring from anthers to pistils.

The importance of particular pollen grain from allergological point of view depends both on (1) pollen allergological potency and on (2) pollen abundance in the atmosphere. Keeping in mind both of above-mentioned prerequisites, 12 pollen types originating from anemophilous plants are of particular allergological interest: ragweed (*Ambrosia*), alder (*Alnus*), mugwort (*Artemisia*), birch (*Betula*), goosefoots (Chenopodiaceae), hazel (*Corylus*), cypresses including yews (Cupressaceae/Taxaceae), olive (*Olea*), plane tree (*Platanus*), grass (Poaceae), oak (*Quercus*) and wall pellitory (including stinging nettle) (*Urtica/Parietaria*).

The purpose of this chapter is an overview of what is known about pollen source location: Inventories and how they can be constructed.

2.1.2 Inventories

An inventory in environmental science is in general an aggregation of all available material with respect to abundance and distribution of subject on some sort of geographical area (big or large). Within air pollution, this is often related to chemical air pollutants. Such inventories are typically a gridded estimate of the annual release of the pollutant, and they can be used (1) by law makers and advisory bodies for development exposure limits on local, regional or international scale; (2) by atmospheric transport modellers to study processes and make scenarios and finally (3) by forecasters in daily routines to inform the public about the current air quality.

In chemical air pollution, inventories are usually made for anthropogenic sources such as traffic, industry, agriculture, etc., and include pollutants such as nitrogen monoxide + nitrogen dioxide (NO_x), sulphur dioxide (SO_2), ammonia (NH_3), volatile organic compounds (VOC), etc., but some of the inventories can also include emissions from nature (Simpson et al. 1999). Emissions from nature fluctuate to a much higher degree than their anthropogenic counterparts and are therefore often simulated by using advanced models like MEGAN (Model of Emissions of Gases and Aerosols from Nature) (Guenther et al. 2006). Models like MEGAN in general rely on locations of the sources. Similarly, pollen emission models rely on the location

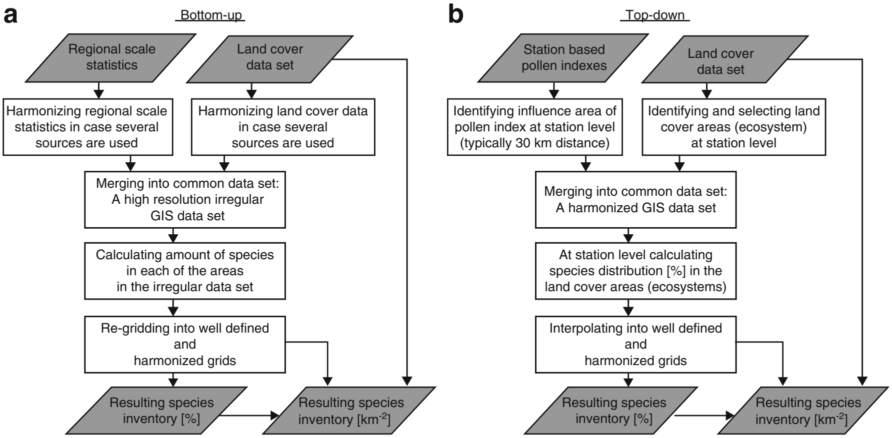

Fig. 2.1 Bottom-up (**a**) and top-down (**b**) approaches for making species inventories for allergy-related plants (see text for description)

of allergenic pollen sources. The location of allergenic pollen sources can be used by aerobiologist in explaining measured levels of pollen concentrations (e.g. Skjøth et al. 2009) as well as in the daily advice of allergenic sufferers on a local scale or recommendations with respect to travelling in between countries (Nillsson and Spieksma 1994).

Predictions of atmospheric concentrations of pollutants are in general carried out using mathematical models. New types of models for allergenic pollen are source-orientated models that have recently been introduced in aerobiology (Helbig et al. 2004; Pasken and Pietrowicz 2005; Schueler and Schlünzen 2006; Skjøth 2009; Sofiev et al. 2006; Vogel et al. 2008). These models use mathematical formulae of atmospheric transport and diffusion to calculate concentrations at various distances from a known source or release site. The character of the source is typically based on an inventory (Fig. 2.1), which can be constructed using bottom-up approaches (Sect. 2.2) or top-down approaches (Sect. 2.3).

The emission inventories are considered among the biggest uncertainties in the application of transport models (Russell and Dennis 2000), and it has been shown that dedicated focus on the inventories and the corresponding release mechanisms (Gyldenkærne et al. 2005) can significantly improve model results and understanding (Skjøth et al. 2004, 2011). In comparison to chemical air pollutants, very limited work has been done with respect to localization and inventorying the sources of allergenic airborne pollen. D'Amato et al. (2007) included information on general pollen source distribution in review concerning allergenic pollen and pollen allergy in Europe. But gridded inventories of allergenic pollen sources are very rare compared to their counterparts in chemical air quality. Additionally, making inventories of pollen sources is a scale-dependent problem (Fig. 2.2) as observed by Skjøth (2009) who used different remote sensing products to identify tree-covered areas. Coarse-resolution data is usually easy to obtain and handle but also introduces a risk of losing valuable information (Fig. 2.2a).

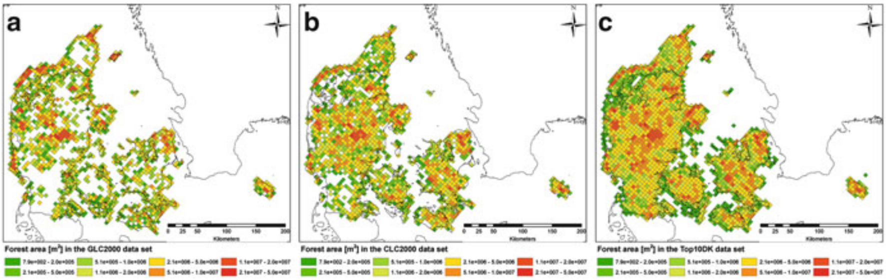

Fig. 2.2 Forest cover gridded to the DEHM-Pollen model domain using (**a**) GLC2000 (global), (**b**) CLC2000 (European) and (**c**) Top10DK(Danish) data sets resulting in 7, 9 and 13% forest cover of Denmark, respectively (Source: Skjøth 2009)

High-resolution data are much more demanding to obtain and analyse (Fig. 2.2c) but may also reveal that in some areas, the majority of sources cannot be identified by using coarse-resolution data. The focus of this chapter is to review what has been done in respect of inventories of airborne pollen sources by:

– Reviewing and discussing available data and methodologies that can be useful for production of pollen source inventories in Europe
– Presenting current knowledge on source locations of the 12 pollen types relevant to allergy
– Suggesting future research and directions for improvement of airborne pollen inventories

2.2 Methodologies for Making Bottom-Up Inventories and Their Application

Bottom-up inventories are typically produced by using statistical analysis of data with the respect to location and amount of the pollutant. For pollen-producing species, this includes location and amount within a given geographical area (Fig. 2.1a). Statistical data with respect to tree distribution and population abundance (in particular for olive, oak, alder and birch) can be obtained from forest inventories and crop databases. The statistical data are then aggregated by using a model – often a simple one – to some sort of gridded dataset. This aggregation also often uses additional information such as land cover information to upscale the distribution information to a larger geographical domain. This information is generally used in forest inventories (Forestry Commission 2001) and has at European scale been applied by Simpson et al. (1999), Köble and Seufert (2001) and Skjøth et al. (2008), where the latter is currently considered the most comprehensive and detailed inventory with respect to allergenic species from forest trees. A related source to land cover data is remote sensing data, either in its original form as digital images of the earth or analysed data such as the Corine Land Cover data set (European Commission 2005). Remote sensing data can typically be used for mapping of relevant ecosystems such as conifer or broadleaved forest but not for distinguishing between allergenic tree species (Table 2.1).

Table 2.1 Error matrix from a species-specific classification, including forest trees with allergenic pollen

Region/class	Ash	Sycamore	Birch	Beech	Oak	Conifers	Other	Sum	Producer acc
Ash	16	2	11	1	1	0	0	31	51.6
Sycamore	5	50	13	10	1	0	0	79	63.3
Birch	7	26	29	1	0	2	0	65	44.6
Beech	26	87	32	235	75	4	0	459	51.2
Oak	0	9	5	49	461	22	0	546	84.4
Conifers	2	1	1	2	39	644	1	690	93.3
Other areas	0	0	0	0	0	0	200	200	100.0
Sum	56	175	91	298	577	672	201	2,109	
User acc	28.6	28.6	31.9	78.9	79.9	95.8	99.5		

Based on results from Bonde (2009) by using the SPOT5 satellite over a well-defined forest area in Denmark

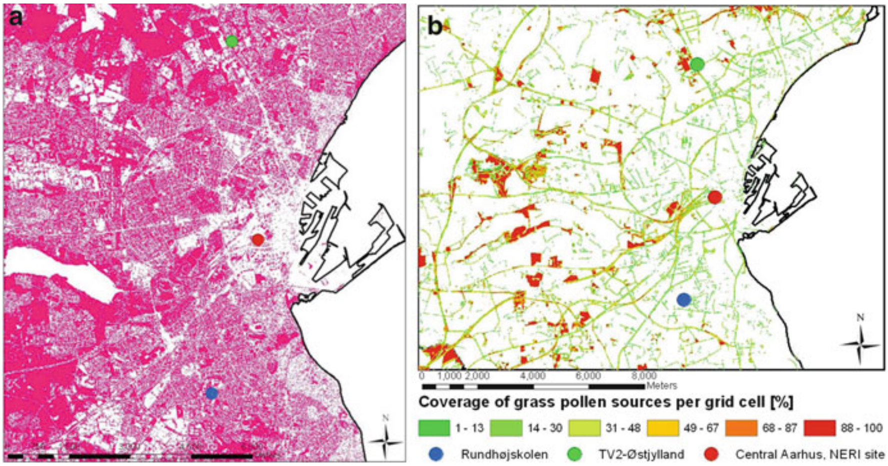

Fig. 2.3 (**a**) Very high-resolution RS image over the city of Aarhus showing grass locations (*pink*) and location of three pollen traps for grass pollen analysis. (**b**) Gridded inventory of grass flowering areas over the city of Aarhus and location of three pollen traps (Source: Skjøth et al. 2010a)

Remote sensing can also be used for mapping ground-based vegetation such as grass areas (Skjøth et al. 2010a), but here, the limitation is that a large fraction of these areas are crops or grass areas that are regularly cut and therefore do not flower. Therefore, management schemes and crop databases can be used in combination with remote sensing in order to identify possible grass flowering areas among the ground-based vegetation (Fig. 2.3).

Finally, *Olea* is a special case as this species is an important crop in Europe with the majority of the trees being located in olive groves, with geographically known locations. The location of these olive groves can with high detail be identified on the

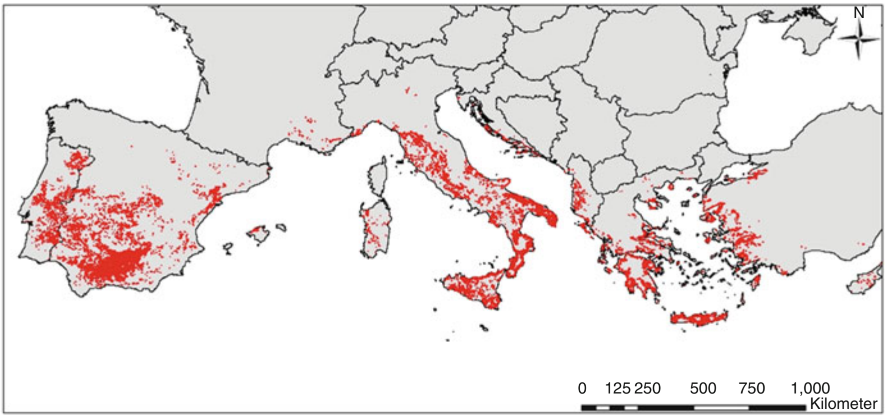

Fig. 2.4 Location of olive groves (*red*) in Europe from the CLC2006 data set

pan-European Corine Land Cover data set CLC2000 (Fig. 2.4) and must therefore be considered the pollen source with the highest accuracy with respect to distribution and amount.

Other sources of airborne pollen such as *Platanus*, Cupressaceae and *Corylus* are to a large degree ornamentals and present in a very limited degree in the main European forests. For these species statistical distribution information, in particular regional scale, are not available. Similarly, statistical information concerning abundancy and distribution for weeds are hardly available. Information can be obtained from sources such as Flora Europaea (Tutin et al. 1964) and the Nobanis network (http://www.nobanis.org/), but these sources deal with presence/absence of plants and not their abundance which makes these sources of limited use for making bottom-up inventories. In addition, Flora Europaea gives plant distribution information on a country-based scale, leading to generalization even in countries with obvious biogeographic diversity such as France, Germany and Switzerland. Usage of local Floras can help overcome this scaling problem, but such publications are unavailable for many areas and are often out of date. Bottom-up inventories for all 12 pollen species do therefore not seem likely to be obtained at a European scale within the near future.

2.3 Methodologies for Making Top-Down Inventories

Conversely to bottom-up approaches, top-down approaches often use a measured quantity as a starting point and then a backwards calculation method for estimating the geographical distribution of the species of interest (Fig. 2.1b). In aerobiology, this information can be obtained from basic results in aerobiology, such as pollen calendars or studies including source-receptor analysis (Peternel et al. 2005). This approach may be aggregated to European scale (Nillsson and Spieksma 1994) on a very coarse resolution using main biogeographical regions such as central Scandinavia or take more advanced methods into account such as land cover information and knowledge of preferred habitats for specific species (Skjøth et al. 2010b). The most widely covered database of information with respect to allergenic species

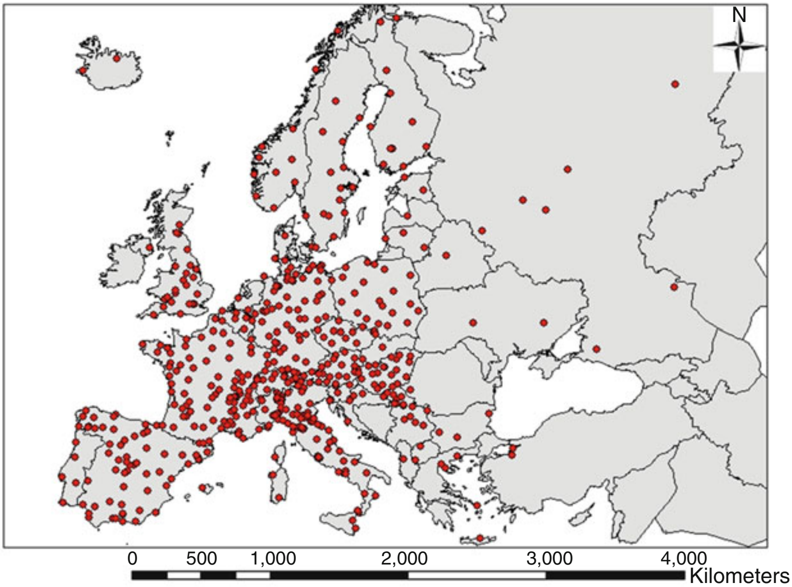

Fig. 2.5 Location of the 521 EAN stations used in the production of the distribution maps (Figs. 2.6, 2.7, and 2.8)

is the European Aeroallergen Network (EAN), which has measured airborne pollen and calculated annual pollen indexes for all 12 allergenic pollen species at 257–521 different stations in Europe (Fig. 2.5 and Table 2.2).

Here, a simple approach by using the average pollen index of all available annual indexes for the period 2000–2009, simple interpolation between the stations (up to 400 km), buffer zones of 200 km and presence/absence information in Flora Europaea is used to summarize species distribution and abundance according to the European Aeroallergen Network. Additionally, the typical habitat is listed, and the EAN distribution is compared with available large-scale inventories that include geographical coverage and abundance of the species.

2.4 Top-Down and Bottom-Up Information Concerning the 12 Most Allergenic Pollen Types

2.4.1 Alnus

Ecological preference: Consists of mainly five species in Europe, where *Alnus incana* and *Alnus glutinosa* are the most common. According to Flora Europaea (Tutin et al. 1964), the species are present in most of Europe, and typical habitats are forest, woodlands and especially for *Alnus glutinosa* wet areas, such as in bogs and streams, where few other species will survive.

Table 2.2 Pollen species, number of data stations with data for each species and coverage of distribution maps (above 20 grains), maximum and mean value in the maps

Taxon	Number of stations	Land area covered [km^2]	Max	Mean
Alnus	468	5,602,964	8,055	1,048
Ambrosia	368	2,974,812	14,590	697
Artemisia	471	5,604,016	2,287	245
Betula	461	6,005,064	32,708	3,782
Chenopodiaceae	430	4,847,776	3,013	211
Corylus	457	5,033,640	3,239	398
Olea	257	1,911,564	51,094	1,253
Platanus	402	3,516,256	23,352	1,084
Poaceae	521	6,171,880	12,353	2,502
Quercus	440	5,272,036	19,587	2,011
Taxaceae + Cupressaceae	430	4,624,496	36,442	3,064
Urtica + *Parietaria*	471	5,593,080	68,652	4,128

Top-down approach from EAN (Fig. 2.6a): 468 stations have reported pollen indexes with an average of up to 8055. The geographical area is most of Europe from Scandinavia to central Spain and Italy. Data coverage ends in Russia, Ukraine, Romania and Turkey. Highest densities are found in the Boreal region including Poland, Lithuania, Latvia, Estonia, Belarus, Russia and Finland.

Comparisons to bottom-up information: The European scale inventory by Skjøth et al. (2008) suggests *Alnus* coverage over most of Europe from Norway/Finland to central Spain and southern Italy as well as significant coverage in Belarus, Ukraine and Russia in the east. Highest densities are found in the Boreal region from Poland, Lithuania, Latvia and Estonia and medium density in parts of Germany and most of Scandinavia.

2.4.2 Ambrosia

Ecological preference: One native (*A. maritima*) and four naturalized (*A. artemisiifolia*, *A. coronopifolia*, *A. trifida*, *A. elatior*) species could be considered as source of *Ambrosia*-type airborne pollen. *A. maritime* inhabits marine sands of the Mediterranean region, while others prefer riparian and ruderal habitats often colonizing agricultural fields (Hansen 1976).

Top-down approach from EAN (Fig. 2.6b): 368 stations have reported pollen indexes with an average up to 14,590. The geographical area is Central and Eastern Europe ranging from Germany/Poland to Italy and Greece. Highest densities are found in the Carpathian Basin and a few hotspots in the Po (Italy) and Rhone (France) valleys, respectively. There is limited data coverage in Russia and Ukraine, but the measurements suggest peak concentrations in some areas of Ukraine.

Comparisons to bottom-up information: N/A

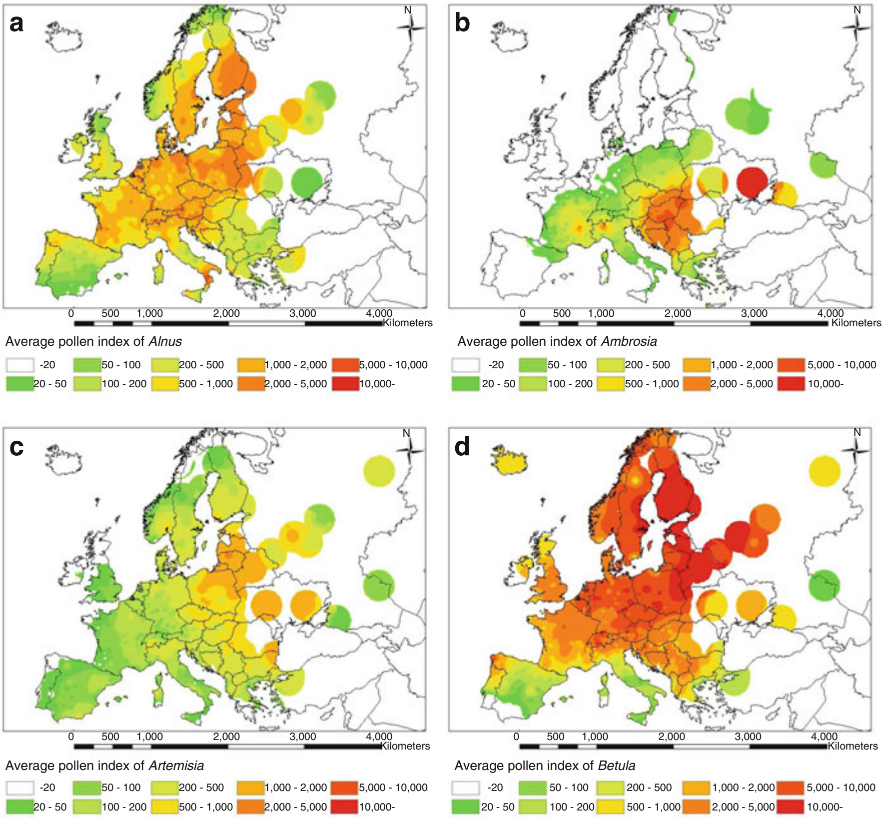

Fig. 2.6 (**a–d**) Average annual pollen index at EAN stations (Table 2.2) based on bilinear interpolation between stations, a maximum distance of 200 km to each station and Flora Europaea to determine presence on national scale

2.4.3 Artemisia

Ecological preference: Numerous species (57) belonging to the genus *Artemisia* are a source of the *Artemisia* airborne pollen type all around Europe (Tutin 1976). The most common species of *Artemisia* in Europe are *A. vulgaris*, *A. annua* and *A. verlotorum* which grow mainly in Southern Europe. All of these are present both in urban and suburban areas (D'Amato et al. 2007).

Top-down approach from EAN (Fig. 2.6c): 471 stations have reported pollen indexes with an average up to 2,287. The geographical area is most of Europe from central parts in Scandinavia to southern Spain and Italy. Highest densities are found in Poland, Lithuania, Latvia and Ukraine and medium densities in Czech Republic, Slovakia, Hungary, Serbia and Romania.

Comparisons to bottom-up information: N/A

2.4.4 *Betula*

Ecological preference: *Betula* airborne pollen in Europe originates from four native species (*B. pubescens*, *B. pendula*, *B. humilis*, *B. nana*) and two non-native species (*B. papyrifera*, *B. utilis*) often planted as ornamentals (Walters 1993).

Top-down approach from EAN (Fig. 2.6d): 461 stations have reported pollen indexes with an average up to 32,708. The geographical area is most of Europe from Scandinavia to central Spain and Italy. Data coverage ends in Russia, Ukraine, Romania and Turkey. Highest densities are found in the Boreal region including Poland, Lithuania, Latvia, Estonia, Belarus, Russia and Finland.

Comparisons to bottom-up information: The European scale inventory by Skjøth et al. (2008) suggest *Betula* coverage over most of Europe from Scandinavia to central Spain and southern Italy as well as significant coverage in Belarus, Ukraine and Russia in the east. Highest densities are found in the Boreal region from Lithuania, Latvia and Estonia and medium density in parts of Germany and Poland.

2.4.5 *Chenopodiaceae*

Ecological preference: The majority of species are halophytes or ruderals preferring marine habitats, steppe and semi-desert regions (Edmondson 1993). The most widespread species are considered weeds, but there are also agricultural crops such as sugar beet.

Top-down approach from EAN (Fig. 2.7a): 430 stations have reported pollen indexes with an average up to 3,013. The geographical area is Europe excluding most of Scandinavia and the British Isles. Highest densities are found on the Iberian Peninsula and Eastern Europe including the Czech Republic, Slovakia and the countries in the Carpathian Basin.

Comparisons to bottom-up information: N/A

2.4.6 *Corylus*

Ecological preference: Three species (*C. avellana*, *C. colurna*, *C. maxima*) are the source of the *Corylus* pollen type. Although all grow naturally in Europe, many are planted as ornamentals or in nut production fields (Tutin 1993).

Top-down approach from EAN (Fig. 2.7b): 457 stations have reported pollen indexes with an average up to 3,239. The geographical area is most of Europe from Scandinavia to central Spain and Italy. Data coverage ends in Russia, Ukraine, Romania and Turkey. Highest densities are found in Central Europe, especially the Alpine region in France, Switzerland and Austria.

Comparisons to bottom-up information: N/A

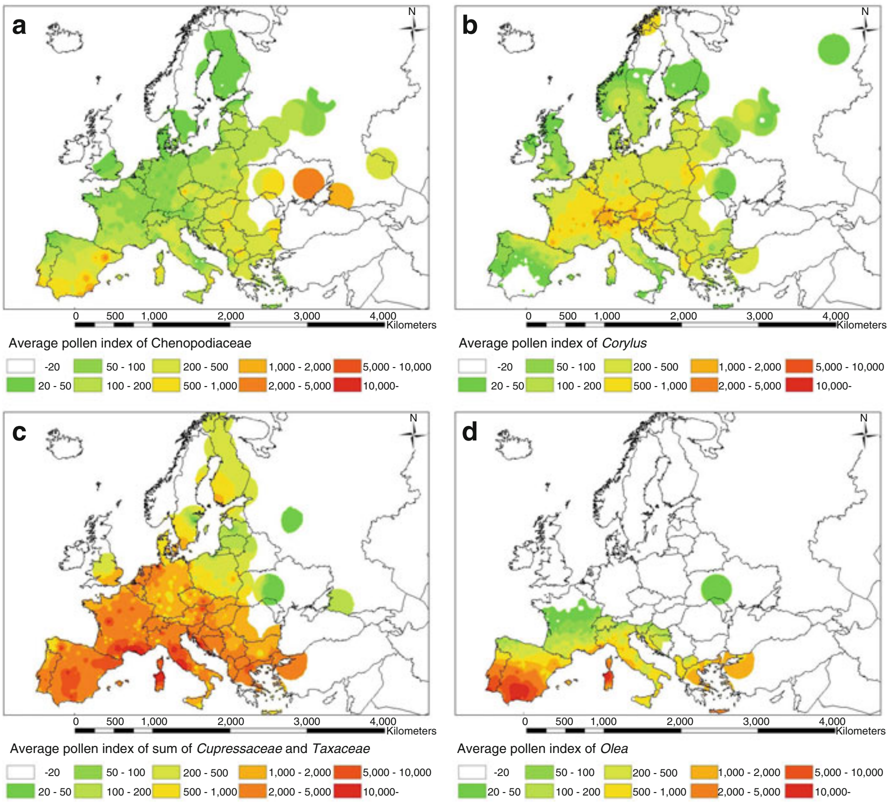

Fig. 2.7 (**a**–**d**) Average annual pollen index at EAN stations (Table 2.2) based on bilinear interpolation between stations, a maximum distance of 200 km to each station and Flora Europaea to determine presence on national scale

2.4.7 Cupressaceae/Taxaceae

Ecological preference: One species (*Taxus baccata*) classified in the Taxaceae family and numerous species classified into five genera (*Cupressus*, *Chamaecyparis*, *Juniperus*, *Thuja*, *Tetrachius*) of the Cupressaceae family produce this pollen type. The former grows naturally or is often planted as ornamental all around Europe except east and above 63° N (Moore 1993a). The latter are widely distributed with some being planted as ornamentals, for shelter or for timber (Moore 1993b).

Top-down approach from EAN (Fig. 2.7c): 430 stations have reported pollen indexes with an average up to 36,442. The geographical area is most of Europe from parts of Scandinavia to Spain and Italy. Highest densities are found in the western and southern parts of Europe, while relative low densities are found in the Boreal region.

Comparisons to bottom-up information: N/A

2.4.8 Olea

Ecological preference: Species *Olea europaea* and its cultivar variety are considered as the only source of this pollen type in Europe. The species naturally inhabits dry and rocky places of the Mediterranean region and also at Krim peninsula. *O. europaea* is introduced to southern Switzerland (do Amaral Franco and da Rocha Afonso 1972).

Top-down approach from EAN (Fig. 2.7d): 257 stations have reported pollen indexes with an average up to 51,094. The geographical area is limited to Southern Europe, mainly below the Alpine region. Highest densities are found in southern Spain, and lowest densities are found in central France and areas in the Carpathian Basin with data coverage.

Comparisons to bottom-up information: The CLC2006 data set (Fig. 2.2) with location of olive groves suggests highest densities in southern Spain, Portugal and Italy. Most easterly parts are found in western parts of Turkey, and most northern parts are found in Croatia, France and Italy.

2.4.9 Platanus

Ecological preference: *Platanus* airborne pollen sources in Europe are *P. orientalis* and *P. acerifolia*. Natural habitats are damp woods and streamsides, but both species are commonly planted in much of Europe as roadside trees (Tutin and Edmondson 1993).

Top-down approach from EAN (Fig. 2.8a): 402 stations have reported pollen indexes with an average up to 23,352. The geographical area is most of Europe from parts of Scandinavia to central Spain and Italy. High densities are found in a number of isolated locations near certain large urban areas such as London, Madrid, Milano and Vienna, respectively.

Comparisons to bottom-up information: N/A

2.4.10 Poaceae

Ecological preference: Pollen of this type originates from numerous ubiquitous species (Tutin 1980) that inhabit both natural and artificial grasslands. In addition, many species are cultivated as wheat in agriculture.

Top-down approach from EAN (Fig. 2.8b): 521 stations have reported pollen indexes with an average up to 12,353. The geographical area is Europe and the largest of all pollen species. Data coverage is limited in Belarus, Russia, Ukraine, Romania and Turkey.

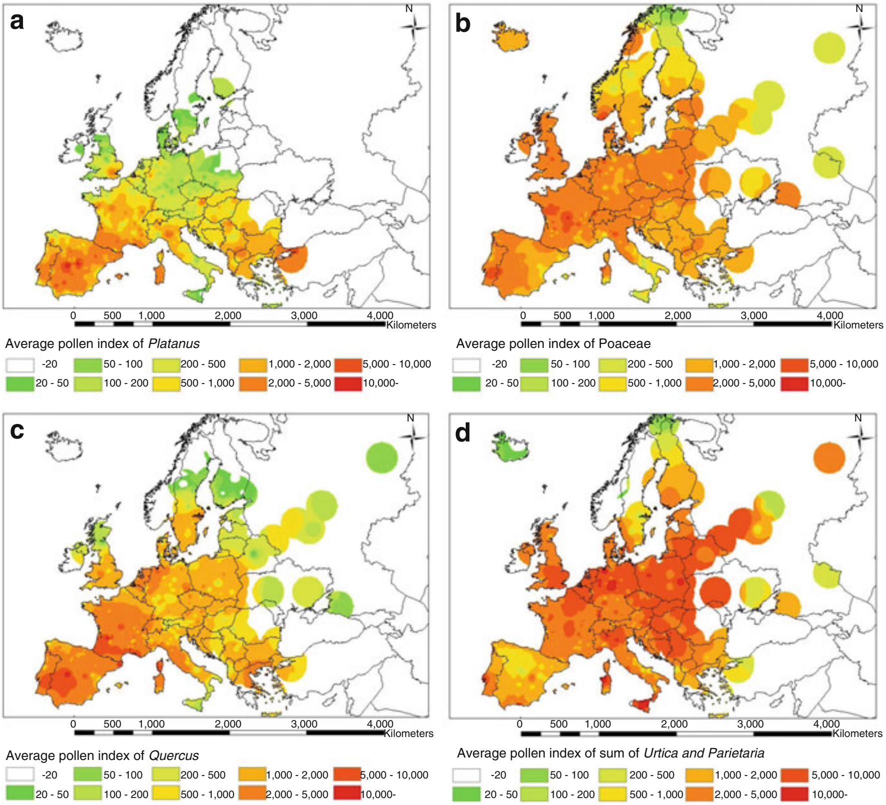

Fig. 2.8 (**a**–**d**) Average annual pollen index at EAN stations (Table 2.2) based on bilinear interpolation between stations, a maximum distance of 200 km to each station and Flora Europaea to determine presence on national scale

Highest densities are found in a relatively large area from Denmark and the British Isles in the North to the Iberian Peninsula and central Italy.

Comparisons to bottom-up information: N/A

2.4.11 Quercus

Ecological preference: Airborne pollen originates from a number of species (22) distributed all around Europe (Schwarz 1993).

Top-down approach from EAN (Fig. 2.8c): 440 stations have reported pollen indexes with an average up to 19,587. The geographical area is most of Europe from central Scandinavia to southern Spain and Italy. Highest densities are found in southern France and Spain and medium densities in most of Europe from southern Sweden and England in the North to central Italy and Greece in the South.

Comparisons to bottom-up information: The European scale inventory by Skjøth et al. (2008) suggests *Quercus* coverage over most of Europe from southern Sweden in the North to Spain in the South. Additionally, this inventory is divided into species such as *Quercus rubra*, *Q. petraea*, *Q. suber*, etc.

2.4.12 Urtica/Parietaria

Ecological preference: Airborne pollen originates from species classified in two genera *Urtica* and *Parietaria*. The most important are *U. dioica* (Ball 1993) and *P. judaica* that is widespread in ruderal rocky habitats (Ball 1993).

Top-down approach from EAN (Fig. 2.8d): 471 stations have reported pollen indexes with an average up to 68,652. The geographical area is most of Europe from parts of Scandinavia in the North to Spain and Italy in the South. Data coverage ends in Russia, Ukraine, Romania and Turkey. Highest densities are found in a relatively large area in Central Europe including southern England, Belgium, the Netherlands, parts of Germany and Poland. Relatively low densities are found in parts of Scandinavia, Spain and South-eastern Europe.
Comparisons to bottom-up information: N/A

2.5 Overall Conclusions

In general very little is known about location of pollen sources. Most well known are the location of tree species such as *Olea*, *Quercus*, *Alnus* and *Betula*. Here, *Olea* is a special case, as the majority of *Olea* trees are found in olive groves that are mapped with high detail in Europe (Fig. 2.4). *Alnus*, *Betula* and *Quercus* have been mapped using both top-down methods in the EAN (Figs. 2.6a, d, 2.8c) and bottom-up methods (Skjøth et al. 2008). On a European scale, the distribution and density of these three species is very similar, but on a regional to local scale such as over the UK, the differences can be significant.

The remaining species *Ambrosia*, *Artemisia*, Chenopodiaceae, *Corylus*, Cupressaceae, *Platanus*, Poaceae, and *Urtica/Parietaria* have only been mapped with respect to abundancy on a European scale using the top-down approach in the EAN (Figs. 2.6b, c, 2.7a, b, c, 2.8a, b, d). Other inventories such as the NOBANIS (North European and Baltic Network on Invasive Alien Species) network only register presence/absence. At a regional scale, *Ambrosia* has recently been mapped in the Carpathian Basin using an ecosystem-based approach in combination with airborne pollen data and detailed land cover data (Skjøth et al. 2010b). This methodology is likely to be applicable in other regions as well as for other species such as *Artemisia* and *Platanus*, where typical ecosystems can be identified in European scale land cover data sets such as the Corine Land Cover. Other species such as Chenopodiaceae, *Corylus* and *Cupressaceae*, Poaceae and *Urtica/Parietaria* can

Table 2.3 Satellite relevant for mapping of allergenic species on local, regional or European scale, the main properties and availability. "–" without ending means that the satellite is still active

Satellite/instrument	Resolution at nadir	Period	Bands (n)	Swath	Accessibility
Landsat 1–3	79	1972–1983	4	185 km	Free
Landsat 4	30 m	1982	6	185 km	Free
Landsat 5	30 m	1984	6	185 km	Free
Landsat 7/ETM+	15	1999–2003!	6	183 km	Free
NOAA AVHRR	1.1 km	1981–	5	2,500 km	Free
SPOT1	10 m /20 m	1986–1990	1/3	60 km	Free*
SPOT2	10 m /20 m	1990–	1/3	60 km	Free*
SPOT3	10 m /20 m	1993–1997	1/3	60 km	Free*
SPOT4	20 m	1998–	1/3	60 km	Free*
SPOT5	2.5 m/10 m	2002–	1/3	60 km	Free*
Terra (ASTER)	15/30/90	1999–	15	2,330 km	Free
IRS-P6	5.8/23	2003–	1/4	23/141 km	Free*
IKONOS	0.8 m/3.2 m	1999–	1/4	11 km	Commercial
KOMPSAT-2	1 m/4 m	2006	1/4	15 km	Commercial/free*
ENVISAT/MERIS	300 m	2002–2012	15	1,150 km	Free*
GeoEye-1	0.4/1.6	2008	1/4	15 km	Commercial
Formosat-2	2 m/8 m	2004–	1/4	24 km	Commercial/free*

Free*: Available free from the European Space Agency for Category-1 users at www.esa.int or through simple registration

Free: Available free on the internet through Warehouse Inventory Search Tool (WIST), https://wist.echo.nasa.gov/wist-bin/api/ims.cgi?mode=MAINSRCH&JS=1

most likely also be mapped by using an ecosystem-based approach, but it is also likely that the approach then needs an improvement in methods, as the pollen observations in the EAN from several of these species originate from a number of different species with different pollen production and different ecological preference.

Remote sensing has recently been introduced as an additional source of information for mapping of allergenic species. Its use is promising and has by far been explored enough. Nevertheless, existing use of remote sensing has already shown two major limitations. (1) Satellites need at least four channels (3 colour and one near infrared) for a good identification of different types of vegetation but are still not able to distinguish plants and trees at the species level (Table 2.1), which means that satellite products need additional information such as statistics of species distribution in forests or similar ecosystems that can be observed from space. (2) Satellites need medium- to high-resolution spatial coverage in order to correctly identify the majority of the sources over Europe. Pre-calculated global data sets like the GLC2000 (Bartalev et al. 2003; Fritz et al. 2003) do not meet that criteria. The Corine Land Cover or related data sets like Image2000 or JRC forest cover (Schuck et al. 2003) are likely to meet this criteria in most countries. Higher resolution than the CLC2000 data set or JRC forest cover is desired in some areas and required in case the major source is found in urban areas such as the KOMPSAT-2 satellite or commercial satellites like Quickbird satellite (Table 2.3).

In the year 2013, the ESA (European Space Agency) will launch the first of a pair of Sentinel-2 satellites. This pair of satellites is very well designed for the needs in mapping allergological relevant species as they combine a high revisit time, high spatial resolution and multispectral imagery (13 bands) that are well designed for mapping vegetation. This suggests that aerobiology and the mapping of the relevant species can be advanced significantly today by using existing remote sensing products and that these possibilities will be further improved within the next few years.

Overall, the EAN data set is the largest and, for a number of pollen relevant plant species, also the only large-scale data set for mapping abundancy such as *Urtica* and Chenopodiaceae, and Figs. 2.6, 2.7, 2.8 are examples of how distribution maps can be produced (see summary in Table 2.2). However, this methodology also has four obvious limitations. (1) Station coverage is highly variable (Fig. 2.5 and Table 2.2) with some stations having observations during the entire period while others only for 1 year. This means that the distribution maps have a solid database in Central Europe, while other areas such as Eastern Europe have very limited or no data coverage. (2) The applied size of buffer zones can also be questioned. Data from pollen traps is a point measurement, and the introduction of a buffer zone where interpolation and data coverage is valid will introduce an error. It is not known how large this error is. (3) The database will be subject to errors in the data reporting or misclassification of the pollen grains in the microscope. (4) The pollen traps capture pollen within an area, which will be affected by amounts of plants, geographical variation in pollen production and atmospheric transport. One of these four limitations might be the reason to certain high-density hotspots seen in southern Italy for *Alnus* (Fig. 2.6a) or low-density areas seen in Scandinavia for *Betula* (Fig. 2.6d). Another example is the distribution map for *Olea*. In these maps, Hungary is white despite pollen counts of *Olea* being registered in the EAN database. These registrations could potentially be a misdetermination with *Ligustrum* pollen, or the pollen could originate from olives growing in pots because according to Flora Europaea, olive trees are not present in Hungary. Similarly, the Spanish network by definition does not upload *Ambrosia* observation to the EAN data, although measurements indicate small quantities of *Ambrosia*, which is also supported by Flora Europaea, which suggests a presence of *Ambrosia* in Spain. Similarly, the use of buffer zones and interpolations shows *Olea* distribution in Switzerland because Flora Europaea suggests olive trees in Switzerland. As such, these examples show the limitation of this very simple method for making distribution maps. Remote sensing products have been proven as a valuable tool for additional information for mapping pollen species. Many regional scale products are freely available from these satellites, including the Corine Land Cover (Landsat satellite), Globcover (Envisat Satellite) or the GLC2000 (SPOT satellite) or more detailed products such as the JRC forest mapping (Landsat satellite) (Schuck et al. 2003): http://forest.jrc.ec.europa.eu/forest-mapping or the Urban Atlas (SPOT 5): http://www.eea.europa.eu/data-and-maps/data/urban-atlas. However, better information over a specific area can usually be obtained by detailed analysis of remote sensing pictures that are used to produce data sets such as CLC2000 data set (Schuck et al. 2003) or other similar products. However, remote sensing can so far not be used as a stand-alone product for mapping sources on the species level. Remote sensing products (CLC2000, Image2000, etc.) need additional information such as highly detailed ground-based statistics (e.g. Skjøth et al. 2008) in order to apply bottom-up approaches for making inventories. These inventories will then be limited by the geographical coverage of the region with statistics, which means that a large uncertainty will be present in regions such as Ukraine and relatively small in sub-national regions of the UK or Denmark. Most medium to coarse-scale resolution remote sensing images can be obtained free of charge (Table 2.3), while high-resolution satellites such as Quickbird or Ikonos are commercial. These satellites are usually used for dedicated urban scale investigations and are well designed for identifying ornamentals trees including *Platanus*, *Betula* and Cupressaceae. A recent possibility for urban scale mapping – in case allergenic plants are available – is the Kompsat-2 satellite. Kompsat-2 is a high-resolution satellite, and images over a large amount of European cities can be obtained free of charge through Category-1 proposals with the European Space Agency. This possibility however remains to be explored. Finally, remote sensing products can also be used on the large scale in combination with pollen indexes in order to apply top-down approaches for an ecosystem-based method for mapping location of pollen species in Europe (Skjøth et al. 2010b). This methodology will however still be limited by trap coverage and the fact that the local pollen index is influenced by variations in pollen production and atmospheric transport. Nevertheless, the methodology possess a significant potential for detailed mapping of all major pollen species with high detail over Europe including those that be mapped cannot using bottom-up approaches due to insufficient information.

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