

Applied palynology as a trans-disciplinary science: the contribution of aerobiology data to forensic and palaeoenvironmental issues

Anna Maria Mercuri

Received: 4 August 2014 / Accepted: 16 January 2015
© Springer Science+Business Media Dordrecht 2015

Abstract The paper provides examples of integrated researches putting aerobiology at the centre of methodological approaches of applied palynology. Data from airborne pollen monitoring have demonstrated to be useful to obtain inferences about different environmental issues. For example, seasonality is fruitfully investigated with the help of pollen calendars. The close connection that may exist between aerobiology and forensic palynology is demonstrated by a study on airborne pollen with cytoplasm trapped by corpses; pollen calendars may be a reference tool for establishing the season of death in case of murders or other crimes. Palaeoclimate research can obtain fruitful information from studies on long-distance transport and the comparison of past spectra with the representativeness of pollen in modern spectra. Modern pollen monitoring suggests that the long-distance transport may be a routine (as *Alnus viridis* in the southern Po Valley) or an episodic event; the very local geomorphological and phytogeographical peculiarities of a given area must be known to interpret pollen spectra. The pollen produced by trees that have had a fundamental importance in our cultural development (*Prunus*, *Olea* and *Castanea*) is among the most interesting archaeobotanical topic to understand the

relationship between humans and environmental resources. Sometimes, data cannot be compared because yearly sums and percentages of one taxon on the total pollen counts are not commonly reported in the aerobiological literature. Finally, the decline in *Taxus* pollen in a warming climate is reported among the case studies that illustrate the relevance of the aerobiological research to interpret past climate records and to study long-term climate changes.

Keywords Pollen calendar · Seasonality · Long-distance transport · Cultural trees · Palaeoenvironment · Climate change

1 Introduction

Palynology is a trans- and inter-disciplinary science. The basic research on botanical taxonomy, phylogeny, reproductive biology and phenology regards pollen as the object of biodiversity and evolutionary studies (Erdtman 1969), and the male gametophyte is analysed per se.

Conversely, the applicative research focuses on other issues, and pollen is used to measure environmental variables including the quality of food and air (e.g. Fægri and Iversen 1989; Loveaux et al. 1978; Frenguelli and Mandrioli 1990, respectively). Therefore, a gap exists between the research *on pollen* as an object (basic palynology) and the research *with pollen*

A. M. Mercuri (✉)
Laboratorio di Palinologia e Paleobotanica, Dipartimento
di Scienze, della Vita Università di Modena e Reggio
Emilia, Viale Caduti in Guerra 127, 41121 Modena, Italy
e-mail: annamaria.mercuri@unimore.it

as a measurement tool (applied palynology). Nevertheless, research and applicative analyses have a common framework thanks to the specific pollen morphology and the tremendous decay-resistance of pollen wall. Pollen morphology, upon which all the analyses are based, is the deep link between the fields of palynology, while quantitative analysis is applicable to almost all outputs.

Applied palynology may be further distinguished into a large set of applications that deal with the seasonality and airborne transport, botanical and geographical origin of plant sources, weather and climate changes, environmental transformations and palaeoecology. Together with archaeobotany, which includes analyses of all plant remains from archaeological sites, palynology studies dynamics of the long-term relationships between culture and nature. Continuous land use and resource exploitation brought to the development of cultural landscapes; by definition, these landscapes are at the base of tangible and intangible heritage of our civilization (Birks 2012; Mercuri 2014). By applying ‘ecological criteria’ to the reconstruction of past cultural landscapes, palynology may be used as a sophisticated tool for identifying the human influence and impact in diachronical sequences (Mercuri et al. 2010). As expression of a microscopical biodiversity, palynology has an important role in assessing floristic richness and naturalness against human-driven environmental changes. At the final end, palynology is important to study past and present climate and landscape transformations at times of global change (e.g. Mercuri et al. 2015 and references therein).

The links between the fields of applied palynology are important to solve queries about pollen presence and abundance in palaeoenvironmental reconstructions, taphonomy and interpretation of archaeological layers, allergy and air quality in urban and rural areas, biomonitoring and trajectories of pollutants or plant diseases, phytogeography and natural products and in a number of investigations conceptually very different from each other (Dimou 2012; Frenguelli 1998; Hernández-Ceballos et al. 2011; Sadori et al. 2013a; Seijo and Jato 2001; Seppä 2013; Šikoparija et al. 2012; Tonelli et al. 1990; Velasco-Jiménez et al. 2014; Ziello et al. 2012). There is agreement that interdisciplinary is a good approach to obtain veritable environmental inferences. However, practical and theoretical barriers sometimes limit the scientific

debate between the ‘palaeo’ and ‘actuo’ palynologists. These barriers include, for example, the different expertise (e.g. geologists vs. biologists), the main field of project applications (e.g. palaeoclimate vs. air quality forecasting) or the preservation state of the pollen under study (fossil/sub-fossil vs. fresh, i.e. absent or present cytoplasm).

For these and other interconnected reasons, the integration between past and present pollen assemblages is negligible. From one hand, in fact, analyses of modern surface samples are fairly common. They include the study of topsoil and mosses, which trap pollen rain after its drop, sometimes also combined with vegetation survey (Mazier et al. 2008; Florenzano et al. 2015). A large body of the literature has been devoted to both pollen productivity estimates and airborne transport from plant sources into stratigraphical deposits (e.g. Relevant Source Area of Pollen: Broström et al. 2008; Hjelle and Sugita 2012). Large reference datasets become established that help palaeoenvironmental reconstructions based on surface pollen samples from China (Luo et al. 2010), Africa (Gajewski et al. 2002) and the Euro-Siberian and Mediterranean regions (Davis et al. 2013).

From the other hand, most of the available aerobiological literature seems ignored, and low is known on the possible applications of aerobiology to palaeoenvironmental research issues. Pollen studies exploiting data from both the surface sediments and air samples are virtually absent (but see below Luo et al. 2014). Properly, Fernández-Llamazares et al. (2014) have recently stressed the potential applications of airborne pollen monitoring to the conservation of plant diversity, a topic that classically may link palaeoecologists and ecologists (Mercuri et al. 2013a). Their synthesis reports on the monitoring of spread of invasive plants, the gene flow through pollen and vegetation response to climate change in high mountains. They also claim that aerobiology, which has proved to be a multidisciplinary science since its beginnings, is among the best sciences to face modern conservation management strategy. More focus on natural areas and on studies of historical pollen series in programmes of biodiversity conservation is needed (Fernández-Llamazares et al. 2014, p. 117).

As a further contribution to the debate about applications that aerobiology can supply to the other fields of palynology, this paper reports on cases where

data from airborne pollen monitoring were useful to obtain inferences about environmental issues. The examples are reported to underline the role that the study of airborne pollen and pollen calendars compilation may have in knowing more about pollen sources, transport and seasonality in pollen spectra. Pollen preservation and representativeness of plants are issues that deal with all the different samples taken from crime scenes, archaeological layers or sediment cores. The review aims at showing how the information obtained through pollen monitoring can be informative for environmental inferences in forensic sciences, archaeobotany and palaeobotany (Fig. 1).

2 Seasonality and pollen calendars: concepts relevant to forensic investigations

The importance of the principles of aerobiology is acknowledged in forensic palynology (Bryant 2009; Adams-Groom 2012), but there are only few examples of integrated studies.

Recently, a longitudinal study (25 years) on the possible association between atmospheric pollen and suicide risk in Denmark has found that a positive correlation between air pollen counts and suicidability

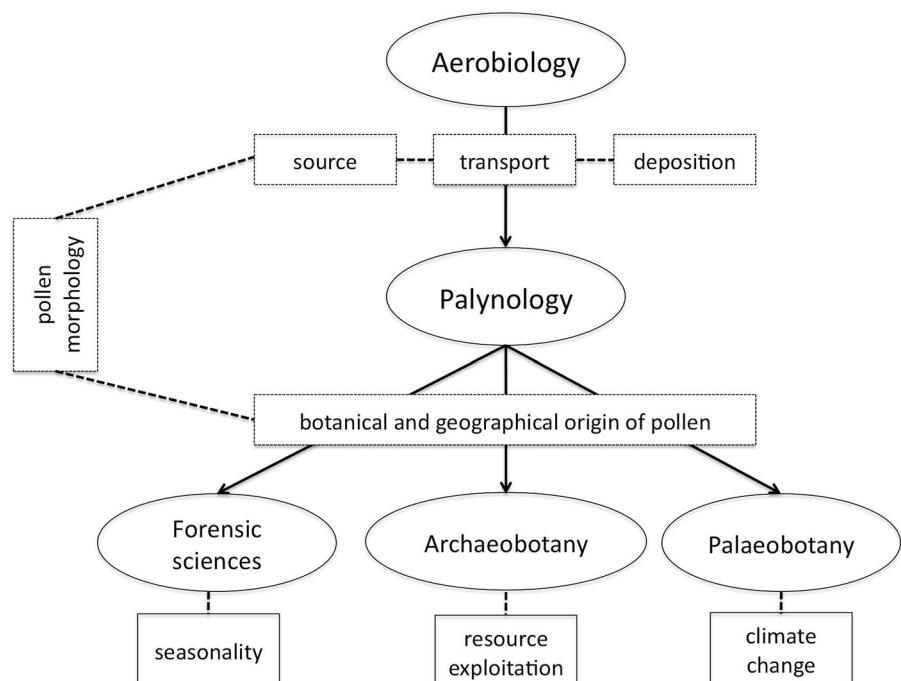
may be found leading to novel research directions (Qin et al. 2013).

Basically, plants have specific blooming periods that depend on the genotypes, phenology, age of individuals, geographical distribution and weather. Different species shed pollen at different months. Sometimes, anomalous pollen grains are released, and empty pollen (e.g. *Corylus*) can be found in slides from aerobiological monitoring. But usually, pollen preserves cytoplasm for some days, and artificial and natural spore traps largely capture fresh pollen grains.

Hair and body can act as spore traps. As people trap particles from the air they pass through, the pollen trapped in the last few days before their death is expected to prevail in the same way that experiments have demonstrated that, when mixing of pollen occurs at different sites, the pollen found in sediments from wearing footwear largely reflects pollen content of the last site (Riding et al. 2007). Therefore, the pollen trapped by hair and bodies in the last few days of life may be helpful for detecting the season of death.

This is significantly informative in case of palaeoforensic and forensic investigations (Snyder Sach 2001; Groenman-van Waateringe 2011; Bryant et al. 2012). In 1998, Henry Gee wrote in Nature News about ‘one of the rare instances in which pollen has

Fig. 1 Aerobiology and main relationships with palynology and related sciences



come to the aid of a murder investigation—a case, after the event, of saying it with flowers’ (Gee 1998). It reports on the research carried out by Szibor et al. (1998) who take ‘an unusual route to solve the gruesome riddle by looking up the victims’ noses’. In February 1994, 32 male skeletons were unearthed thanks to an archaeological excavation in a common grave in Magdeburg but the cause of this dramatic event was not known. Historical data put under suspicion two different groups: the Gestapo (Nazi forces) that had been in control of the area until 1945 and the Soviet forces that took over after that date. An analysis of pollen washed from the skulls revealed that the nasal cavities of corpses still contained high concentrations of pollen of *Plantago*, a weed that has pollination season in June and July. These months coincided with the season of the 1953 uprising in east Germany. Combined with other evidence from the bones and teeth, pollen ‘pointed an accusing finger at Soviet forces’. This is an example of link between archaeopalynology, forensic science and aerobiology.

Montali et al. (2006) carried out an experimental study to test pollen from corpses as indicator of the season of death. The research was based on the principle that human bodies may be spore traps. Pollen sampling was carried out on a total of 47 corpses transported to the morgue soon after the death at Parma, northern Italy. The investigation started on 19 corpses that were taken to the morgue in January–February 2003 and were studied to select points and techniques of sampling for pollen analyses (unpublished data). Coroner collected pollen from the facial skin, nasal cavities, eyebrows and hair. As these are exposed points suitable to trap particles from the air, corpses were found to have largely trapped pollen dispersed in the air at the last time before death. The pollen grains were well preserved and with cytoplasm showing they were fresh and not trapped after deposition on surface soils (Fig. 2). The state of preservation is, in fact, the basic character to establish that pollen is not ‘too old’ and that can be considered a good seasonal marker. A second step of sampling was carried out on other 28 corpses taken to the morgue in the period between June 2003 and May 2004. The pollen from these corpses was compared with the airborne pollen obtained from the monitoring stations located in the town and region. Based on pollen calendars, all the pollen grains from corpses were assigned to three main seasonal groups according to

the local aerobiological data (Fig. 3; see also Montali et al. 2006, p. 215):

- (A) Winter/spring pollen (from January to the first half of April): *Alnus*, *Carpinus*, *Corylus*, *Fraxinus*, *Juglans*, *Populus*, *Quercus*, *Ulmus* and *Taxus*;
- (B) Spring/summer pollen (from the second half of April–July): *Castanea*, *Picea*, *Pinus*, *Platanus*, *Robinia*, *Tilia* and *Papaver rhoeas* type;
- (C) Summer/autumn pollen (from August to December): *Humulus*, *Amaranthaceae*, *Apiaceae*, *Asteraceae*, *Mercurialis*, *Plantago*, *Rumex* and *Urticaceae*. Some pollen grains with low identification resolution were not attributed to a specific season because they are usually recorded and significant in more than one period (*Juniperus* type, *Brassicaceae*, *Fabaceae*, *Poaceae* and *Ranunculus* type).

The main results obtained from this experimental research are:

1. Human bodies may be efficient spore traps.
2. The quantity of pollen (pollen concentration) is not strictly season-related as many variables influence the pollen amount that may be found in the different cases and sampling points. Outdoor or indoor, urban or country, proximity to the plants and washing effects are only a few examples of the different frameworks that can influence the number of pollen grains recorded on corpses.
3. The quality of pollen (floristic list) gives information about the season: prevalent pollen types in a body—taken from the points exposed to the air—are prevalent or characteristic of one season of the region where the deaths occurred.
4. Airborne pollen calendars can help to compare the pollen on corpses, when it is found with cytoplasm and it is taken from the points exposed to the air, with pollen in the air to assess the time of death. This research encourages improving the consultation of the local pollen calendars—if available—in assessing reports.

Although the time of death is more precisely revealed, for example, by entomology (Bugelli et al. 2014; Vanin et al. 2013), pollen may couple with information with other inferences about the link between suspect/object and site/latitude in the case

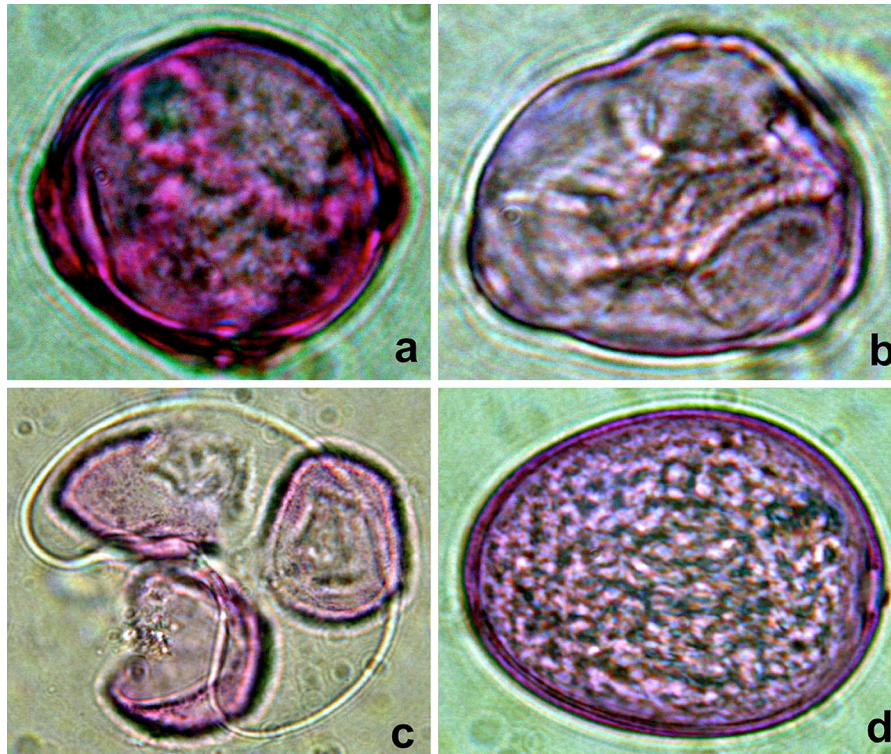


Fig. 2 Pollen with cytoplasm collected from corpses (unpublished cases): **a** *Alnus* (24 µm) from eyebrows, case 26-02-2003; **b** *Corylus* (22 µm) from nose, case 05-02-2003; **c** *Taxus*

(25 µm) from eyebrows, 21-01-2003; **d** *Poaceae* (35 µm) from eyebrows, 28-02-2003

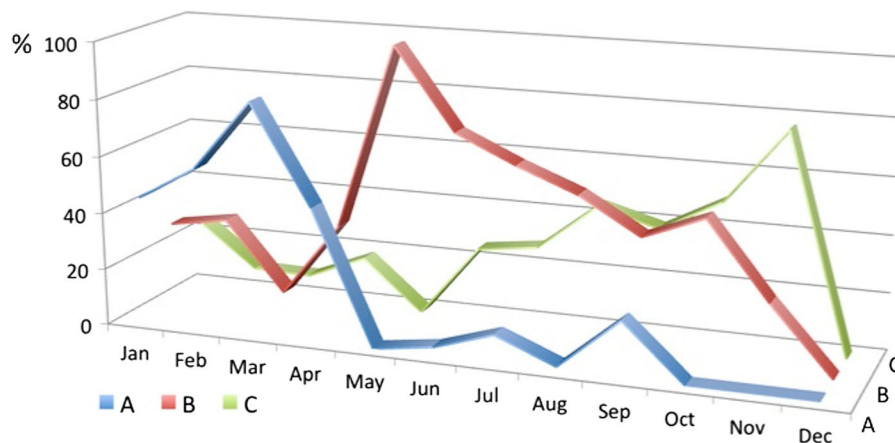


Fig. 3 Pollen calendar from corpses (pollen found on nose, eyebrows and face; Montali et al. 2006): corpses were taken to the morgue of Parma in different months (x-axis) corresponding to the known season of death; several pollen grains were found on each corpse; all the pollen grains found month by month (from one or more corpses, depending on the arrivals to the morgue) were grouped into three main seasons—A, B or C; these seasons were established on the basis of aerobiological monitoring data (station of Parma, in northern Italy); the

percentage of each seasonal group (y-axis) was calculated month by month. Curves show that pollen grains that are common in air during the period A (winter/spring) were especially found on corpses dead in March–April; those common in air during the period B (spring/summer) prevailed in the corpses dead in May–July, and those in the period C (summer/autumn) prevailed in corpses dead in August–November. The study was conducted in cooperation with the Scientific Investigation Unit—RIS of Parma

of travels and movements of persons or objects or substances in an area (Mildenhall et al. 2006).

Bryant (2009) states that ‘successful use of pollen and spores in forensic applications may depend on the palynologist’s knowledge and experience’. This should not be addressed only by including general botanical and geological issues. Once again, the composite approach performed by the exemplar cases reported in this paragraph demonstrates that experience in several fields of palynology may be useful to forensic palynologists because they have to face complex contexts. As any record (pollen sample, crime scene, research set) is unique, the more they know on palynology—including aerobiology—the more they can rely the analyses on a strong theoretical and methodological scientific background.

3 The long-distance transport and wind direction: some palaeoenvironmental implications

In their review on the current airborne global transport of desert dusts, Kellogg and Griffin (2006) stressed large dust events as mechanisms for transporting aerosolized microbiota—pollen, fungi and bacteria—around the globe. Pollen transport via Saharan dust from north Africa to south-western Spain (Cordóba) was argued from modern aerobiological studies (Cariñanos et al. 2004). In fact, *Cannabis*, *Cupressus*, *Pinus*, *Platanus* and *Sambucus*, which are non-native in the area, were exclusively detected during those days in which the dust clouds were present, and the airborne transport of *Cannabis* pollen from north Africa to south-western Spain was simultaneously detected in other airborne pollen monitoring stations in 1999.

Long-distance transport of pollen is a classical topic in the field of past and current pollen rain interpretations (Raynor et al. 1974; Mandrioli et al. 1982). In both studies on current and past pollen rain, alloctonous pollen is often interpreted as being included in sediments after long-distance atmospheric transport (*Casuarina* from Australia to New Zealand: Close et al. 1978; *Cedrus* from north Africa to central Mediterranean: Magri and Parra 2002). Reversely, the long-distance transport of *Pinus*, evergreen oak and broadleaved tree pollen from Mediterranean regions to central and southern Sahara has been repetitively demonstrated in past pollen records, sometimes

increasing during dry periods (e.g. Giresse 2008; *Artemisia* and *Ephedra* at Lake Yoa, Chad: Lézine et al. 2011; *Alnus* and *Populus* at the necropolis of Gobero, Niger: Giraudi and Mercuri 2013).

The current long-distance transport of some anemophilous pollen, such as *Ambrosia* and *Betula* upon which the focus was on allergenic properties, has been shown by several researches (Cecchi et al. 2010). High values of *Ambrosia* pollen were recorded over the central Italy where ragweed plants are few or virtually absent (Cecchi et al. 2007). The transport of *Ambrosia* pollen from the Pannonian plain to Scandinavia is described by Šikoparija et al. (2013). After considering weather, orographic situation and the airborne pollen data from a network of 16 monitoring stations, the authors concluded that some foehn winds and peculiar environmental conditions are suitable for both the dispersal of ragweed pollen and for the moving northward the pollen bearing air masses into Poland and beyond.

Important implications for palaeoclimate and palaeoenvironmental reconstructions rise from the evidence that pollen may be transported at a very long distance from its source and that therefore it may be descriptive of events other than just the local changes in vegetation and habitats occurring under climate oscillations. The research based on modern monitoring of airborne pollen suggests that the long-distance transport may be a *routine* or an *episodic* event. This is a basilar difference that cannot be resolved without a deep understanding of the very local geomorphological and phytogeographical peculiarities of each given area.

As an example of routine event, the pollen of *Alnus* cf. *viridis* was systematically recorded by the spore traps located in northern Italy, in the southern side of the Po Valley (below 100 m asl at Vignola, Modena: 1990–2007). As this region is out of the distribution area of *Alnus viridis* (Chaix) DC trees, the systematic recording of this pollen is due to a seasonal long-distance transport from northern regions. The European Green Alder, or Mountain Alder, is an Arctic–Alpine tree that is native of central/eastern Europe and north America; three subspecies are distributed in Europe: ssp. *viridis*, in central Europe and Balkans; ssp. *fruticosa* (Rupr.) Nyman, in northern Asia and north America; ssp. *suaveolens* (Req.) Ball, in Corsica (Tutin et al. 1993). In Italy, the subspecies *viridis* and *fruticosa* only grow in northern regions, between 500

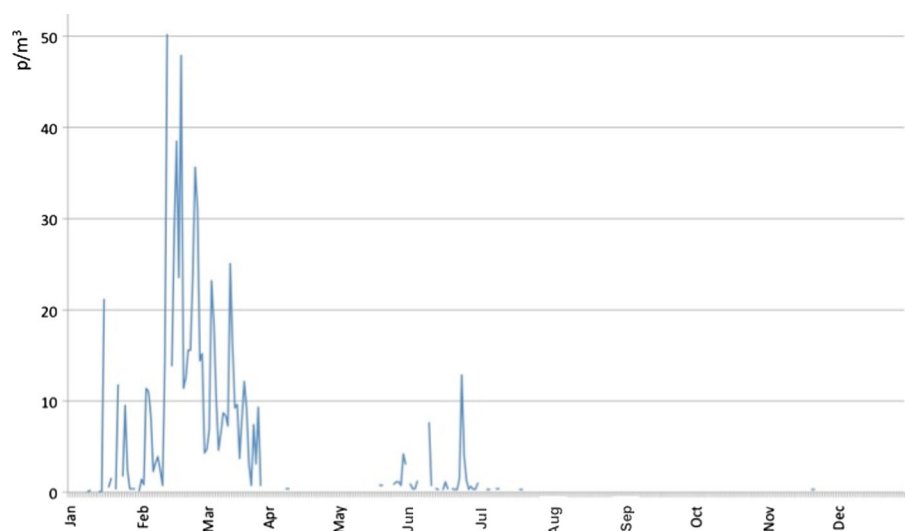
and 2300 m asl, in the Alps and Piedmont Apennines. The fossil record (i.e. high percentages of pollen indicating local presence) shows that *Alnus* cf. *viridis* grew in the Gran Sasso glacier area in central Italy at around 4500–4300 cal. year BP (Zanchetta et al. 2012). Today, the blooming period is May–June. In Italy, there are three other species of alder: *A. glutinosa* (L.) Gaertner, *A. cordata* (Loisel.) Desf. that bloom between late February and April; and *A. incana* (L.) Moench that can bloom also in May. Accordingly, *Alnus* pollen is high in February and early March, with monthly sum concentration >500 pollen/m³ air (e.g. 14 % of the total pollen recorded in February, and 2 % in March 1998; 8 % in February, and 3 % in April 2000). The pollen of *Alnus* cf. *viridis* is observed later, between May and July, and represents ca. 1 % or less of the total pollen of June (Fig. 4). The low daily concentrations (ca. 10 p/m³) were especially observed between the 12 a.m. and the 8 p.m. As the species is absent from the area, it is not possible to distinguish a locally emitted and a long-range transport component of its atmospheric content (as, for example, Stach et al. 2007 apply to *Ambrosia* pollen in Poland). The comparison between airborne pollen and meteorological data showed that the presence of this pollen was simultaneous with an anticyclonic maximum at north of the Alps, with wind from the east–north-east direction in the medium–low troposphere usually present in late spring/summer seasons. Some variability was observed in the years, but in general, green alder pollen has been always

recorded in the summer pollen rain far from the distribution area of the plants depending on high air masses circulation from the north-eastern Alps and northern Balkans (Accorsi et al. 1998).

Recurrent seasonal arrivals from long distance are reported in northern and central Europe. Historical pollen records of *Betula* show significant pre-seasonal pollen episodes, observed almost every year from 2000 to 2006, in Denmark (Copenhagen) with Germany or Poland as source regions in almost all episodes (Skjøth et al. 2007). Substantial amounts of *Corylus* and *Alnus* pollen grains were recorded in south Poland (Rzeszów) before the local onset of their pollen seasons (Puc and Kasprzyk 2013). These are described as fairly common events and confirm that the long-range transport can significantly modify pollinating seasons, i.e. the start time and duration of high atmospheric pollen concentrations (Sofiev et al. 2006). In these cases, moreover, the pollen input may be expected to have some influence in the yearly average data over long-time pollen series of the region. This may also become part of the biostratigraphy accumulated in sediments of the area.

The case of episodic long-distance events comes from Catalonia. The peak days of *Fagus* pollen recorded at six monitoring stations were associated with northern European air masses (Belmonte et al. 2008). This was an interesting novelty that revised the common prejudice that this pollen cannot be transported far from its source forest. However, the authors concluded that outstanding *Fagus* pollen

Fig. 4 Pollen of *Alnus* from the pollen monitoring station of Vignola (northern Italy; year 1990). The monthly sum of daily concentration shows peaks in two periods: pollination from January to April is considered from local sources while pollination from the end of May to July is considered from long-distance transport (*Alnus viridis*)



concentrations were actually observed in 2 years (2004 and 2006), and therefore, pollen can only occasionally be transported very far from the source areas. A true comparison with palaeoenvironmental evidences is not possible yet. Pollen counts refer to a long temporal series (23 years: 1993–2007), but only the period March–June is considered. To obtain records fully similar to the pollen rain analysed during stratigraphical studies, the percentage of this pollen calculated over the total yearly sum and as average value over several years should be considered. The incidence of such long-distance pollen transport at palaeorecord resolution should be assessed before interpolating aerobiological data into palaeoenvironmental inferences.

Pollen dispersal can cover thousands of kilometres (Belmonte et al. 2008; Ziello et al. 2012). This is known to have a twofold relevance for palaeoenvironmental reconstructions: from one side, it may be a font of bias if the presence of allochthonous pollen is interpreted as an indication of plants living locally; from another side, it may be a useful index of windy events also giving interesting hints on circulation of air masses. Overall, we can agree with Pan et al. (2013) that ‘strong winds may pick up the pollen grains from the topsoil into the air stream’ but this only leads ‘to an increase in pollen concentration in the air that is irrelevant to the normal and natural course of pollen transport and deposition’.

The risks of erroneous interpretation in pollen data in the arid regions are claimed by Pan et al. (2013) who studied the transport of airborne *Picea schrenkiana* pollen on the northern slope of Tianshan Mountains (Xinjiang, China; 2001–2006) and its implication for palaeoenvironmental reconstruction. Although *Picea* pollen is heavy and has a high fall speed (Sugita et al. 1999), they conclude that wind can transfer this pollen from a source forest over at least 70 km (Pan et al. 2013, p. 168). In the Po Valley, *Pinus* pollen is known to have dominated spectra, especially those from the plain, as a result of long-distance transport from the Apennines to the open grasslands which were spreading over plains during the cool phase of the early Holocene around 11.5–9.5 years cal. BP (Mercuri et al. 2012). *Pinus* woodlands were distributed at higher vegetation belts. Actually, the overrepresentation of pine pollen is well known in marine cores due to the highly buoyancy of its saccate pollen (e.g. Williams 2010). There is, therefore, a similar

‘behaviour’ of pollen in open sites, and the plain acts as a desert for recording the long-distance transport of airborne particles.

4 Aerobiology and the cultural trees: the focus on topics of archaeobotany

The understanding of the relationships between humans and the environment is at the centre of ecological, geographical and bioarchaeological studies. Many layers from archaeological sites preserve micro- and macro-botanical finds that were mainly formed after human selection and transport (e.g. Mercuri et al. 2014). Trees are at the base of very ancient relationships as they can supply food and fuel and have symbolic meanings in almost all cultures.

Most palaeoenvironmental and archaeobotanical research is therefore focused on trees for which pollen records are actually more ambiguous than macroremains (namely charcoals/woods and fruits/seeds). The low representativeness of entomophilous fruit-bearing plants or the significance of the spreading of some trees with special cultural meaning in Mediterranean areas are among the cases of interest in these studies and are, therefore, reported below.

Airborne pollen concentrations are reported as daily concentrations; the annual pollen index (API) is the sum of average daily pollen concentrations over the year (Ziello et al. 2012). The *yearly percentage* of taxon (x) is calculated as API (x) over the API (total); it represents the quantity of pollen recorded along all the seasons, including both pollination season and the other months. This percentage value referring to pollen in the air may be compared to the percentage in pollen spectra from surface samples. The latter is calculated on row counts and represents an average of the pollen rain deposited on the ground for several years. In fact, air pollen flora has a pronounced seasonal character, while pollen in surface sediments mirrors a combination of annual pollen characteristics (Luo et al. 2014).

4.1 *Prunus* and the low pollen production of entomophilous trees

Low-pollen producer and low dispersal plants are known to be underrepresented in pollen spectra. This implicates a loss of information in the case of plants

that may have had an important role in food supply since pre-agriculture periods are not easily recorded in past pollen spectra. But what is the lowest pollen percentage representing many fruit trees living in one area?

Today, some ornamental species of *Prunus* are part of the urban flora. Although its yearly percentage is very low (0.01 % in Tulsa–Oklahoma: Levetin et al. 2000), this pollen may be recorded in the urban pollen rain (Hernández-Prieto et al. 1998; Bianchi and Olabuenaga 2006). Moreover, crop species of *Prunus* are grown in orchards and constitute some of the world's most important fruit plants.

In a highly productive region such as the Po Valley in northern Italy, where a renowned cherry ('ciliegia di Vignola') is produced, the pollen of fruit trees was 0.2 % of the annual percentage (Mercuri et al. 1992). The blooming period was March–April when daily concentrations were about 4–15 p/m³. The spore trap was at about 15 m on a building located in the village of Vignola. One moss polster collected at the ground just out of the village showed a higher but comparable low value (0.4 %), while two surface soils taken at the centre of orchards had values significantly higher but not prevalent in spectra (8–9 %). Therefore, pollen dispersal of *Prunus* species is low even in orchards, and the concentration in air is so low that it may become insignificant also in the yearly sum of country areas specialized in this cultivation.

Aerobiological data give a measure of how much this pollen may be rare and suggest that even a very low percentage of *Prunus* in pollen spectra should be evidence of a large distribution of trees in the source area.

4.2 Olive tree and the representativeness of its pollen

Olea europaea L. is the emblem of the Mediterranean climate, and the wild forms are the main components of macchia and garigue formations. There is evidence that this tree has a very long cultural history in Mediterranean regions. Olives are among the first fruits collected by hunter-gatherers in the Levant where the primary area of domestication was found (Edwards et al. 2004; Kaniewski et al. 2012). Endocarps are found in the archaeobotanical record at least since the Neolithic, and pollen curves increase as favoured by human activities besides warming phases

(Bottema and Sarpaki 2003; Kouli 2012; Sadori et al. 2013b). Therefore, the knowledge on spread, domestication and production of olive trees is a key issue for the understanding of the possible links between past and modern agriculture (Mercuri et al. 2013b).

As trees are wind-pollinated, the pollen is normally spread in the air. In order to assess the representativeness of *Olea* pollen in soil samples taken at different distances from sources, Florenzano et al. (2011) analysed several surface pollen samples from five olive groves distributed in a region of southern Italy (Basilicata) where agriculture continues to be a major economic base. The surface soils were taken into and around the olive groves. Pollen analyses showed that the percentage of *Olea* in spectra declines with increasing distance from the source and falls more

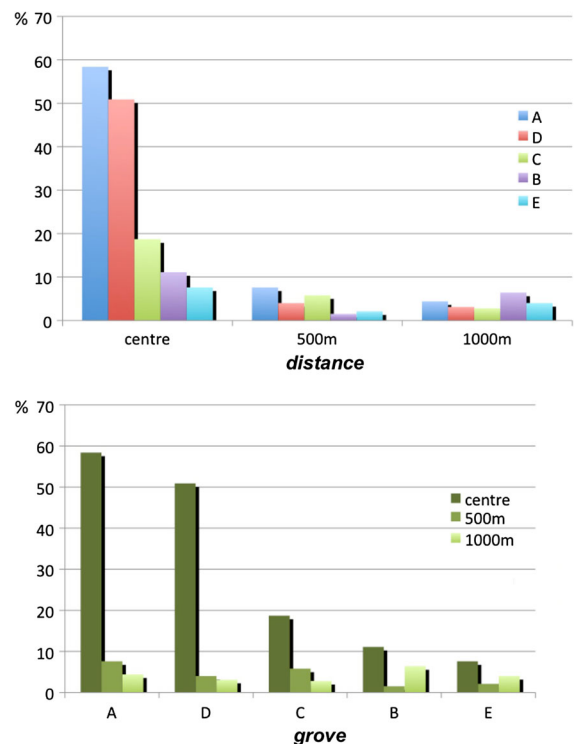


Fig. 5 Percentage of *Olea* pollen found in surface soil samples taken at different distance (centre, 500, 1,000 m) from five olive groves (A, B, C, D, E: letters follow the order of sampling while histograms are drawn following the decreasing percentage of *Olea* pollen observed at the centre of the orchard). The samples taken at the centre of orchards show percentages of *Olea* pollen higher than those in samples taken at increasing distance; the percentages resulted particularly variable at the centre (from ca. 8 to ca. 60 %) also depending on the size and extension of groves (according to the research by Florenzano et al. 2011)

than ten times down at just 500 m far from the centre of the groves (Fig. 5). Airborne pollen captured by spore traps in the same area (years 2005–2006, ARPAB monitoring station of Matera) shows that the pollination season is May–June, with daily maxima of about 300 p/m³. The yearly percentage of *Olea* was about 10 %; interestingly, the mean value in spectra from the surface soils collected in and around the olive groves was similar, 13 %. At any rate, as already observed for the *Prunus* pollen, this pollen is generally less abundant in the air than in the soil layers.

Aerobiological research demonstrates that olive-growing areas give different contribution to airborne pollen rain depending on the size of groves (pollen sources) and prevalent wind direction (Hernández-Ceballos et al. 2012). A set of detailed research on this pollen focused on the determination of the pollen season for agricultural and ecological purposes, their relevance for bee's foraging and forecasting to improve agronomic management (Dimou 2012; Galán et al. 2001, 2004, 2008). Olive pollen is one of the main components in the biological aerosol with important impact on human health in the Mediterranean countries (Fornaciari et al. 2000). The huge body of the literature has the potentiality to deepen both the knowledge on the history and future exploitation of the species. Unfortunately, the different fields of research are often parallel, and possible interconnections have to be further developed. For example, the pollen index (PI) that records the sum of daily airborne pollen data throughout the entire pollination season is reported to be variable from 10 to 34 depending on the meteorological conditions in Córdoba (Oteros et al. 2013). However, the (actual or estimated) yearly percentage of *Olea* pollen is not usually reported in aerobiological papers. This may be among the causes that prevent easy comparison between local aerobiological data and pollen spectra obtained from sediments and surface soils of a given area.

4.3 *Castanea* pollen and the debate on chestnut tree as a native species in Italy

The yearly percentage of *Castanea* pollen is indeed reported in several research papers: in Spain: ca. 2 % on average in Salamanca (Rodríguez de la Cruz et al. 2008); ca. 2 % in Vigo, 4 % in Ourense, 5 % in Santiago (Jato et al. 2001); in Croatia: 3 % in Zagreb,

6 % in Samobor (Hrga et al. 2010); in Turkey: 4 % in Zonguldak (Kaplan 2004). Chestnut is a high pollen-producer species, and the long-distance transport of this pollen is well known (Conedera et al. 2004 and references therein). In the northern Apennines, chestnut trees grow in large woods distributed in the hills today, and the development of this 'chestnut landscape' was found to date back to about 700 years ago (Mercuri et al. 2012).

Long-term data of airborne pollen of chestnut collected from the aerobiological monitoring station of Vignola in northern Italy, mentioned above, have been recently published within a supra-regional palaeoenvironmental reconstruction (1990–2007; Mercuri et al. 2012). The aerobiological results have been elaborated to produce a set of reference values that may be useful for the understanding of the development of plant landscape in Italy and for past environmental reconstructions (Table 1). Surface samples collected from monospecific woods add information: they amount up to 90 % in modern pollen spectra representing values that cannot be found in past records. Data from the monitoring station of Vignola, however, show that chestnut pollen is important in the summer airborne rain, but it falls to 6 % on average—ranging from 0.7 to 10 % per year—when its value is calculated on yearly basis. Although such pollen grains are a minor part of the regional annual pollen rain in northern Apennines, these researches including studies on the modern pollen rain show that a relatively small amount of pollen is compatible with the presence of chestnut trees living in the area (Mercuri et al. 2012). Data comparison can contribute to improve knowledge on the history of *Castanea* in Italy, an issue that it is still fairly controversial. Though the basic data used for the interpretations were partially erroneous (Krebs et al. 2004 reported a value of *Castanea* pollen that was miscalculated from a paper by Bertolani-Marchetti et al. 1994), there is a high likelihood that *Castanea* refugia occurred in northern Italy, the north-western hills being the most suitable refugium area. Chestnut is common in Holocene pollen spectra and notably increases in the hill belt since the last 3000 years. This phase saw the development of various cultures such as Iron Age, Etruscan/Celtic, Roman, Mediaeval and modern, which had very different considerations of the role of nature and economy. Probably most of the success of this tree was greatly a human-driven spreading.

Table 1 Chestnut pollen in air and in sediments

A—Pollen in the air (monitoring station of Vignola, northern Italy)

Year	1998	1999	2000	2001	2002	2003	2004	Mean
Day of maximum of <i>Castanea</i> in the air	07-Jul	06-Jul	23-Jun	22-Jun	03-Jul	20-Jun	09-Jul	
Maximum daily conc.	267	659	456	226	348	343	190	356
% on daily maximum	66	71	53	44	81	68	79	66
Yearly sum of <i>Castanea</i> conc.	3,666	5,441	3,949	2,935	2,573	333	1,000	2,842
Annual total pollen	36,633	76,340	50,087	45,181	61,283	47,813	31,170	49,787
% of <i>Castanea</i> on the yearly sum	10.0	7.1	7.9	6.5	4.2	0.7	3.2	5.7

B—Pollen in sediments (Holocene phases) and surface samples (recent: last 50 years)

	Preboreal	Boreal	Atlantic	Subboreal	Subatlantic	Recent	Total number of sites	Total sites in the synthesis (2000)	Samples considered per phase
Sites									
Plain	1	2	3	11	18	16	37	73	829
Hill ^a	1	1	2	3	11	20	27	31	156
Mountain	0	3	6	11	27	47	67	52	355
Number of sites	2	6	11	25	56	83	131	155	1,306
Percentages									
Plain	0.1	0.1	0.2	0.7	0.8	1.6			
Hill ^a	2.0	1.8	0.5	0.6	11.9	9.2			
Mountain	—	0.1	0.2	1.0	2.9	7.5			
Mean % of <i>Castanea</i> per phase (AP + NAP)	0.7	0.6	0.3	0.8	5.0	6.0			

(A) airborne pollen in the years 1998–2004. *Castanea* concentrations (p/m^3) from the aerobiological monitoring station of Vignola (125 m asl, in the hill belt of Modena area), run by the Laboratory of Palynology and Palaeobotany of Modena. Data are elaborated with Aerobiologia 2.0 (Mercuri et al. 1997) and GEPO programs, and are archived in the R.I.M.A. (Rete Italiana di Monitoraggio Aerobiologico) database; (B) mean average per phase of chestnut pollen found in sediment cores, archaeological layers and surface soil samples; Preboreal, Boreal, Atlantic, Subboreal and Subatlantic refer to main chronological phases for millennial environmental fluctuations that took place during the Holocene, while ‘Recent’ corresponds to the last 50 years (data elaborated from Accorsi et al. 2004)

^a Pavullo nel Frignano is located in the hill belt of Modena, and its data were elaborated from Bertolani et al. 1994 (Mercuri et al. 2012, modified)

5 Aerobiology and the long-term climate change reconstruction

Many studies have addressed the response of phenology, especially but not only of anemophilous plants to global warming from an aerobiological perspective (van Vliet et al. 2002; *Betula*: Frei and Gassner 2008; *Olea*: Galán et al. 2005; Vázquez et al. 2003; *Prunus*: Mimet et al. 2009; *Platanus*: Tedeschini et al. 2006; Mimet et al. 2009; *Quercus*: Grewling et al. 2014; *Ambrosia*: Ziska et al. 2011). Among others, an

increasing trend of the mean API against mean local temperature is widely reported for many taxa including Taxaceae/Cupressaceae pollen (Clot 2003; Ziello et al. 2012).

Although Taxaceae are not routinely separated from Cupressaceae, Mercuri et al. (2013c) distinguished this pollen in slide readings because the analyses were carried out aiming at collecting data useful for study on palynological biodiversity. This research shows that the two families have contrasting patterns in northern Italy. Long-term study

demonstrated that airborne pollen of *Taxus* has decreased, while total woody pollen abundance, including Cupressaceae, has increased in recent years (1990–2007; Fig. 5). The trend of the yew pollen season shows a delay at the beginning, a shortening of the pollen period, and an advance of the end of the pollen season. This was interpreted as a response to the current global climate warming (Mercuri et al. 2013c).

Many researches report on the correlation between pollen monitoring data and temperatures and underline the significantly different responses of trees to climate change. In northern Europe, *Alnus*, *Betula*, *Corylus* and *Ulmus* show an early pollination under warming conditions. In Italy, the most important early pollination occurs in spring-flowering trees, while a delay of the beginning of the pollen season occurs in winter-flowering plants (*Alnus*, *Corylus*, *Cryptomeria*, *Ulmus*) (Frenguelli 2002; Tedeschini et al. 2003, 2006). *Taxus* follows the behaviour of winter-flowering plants: (1) late pollination occurs more often and most likely after warm autumn temperatures and (2) less frequently, an earlier pollination is favoured at low autumn temperatures (Mercuri et al. 2013). The decrease in pollen production and the shortening of the flowering season point to the decline in yew pollen in the air as a response to the global warming of the last few years. Accordingly, *Taxus* has the highest percentages in past pollen diagrams from cold or cool periods. High percentages of pollen, sometimes associated to macroscopic remains of *T. baccata*, occurring with other evergreens such as *Abies* and *Ilex*, has been recorded in interglacial deposits from Ireland, and also eastwards in north-central Europe to Poland, where it indicates the penetration of oceanic conditions of climate well into continental Europe (Jessen et al. 1959). In southern Europe, Yew was a declining tree as the climate has become less oceanic. In Italy, *Taxus* was present in the first part of the mid-Holocene but rapidly vanished at about 3,900 cal. BP, under climate warming and increasing influence of Bronze Age cultures (Mercuri et al. 2012). The decline might have had, therefore, a twofold reason where natural causes including ecological needs and competition, and anthropogenic causes (e.g. deforestation or heavy grazing) may be responsible (Thomas and Polwart 2003; Deforce and Bastiaens 2007). Among the different causes, aerobiological data support the interpretation that Yew may have been favoured in

cold or cool climate conditions and that it is currently affected by increasing temperatures.

6 Conclusions

Pollen rain variability causes very different pollen input in air masses depending on productivity (genetic feature) and seasonality (combined physiology and environmental features): this obvious concept relies on systematic dataset collection through pollen monitoring.

Therefore, aerobiology can intrinsically contribute to the other fields of applied palynology. Although pollen collected from spore trap is still rarely employed out of the classical aerobiological application, it is evident that artificial spore traps improve the knowledge on pollen production, transport and seasonality. An interesting example comes from a research on palaeoclimate that combined sediment and spore trap pollen analyses.

In order to give a reference to reconstruct the palaeoclimate of the south China Sea, Luo et al. (2014) carried out a comparison of modern pollen distribution between the northern and southern parts of the study area. The research was based on the combination of analyses of 107 surface sediment samples and 28 air pollen samples selected from northern and southern parts of the south China Sea from August to September and in December 2011. Airborne pollen types and concentrations had a close relationship with wind direction and distance from the sampling point to the continent. Sediment samples were influenced by the summer monsoon-forced marine current and taphonomical peculiarities. As expected, the comparison between ten air pollen and ten surface sediment samples showed that pollen and spores in the air were mainly herbaceous and woody pollen with seasonal characteristics; the surface sediments may also show a combination of annual pollen characteristics. More research is needed making a methodological bridge between pollen in the air and pollen in sediments.

This review article has enlightened several aspects where aerobiology may be important to solve forensic and palaeoenvironmental issues:

- A close connection exists between forensic palynology and aerobiology, because the airborne

pollen calendars may be a reference tool for establishing the season or month when an unknown death or other crime occurred; pollen grains from corpses more or less well correspond to the seasons of death and match the general seasonal trend of pollen in the air.

- The bulk of pollen is deposited near the source plant, and different taxa exhibit varying attitude to the long-range transport of their pollen. In European countries, many genera belonging to the order Fagales (*Alnus*, *Betula*, *Carpinus*, *Corylus*, *Ostrya*, *Fagus*, *Quercus*, *Castanea*) are wind-pollinated trees generating among the vast amounts of pollen to ensure fertilization in receptor areas (Sofiev et al. 2013). They are among the most important pollen grains also in past spectra. Although most of the data are not always reported in a comparable way, aerobiology furnishes a valuable set of reference data on the long-distance transport recorded today.
- The research on pollen monitoring suggests that the long-distance transport may be a routine or an episodic event. This is a basilar difference for the palaeoenvironmental records, and only knowledge on local geomorphological and phytogeographical peculiarities of a given area can help the correct interpretation. This also suggests that high-resolution records (e.g. peat cores) may more easily intercept episodic events, while low-resolution records may show average data over several years thus substantially ignoring sporadic inclusion of low-distance pollen.
- There is high likelihood of pollen transport from long distance in open environments as deserts and treeless plains.
- Considering trees that have a long ‘cultural history’, it is fairly common that pollen is less abundant in the air than in the soil layers, and that percentages in pollen spectra decline with increasing distance from the source. In the case of entomophilous trees, a very low percentage of *Prunus* in pollen spectra is evidence of a large distribution of trees. *Olea* plants give different contribution to airborne pollen rain depending on the size of groves and wind directions. Also a relatively small amount of pollen of *Castanea* is compatible with the presence of chestnut trees living in the study area.

It is a long time since Prentice (1988) stated that the knowledge on aerobiological data is useful to

interpret pollen diagrams of the past. However, the potentialities of the integration between past and present pollen assemblages are not fully exploited. The application of aerobiological studies to past palaeoenvironmental reconstructions is a promising, and not still completely explored, field of investigation. There is evidence that aerobiology may be vector of new important inferences about past, present and future of environmental transformations, human impact and climate change.

References

- Accorsi, C. A., Bandini Mazzanti, M., Lombroso, L., Santangelo, R., & Torri, P. (1998). La stazione meteorologica-aeropollinica di Modena (Nord-Italia): il caso di *Alnus viridis*. In C. A. Accorsi, M. Bandini Mazzanti, D. Labate, G. Trevisan Grandi (Eds.), *Studi in ricordo di Daria Bertolani Marchetti*. Deputazione di Storia Patria per le Antiche provincie Modenesi, ser. 150 (pp. 205–212), Modena: Aedes Muratoriana.
- Accorsi, C. A., Bandini Mazzanti, M., Forlani, L., Mercuri, A. M., Trevisan Grandi, G. (2004). Holocene forest vegetation (pollen) of the Emilia-Romagna plain—northeastern Italy. In: F. Pedrotti & J. M. Gehu (Eds.), *La végétation postglaciaire du passé et du présent syngénèse. Synécologie et Systématique. Colloques Phytosociologiques*, 28, 1–103.
- Adams-Groom, B. (2012). Forensic Palynology. In N. Márquez-Grant & J. Roberts (Eds.), *Forensic ecology handbook: From crime scene to court*. Chichester: Wiley.
- Belmonte, J., Alarcón, M., Ávila, A., Scialabba, E., & Pino, D. (2008). Long-range transport of beech (*Fagus sylvatica* L.) pollen to Catalonia (north-eastern Spain). *International Journal of Biometeorology*, 52, 675–687.
- Bertolani-Marchetti, D., Accorsi, C. A., Bandini Mazzanti, M., Dallai, D., Forlani, L., et al. (1994). Palynological diagram of the peat-bog near Pavullo nel Frignano (Modena, Italy) in the framework of Tuscan/Emilian Apennines vegetation history. *Historical Biology*, 9, 91–101.
- Bianchi, M. M., & Olabuenaga, S. E. (2006). A 3-year airborne pollen and fungal spores record in San Carlos de Bariloche, Patagonia, Argentina. *Aerobiologia*, 22(4), 247–257.
- Birks, H. J. B. (2012). Ecological palaeobiology and conservation biology: Controversies, challenges, and compromises. *International Journal of Biodiversity science, Ecosystem services & Management*, 8(4), 292–304.
- Bottema, S., & Sarpaki, A. (2003). Environmental change in Crete: A 9000-year record of Holocene vegetation history and the effect of the Santorini eruption. *The Holocene*, 13(5), 733–749.
- Broström, A., Nielsen, A. B., Gaillard, M. J., Hjelle, K., Mazier, F., et al. (2008). Pollen productivity estimates of key European plant taxa for quantitative reconstruction of past vegetation: A review. *Vegetation History and Archaeobotany*, 17, 461–478.

- Bryant, V. M. (2009). Palynology. In A. Jamieson & A. Moenssens (Eds.), *Wiley Encyclopedia of Forensic Science* (pp. 1954–1968). Portsmouth: Wiley.
- Bryant, V. M., Kampbell, S. M., & Hall, J. L. (2012). Tobacco pollen: Archaeological and forensic applications. *Palynology*, 36, 208–223.
- Bugelli, V., Forni, D., Bassi, L. A., Di Paolo, M., Marra, D., et al. (2014). Forensic entomology and the estimation of the minimum time since death in indoor cases. *Journal of Forensic Sciences*. doi:10.1111/1556-4029.12647.
- Cariñanos, P., Galán, C., Alcázar, P., & Domínguez, E. (2004). Analysis of the particles transported with dust-clouds reaching Córdoba, southwestern Spain. *Archives of Environmental Contamination and Toxicology*, 46, 141–146.
- Cecchi, L., Torrigiani, T., Albertini, R., Zanca, M., Ridolo, E., et al. (2007). The contribution of long-distance transport to the presence of *Ambrosia* pollen in central northern Italy. *Aerobiologia*, 23, 145–151.
- Cecchi, L., Testi, S., Campi, P., & Orlandini, S. (2010). Long-distance transport of ragweed pollen does not induce new sensitizations in the short term. *Aerobiologia*, 26(4), 351–352.
- Close, R. C., Moar, N. T., Tomlinson, A. I., & Lowe, D. (1978). Aerial dispersal of biological-material from Australia to New Zealand. *International Journal of Biometeorology*, 22, 1–19.
- Clot, B. (2003). Trends in airborne pollen: An overview of 21 years of data in Neuchâtel (Switzerland). *Aerobiologia*, 19, 227–234.
- Conedera, M., Krebs, P., Tinner, W., Pradella, M., & Torriani, D. (2004). The cultivation of *Castanea sativa* (Mill.) in Europe, from its origin to its diffusion on a continental scale. *Vegetation History and Archaeobotany*, 13, 161–179.
- Davis, B. A. S., Zanon, M., Collins, P., Mauri, A., Bakker, J., et al. (2013). The European modern pollen database (EMPD) project. *Vegetation History and Archaeobotany*, 22, 521–530.
- Deforce, K., & Bastiaens, J. (2007). The Holocene history of *Taxus baccata* (Yew) in Belgium and neighbouring regions. *Belgian Journal of Botany*, 140, 222–237.
- Dimou, M. (2012). Comparison of phenological, aerobiological and melissopalynological patterns of *Olea europaea*. *Apidologie*, 43, 103–112.
- Edwards, P. C., Meadows, J., Sayej, G., & Westaway, M. (2004). From the PPNA to the PPNB: New views from the southern Levant after excavations at Zahrat adh-Dhra' 2 in Jordan. *Paléorient*, 30, 21–60.
- Erdtman, G. (1969). *Handbook of Palynology. Morphology–taxonomy–ecology. An introduction to the study of pollen grains and spores*. Copenhagen: Verlag Munksgaard.
- Fægri, K., & Iversen, J. (1989). In K. Fægri, P. E. Kaland, & K. Krzywinski (Eds.), *Textbook of pollen analysis* (4th ed.). Chichester: Wiley.
- Fernández-Llamazares, Á., Belmonte, J., Boada, M., & Fraixedas, S. (2014). Airborne pollen records and their potential applications to the conservation of biodiversity. *Aerobiologia*, 30, 111–122.
- Florenzano, A., Benassi, S., & Mercuri, A. M. (2011). Pioggia pollinica e qualità dell'aria: polline di *Olea* negli uliveti dal caso studio della Basilicata. *Atti della Società del Naturalisti e Matematici di Modena*, 142, 175–189.
- Florenzano, A., Marignani, M., Rosati, L., Fascetti, S., & Mercuri, A. M. (2015). Are Cichorieae an indicator of open habitats and pastoralism in current and past vegetation studies? *Plant Biosystems*, 149. doi:10.1080/11263504.2014.998311.
- Fornaciari, M., Romano, B., Galán, C., Mediavilla, A., & Domínguez, E. (2000). Aeropalynological and phenological study in two different Mediterranean olive areas, Córdoba (Spain) and Perugia (Italy). *Plant Biosystems*, 134, 199–204.
- Frei, T., & Gassner, E. (2008). Climate change and its impact on birch pollen quantities and the start of the pollen season: an example from Switzerland for the period 1969–2006. *International Journal of Biometeorology*, 52, 667–674.
- Frenguelli, G. (1998). The contribution of aerobiology to agriculture. *Aerobiologia*, 14, 95–100.
- Frenguelli, G. (2002). Interaction between climatic changes and allergenic plants. *Monaldi Archives for Chest Disease*, 57, 141–143.
- Frenguelli, G., & Mandrioli, P. (1990). Airborne pollen monitoring in Italy. *Review of Palaeobotany and Palynology*, 64, 41–43.
- Gajewski, K., Lézine, A.-M., Vincens, A., Delestand, A., & Sawadab, M. (2002). The African pollen database. Modern climate–vegetation–pollen relations in Africa and adjacent areas. *Quaternary Science Reviews*, 21, 1611–1631.
- Galán, C., Cariñanos, P., García-Mozo, H., Alcázar, P., & Domínguez-Vilches, E. (2001). Model for forecasting *Olea europaea* L. airborne pollen in south-west Andalusia, Spain. *International Journal of Biometeorology*, 45, 59–63.
- Galán, C., Vázquez, L., García-Mozo, H., & Domínguez, E. (2004). Forecasting olive (*Olea europaea*) crop yield based on pollen emission. *Field Crops Research*, 86, 43–51.
- Galán, C., García-Mozo, H., Vázquez, L., Ruiz, L., de la Guardia, C. D., & Trigo, M. M. (2005). Heat requirement for the onset of the *Olea europaea* L. pollen season in several sites in Andalusia and the effect of the expected future climate change. *International Journal of Biometeorology*, 49, 184–188.
- Galán, C., García-Mozo, H., Vázquez, L., Ruiz, L., de la Guardia, C., & Domínguez-Vilches, E. (2008). Modeling olive crop yield in Andalusia, Spain. *Agronomy Journal*, 100, 98–104.
- Gee, H. (1998). Season of death. *Nature* (published online). doi:10.1038/news981008-2.
- Giraudi, C., & Mercuri, A. M. (2013). Early to middle Holocene environmental variations in the Gobero Basin. In Garcea, E. A. A. (Ed), *Gobero: The no-return frontier archaeology and landscape at the Saharo-Sahelian Borderland*. (pp. 114–126). Journal of African Archaeology Monograph Series 9, Frankfurt: Africa Magna Verlag.
- Giresse, P. (2008). *Tropical and sub-Tropical west Africa—Marine and continental changes during the late quaternary* (Vol. 10). Amsterdam: Elsevier Science.
- Grewling, Ł., Jackowiak, B., & Smith, M. (2014). Variations in *Quercus* sp. pollen seasons (1996–2011) in Poznań, Poland, in relation to meteorological parameters. *Aerobiologia*, 30, 149–159.

- Groenman-van Waateringe, W. (2011). The Iceman's last days—The testimony of *Ostrya carpinifolia*. The free library (June, 1). <http://www.thefreelibrary.com/>. The iceman's last days—The testimony of *Ostrya carpinifolia*.-a0262582518. Accessed July 17 2014
- Hernández-Ceballos, M. A., García-Mozo, H., Adame, J. A., Domínguez-Vilches, E., De la Morena, B. A., Bolívar, J. P., & Galán, C. (2011). Synoptic and meteorological characterisation of olive pollen transport in Córdoba province (south-western Spain). *International Journal of Biometeorology*, 55, 17–34.
- Hernández-Ceballos, M. A., García Mozo, H., Adame, J. A., & Galán, C. (2012). Last advances in the study of olive airborne pollen dynamic. In C. A. Savalas & S. M. Nicolau (Eds.), *Olive consumption and health*: Nove Science Publisher.
- Hernández-Prieto, M., Lorente Toledano, F., Romo Cortina, A., Dávila González, I., Laffond Yges, E., & Calvo Bullón, A. (1998). Pollen calendar of the city of Salamanca (Spain). Aeropalinological analysis for 1981–1982 and 1991–1992. *Allergologia et Immunopathologia*, 26(5), 209–222.
- Hjelle, K. L., & Sugita, S. (2012). Estimating pollen productivity and relevant source area of pollen using lake sediments in Norway: How does lake size variation affect the estimates? *The Holocene*, 22, 313–324.
- Hrga, I., Mitic, B., Alegro, A., Dragojlovic, D., Stjepanovic, B., & Puntaric, D. (2010). Aerobiology of sweet chestnut in north-west Croatia. *Collegium Antropologicum*, 34, 501–507.
- Jato, V., Aira, M. J., Dopazo, A., Iglesias, M. I., Méndez, J., & Rodríguez-Rajo, F. J. (2001). Aerobiology of *Castanea* pollen in Galicia. *Aerobiologia*, 17, 233–240.
- Jessen, K., Andersen, S. T., & Fakrington, A. (1959) The interglacial deposit near Gort, Co Galway, Ireland. In *Proceedings of the Royal Irish Academy, Section B*, 60, (pp. 3–77)
- Kaniewski, D., Van Campo, E., Boiy, T., Terral, J. F., Khadari, B., & Besnard, G. (2012). Primary domestication and early uses of the emblematic olive tree: Palaeobotanical, historical and molecular evidence from the middle East. *Biological Reviews*, 87(4), 885–899.
- Kaplan, A. (2004). Airborne pollen grains in Zonguldak, Turkey, 2001–2002. *Acta Botanica Sinica*, 46, 668–674.
- Kellogg, C. A., & Griffin, D. W. (2006). Aerobiology and the global transport of desert dust. *Trends in Ecology & Evolution*, 21(11), 638–644.
- Kouli, K. (2012). Vegetation development and human activities in Attiki (SE Greece) during the last 5,000 years. *Vegetation History and Archaeobotany*, 21(4–5), 267–278.
- Krebs, P., Conedera, M., Pradella, M., Torriani, D., Felber, M., & Tinner, W. (2004). Quaternary refugia of the sweet chestnut (*Castanea sativa* Mill.): An extended palynological approach. *Vegetation History and Archaeobotany*, 13, 145–160.
- Levetin, E., Rogers, C. A., & Hall, S. A. (2000). Comparison of pollen sampling with a Burkard Spore Trap and a Tauber Trap in a warm temperate climate. *Grana*, 39, 294–302.
- Lézine, A. M., Zheng, W., Braconnot, P., & Krinner, G. (2011). Late Holocene plant and climate evolution at Lake Yoa, northern Chad: Pollen data and climate simulations. *Climate of the Past*, 7(4), 1351–1362.
- Loveaux, J., Maurizio, A., & Vorwohl, G. (1978). Methods of melissopalynology. *Bee World*, 59, 139–157.
- Luo, C., Zheng, Z., Tarasov, P., Nakagawa, T., Pan, A., Xu, Q., et al. (2010). A potential of pollen-based climate reconstruction using a modern pollen—Climate dataset from arid northern and western China. *Review of Palaeobotany and Palynology*, 160, 111–125.
- Luo, C., Chen, M., Xiang, R., Liu, J., Zhang, L., & Lu, J. (2014). Comparison of modern pollen distribution between the northern and southern parts of the south China Sea. *International Journal of Biometeorology*. doi:10.1007/s00484-014-0852-2.
- Magri, D., & Parra, I. (2002). Late Quaternary western Mediterranean pollen records and African winds. *Earth and Planetary Science Letters*, 200, 401–408.
- Mandrioli, P., Negrini, M. G., & Zanotti, A. (1982). Airborne pollen from Yugoslavian coast to Po Valley. *Grana*, 21, 121–128.
- Mazier, F., Brostrom, A., Gaillard, M. J., Sugita, S., Vittoz, P., & Buttler, A. (2008). Pollen productivity estimates and relevant source area of pollen for selected plant taxa in a pasture woodland landscape of the Jura Mountains (Switzerland). *Vegetation History and Archaeobotany*, 17(5), 479–495.
- Mercuri, A. M. (2014). Genesis and evolution of the cultural landscape in central Mediterranean: The 'where, when and how' through the palynological approach. *Landscape Ecology*, 29(10), 1799–1810.
- Mercuri, A. M., Venturi, L., & Accorsi, C. A. (1992). Aero- and bryopalynological evidence of widespread Prunoideae and Maloideae orchards in Vignola (Modena, northern Italy). *Aerobiologia*, 8(1), 109–114.
- Mercuri, A. M., Accorsi, C. A., Bandini Mazzanti, M., Ferrarini, S., Venturi, L. (1997) Aerobiologia 2.0: A software for processing aeropollen data. *Journal of Environmental Pathology Toxicology and Oncology*, 16, 191–194.
- Mercuri, A. M., Sadori, L., & Blasi, C. (2010). Archaeobotany for cultural landscape and human impact reconstructions. *Plant Biosystems*, 144, 860–864.
- Mercuri, A. M., Bandini Mazzanti, M., Torri, P., Vigliotti, L., Bosi, G., et al. (2012). A marine/terrestrial integration for mid-late Holocene vegetation history and the development of the cultural landscape in the Po valley as a result of human impact and climate change. *Vegetation History and Archaeobotany*, 21, 353–372.
- Mercuri, A. M., Marignani, M., & Sadori, L. (2013a). 2013 Palynology: The bridge between palaeoecology and ecology for the understanding of human-induced global changes in the Mediterranean area. *Annali di Botanica (Roma)*, 3, 107–113.
- Mercuri, A. M., Bandini Mazzanti, M., Florenzano, A., Montecchi, M. C., & Rattighieri, E. (2013b). *Olea*, *Juglans* and *Castanea*: The OJC group as pollen evidence of the development of human-induced environments in the Italian peninsula. *Quaternary International*, 303, 24–42.
- Mercuri, A. M., Torri, P., Casini, E., & Olmi, L. (2013c). Climate warming and the decline of *Taxus* airborne pollen in urban pollen rain (Emilia Romagna, northern Italy). *Plant Biology*, 15, 70–82.
- Mercuri, A. M., Allevato, E., Arobba, D., Bandini Mazzanti, M., Bosi, G., et al. (2014). Pollen and plant remains from

- Holocene archaeological sites: A dataset for the understanding of the bio-cultural diversity of the Italian landscape. *Review of Palaeobotany and Palynology*. doi:10.1016/j.revpalbo.2014.05.010.
- Mercuri, A. M., Marignani, M., & Sadori, L. (2015). Palaeoecology and long-term human impact in plant biology. *Plant Biosystems*, 149. doi:10.1080/11263504.2014.998309
- Mildenhall, D. C., Wiltshire, P. E. J., & Bryant, V. M. (2006). Forensic palynology: Why do it and how it works. *Forensic Science International*, 163, 163–172.
- Mimet, A., Pellissier, V., Quénol, H., Aguejda, R., Dubreuil, V., & Rozé, F. (2009). Urbanisation induces early flowering: Evidence from *Platanus acerifolia* and *Prunus cerasus*. *International Journal of Biometeorology*, 53, 287–298.
- Montali, E., Mercuri, A. M., Trevisan Grandi, G., & Accorsi, C. A. (2006). Towards a 'crime pollen calendar'—Pollen analysis on corpses throughout one year. *Forensic Science International*, 163, 211–223.
- Oteros, J., García-Mozo, H., Hervás-Martínez, C., & Galán, C. (2013). Year clustering analysis for modelling olive flowering phenology. *International Journal of Biometeorology*, 57, 545–555.
- Pan, Y., Yan, S., Behling, H., & Mu, G. (2013). Transport of airborne *Picea schrenkiana* pollen on the northern slope of Tianshan Mountains (Xinjiang, China) and its implication for paleoenvironmental reconstruction. *Aerobiologia*, 29, 161–173.
- Prentice, I. C. (1988). Records of vegetation in time and space: The principles of pollen analyses. In B. Huntley & T. Webb III (Eds.), *Vegetation history. Handbook of vegetation science* (Vol. 7, pp. 17–42). Dordrecht: Kluwer.
- Puc, M., & Kasprzyk, I. (2013). The patterns of *Corylus* and *Alnus* pollen seasons and pollination periods in two Polish cities located in different climatic regions. *Aerobiologia*, 29, 495–511.
- Qin, P., Waltoft, B. L., Mortensen, P. B., & Postolache, T. T. (2013). Suicide risk in relation to air pollen counts: A study based on data from Danish registers. *BMJ Open*, 3, e002462. doi:10.1136/bmjopen-2012-002462.
- Raynor, G. S., Hayes, J. V., & Ogden, E. C. (1974). Mesoscale transport and dispersion of airborne pollens. *Journal of Applied Meteorology*, 13, 87–95.
- Riding, J. B., Rawlins, B. G., & Coley, K. H. (2007). Changes in soil pollen assemblages on footwear worn at different sites. *Palynology*, 31, 135–151.
- Rodríguez de la Cruz, D., Sánchez Reyes, E., & Sánchez Sánchez, J. (2008). Aerobiological study of Fagaceae pollen in the middle-west of Spain. *Aerobiologia*, 24, 67–76.
- Sadori, L., Bertini, A., Combourieu-Nebout, N., Kouli, K., Mariotti Lippi, M., et al. (2013a). Palynology and Mediterranean vegetation history. *Flora Mediterranea*, 23, 141–156.
- Sadori, L., Ortu, E., Peyron, O., Zanchetta, G., Vannièr, B., Desmet, M., & Magny, M. (2013b). The last 7 millennia of vegetation and climate changes at Lago di Pergusa (central Sicily, Italy). *Climate of the past*, 9, 1969–1984.
- Seijo, M. C., & Jato, M. V. (2001). Distribution of *Castanea* pollen in Galician honeys (NW Spain). *Aerobiologia*, 17(3), 255–259.
- Seppä, H. (2013). Pollen Analysis, Principles. In S. A. Elias & C. J. Mock (Eds.), *The encyclopedia of quaternary science* (2nd ed., pp. 794–804). Amsterdam: Elsevier Academic.
- Šikoparija, B., Skjøth, C. A., Radišić, P., Stjepanovic, B., Hrga, I., Apatini, D., Magyar D. et al. (2012). Aerobiology data used for producing inventories of invasive plants. In *Proceedings of the international symposium on current trends in plant protection*, Belgrade, Serbia, (pp. 7–14).
- Šikoparija, B., Skjøth, C. A., Kübler, K. A., Dahl, A., Sommer, J., et al. (2013). A mechanism for long distance transport of *Ambrosia* pollen from the Pannonian Plain. *Agricultural and Forest Meteorology*, 180, 112–117.
- Skjøth, C. A., Sommer, J., Stach, A., Smith, M., & Brandt, J. (2007). The long-range transport of birch (*Betula*) pollen from Poland and Germany causes significant pre-season concentrations in Denmark. *Clinical and Experimental Allergy*, 37, 1204–1212.
- Snyder Sach, J. (2001). *Corpse: Nature, forensics, and the struggle to pinpoint time of death*. Cambridge: Basic Books Perseus Pub.
- Sofiev, M., Siljamo, P., Ranta, H., & Rantio-Lehtimäki, A. (2006). Towards numerical forecasting of long-range air transport of birch pollen: Theoretical considerations and a feasibility study. *International Journal of Biometeorology*, 50(6), 392–402.
- Sofiev, M., Siljamo, P., Ranta, H., Linkosalo, T., Jaeger, S., et al. (2013). A numerical model of birch pollen emission and dispersion in the atmosphere. Description of the emission module. *International Journal of Biometeorology*, 57(1), 45–58.
- Stach, A., Smith, M., Skjøth, C. A., & Brandt, J. (2007). Examining *Ambrosia* pollen episodes at Poznan (Poland) using back-trajectory analysis. *International Journal of Biometeorology*, 51, 275–286.
- Sugita, S., Gaillard, M. J., & Brostrom, A. (1999). Landscape openness and pollen records: A simulation approach. *The Holocene*, 9, 409–421.
- Szibor, R., Schubert, C., Schöning, R., Krause, D., & Wendt, U. (1998). Pollen analysis reveals murder season. *Nature*, 395, 449–450.
- Tedeschini, E., Dioguardi, D., & Frenguelli, G. (2003). L'inizio della pollinazione di alcuni taxa come indice dei cambiamenti climatici. *Abstract 98° Congresso della Società Botanica Italiana* (Catania 24–26 September), Catania: 78.
- Tedeschini, E., Rodríguez-Rajo, F. J., & Caramiello, R. (2006). The influence of climate change in *Platanus* spp. pollinating in Spain and Italy. *Grana*, 45, 222–229.
- Thomas, P. A., & Polwart, A. (2003). *Taxus baccata* L. *Journal of Ecology*, 91, 489–524.
- Tonelli, D., Gattavecchia, E., Ghini, S., Porri, C., Celli, G., & Mercuri, A. M. (1990). Honey bees and their products as indicators of environmental radioactive pollution. *Journal of Radioanalytical and Nuclear Chemistry*, 141(2), 427–436.
- Tutin, T. G., Heywood, V. H., Burges, N. A., Valentine, D. H., Walters, S. M., & Webb, D. A. (1993). *Flora Europaea*. Cambridge: University Press.
- van Vliet, A. J. H., Overeem, A., De Groot, R. S., Jacobs, A. F. G., & Spieksma, F. T. M. (2002). The influence of temperature and climate change on the timing of pollen release in the Netherlands. *International Journal of Climatology*, 22, 1757–1767.

- Vanin, S., Zanotti, E., Gibelli, D., Taborelli, A., Andreola, S., & Cattaneo, C. (2013). Decomposition and entomological colonization of charred bodies—A pilot study. *Croatian Medical Journal*, 54(4), 387–393.
- Vázquez, L. M., Galán, C., & Domínguez-Vilches, E. (2003). Influence of meteorological parameters on *Olea* pollen concentrations in Córdoba (south-western Spain). *International Journal of Biometeorology*, 48, 83–90.
- Velasco-Jiménez, M. J., Alcázar, P., Valle, A., Trigo, M. M., Minero, F., Domínguez-Vilches, E., & Galán, C. (2014). Aerobiological and ecological study of the potentially allergenic ornamental plants in southern Spain. *Aerobiologia*, 30(1), 91–101.
- Williams, C. G. (2010). Long-distance pine pollen still germinates after meso-scale dispersal. *American Journal of Botany*, 97(5), 846–855.
- Zanchetta, G., Giraudi, C., Sulpizio, R., Magny, M., Drysdale, R. N., & Sadori, L. (2012). Constraining the onset of the Holocene “Neoglacial” over the central Italy using tephra layers. *Quaternary Research*, 78, 236–247.
- Ziello, C., Sparks, T. H., Estrella, N., Belmonte, J., Bergmann, K. C., et al. (2012). Changes to airborne pollen counts across Europe. *PLoS One*, 7(4), e34076.
- Ziska, L., Knowlton, K., Rogers, C., et al. (2011). Recent warming by latitude associated with increased length of ragweed pollen season in central north America. *Proceedings of the National Academy of Sciences of United States of America*, 108, 4248–4251.