Review of Palaeobotany and Palynology 185 (2012) 1–12

Contents lists available at SciVerse ScienceDirect

Review of Palaeobotany and Palynology

journal homepage: www.elsevier.com/locate/revpalbo

Research paper

Assessing the proportion of “extra-local” pollen by means of modern aerobiological and phenological records — An example from Scots pine (*Pinus sylvestris* L.) in northern Finland

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ARTICLE INFO

Article history:
Received 27 February 2012
Received in revised form 11 July 2012
Accepted 20 July 2012
Available online 31 July 2012

Keywords:
Pinus sylvestris
Finland
pollen analysis
atmospheric transport

ABSTRACT

Detecting “extra-local” pollen, and especially long-distance transport events, in fossil pollen data is a problematical task, particularly when one species dominates both the vegetation and the pollen counts, as is the case with Scots pine (*Pinus sylvestris*) in Fennoscandia. As a step towards elucidating this, modern airborne pollen data were analysed in northern Finland along a north–south transect (Kevo north of the pine forest limit, and Rovaniemi and Oulu within the pine forest) for the years 1977–2008 (Kevo), 2002–2008 (Rovaniemi) and 1997–2008 (Oulu). By using phenological observations, the “extra-local” (“preflowering”) pine pollen, occurring before the onset of local male flowering, could be detected. Preflowering pine pollen represents only that “extra-local” pollen deposited before the onset of local pollen shedding and, therefore, underestimates the annual “extra-local” pine pollen amount. For Kevo a maximum estimation of total “extra-local” pine pollen could be calculated, which was 34%. The preflowering values nevertheless provide a minimum estimation of total “extra-local” pine pollen, because, within the period studied, the pollen shedding onset dates at the three sites were delayed in a northwards direction by, on average, 8–9 days from one study site to the next, which was mostly longer than the duration of local flowering. Kevo had the lowest total pine pollen values due to its position north of the pine forest limit, of which 11% was preflowering. The highest average total pine pollen values and 15% preflowering were found at Rovaniemi, while Oulu had the smallest amount of preflowering pollen (6%) but a high total pine pollen sum. Rovaniemi and Kevo had several years with more than 10% preflowering pollen. The variation in preflowering data was highest at Kevo. In five years, its percentage was remarkably high (>20%) and occurred at least two weeks before the local male flowering onset, suggesting a pollen source further away. Clear long-distance transport events could be detected at Kevo in 2001 and 2008. In the 2001 event, the wind came from southerly directions, so the possible pollen source was in southern Finland several hundred km to the south. The amount of “extra-local” preflowering pine pollen is on average only 6 to 15% of total pine pollen at the northern Finnish sites, and much of it would seem to originate from sources closer to the site than expected. These average preflowering pine pollen percentages provide a minimum estimation of the proportion of pollen originating from “extra-local” sources, which can be applied to fossil pollen data, where one sample comprises several years.

1. Introduction

1.1. Possibilities for detecting long-distance transported pollen

Pollen analysis is a widely used tool for reconstructing vegetation history following the establishment of the method by von Post, 1916. It has also been known for a long time that the presence of “extra-local” pollen in fossil pollen assemblages, that is pollen originating from areas far away from the sampling site, can complicate the reconstruction of vegetation (e.g. Hesselman, 1919; Erdtman, 1937). The “extra-local” character of part of the pollen becomes particularly obvious when exotic pollen is found in remote areas like Arctic islands (van der Knaap, 1987; Johansen and Hafsten, 1988; van der Knaap, 1988; Johansen, 1991), Greenland (Rousseau et al., 2003, 2006) or in Antarctica (van der Knaap and van Leeuwen, 1993; Sharma et al., 2002), but is less easy to detect if the long-distance transported pollen taxon is also produced by the local vegetation.

For reconstructing the vegetation history of a specific area, the timing and routes of migration of the species are crucial prerequisites. This paper is part of a study focussing on the postglacial migration of Scots pine

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http://dx.doi.org/10.1016/j.revpalbo.2012.07.014

(*Pinus sylvestris* L.) into northern Fennoscandia. When the first local presence of Scots pine at different sites and the location of its glacial refugia are known, its migration routes can be traced back. But how can the local presence of a species be detected? Due to the inevitable presence of long-distance transported pollen, the mere presence of pollen cannot provide reliable results. Mega- and macrofossils are the most authentic evidence of the local presence of a species (Birks and Birks, 2000; Birks, 2003; Helama et al., 2004), but they are not found everywhere, nor in a continuous series nor at all times of interest. Long Scots pine tree-ring records exist, covering approximately the last 7500 years in northern Finland (Eronen et al., 2002; Helama et al., 2002, 2008) and 7400 years in northern Sweden (Grudd et al., 2002), and single pine megafossil findings from elsewhere in Fennoscandia have been dated to even older ages (e.g. Kullman, 2002), but the available data are still not comprehensive enough for the reconstruction of migration routes. Genetic analyses from ancient pollen provide very valuable information about the local history of trees. For example Parducci et al., 2012 could detect pine DNA in very old sediments from northern Norway, but such data are still sparse.

Fossil pollen, on the other hand, is ubiquitously found in mire and lake sediments, but, as is well-known, the pollen signal is inevitably blurred by long-distance transport, which makes it difficult to pinpoint the first local presence of a species at a site. The degree of blurring depends on the ratio between the non-local and the local pollen and can differ from site to site. The presence of pine stomata and the use of pollen accumulation rates (influx or PAR: pollen grains cm^{-2} year^{-1}) rather than pollen percentage data can provide more reliable information about local vegetation, but mostly, especially in older pollen diagrams, only percentages are published and stomata are rarely recorded. The proportion of “extra-local” pine pollen can become quite high in pollen diagrams from open tundra areas (e.g. Aario, 1940; Wohlfahrt et al., 2004), so there seems to be an overrepresentation problem for pine in percentage pollen diagrams from north of the pine forest limit (Faegri and Iversen, 1989). In mountainous areas like the Alps, species typically growing at lower altitudes or restricted to certain valleys but for which the pollen is found at higher altitudes, or in different valleys, can similarly complicate the picture (David, 1993; Ortu et al., 2008), but this is more easily detected. In the case of birch, which is also widespread in northern Fennoscandia, Hicks et al. (1994) and Oikonen et al. (2005) used two subspecies to estimate the proportion of non-local birch pollen at Kevo in annual pollen deposition samples from modified Tauber traps, by distinguishing *Betula tortuosa*-type pollen originating from the local mountain birch (*Betula pubescens* ssp. *czerepanovii*) stands from *B. pubescens*-type pollen originating from the mainly non-local tree birch (*B. pubescens* ssp. *pubescens*). For pine, this method is not possible in Finland, because *Pinus sylvestris* (Scots pine) is the only species. When large areas are covered by the same tree species and there are no or very few “exotic” pollen taxa recorded which could give a hint of a pollen source farther away, the detection of the first local presence of trees by pollen can be difficult. This also has relevance for the genetic history of Scots pine, since pollen transport over long distances can have an impact on gene flow, if the pollen is still germinable (Williams, 2010). There is, therefore, an urgent need to quantify this “extra-local” proportion of the annual Scots pine pollen sum. Here, modern pollen data and phenological observations become important, since the date of onset of local pine pollen shedding at a site delimits locally produced pollen from “preflowering” pollen that must originate from non-local sources. After the local onset of male flowering, the pollen sources cannot be distinguished from each other; they can be local and “extra-local”, also including refloated pollen. Preflowering pollen is defined here as the occurrence of pollen of certain species at the study site before the onset of their local male flowering without referring to the place of origin (Ranta et al., 2008). “Local” is defined here as occurring within 500 m of the study site. This contrasts with “long-distance transported” pollen, which is pollen of species outside their normal distribution area or at an atypical time (Lindgren et al., 1995) and originating from beyond the region (here defined as up to 100 km). In this study we define long-distance as originating beyond 100 km.

Pollen in fossil sediment samples (depending upon the thickness of the sample and the rate of accumulation of the sediment) usually comprises several years or even decades of pollen deposition. Modified Tauber traps (Hicks et al., 1996), which are situated at ground level, are designed to monitor modern pollen deposition to allow a better interpretation of the fossil pollen deposition data. The collection period can be controlled, so they usually provide data at an annual resolution (Hicks, 1985). For the delimitation of non-local and long distance transported pollen, modern airborne pollen data collected by Burkard samplers are most useful (Hicks, 1992), because they are available at a daily or even hourly resolution. There is a good relationship between the annual pollen sums collected by modified Tauber traps and by Burkard samplers (Hicks et al., 1994; Levetin et al., 2000; Ranta et al., 2008), so the latter can be used for interpreting fossil pollen data. When the onset of local male flowering of pine is known, the total amount and proportion of preflowering pine pollen can be calculated from the daily airborne pollen data.

1.2. Prerequirements for long-distance transport

The potential for pine pollen to be dispersed over long distances is good compared with that of other species due to its lower fall speed caused by the pollen size, weight and aerodynamic properties (Erdtman, 1969; Schwendemann et al., 2007). Pollen productivity also affects the amount of pollen of a certain species in the samples. This is mainly controlled by climatic conditions and differs between areas. In the south the climatic conditions are more favourable, resulting in higher numbers of pine pollen. July temperature of the year prior to the year of pollen emission strongly affects pine pollen production and, therefore, also the amount of pollen emitted in the flowering year (Autio and Hicks, 2004). The abundance of a species in the pollen source area is also relevant. In northern Finnish forests pine dominates, so for this reason, there is also more pine pollen around to be deposited. It is very likely that birch and pine pollen, in particular, are taken up by thermals and turbulent winds and transported at high altitudes over distances up to several hundreds of km. The uptake to such heights requires propitious meteorological conditions such as dry, warm weather, wind and wind gusts. When the thermal conditions are unstable (usually during the day), the pollen is taken up, and when conditions become stable, as typically during the night, the pollen will sink and be deposited (Faegri and Iversen, 1989; Jackson and Lyford, 1999). It is therefore very likely that the pollen travels continuously only for one day, even at high altitudes, and is deposited during the night. This was also suggested by Lindgren et al. (1995) based on calculations of fall speed and airborne transport distance of Scots pine pollen. Light pollen grains have also been shown to travel more than 1000 km per day at over 1 km altitude (Sofiev et al., 2006). Airborne transport lasting several days and thus resulting in a distance of nearly 3000 km was reported from the Canadian Arctic, but such events seem to occur very rarely (Campbell et al., 1999). Refloatation and redeposition of pollen are, of course, possible. For transport, the vegetation structure can also play a role (von Stedingk et al., 2008), especially the height and density of the vegetation cover. When Scots pine migrated into Fennoscandia, most pollen and macrofossil diagrams suggest that the landscape was mainly characterised by an open birch-tundra (i.e. Barnekow, 2000; Bjune et al., 2004; Elverland and Vorren, 2008), interspersed with lakes, mires and bare fell areas, thus relatively low growing vegetation which causes less obstruction and allows higher wind speeds, even close to the ground.

1.3. Interdisciplinary approach

Plenty of aerobiological studies exist with regard to allergenic taxa such as *Ambrosia*, Poaceae, *Corylus* or *Betula* (Hjelmroos, 1991; Oikonen et al., 2005; Ranta et al., 2006) and efficiently-working