

Prediction of birch airborne pollen counts by examining male catkin numbers in Hokkaido, northern Japan

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Abstract Birch pollen is a very common cause of pollinosis in Hokkaido, northern Japan. Birch airborne pollen concentrations vary each year; hence, the development of a method for predicting annual airborne pollen concentration is very important in preventing widespread symptoms of pollinosis. In the current study, we investigated airborne pollen counts and male catkin numbers (male flower index) of birch in four cities of Hokkaido between 2002 and 2008. Airborne pollen surveys were conducted using Durham's sampler, and male catkin numbers determined for three major birch species (*Betula platyphylla* var. *japonica*, *B. emanii*, and *B. maximowicziana*). We found an annual variation in male flower index for all the three birch species investigated. This variation worked in combination with the amount of precipitation during the pollen season to influence total birch pollen counts. In conclusion, the male catkin numbers of three major birch species reliably predict airborne pollen counts in Hokkaido, but only when the effect of precipitation during pollen season is considered.

Keywords Airborne pollen · Birch · Male flower · Pollinosis · Prediction

1 Introduction

The most allergenic tree pollen in north, central, and eastern Europe is birch (*Betula* spp.) pollen (WHO 2003). Birch pollen is also a very common cause of pollinosis in Hokkaido, northern Japan (Wagatsuma et al. 1972). The incidence of birch pollinosis has been increasing and presently accounts for over 60% of pollinosis cases in Hokkaido (Gotoda et al. 2001). Birch pollinosis not only causes rhinitis and asthmatic reactions but also oral allergy syndrome. In Hokkaido, more than 40% of birch pollinosis patients were found to be hypersensitive to apple pulp (Yamamoto et al. 2004).

The start of the pollen season and birch pollen quantities vary each year, and the development of a method for predicting these is very important for mitigating pollinosis symptoms in the general population (Adams-Groom et al. 2002; Dahl and Strandhede 1996; Emberlin et al. 2002; Frei and Gassner 2008; Kanaseki 2004; Masaka and Maguchi 2001; Ranta et al. 2006; Shirasaki et al. 2003; Sofiev et al. 2006). An examination of male flowers has been used to improve predictions of birch pollen levels, and the relationship between catkin numbers and airborne birch pollen

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counts has been studied in Europe (Ranta et al. 2008). Indeed, it is possible to examine the male catkins of birch before they disperse pollen in the autumn. Yasaka (2005) demonstrated an observational method for quantitatively estimating the number of male catkins in birch.

There are six species of birch in Hokkaido, three of which can be considered major: *Betula platyphylla* Sukatchev var. *japonica* (Miq) Hara, *B. emanii* Cham., and *B. maximowicziana* Regel. Airborne birch pollen is predominantly distributed from natural forests in Hokkaido, and while birch comprises more than 10% of this natural resource, there is little information concerning the extent to which each of the various major birch species features. Birch pollen accounts for 20–36% of the airborne pollen in Hokkaido (Kobayashi et al. 1998; Takeuchi et al. 1999). However, it is very difficult to distinguish *Betula* species reliably using pollen morphology criteria, and the extent to which particular *Betula* species contribute to airborne birch pollen is not known.

Due to these reasons, when we use the investigation of male flowers of birch to broadcast the annual pollen values, we have to reveal which birch species is adequate for the prediction. There is a potential for meteorological conditions during the pollination season to affect the dispersal of birch pollen. For example, rain may remove pollen from the air (Ranta et al. 2008). Effects associated with local weather conditions, and any further effects associated with species differences, thus make it possible for the annual total pollen count to be site-dependent. Accordingly, in the current study, we investigated how male flower catkin numbers and precipitation during the pollen season are related to annual airborne pollen counts in four different cities of Hokkaido. This was done with the intent of using male catkin numbers for predicting annual airborne pollen counts.

2 Study site and methods

2.1 Airborne pollen survey

Airborne pollen surveys were performed between 2002 and 2008 at the Hokkaido Institute of Public Health in Sapporo city (43°5'N, 141°20'E, 13 m in

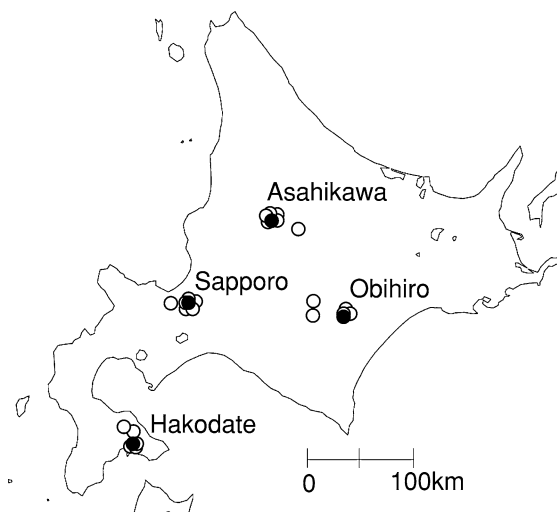


Fig. 1 Locations of the birch (*Betula* spp.) airborne pollen (●) and male catkin (○) study sites in Hokkaido, northern Japan

elevation), the Obihiro Health Center in Obihiro city (42°56'N, 143°13'E, 37 m in elevation), the Kamikawa Health Center in Asahikawa city (43°48'N, 142°26'E, 133 m in elevation), and the Oshima Health Center in Hakodate city (41°49'N, 140°45'E, 32 m in elevation; Fig. 1). Airborne pollen surveys were conducted every day between April and June by using Durham's sampler, within which pollen was collected on applied petrolatum glass slides. The glass slides were stained with gentian violet, and the amount of pollen in a 3.24-cm² (1.8 × 1.8 cm) area counted under a microscope. The daily pollen counts were summed within pollen seasons and expressed as total annual pollen counts. As it is difficult to distinguish *Betula* species reliably using pollen morphology criteria, all *Betula* species were treated as one group, without further categorization.

2.2 Male catkin survey

Male catkin surveys were carried out for the three major *Betula* species (*B. platyphylla*, *B. emanii*, and *B. maximowicziana*) within each of the four cities or their surrounds. The number of study sites was six in Sapporo (43°01'–43°06'N, 141°13'–141°52'E, 15–550 m in elevation), six in Asahikawa (43°39'–43°62'N, 142°18'–142°62'E, 110–1,000 m in elevation), five in Obihiro (42°54'–43°05'N, 142°45'–143°13'E, 30–1,100 m in elevation), and four in Hakodate (41°51'–41°59'N, 140°39'–140°44'E,

40–600 m in elevation; Fig. 1). Surveys were carried out in the autumns of 2001–2007 in Sapporo, Asahikawa, and Obihiro, and in the autumns of 2002–2007 in Hakodate. More than ten trees were sampled at each site, with these being natural specimens for *B. emanii* and *B. maximowicziana*, and either planted or natural specimens for *B. platyphylla*. For *B. emanii* and *B. maximowicziana*, the male catkin study site was at times some distance from the airborne pollen survey site, with the longest distance between these being 20 km for Sapporo and Hakodate, 30 km for Asahikawa, and 40 km for Obihiro.

Where possible, annual male catkin production was measured for the same trees each year. The number of male catkins (A) and the ratio of flowering branches (B) were recorded for 10–20 branches per tree, from November to December. Branches with a length of 50 cm were randomly selected each year. The product of A and B (hereafter, male catkin number) was used to quantitatively estimate the male catkin number for any given tree, as per Yasaka (2005).

2.3 Data analysis

For each species, an indicator of male catkin production in each year of each city (hereafter, male flower index) was calculated as an annual mean male catkin number, which was obtained by averaging the male catkin numbers of all trees for each city. The fluctuation patterns of annual pollen concentrations were compared among cities using the Kendall τ rank correlation coefficient of the annual total pollen counts. This analysis was performed by non-parametric statistic because the total number of pollen in a 3.24-cm^2 (count data) were used as the pollen concentration. The extent to which the male flower index of the three major birch species predicted total airborne pollen counts was investigated using a generalized linear model (GLM) with a Poisson error structure, and in which the precipitation during pollen season (May) was included. We also investigated the influence of monthly mean temperature; however, because there were no specific effects, only the results concerning the precipitation were presented. Meteorological data were collected from meteorological stations near each of the airborne pollen study sites. Akaike's information criterion (AIC) was used to select between models.

3 Results

3.1 Annual variation in airborne pollen counts

The fluctuation patterns of the yearly total airborne pollen counts in the four study cities are shown in Fig. 2. The annual total pollen counts differed between cities, with the mean of the yearly total for the 7 years of study highest in Sapporo and lowest in Hakodate. The Kendall τ rank correlation coefficients for the annual total pollen counts are shown in Table 1, and indicate the degree of similarity among cities with regards to the fluctuation patterns in these. A significant degree of similarity in the fluctuation patterns of the annual total pollen counts was found across the cities of Sapporo, Asahikawa, and Hakodate (Kendall τ rank correlation coefficients, $P < 0.05$), but not between Obihiro and any of these (Kendall τ rank correlation coefficients, $P > 0.05$).

3.2 Annual variation in male catkin production

Annual variations in male flower index are shown in Fig. 3. The male flower index of *B. platyphylla*

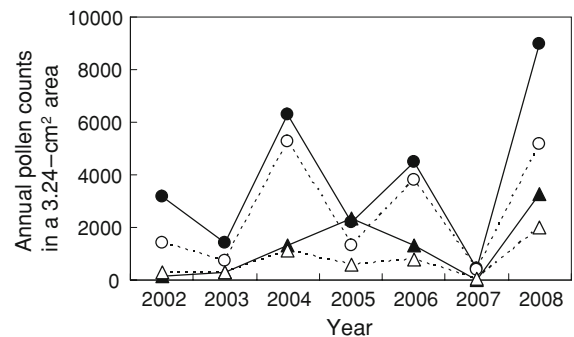


Fig. 2 Annual variation in total airborne pollen counts of birch in the four study cities (2002–2008). ●Sapporo, ○Asahikawa, ▲Obihiro, △Hakodate

Table 1 Kendall τ rank correlation coefficients for the relationship in total annual birch (*Betula* spp.) pollen counts between cities

	Hakodate	Obihiro	Asahikawa
Sapporo	0.71*	0.49	0.90**
Asahikawa	0.62*	0.39	
Obihiro	0.59		

* $P < 0.05$

** $P < 0.01$

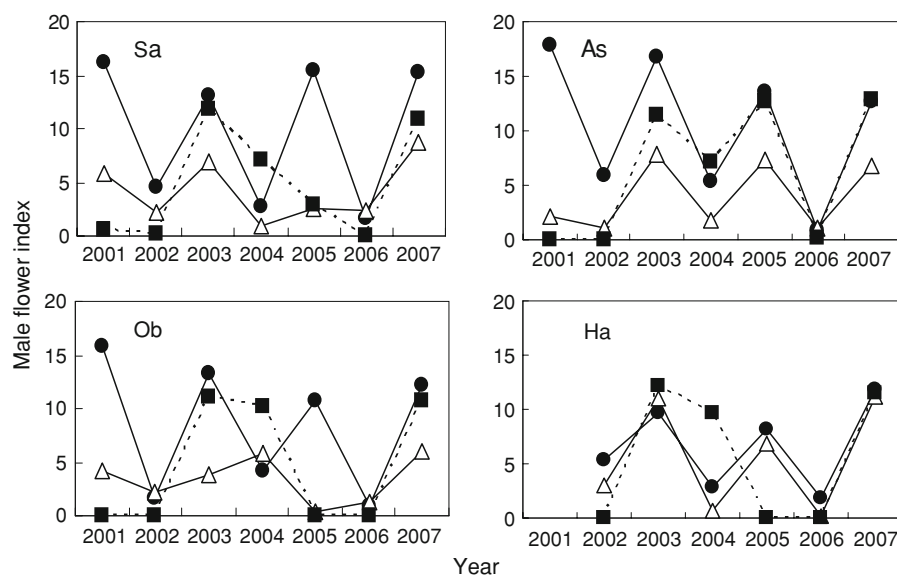


Fig. 3 Annual variation in male flower index of birch in the four study cities (2001–2007). ● *B. platyphylla*, ■ *B. maximowicziana*, △ *B. emanii*. Sa Sapporo, As Asahikawa, Ob Obihiro, Ha Hakodate

revealed a biennial flowering, and had a value <1 in only 6% of surveys (i.e., those in Asahikawa and Obihiro in 2006). In contrast, the male flower index of *B. emanii* was >10 in only 6% of surveys (i.e., those in Hakodate in 2003 and 2007), and was lower than that of both *B. platyphylla* and *B. maximowicziana* (Table 2). The male flower index of *B. maximowicziana* was relatively high in 2003 and 2007 and low in all cities in 2002 and 2006. Indeed, the annual variation in male flower index was high for *B. maximowicziana* (Table 2), with values <1 in 59% and >10 in 37% of surveys (Fig. 3).

3.3 Relationship between airborne pollen counts and male flower index

The results of the GLM analysis investigating how the male flower index for each of three birch species and precipitation during pollen season (May) relate to

annual birch pollen counts are shown in Table 3 and Fig. 4. For each of Sapporo, Asahikawa, and Hakodate, the best model contained the male flower index for all three birch species and precipitation as explanatory variables. Precipitation was negatively related to airborne pollen counts at all study sites, although its inclusion made particular improvements on the goodness of fit of models for Sapporo. Precipitation was not a significant variable in the best model for Obihiro, which included the male flower index of all three birch species as per the other study sites but did not fit as well as the best models for these (Fig. 4).

4 Discussion

There were significant annual fluctuations among the birch airborne pollen concentration values of the four

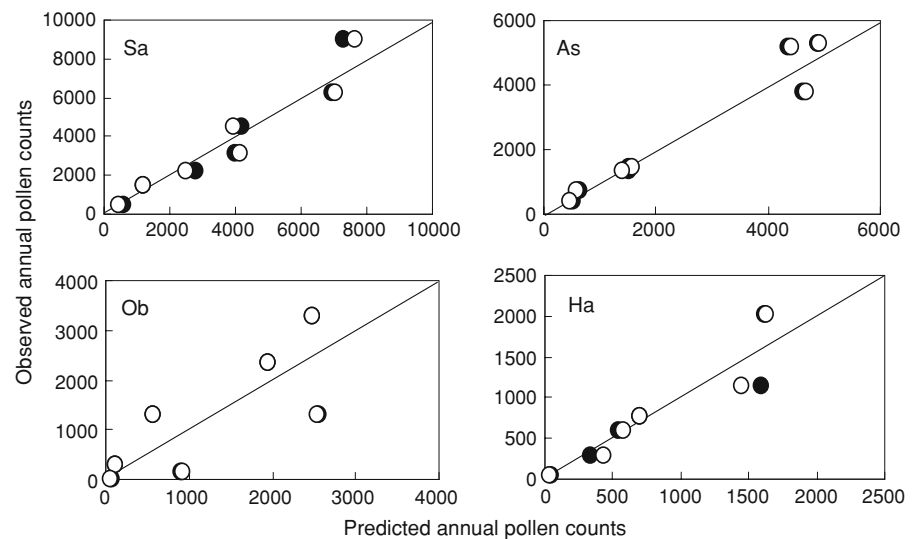
Table 2 Male flower indices of the three birch species across study years; values are mean, standard deviation, and coefficient of variation (CV)

	Mean ± SD (CV)		
	<i>B. platyphylla</i>	<i>B. maximowicziana</i>	<i>B. emanii</i>
Sapporo	9.9 ± 6.6 (66.7)	4.8 ± 5.2 (106.7)	4.2 ± 2.9 (70.0)
Asahikawa	10.4 ± 6.4 (61.7)	6.3 ± 6.2 (97.6)	4.0 ± 3.1 (78.6)
Obihiro	8.4 ± 6.0 (71.6)	4.6 ± 5.7 (124.9)	3.4 ± 2.2 (65.5)
Hakodate	6.7 ± 4.0 (59.5)	5.6 ± 6.1 (110.6)	5.5 ± 5.0 (91.1)
Average across sites	8.8 ± 5.7 (64.9)	5.3 ± 5.8 (109.9)	4.2 ± 3.3 (76.3)

Table 3 Results for GLM analyses using the male flower index of three major birch species and precipitation during pollen season (May) to predict annual birch pollen counts; the best three models for each city studied are shown

Study site	AIC	Regression coefficient			
		<i>B. platyphylla</i>	<i>B. maximowicziana</i>	<i>B. emanii</i>	Precipitation
Sapporo	809.4	171.4	299.2	236.2	−4.64
	920.3	193.0	306.6	112.8	
	1,036.5	230.7	320.8		0.58
Asahikawa	478.8	38.3	79.4	458.0	−1.99
	498.3	33.3	73.1	447.3	
	608.0		31.1	601.2	
Obihiro	2,994.0	53.1	160.6	16.6	
	2,995.7	53.7	160.0	17.4	−0.06
	3,017.3	56.5	166.5		
Hakodate	283.8	81.0	43.2	23.4	−1.09
	287.5	105.9	42.9		−1.49
	319.0	22.6	45.8	73.8	

Fig. 4 Relationships between predicted and observed annual airborne pollen counts of birch in the four study cities.
○Prediction by the best model containing both precipitation and male flower index, ●Prediction by the best model containing male flower index only. *Sa* Sapporo, *As* Asahikawa, *Ob* Obihiro, *Ha* Hakodate



study cities in Hokkaido, northern Japan. The amount of total airborne pollen was quite different among the cities in any given year. These results are similar to those of other studies in Hokkaido (Kobayashi et al. 1999; Masaka and Maguchi 2001; Shirasaki et al. 2003; Kanaseki 2004). Differences in airborne pollen counts between the study sites within each city were also observed; for instance, the amount of airborne pollen differed between study sites in Sapporo on two occasions (Kobayashi et al. 1999; Shirasaki et al. 2003). More information on the surrounding environment and weather conditions of the study sites is needed before the reasons for differences in airborne pollen counts between and within cities are fully

understood. While the pattern of annual fluctuation in airborne pollen counts was synchronous across Sapporo, Asahikawa, and Hakodate, a different pattern was found for Obihiro. This suggests that differences in the amount and fluctuation pattern of airborne pollen counts between sites must be considered for an effective prediction of birch airborne pollen concentrations in Hokkaido to be made.

The coefficient of variation (CV) of annual flower and seed production is often used to estimate quantitatively the extent of annual fluctuations (Kelly 1994; Herrera et al. 1998; Yasaka et al. 2003; Yasaka et al. 2008); this is because the numbers of flowers and seeds produced per tree differs greatly among

species. For example, in a sample of more than 100 woody plants located in various areas, 17% had a CV value <60, 36% had a CV value of 60–120, and 47% had a CV value >120 (Herrera et al. 1998). Compared to these reports, we found the CV values of the three major birch species in Hokkaido to be moderate. Nevertheless, annual variations in the male flowers of these birch species is the likely cause of the annual fluctuations in airborne pollen concentrations in the cities of Hokkaido.

The dispersal and transport of pollen from numerous taxa are influenced by several meteorological factors, such as wind, rainfall, air temperature, and relative humidity (Mandrioli 1989; Adams-Groom et al. 2002; Vázquez et al. 2003). In line with this, we found in the current study that precipitation acted alongside the annual variation of male flowers to influence the total pollen counts of birch in Hokkaido. Pollen was not detected in the sampler during rainy years, due to it being washed out of the atmosphere under these conditions. A rain-induced lowering of atmospheric pollen must therefore be considered when using the male flower index to predict annual total pollen, particularly in especially rainy years. This negative effect of rain on pollen dispersal could also decrease the seed production of birch species.

Excluding the precipitation effect, the best model for predicting annual total pollen counts included the male flower index for all three major birch species; this was the case for all study sites. The flowering time of these birch species differs significantly, with *B. platyphylla* flowering several weeks earlier than the other two species (Yasaka 2005). Daily birch pollen numbers generally peak twice in Hokkaido (Kobayashi et al. 1999), with the first peak dependent upon the dispersal of pollen from *B. platyphylla*, and the second peak dependent upon the dispersal of pollen from other birch species. Our results thus show that an effective prediction of total pollen counts of birch in Hokkaido requires the male flower production of all three major birch species to be considered. The fit of the model relating male flower index to total pollen count was not as good for Obihiro as for the other three cities studied. The reason for this is not clear, although it may be that the region in which male catkin numbers were surveyed was not the source of airborne pollen in Obihiro. Obihiro had patterns of annual fluctuations in airborne pollen counts different from those of the other three cities.

The greatest distance (40 km) between the sites at which male catkin numbers and airborne pollen were studied was also in Obihiro. This distance might have affected the accuracy of prediction of airborne pollen counts by male catkin numbers. A more effective prediction of airborne pollen counts in Obihiro is likely to be made by considering effects associated with meteorological factors during pollen season, including wind, air temperature, and relative humidity.

The initiation of flower buds on trees is generally affected by the weather conditions of the previous year (Kon and Noda 2007; Masaka and Maguchi 2001; Piovesan and Adams 2001), and the weather cues of the three major birch species need to be determined so that the methods for predicting annual pollen counts in Hokkaido with meteorological data can be improved. In conclusion, the male catkin numbers of three major birch species effectively predict the airborne pollen counts in Hokkaido. However, the effect of precipitation during pollen season must also be considered, particularly in rainy years.

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