

Forecasting Models for Sugi (*Cryptomeria japonica* D. Don) Pollen Count Showing an Alternate Dispersal Rhythm

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ABSTRACT

Background: Pollen information is indispensable for allergic individuals and clinicians. This study aimed to develop forecasting models for the total annual count of airborne pollen grains based on data monitored over the last 20 years at the Mie Chuo Medical Center, Tsu, Mie, Japan.

Methods: Airborne pollen grains were collected using a Durham sampler. Total annual pollen count and pollen count from October to December (OD pollen count) of the previous year were transformed to logarithms. Regression analysis of the total pollen count was performed using variables such as the OD pollen count and the maximum temperature for mid-July of the previous year.

Results: Time series analysis revealed an alternate rhythm of the series of total pollen count. The alternate rhythm consisted of a cyclic alternation of an "on" year (high pollen count) and an "off" year (low pollen count). This rhythm was used as a dummy variable in regression equations. Of the three models involving the OD pollen count, a multiple regression equation that included the alternate rhythm variable and the interaction of this rhythm with OD pollen count showed a high coefficient of determination (0.844). Of the three models involving the maximum temperature for mid-July, those including the alternate rhythm variable and the interaction of this rhythm with maximum temperature had the highest coefficient of determination (0.925).

Conclusions: An alternate pollen dispersal rhythm represented by a dummy variable in the multiple regression analysis plays a key role in improving forecasting models for the total annual sugi pollen count.

KEY WORDS

annual pollen count, dispersal rhythm, forecasting model, periodicity, sugi (*Cryptomeria japonica*)

INTRODUCTION

Pollinosis caused by pollen of the sugi tree (*Cryptomeria japonica* D. Don) is the most significant allergic disease occurring in the spring. In an epidemiological study in 2003, Okuda¹ estimated that at least 13% of the Japanese population suffered from sugi allergy. Based on surveys conducted throughout the country, Kaneko *et al.*² reported that the prevalence was 25% in urban areas in 2004.

Series of annual pollen counts generally show a sharp fluctuation with occasional severe dispersals. Information on numerical forecasts of sugi pollen

grains is therefore essential for both allergic individuals and clinicians. Forecasts based on weather variables during the summer season,³⁻⁹ the number of male flowers on trees,^{10,11} and pollen count in autumn and winter¹² have been documented at various locations during the last three decades.

Since 1987, pollen monitoring has been carried out at the Chuo Medical Center, Tsu, Mie, and forecasts have been made based on the maximum temperature in mid-July of the previous year or by counting small airborne pollen from October to December (OD pollen count) of the previous year. However, these forecasts are potentially imprecise.

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The periodicity of the pollen dispersal pattern has often received attention. Recently, Saito¹³ pointed out that severe dispersals tend to occur periodically, citing the 31 year pollen count (1965–1995) recorded by Shida *et al.*¹⁴ at the National Sagami Hospital. However, periodicity has never been considered in any scheme for forecasting pollen counts.

To make a reliable forecast, it is important to consider the regional characteristics of the pollen dispersal pattern. We noticed an alternate rhythm in the dispersal pattern and therefore addressed the subject of periodicity in this study. Furthermore, we incorporated the periodicity indicated by a time series analysis into a forecasting formula. This is the first study in which periodicity has been used to develop a forecasting model. In addition, we discuss topics such as the limited utility of the forecasting model, the nature of the alternate rhythm of pollen dispersal, and the rhythm shift.

METHODS

POLLEN MONITORING DATA

Airborne pollen grains were collected with a Durham sampler¹⁵ from the roofs of the former Tsu National Hospital (1987–1998) and the Mie Chuo Medical Center (2 kilometers west of the former hospital), the latter at a height of 30 meters. Slides were changed every day between 12:00 and 13:00 from February to May and twice a week during the rest of the year. Pollen grains on the slides (18 × 18 millimeters) were identified and counted after staining with Phöbus Blackly. The total annual pollen count and the OD pollen count in the previous year were expressed as count per centimeter squared. In all years, identification and counting were performed by one of the authors (Ito).

METEOROLOGICAL DATA

Mean daily maximum temperature (X), mean temperature, number of hours of sunlight, rainfall, and relative humidity (%) for the first, middle, and last 10 days of the month from June to August were obtained from the weather observation data on the website of the Tsu Local Meteorological Observatory.¹⁶ To find a meteorological parameter for forecasting the total pollen count (Y), the correlation matrix of the total pollen count with the weather variables was computed.

STATISTICAL ANALYSIS

The autocorrelation function was computed for a series of total pollen counts or OD pollen counts using the series program SYSTAT (version 5.2) for Macintosh.¹⁷

The “on” and “off” years in the alternate dispersal rhythmic pattern were identified as a general rule by the percent change value between the count data of two successive years, according to the following

equation:

Percent change (%) = [(count – previous year’s count)/previous year’s count] × 100.

Any year with a change greater than 20% was designated as an on year and any year with a change below –20% as an off year. Any year within a percent change of ±20% was considered to have the same rhythmic state as that of the previous year.

SYSTAT (version 10.2) for Windows was used in single and multiple regression analyses. To derive a linear relation between pollen count and weather data, pollen count data were transformed to common logarithms. The logarithm of the total pollen count was represented by Y and that of the OD pollen count by X_{w2}. The alternate rhythm was used as the dummy or indicator variable Z, with on year = 1 and off year = 0. Performance of the regression analysis was evaluated with the coefficient of determination (*R*²), the adjusted coefficient of determination (adjusted *R*²), and the standard error (SE) of the estimate. Diagnosis of the residuals was performed using the Durbin-Watson D value (DW) and the first-order autocorrelation coefficient (FOACC). The difference between the predicted and observed values was expressed as the relative error (%) by calculating the ratio of the difference to the observed value, using the following equation:

Relative error (%) = [(predicted – observed)/observed] × 100.

The relative errors were taken as a standard for the practical use of the forecasting model.

RESULTS

TIME SERIES ANALYSIS OF SUGI POLLEN COUNT

Table 1-A shows the total sugi pollen counts for the period 1987–2006 and for August 31, 2007. The autocorrelation function of the total pollen count (Y, log units) computed by the time series analysis indicated the first-order autocorrelation coefficient of –0.570 at time lag 1, which is significant at the 5% level. The significant negative coefficient implies an alternate rhythmic pattern of the annual pollen count series. The time series analysis for the OD pollen count (X_{w2}, log units) of the previous year again revealed the alternate rhythmic pattern with the significant autocorrelation coefficient of –0.516 at time lag 1. The total pollen count series and the OD pollen count of the previous year series exactly synchronized with each other, including the year of shifted rhythm as described later. Consequently, the cross-correlation function between the two sets of time series showed a highly significant coefficient of 0.870 at time lag –1. The OD pollen count of the previous year was therefore considered a useful preceding indicator of the total pollen count.

Table 1-A Total sugi pollen count and the pollen count in October–December (OD pollen count) of the previous year

Year	Total Pollen Count/cm ²	OD Pollen Count/cm ²	Year	Total Pollen Count/cm ²	OD Pollen Count/cm ²
1987	1564	NC	1998	2185	5.2
1988	6498	27.4	1999	2350	15.3
1989	483	1.5	2000	1151	4.8
1990	5580	16.8	2001	7809	47.0
1991	10075	10.5	2002	3012	7.6
1992	1947	2.4	2003	5756	12.5
1993	6211	14.3	2004	392	2.1
1994	630	3.0	2005	8112	98.0
1995	18202	141.3	2006	2816	11.5
1996	2525	7.9	2007	4421 [†]	33.9
1997	5659	15.0			

NC denotes Not counted.

[†] A total pollen count as of August 31, 2007.**Table 1-B** Statistics of the sugi pollen count data

	Total Pollen Count/cm ²			OD Pollen Count/cm ^{2§}		
	All years	On year	Off year	All years	On year	Off year
Mean	4648	7625	1671	23.4	39.8	5.1
Minimum	392	2350	392	1.5	10.5	1.5
Maximum	18202	18202	3012	141.3	141.3	11.5
SD [†]	4271.48	4226.66	977.05	36.28	44.59	3.33
CV(%) [‡]	91.9	55.4	58.5	155.2	112.0	65.2

[†] Standard deviation. [‡] coefficient of variation = (SD/Mean) × 100.[§] Pollen count in October–December of the previous year.

CYCLIC CHANGE OF ON AND OFF YEARS

The rhythmic state on or off years in the total pollen count series was determined by the percent change (Fig. 1). For the 10 on years, the percent changes ranged from 7.6% to 2789%, and for the 9 off years the percent changes ranged from –51% to –93%.

The year 1999, with a change of 7.6%, should be regarded as having the same rhythmic state as 1998 (an off year) according to the rules described above. Nevertheless, this year was determined to be an on year based on the OD pollen count (15.3 per centimeter squared) of the previous year. The OD pollen count of 10 per centimeter squared is the threshold between the rhythmic state of on and off for the coming year. The rhythmic state of the first year of the series, 1987, was not determined because there were no data for 1986; it was simply designated an off year on the basis of the greater pollen count of 1988.

The alternate rhythm was a regular cyclic change between on and off years. There was one exception in 1991, which was expected to be an off year according

to the regular rhythmic order; however, this was a year of exceptionally large pollen dispersal. The OD pollen count of 10.5 per centimeter squared of the previous year was also exceptional in this dispersal pattern. We describe 1991 as a “shifted year”—a year in which there was a rhythm shift from the state of an off year to an on year.

ANNUAL FLUCTUATIONS AND THE ALTERNATE RHYTHM

The total pollen count exhibited a large annual fluctuation, as shown by a coefficient of variation (CV) greater than 90% (Table 1-B). The overall mean count was 4648; the mean of 10 on years was 7625 and that of 10 off years was 1671, about a fifth of the on year mean. The OD pollen count also showed great fluctuation, with a CV of more than 150%. The overall mean was 23.4; the mean of 10 on years was 39.8 and that of the 9 off years was 5.1, about an eighth of the on year mean.

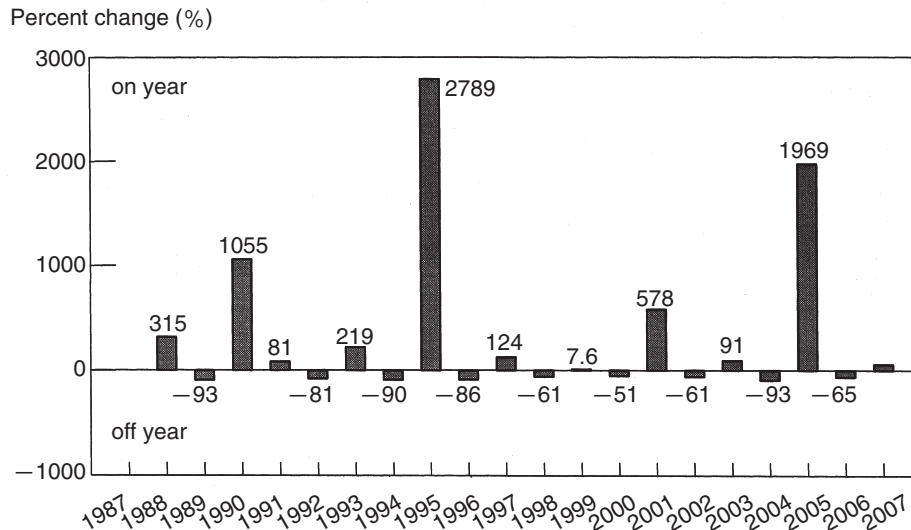


Fig. 1 Percent changes in the total sugi pollen count series for the period of 1987–2006. Percent changes (%) were used to designate on or off years in a series of the total pollen count. The relative change is a ratio of the difference between the pollen counts of two successive years and the preceding year's count. The year with a relative change value larger than 20% was designated as an on year; the year with a value less than -20% as an off year; the year with a value within $\pm 20\%$ was in the same rhythmic state as that of the previous year.

CORRELATION COEFFICIENTS WITH THE PREVIOUS YEAR'S SUMMER WEATHER DATA

In the matrix of the 35 correlation coefficients (Table 2), significant coefficients greater than 0.7 were restricted to the correlations with temperature factors for mid-July or late July. The highest correlation coefficient was 0.805, with the maximum temperature, followed by 0.781, with the mean temperature for mid-July. The maximum temperature for mid-July X was selected as a variable available for forecast regression models.

REGRESSION ANALYSIS FOR TOTAL SUGI POLLEN COUNT

Single or multiple regression analysis for total pollen count Y was performed using three models involving the variable of OD pollen count X_{w2} and another three models including the variable of maximum temperature for mid-July (X). The results of these analyses and the diagnostic statistics of the residuals are summarized in Table 3-A and 3-B.

(1) Models Involving the Variable OD Pollen Count X_{w2} of the Previous Year

Model 1 was the single regression equation relating the total pollen count Y to the independent variable of OD pollen count X_{w2} . The coefficient of determination (R^2) was 0.757. When the alternate rhythm Z and the

interaction in the form of a product ZX_{w2} were included as additional variables, the resulting multiple regression equation (model 3) had a coefficient of determination of 0.844. There was also a slight increase in the adjusted coefficient of determination (adjusted R^2), from 0.742 to 0.813. In model 3, the partial regression coefficient of OD pollen count X_{w2} was significant at the 1% level by the *t*-test, and the partial regression coefficients of alternate rhythm Z and the interaction ZX_{w2} were significant at the 5% level. The standard error of the estimate in model 3 was 0.199, slightly smaller than the value of 0.233 in model 1. However, based on the diagnostic values, the DW value of 1.544 and the first-order autocorrelation coefficient of 0.220 suggest that some periodicity is maintained in the variation of the residuals.

Figure 2-A is a scatter diagram in which the total pollen count Y is plotted against the OD pollen count X_{w2} . The two regression lines, one for on years and the other for off years, appear to differ in the slope. The significance of the interaction ZX_{w2} , as mentioned above, indicates that their slopes differ statistically.

(2) Models Involving the Variable Maximum Temperature for Mid-July X of the Previous Year

Model 4 was a single regression equation relating the total pollen count Y to the independent variable of

Forecasting Models for Sugi Pollen Count

Table 2 Correlation coefficient matrix of total sugi pollen count (log unit) with previous year's summer weather data[†] (1987 – 2006)

Period	Maximum Temperature	Mean Temperature	Sunlight Hours	Rainfall	Relative Humidity
21–30 June	0.124	0.062	0.283	– 0.627 **	– 0.364
1–10 July	0.357	0.382	0.257	– 0.264	– 0.158
11–20 July	0.805 **	0.781 **	0.661 **	– 0.555 *	– 0.526 *
21–31 July	0.637 **	0.777 **	0.682 **	– 0.386	– 0.510 *
1–10 Aug.	0.517 *	0.470 *	0.428	– 0.540 *	– 0.402
11–20 Aug.	0.540 *	0.539 *	0.695 **	– 0.412	– 0.467 *
21–31 Aug.	– 0.216	– 0.116	– 0.208	0.200	0.234

* $p < 0.05$, ** $p < 0.01$.

[†] Cited from the data of Tsu Local Meteorological Observatory.

Table 3-A Results and diagnosis of the regression analysis, data: $n = 19$ (1988–2006)

Model	R ²	Adjust. R ²	SE of Estimate	DW	FOACC	Predictive Formula (probability of t -test)
1	0.757	0.742	0.233	1.304	0.346	$Y = 2.715 + 0.752 X_{W2}$ (0.000)
2	0.795	0.770	0.220	1.570	0.210	$Y = 2.779 + 0.551 X_{W2} + 0.273 Z$ (0.002) (0.101)
3	0.844	0.813	0.199	1.544	0.220	$Y = 2.523 + 0.964 X_{W2} + 0.826 Z - 0.623 Z X_{W2}$ (0.001) (0.013) (0.048)

R² denotes the coefficient of determination; Adjust. R² denotes the adjusted coefficient of determination; SE of estimate denotes the standard error of estimate; DW denotes the Durbin-Watson, D value; FOACC denotes the 1st order autocorrelation coefficient of the residual.

Abbreviation of the variables used are follows:

Dependent variable: Y = Total sugi pollen count, log units.

Independent variables: X_{W2} = OD pollen count in the previous year, log units.

Z = Alternate rhythm; on year = 1, off year = 0.

ZX_{W2} = Interaction between the alternate rhythm and the OD pollen count in the previous year.

Table 3-B Results and diagnosis of the regression analysis, data: $n = 20$ (1987–2006)

Model	R ²	Adjust. R ²	SE of Estimate	DW	FOACC	Predictive Formula (probability of t -test)
4	0.647	0.628	0.276	2.663	– 0.345	$Y = -1.897 + 0.178 X$ (0.000)
5	0.865	0.849	0.176	2.295	– 0.166	$Y = -0.432 + 0.122 X + 0.468 Z$ (0.000) (0.000)
6	0.925	0.911	0.135	1.980	0.003	$Y = -2.934 + 0.208 X + 4.372 Z - 0.131 ZX$ (0.001) (0.001) (0.002)

R² denotes the coefficient of determination; Adjust. R² denotes the adjusted coefficient of determination; SE of estimate denotes the standard error of estimate; DW denotes the Durbin-Watson, D value; FOACC denotes the 1st order autocorrelation coefficient of the residual.

Abbreviation of the variables used are follows:

Dependent variable: Y = Total sugi pollen count, log units.

Independent variables: X = Maximum temperature for mid-July of the previous year.

Z = Alternate rhythm; on year = 1, off year = 0.

ZX = Interaction between the alternate rhythm and the maximum temperature in the previous year.

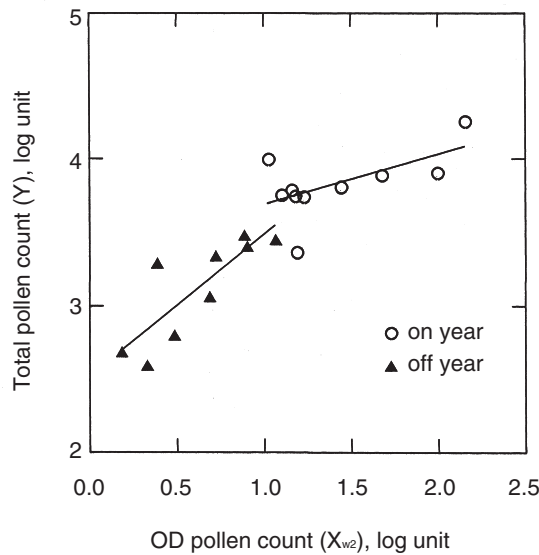


Fig. 2-A Scatter diagram plotting total pollen count (Y) against OD pollen count (X_{w2}) of the previous year. The slopes of the regression lines for on and off years differ slightly. The difference in slope is significant at the 5% level, as shown by the *t*-test for interaction (ZX_{w2}) in the multiple regression analysis of model 3. ○ denotes on year; ▲ denotes off year.

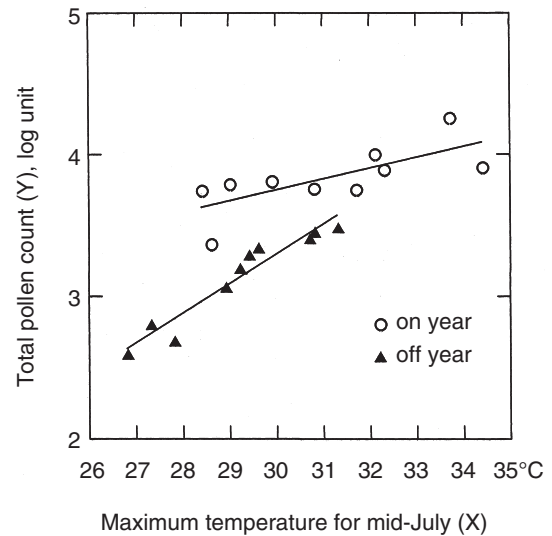


Fig. 2-B Scatter diagram plotting total pollen count (Y) against maximum temperature for mid-July (X) of the previous year. The slopes of the regression lines for on and off years differ markedly. The difference in slope is highly significant at the 1% level, as shown by the *t*-test for interaction (ZX) in the multiple regression analysis of model 6. ○ denotes on year; ▲ denotes off year.

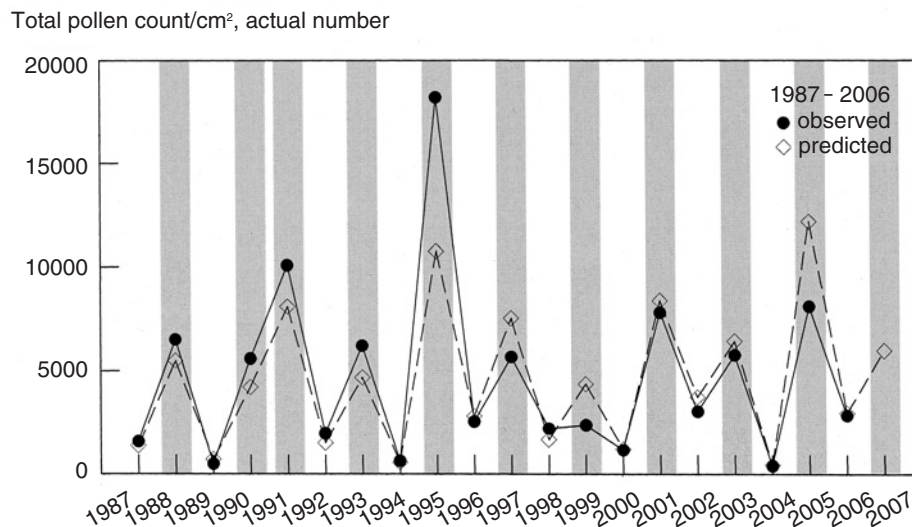


Fig. 3 Observed versus predicted values for total pollen count. Predicted values were obtained using the multiple regression equation of model 6, based on pollen count data for the period 1987–2006. The difference between the predicted and observed values is shown as the relative error (%), that is the ratio of their difference to the observed value. The relative errors for the 20 year interval ranged between –41% and 85% with a median of 3%, wherein: 19 years were within $\pm 50\%$; 14 years within $\pm 21\%$; and one year (1999) had a large value of 85%. Shaded years denote on year; unshaded years denote off year. Solid circles denote observed value; open diamonds denote predicted value.

maximum temperature for mid-July (X), and had a coefficient of determination (R^2) of 0.647. The multiple regression formula of model 5, which included the mid-July maximum temperature X and the alternate rhythm Z, had a higher coefficient of determination (0.865). There was a further increase in the coefficient of determination to 0.925 in model 6, in which one more variable was included—the interaction ZX. Similar steady increases were seen from model 4 to model 6 in the adjusted coefficient of determination. The partial regression coefficients of the three variables in model 6 were all significant at the 1% level by the *t*-test. Furthermore, the DW value of 1.980 and the first-order autocorrelation coefficient of 0.003 in this model imply that no periodicity remained in the residuals.

There was a clear decrease from 0.276 to 0.135 in the standard error of the estimate from model 4 to model 6. Thus, model 6 was chosen as the best forecasting model among those considered in this study.

A scatter diagram plotting the total pollen count Y against the maximum temperature for mid-July X showed two regression lines, one for on years and the other for off years, which differed in the slope (Fig. 2-B). The slope difference was confirmed, as described above, by the significance of the interaction ZX at the 1% level in the *t*-test.

(3) Relative Error of the Prediction

The observed data were compared with the values predicted by model 6 based on data for the period 1987–2006 (Fig. 3). The relative error values for the 20 years ranged between –41% and 85% with a median of 3%, and are summarized as follows: 19 years were within $\pm 50\%$, 14 of the 19 years were within $\pm 21\%$, and one year (1999) had a large relative error of 85%.

(4) Forecasting of Total Pollen Count for the Years 2006 and 2007

Using model 6 (Table 3-B), based on the data for the period 1987–2005, prediction of the total pollen count for 2006 was tested. As the year 2006 was an off year, substituting $Z = 0$ and $X = 30.8^\circ\text{C}$ for the maximum temperature for mid-July in 2005 in the equation (not shown), the predicted value for Y was equal to 3.469. The predicted total pollen count was 2994, which was the inverse logarithm of 3.469. The observed value in 2006 was 2816 and the prediction had a relative error of 6.3%. This was a fair forecast.

Similarly, the total pollen count for 2007 was predicted by model 6. As 2007 was an on year, we substituted $Z = 1$ and $X = 30.4^\circ\text{C}$ for the maximum temperature for mid-July in 2006 in the equation. The predicted total pollen count was 5985. The observed value was 4421 as of August 31, 2007 (Table 1-A). The relative error was 35.4%, i.e., the forecast value overestimated the observed value by 35.4%.

DISCUSSION

POLLEN SAMPLING METHOD

The pollen counting data of the present study were obtained by the gravity method with a Durham sampler, which has been widely used throughout Japan since the 1970s. It is useful for allergy clinics as a routine means of counting a large number of pollen grains in a short time. On the other hand, volumetric pollen sampling with a Burkard sampler is common in Europe and the USA. A statistically significant correlation between count data obtained with the Durham and Burkard samplers was reported by Kishikawa *et al.*¹⁸ Furthermore, Imai *et al.*¹⁹ found a high correlation between count data obtained with a Durham sampler and with a newly developed automatic pollen counter.

Concerning the general assessment of the Durham sampler data, its correlations with the prevalence, day of onset, and medical costs of sugi pollinosis have been reported.^{1,20,21} Therefore, the Durham data are regarded as reasonable indicators and a critical warning sign for health-care policy.

ALTERNATE DISPERSAL RHYTHM

In a pioneering ecological study, Saito²² examined male flower production of sugi forest stands by the litter trap method, and found regular alternation between a productive year (on year) and an unproductive year (off year) of male flowers during the period 1983–1994, except 1991. The alternate rhythm and the exceptional year of 1991 reported in that study coincide with the pollen count data of the present study. Saito's opinion about the cause of the rhythm shift in 1991 will be discussed later.

Taira *et al.* reported the relationship of the amount of atmospheric pollen to the male flower index²³ and the preseason pollen count²⁴ (referred to as the OD pollen count in this study), and they used these as parameters in developing forecasting models.

The number of male flowers in autumn and the number of preseason airborne pollen grains are both biological factors that show an inter-annual fluctuation in rhythm with pollen dispersal in the period of full bloom in the next spring. From a broader viewpoint, the alternate pollen dispersal rhythm can be regarded as an autonomous biorhythm of sugi trees. Taira *et al.*²⁵ also attributed the annual change in airborne pollen count basically to physiological changes occurring in sugi trees.

According to our recent study, the alternate rhythm was synchronized during the past 10–25 years at 12 sites in eight medical facilities in Mie, Gifu, Aichi, and Shizuoka prefectures on the Pacific slope of the Tokai regional zone.²⁶ Similar alternate rhythms were also recognized in the monitoring data reported in studies in the prefectures of Toyama,¹² Kagawa,⁷ and Oita.²⁷ There is a possibility that the

rhythm occurs widely in western Japan.

In the present report, the term “alternate rhythm” is used in a broad sense, and includes cases in which cycles of 3 years or more occur in a regular biennial sequence (i.e., a 2-year cycle). The alternate rhythm should consist of pairs of consecutive years comprising an on year followed by an off year or an off year followed by an on year; however, it sometimes contains irregular pairs such as consecutive on or off years. A change from an on year to an off year or vice versa is called a rhythm shift.

The alternate rhythm is well known in fruit trees in their fruiting behavior, where it is generally termed “alternate bearing.” For example, olive trees display alternate bearing and produce allergenic pollen grains. Monitoring of airborne olive pollen grains has been carried out,²⁸ and pollen count data are used by agronomists as a parameter for forecasting fruit yields in olive plantations in Andalusia in southern Spain.²⁹ In the two studies cited here, years of high pollen count correspond well with those of high olive production in the area concerned.

The alternate dispersal rhythm of airborne pollen in sugi trees appears to be a phenomenon similar to the alternate changes found in fruit trees. The trigger of the biorhythm and the factors generating the alternate rhythm in fruit-bearing trees have been discussed in an extensive review by Monselise and Goldschmidt.³⁰ Although the complex mechanism of the biorhythm has not yet been resolved, they assumed that it is an adaptive trait against climatic factors unfavorable to the reproductive growth, and that carbohydrate stress plays an important role in the rhythmic behavior during all the years of the tree's lifetime.

LIMITED UTILITY OF THE FORECAST FORMULA

General forecasts of sugi pollen count for 2007 predicted a count of only 20–40% of the mean pollen count owing to the relatively low number of hours of sunlight in July 2006. According to the data monitored at our hospital, the mean for the last 20 years was 4648 (Table 1-B). Thus, the percentage value provided by the general forecasts corresponds to 1000–2000 pollen grains per centimeter squared. Any periodicity of yearly pollen dispersal was not considered in making the general forecast.

Our predicted value, based on the formula of model 6, involving periodicity (Table 3-B), exceeded the observed value by 35%, as mentioned above; however, our predicted value seems to be more realistic than the general forecast, particularly with regard to disease prevention.

Differences between the observed and predicted values exhibited yearly variation (Fig. 3). Although the relative errors in most cases were within $\pm 50\%$, there was a 1 in 20 years possibility of making a wrong forecast.

HOW TO FORESEE WHETHER THE COMING YEAR WILL BE AN ON OR OFF YEAR

A marked feature of the forecasting models reported in this study is the use of a variable description of the alternate rhythm. However, this can also be a disadvantage of the models, because the value of the variable (0 or 1 according to whether it is an on or an off year) should be known and is applied in the equations when making a prediction. Therefore, it is essential to know whether the coming year is an on or an off year before computation of the equations.

For this purpose, we are anticipating the rhythmic state for the coming year by means of the two criteria, the regular biennial order in the total pollen count and the size of OD pollen count. A threshold of the OD pollen count between on and off years is about 10 per centimeter squared (Table 1-B), although their ranges overlap a little.

To provide a useful forecasting method, we conducted discriminant analysis with the following four variables: total sugi pollen count, OD pollen count, Hinoki family (Cupressaceae) pollen count, and maximum mid-July temperature. The outlook for the method is favorable. The next step is an extension of the forecasting method to predict years of rhythm shift.

CLIMATE FACTORS AFFECTING THE BIORHYTHM

There was a rhythm shift in 1991, the cause of which may have been related to the weather conditions of 1990; this shift had been predicted from the preceding indicator, the OD pollen count of the previous year. Saito²² suggested that the cause of the rhythmic change in male flower production was the hot, dry weather of late June and July in 1990.

To find a clue to the nature of the biological rhythm, it seems important to investigate the climate factors that caused the rhythm shift of 1991. Usually, a hot summer has an effect on sugi trees, promoting flower bud development and increasing pollen production, while the effect of a cool summer is the reverse. The summers of 1988 and 1989 were cool, and there was intense heat in the summer of 1990. At present we consider that the drastic temperature change in summer, particularly in July, caused the shift in the pollen dispersal rhythm in 1991.

In the last 20 years there have been four years of hot summers with 1–3°C higher than normal, and four years of cool summers with an average July temperature of 1–2°C lower than normal. Was the abnormal weather in these years due to climate changes associated with global warming? With continued global warming, rhythm shifts are expected to become more frequent. To maintain reliable forecasting in the face of the uncertainties in the near future, advanced forecasting technology based on basic studies of bio-

rhythms will be required.

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REFERENCES

- Okuda M. Epidemiology of Japanese cedar pollinosis throughout Japan. *Ann Allergy Asthma Immunol* 2003;**91**: 288-96.
- Kaneko Y, Motohashi Y, Nakamura H, Endo T, Eboshida A. Increasing prevalence of Japanese cedar pollinosis: A meta-regression analysis. *Int Arch Allergy Immunol* 2005; **136**:365-71.
- Usami A, Furuya K, Endo H. [Studies on the prediction of the annual total pollen count of Sugi (*Cryptomeria japonica* D. Don)]. *Jpn J Allergol* 1980;**29**:780-5 (in Japanese).
- Yamazaki F. [Studies of the pollen grains causative of pollinosis (10): Correlation between Sugi pollinosis and mean ten-day temperature in July]. *Jpn J Allergol* 1985;**34**: 305-9 (in Japanese).
- Takahashi Y, Kawashima S. [A new prediction method for the total pollen counts of *Cryptomeria japonica* based on variation in annual summertime temperature]. *Jpn J Allergol* 1999;**48**:1217-21 (in Japanese).
- Murayama K. [Yearly variation of pollen counts and pollen forecast]. *Igaku no Ayumi* 2002;**200**:417-21 (in Japanese).
- Kobayashi R, Karaki M, Mori N. [Pollen dispersion of Japanese cedar and Japanese cypress in Kagawa Medical University of Kagawa prefecture]. *Jpn J Allergol* 2003;**52**: 15-9 (in Japanese).
- Tanaka K, Okada K, Kakami T, Yoshida S, Taguchi M, Yamazaki F. [Forecast of Japanese cedar pollen scattering counts of 2005 at Ogaki City, Gifu prefecture, Japan]. *Jpn J Palynol* 2005;**51**:13-6 (in Japanese).
- Sahashi N. [Thirty years with cedar pollen]. *Farumashia* 2006;**42**:156-61 (in Japanese).
- Kim S, Nakanishi T, Ogasawara H. [Male flower differentiation in relation to the forecast of Japanese cedar (*Cryptomeria japonica*) airborne pollen grains]. *Jpn J Palynol* 2000;**46**:125-32 (in Japanese).
- Yuta A, Ukai K, Sakakura Y *et al.* [Prediction of the total Japanese cedar pollen counts based on male flower-setting conditions of standard trees]. *Jpn J Allergol* 2002; **51**:577-82 (in Japanese).
- Taira H, Yoshii E, Teranishi H. [The characteristic of the pollen disposal of *Cryptomeria japonica*]. *Jpn J Allergol* 2004;**53**:1187-94 (in Japanese).
- Saito Y. [Japanese cedar pollinosis—Past, Present and Future]. *Jpn J Palynol* 1999;**45**:55-62 (in Japanese).
- Shida T, Furuya K, Kutsuwada K *et al.* [Changes in airborne pollen grains during the 31-years from 1965 to 1995 in Sagami-hara]. *Jpn J Palynol* 1998;**44**:47-60 (in Japanese).
- Durham OC. The volumetric incidence of atmospheric allergens. IV. A proposed standard method of gravity sampling, counting and volumetric interpolation of results. *J Allergy* 1946;**17**:79-86.
- Tsu Meteorological Observatory. <http://www.tokyo-jma.go.jp/home/tsu/>.
- Wilkinson L, Hill M, Vang E. *SYSTAT: Statistics*, Version 5.2 Edition. Evanston, Illinois, USA: Systat, 1992.
- Kishikawa R, Horiuchi T, Togawa A *et al.* [Juniper pollen monitoring by Burkard sampler in Galveston, Texas, USA and Japanese cedar pollen counting in Fukuoka Japan—Introduction of Pan American Aerobiology Association protocol counting technique]. *Jpn J Allergol* 2004;**53**:582-8 (in Japanese).
- Imai T, Nohara O, Endo T, Fukaya S. [Usefulness and practical use of an automatic counter for scattering pollens in spring]. *Jpn J Allergol* 2005;**54**:559-68 (in Japanese).
- Dejima K, Takenaka H, Mizukoshi F *et al.* [A relationship between the annual onset day of Japanese cedar pollinosis and pollen dispersion]. *Jpn J Allergol* 1992;**41**:1405-12 (in Japanese).
- Yuta A, Miyamoto Y, Hattori R, Ogihara H, Takeuchi K, Majima Y. [The influence of medical economy from the aspect of medical direct costs by a difference of the number of the pollen scattering on an allergic-specific immunotherapy for Japanese cedar pollinosis]. *Jpn J Allergol* 2007;**56**:1366-71 (in Japanese).
- Saito H. [Sugi pollen disease from the forester's viewpoint with special respect to pollen production in some forests]. *Pract Otol (Kyoto)* 1995;**76**:6-19 (in Japanese).
- Taira H, Teranishi H, Kenda Y. [Comparison of predictive methods of Sugi (*Cryptomeria*) atmospheric pollen counts using mean temperature, solar radiation and male flowering index]. *Jpn J Allergol* 1997;**46**:489-95 (in Japanese).
- Taira H, Teranishi H, Kenda Y. Preseasonal scattering of *Cryptomeria japonica* pollen in Japan, with reference to the dormancy of the male flowers. *Allergol Int* 2000;**49**: 263-8.
- Taira H, Teranishi H, Kenda Y. The formation of pollen in male flowers and yearly atmospheric pollen counts of *Cryptomeria japonica* in the following year. *Allergol Int* 1988;**47**:297-302.
- Ito Y, Hattori R, Mase H, Watanabe M, Shiotani I. [An alternate dispersal rhythm of the sugi pollen counts in Tokai area]. *Jpn J Allergol* 2007;**56**:1187 (in Japanese).
- Watanabe T, Suenaga S, Matsushita F, Suzuki M. [Prediction of atmospheric Japanese cedar pollen counts in Oita University Faculty of Medicine Complex]. *Jpn J Allergol* 2005;**54**:1272-8 (in Japanese).
- Galán C, Cariñanos P, García-Mozo H, Alcázar P, Domínguez-Vilches E. Model for forecasting *Olea europaea* L. airborne pollen in South-West Andalusia, Spain. *Int J Biometeorol* 2001;**45**:59-63.
- Gonzalez Minero FJ, Candau P, Morales J, Tomas C. Forecasting olive crop production based on ten consecutive years of monitoring airborne pollen in Andalusia (South Spain). *Agric Ecosyst Environ* 1998;**69**:201-15.
- Monselise SP, Goldschmidt EE. Alternate bearing in fruit trees. *Hortic Rev* 1982;**4**:128-73.