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A Five-year (1991–1995) Census of Airborne Pollen in Chiba, Central Japan, with Reference to its Ecological Considerations

Chuh Yonebayashi

Natural History Museum and Institute, Chiba
955–2 Aoba-cho, Chuo-ku, Chiba 260, Japan

Abstract A generalized pollen calender based on a five-year (1991–1995) census was used to clarify seasonal changes in airborne pollen in Chiba, central Japan. The maximal values of tree pollen types in spring tend to occur earlier in Chiba than in northern Japan, while those of herbaceous pollen types occurred later in summer to autumn. Variation in the magnitude of the annual catch showed biennial (2-year cycle) flowering patterns in many tree pollen types. Although similar patterns are reported from Europe (*Betula, Alnus, Quercus* and *Fagus*) and Japan (*Carpinus*), a 15-year observation at Niigata (ca. 270 km NNW of Chiba) does not show that 2-year pollen cycles are common among trees. The low catches of herbaceous pollen types in 1995 were attributed to "winter killing".

Key words: airborne pollen, anemophily, seasonal change, annual variation, palynology.

Anemophily is the dominant means of pollination among angiosperms in some environments (e.g. northern deciduous forests and savanna) as well as gymnosperms (Whitehead, 1969). Airborne pollen behavior is highly important for the reproduction of anemophilous species. The pollination ecology of these species should be discussed on the basis of empirical airborne pollen data. However, little is known about long-term airborne pollen behavior in Japan (Fujisaki, 1988; Igarashi, 1987) except for that of *Cryptomeria japonica* (e.g. Ogasawara *et al.*, 1991; Saito, 1995), whose pollen is the most serious pollen allergen in Japan. Therefore, a pollen trap was set in Chiba, central Japan, to obtain information on airborne pollen behavior, and the results of observations conducted for five consecutive years, 1991–1995, are presented here.

This paper focuses on the following fundamental questions: (i) How does the airborne pollen change seasonally in quantity and assemblage? (ii) How does the year-to-year variation in the magnitude of pollen incidence occur?

Study Area and Vegetational Background

The site selected for this study is situated on a diluvial upland southeast of Chiba City center, central Japan (35°35′50″N; 140°08′25″E; 20 m a.s.l.). The Ecology Park, an observation field for the Natural History Museum and Institute, Chiba, and Aoba-no-mori Park, which was under construction as an urban park when this study started, are located to the south of the site. Apartment houses lie to the west of the site, and development land for residential areas lies to the north and east. Mean, maximum and minimum monthly temperatures during the study period (1991–1995) and in the previous year at the site are shown in Table 1.

Since the National Institute of Animal Industry, along with pasture, was located at the study area until 1980, many kinds of introduced grass for pasture; e.g. *Lolium multiflorum, Festuca rubra* and *Dactylis glomerata,* as well as exotic plants, grow in the area. In the Ecology Park there are 9 kinds of small forest stand; e.g. *Castanopsis sieboldii* forest, *Quercus acuta* forest, *Pinus densiflora* forest, *Carpinus tschonoskii–Quercus serrata* forest etc., which are planted as examples of forest

Table 1. Mean, maximum and minimum monthly temperatures observed at the study site, 1990–1995.

Month	Mean							Maximum							Minimum						
	1990	1991	1992	1993	1994	1995	Average	1990	1991	1992	1993	1994	1995	Average	1990	1991	1992	1993	1994	1995	Average
Jan.	3.8	4.7	5.0	4.6	4.1	4.7	**4.5**	17.6	12.8	14.3	13.3	17.5	15.8	**15.2**	−4.3	−5.8	−3.7	−2.8	−5.8	−5.4	**−4.6**
Feb.	6.7	5.4	5.7	6.3	5.3	4.9	**5.7**	18.0	16.0	18.8	20.7	15.1	13.8	**17.1**	−3.3	−4.5	−4.1	−4.6	−3.7	−5.5	**−4.3**
Mar.	9.4	8.5	8.5	7.3	6.8	7.8	**8.1**	19.8	20.7	21.0	18.9	17.4	20.3	**19.7**	−0.9	−2.6	−1.0	−2.6	−2.1	−0.9	**−1.7**
Apr.	13.6	13.8	14.3	12.0	14.4	14.1	**13.7**	22.3	23.6	25.3	25.0	24.8	25.2	**24.4**	2.2	2.2	3.6	−0.4	3.6	−0.1	**1.9**
May	18.0	17.7	16.4	17.4	18.2	18.1	**17.6**	28.6	26.8	27.7	29.1	27.4	26.5	**27.7**	8.9	4.2	6.8	5.4	7.5	9.9	**7.1**
Jun.	22.3	22.4	19.3	20.7	21.2	19.7	**20.9**	34.5	34.4	27.2	30.1	30.6	28.2	**30.8**	15.1	11.6	12.7	12.3	14.0	12.7	**13.1**
Jul.	24.6	25.6	24.3	21.7	27.0	25.5	**24.8**	35.4	36.3	35.0	32.3	36.3	35.4	**35.1**	16.5	19.4	17.0	13.9	21.0	19.4	**17.9**
Aug.	27.3	24.5	26.0	24.2	27.8	28.3	**26.4**	35.5	34.4	33.2	33.4	38.2	36.5	**35.2**	19.8	17.0	17.9	17.9	20.5	21.9	**19.2**
Sep.	23.7	23.2	22.0	21.8	23.7	22.5	**22.8**	34.3	32.9	35.9	30.5	32.8	34.3	**33.5**	14.6	16.9	8.6	12.0	17.5	12.6	**13.7**
Oct.	18.0	17.0	16.1	16.1	19.0	18.1	**17.4**	21.1	27.9	25.6	25.0	28.1	27.5	**25.9**	11.2	8.3	6.5	5.0	10.2	7.7	**8.2**
Nov.	13.7	11.5	12.5	12.6	11.6	10.8	**12.1**	24.8	21.8	23.1	24.0	24.1	22.2	**23.3**	1.5	0.2	2.3	0.5	0.1	−0.1	**0.8**
Dec.	8.1	7.6	7.9	7.5	7.2	5.9	**7.4**	23.0	18.8	19.3	20.9	17.1	16.5	**19.3**	−2.5	−3.0	0.0	−3.6	−3.8	−3.3	**−2.7**
Average	**15.8**	**15.2**	**14.8**	**14.4**	**15.5**	**15.0**	**15.1**	**26.2**	**25.5**	**25.5**	**25.3**	**25.8**	**25.2**	**25.6**	**6.6**	**5.3**	**5.6**	**4.4**	**6.6**	**5.7**	**5.7**

types in the Boso (Chiba) area. However, most of trees in these stands are too young to produce a large amount of pollen. Small patches of secondary forest including *Quercus acutissima, Q. serrata, Carpinus tschonoskii* and *Celtis sinensis* var. *japonica* are scattered in and around the study area. Herbaceous plant communities consisting of annuals such as *Ambrosia artemisiaefolia* var. *elatior, Digitaria ciliaris, Setaria faberi* and *Humulus japonicus* were widely distributed just after the disturbance during the park construction and the land development for residential use. These communities were succeeded by communities consisting of perennials a few years after the disturbance. At present, the Aoba-no-mori Park area is frequently mowed to maintain lawns, while the development land for residential use is dominated by taller grasses such as *Lolium multiflorum* and *Festuca rubra.*

Method

Pollen grains were collected at a height of 1.5 m with a Durham trap; a standard trap that relies on gravity. The total period of collection was five years (from 4 January 1991 to 4 January 1996). The glass slides which were smeared with white Vaseline as a trapping medium were changed at intervals of 1–5 days in spring and mostly 1–7 days in other seasons; exceptional cases were a 13-day interval in 1991, an 11-day interval in 1992, a 10-day interval in 1991, and 8-day intervals in 1993 and 1995. Coarse particles such as sand grains, small insects and plant fragments were removed with a needle under a stereo microscope, and then the samples were mounted in glycerine jelly. Consequently, they were neither acetolyzed, nor stained.

All pollen and spore types within the whole area of the $1.8 \times 1.8\ cm^2$ cover glass were counted. Usage of "-type" and "/" in presenting pollen data follows Birks and Birks (1980). Pollen catches for seasonal change were represented as grain number captured per 1 cm^2 per day, the actual counts being divided by the area of the cover glass and the collecting period, and as the number per year for the annual count. Each date given represents the middle date of the collection interval when longer than two days.

Results

1. Seasonal changes in major taxa

A total of 59 pollen and spore types (37 tree pollen types, 19 non-tree pollen types, and 3 fern spore types) were detected throughout the five-year census. A generalized pollen calender, or a seasonal incidence chart, of selected pollen and spore types for the study area was made from the census results (Fig. 1). The terms used to indicate the quantity of airborne pollen grains throughout this paper are; "common": pollen grains were present in more than two of the five years at the same dates, "abundant": more than 1 grain ($/cm^2/$day) was present for more than two years, "prominent": over 10 grains were present for more than two years. Seasons of the maxima in Fig. 1 represent the range between the earliest and the latest dates of the maximum readings for each year.

The following notes include major pollen and spore types illustrated in Fig. 1 in order of their peak appearance (see also Table 2).

Alnus. Pollen season was from mid-January to early June, but was intermittent after late April. Pollen grains were caught sporadically in small numbers from October to December in some years. Maximum readings varied from early February to early April. It is most likely that the liberation of *Alnus* pollen, which occurred in early spring, was largely affected by the weather during the flowering season. Andersen (1974) has reported that the separation of the *Alnus* pollen was inhibited by night frosts which occurred just after *Alnus* flowering. Source: *A. japonica.*

Cryptomeria. Season mid-January to late May, and minor season from late October to December; caught sporadically in other periods. Prominent from late February to early April. Maximum reading from late February to late March. The value of 406.3 grains recorded on 22 March 1995 was larger than the annual deposition of this pollen type in 1994. Source: planted *C. japonica,* because another possible source, *Metasequoia glyptostroboides,* which is morphologically indistinguishable from *C. japonica,* is rare in and around the study area.

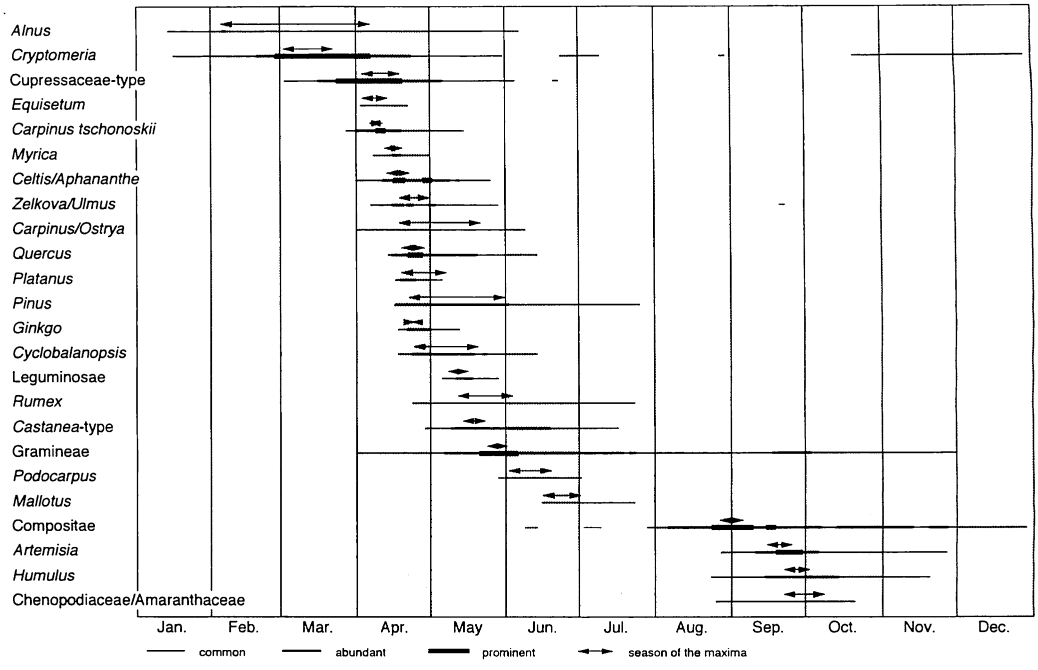

Fig. 1. Generalized pollen calender based on the five-year (1991–1995) census in Chiba, central Japan. The thin lines indicate the periods during which airborne pollen catches were "common": pollen grains were present in more than two of the five years on the same dates, the thick lines indicate an "abundant" pollen catch: more than 1 grain ($/cm^2/day$) was present in more than two years, and the double thick lines indicate "prominent" pollen catch: over 10 grains were present in more than two years. The lines between the solid triangles represent the range of the dates of the maximum reading among the five years.

Cupressaceae-type. This pollen type includes pollen of Cupressaceae, Cephalotaxaceae and/or Taxaceae. Season early March to early June; caught sporadically until late June. Prominent from late March to mid-April. Maximum reading from early to mid-April. Source: *Chamaecyparis obtusa, C. pisifera, Torreya nucifera* etc.

Equisetum. Although quantitatively unimportant, this spore type was selected because the germination of the fertile stem of *E. arvense* is a symbol of spring for the Japanese. Season April; catches in other seasons were sparse. Although maximum reading was recorded in early to mid-April, the peak was obscure. Source: *E. arvense,* a common fern weed.

Carpinus tschonoskii. *Carpinus/Ostrya* pollen grains with more than three pores were classified into this pollen type. Season late March to mid-May; caught sporadically until early July in some years. Abundant from early to mid-April. Fluctuation among the dates of the maximum reading varied within only a week. Source: *C. tschonoskii,* common in the study area.

Myrica. Season early to late April; rare in other seasons. Abundant in mid-April; Maximum readings were recorded in this period. Source: planted *M. rubra.*

Celtis/Aphananthe. Season early April to late May; rare in other seasons. Abundant from mid-April to early May. Maximum reading around mid-April. About two weeks after the highest peak, a second lower peak occurred (Fig. 2). The first and second peaks probably arose from liberation of *Celtis sinensis* var. *japonica* and *Aphananthe aspera* pollen grains, respectively.

Zelkova/Ulmus. Season early April to late May; small amount of pollen frequently caught around late September. Maximum reading mid- to late April. Source: *Zelkova serrata* in spring and *Ulmus parvifolia* in autumn.

Carpinus/Ostrya. Season early April to

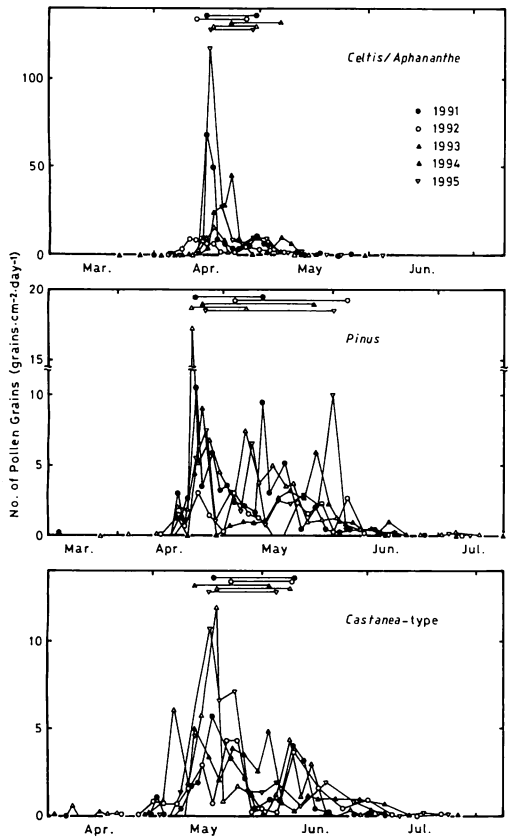

Fig. 2. Seasonal changes in pollen catches of *Celtis/Aphananthe*, *Pinus* and *Castanea*-type in Chiba, 1991–1995. Horizontal lines above each graph indicate the lags between the first and second peaks.

early June, but not abundant; rare in other seasons. Maximum readings were recorded mid-April to late May. Since flowering season of *Carpinus japonica* and *C. laxiflora* planted in the Aoba-no-mori Park was early April, which was almost the same as that of *C. tschonoskii*, the source probably included distant *C. cordata* and *C. japonica*, as well as the neighboring *C. japonica* and *C. laxiflora*. Most grains of this pollen type caught after 21 April (55.4–90.9% of annual catch) would be long-transported pollen, because 91.0–96.6% of the annual catch of *C. tschonoskii* was obtained up to 20 April.

Quercus. This pollen type includes pollen from *Quercus* subgenus *Quercus*. Season mid-April to mid-June. Abundant from mid-April to mid-May. Maximum reading mid- to late April. Source: deciduous oaks; chiefly *Q. serrata* and *Q. acutissima*.

Platanus. To my knowledge, Chiba was the first place in Japan where this pollen type was detected (Yonebayashi, 1994). Season mid-April to early May; catches in other seasons were rare. Abundant from mid- to late April. Maximum readings appeared in this period, except in 1993, when the pollen catch was low. Source: a few planted *P.* ×*acerifolia* trees at ca. 30 m NE of the sampling site.

Pinus. Season mid-April to late July; caught sporadically in other seasons. Abundant from late April to early June. Maximum readings recorded in this period. There were two major peaks; the first in late April to early May and the second two to five weeks later (Fig. 2). *P. thunbergii* and *P. densiflora* probably contributed to the first and second peaks, respectively.

Ginkgo. Season mid-April to mid-May; rare in other seasons. Abundant in late April. Date of maximum readings in this period varied within only three days among the five years. Source: planted *G. biloba*.

Cyclobalanopsis. This pollen type included of pollen from *Quercus* subgenus *Cyclobalanopsis*. Season mid-April to mid-June; caught sporadically until mid-July in some years. Abundant from late April to mid-May. Maximum reading early to mid-May. Source: evergreen oaks; chiefly *Quercus myrsinaefolia*, *Q. acuta* and *Q. glauca*.

Leguminosae. Although entomophilous pollen is rarely caught in a significant amount, this pollen type was well recorded. Season early to late May. Abundant in mid-May. Maximum reading early to mid-May. Source: small *Robinia pseudoacacia* stand ca. 40 m south of the sampling site.

Rumex. Season late April to late July, but not abundant. Maximum reading from mid-May to early June. Source: *R. conglomeratus*, *R. obtusifolius* and *R. acetosella* etc.

Castanea-type. This pollen type includes pollen of *Castanea*, *Castanopsis* and/or *Lithocarpus*. Season late April to mid-July; abundant from early May to mid-June. Pollen count had two major peaks; the highest occurred mid- to late May, and then about three weeks later, in early June, the second peak appeared (Fig. 2). The first and second peaks originated from pollen grains of *Cas-*

Table 2. Synopsis of observations during the five-year (1991–1995) census of airborne pollen in Chiba, central Japan.

Taxa	Annual catch (grains/cm²/year)						Percentage (%)						Date of maximum reading					
	1991	1992	1993	1994	1995	Average	1991	1992	1993	1994	1995	Average	1991	1992	1993	1994	1995	Average
Trees																		
Ginkgo	12.04	47.84	36.11	54.32	39.20	**37.90**	0.25	1.45	0.67	1.50	0.36	**0.67**	25-IV	23-IV	25-IV	22-IV	22-IV	**23-IV**
Pinus	165.74	75.31	122.84	195.99	171.60	**146.30**	3.40	2.28	2.26	5.40	1.58	**2.60**	22-IV	4-V	25-IV	22-IV	26-IV	**25-IV**
Cryptomeria	1247.22	708.02	1671.30	338.27	5127.78	**1818.52**	25.60	21.45	30.79	9.31	47.27	**32.38**	7-III	2-III	28-II	11-III	22-III	**8-III**
CUPRESSACEAE-type	492.59	119.44	856.17	32.10	2038.89	**707.84**	10.11	3.62	15.77	0.88	18.79	**12.60**	1-IV	11-IV	16-IV	15-IV	2-IV	**9-IV**
Podocarpus	5.86	10.80	20.37	4.32	14.20	**11.11**	0.12	0.33	0.38	0.12	0.13	**0.20**	6-VI	4-VI	17-VI	1-VI	19-VI	**9-VI**
Myrica	4.94	4.63	20.37	14.81	14.20	**11.79**	0.10	0.14	0.38	0.41	0.13	**0.21**	17-IV	11-IV	16-IV	14-IV	19-IV	**15-IV**
Salix	3.40	2.47	7.10	3.40	12.96	**5.87**	0.07	0.07	0.13	0.09	0.12	**0.10**	20-III, 19-IV	11-V	3-IV	22-IV	6-IV	**15-IV**
Alnus	32.10	29.94	67.90	58.95	43.83	**46.54**	0.66	0.91	1.25	1.62	0.40	**0.83**	7-III	5-II, 16-III	6-II	6-IV	14-II	**1-III**
Carpinus/Ostrya	27.16	10.19	42.59	3.09	57.41	**28.09**	0.56	0.31	0.78	0.08	0.53	**0.50**	11-V	21-V	13-V	18-IV	9-V	**8-V**
Carpinus tschonoskii	135.49	60.19	130.86	10.80	467.90	**161.05**	2.78	1.82	2.41	0.30	4.31	**2.87**	12-IV	5-IV	11-IV	8-IV	8-IV	**9-IV**
Castanea-type	104.94	107.72	120.37	138.27	161.73	**126.61**	2.15	3.26	2.22	3.81	1.49	**2.25**	18-V	23-V	13-V	18-V	16-V	**18-V**
Cyclobalanopsis	41.98	64.81	51.85	129.32	60.80	**69.75**	0.86	1.96	0.96	3.56	0.56	**1.24**	13-V	11-V	20-V	15-V	9-V	**14-V**
Quercus	229.32	98.15	260.49	307.10	201.54	**219.32**	4.71	2.97	4.80	8.45	1.86	**3.90**	22-IV	18-IV	23-IV	27-IV	29-IV	**24-IV**
Celtis/Aphananthe	350.00	108.02	312.96	173.15	560.19	**300.86**	7.18	3.27	5.76	4.77	5.16	**5.36**	15-IV	13-IV	23-IV	18-IV	17-IV	**17-IV**
Zelkova/Ulmus	83.02	23.15	91.36	12.96	341.05	**110.31**	1.70	0.70	1.68	0.36	3.14	**1.96**	15-IV	30-IV	18-IV	18-IV	17-IV	**20-IV**
Platanus	47.53	12.04	11.11	112.35	86.73	**53.95**	0.98	0.36	0.20	3.09	0.80	**0.96**	22-IV	18-IV	7-V	20-IV	22-IV	**24-IV**
LEGUMINOSAE	25.00	12.04	51.23	21.60	17.28	**25.43**	0.51	0.36	0.94	0.59	0.16	**0.45**	13-V	11-V	16-V	7-V	13-V	**12-V**
Mallotus	3.09	5.86	12.96	39.20	6.79	**13.58**	0.06	0.18	0.24	1.08	0.06	**0.24**	27-VI	1-VII	22-VI	15-VI	26-VI	**24-VI**
Sambucus	3.70	0.31	4.32	19.44	4.32	**6.42**	0.08	0.01	0.08	0.54	0.04	**0.11**	17-IV	18-IV	25-IV	3-IV	8-IV	**14-IV**
Non-trees																		
Humulus	88.27	48.77	136.42	59.57	73.46	**81.30**	1.81	1.48	2.51	1.64	0.68	**1.45**	28-IX	23-IX	28-IX	21-IX	2-X	**26-IX**
Rumex	32.72	17.59	53.09	30.25	35.19	**33.77**	0.67	0.53	0.98	0.83	0.32	**0.60**	23-V	11-V	3-VI	15-V	16-V	**20-V**
CHENOPODIACEAE/ AMARANTHACEAE	7.72	22.84	17.90	12.65	7.72	**13.77**	0.16	0.69	0.33	0.35	0.07	**0.25**	28-IX	30-IX	28-IX	21-IX	2-X	**28-IX**
Macleaya	2.16	6.48	10.49	0.31	1.23	**4.13**	0.04	0.20	0.19	0.01	0.01	**0.07**	20-VII	8-VII	20-VII	1-VI	23-VII	**8-VII**
COMPOSITAE	934.57	863.27	289.81	598.15	285.19	**594.20**	19.18	26.16	5.34	16.47	2.63	**10.58**	31-VIII	26-VIII	31-VIII	5-IX	28-VIII	**30-VIII**
Artemisia	101.23	150.62	227.78	425.00	164.20	**213.77**	2.08	4.56	4.20	11.70	1.51	**3.81**	14-IX	23-IX	21-IX	21-IX	25-IX	**20-IX**
GRAMINEAE	528.70	551.85	591.98	648.46	589.81	**582.16**	10.85	16.72	10.90	17.85	5.44	**10.36**	23-V	1-VI	30-V	24-V	28-V	**27-V**
Typha/Sparganium	3.40	5.25	8.33	8.02	11.42	**7.28**	0.07	0.16	0.15	0.22	0.11	**0.13**	30-VI	14-V	6-VII	2-VII	3-VII	**23-VI**
Trees total	3036.73	1509.26	3928.70	1679.01	9496.29	**3930.00**	62.32	45.71	72.36	46.22	87.53	**69.97**	15-IV	2-III	23-IV	22-IV	22-III	**4-IV**
Non-trees total	1710.49	1684.56	1367.60	1839.20	1238.28	**1568.03**	35.10	51.04	25.20	50.64	11.41	**27.92**	23-V	26-VIII	30-V	21-IX	28-V	**8-VII**
FS total	9.57	11.11	12.96	9.88	13.27	**11.36**	0.20	0.34	0.24	0.27	0.12	**0.20**	12-IV	11-IV	6-II, 16-IV	14-IV	2-IV	**4-IV**
Sub total	4756.79	3204.94	5309.26	3528.09	10747.84	**5509.38**	97.62	97.08	97.80	97.13	99.07	**98.09**	15-IV	2-III	23-IV	22-IV	22-III	**4-IV**
Unknown Pollen	116.05	96.30	119.14	104.32	100.62	**107.29**	2.38	2.92	2.20	2.87	0.93	**1.91**	17-IV	13-III	22-IV	26-IV	12-V	**19-IV**
Total	4872.84	3301.23	5428.70	3632.41	10848.77	**5616.79**	100.00	100.00	100.00	100.00	100.00	**100.00**	15-IV	2-III	23-IV	22-IV	22-III	**4-IV**

tanopsis sieboldii and *Castanea crenata*, respectively. Low pollen counts after the second peaks suggested that *Lithocarpus edulis*, whose flowering time is later than that of *C. crenata*, was not well represented in the pollen catch.

Gramineae. Season early April to late November; caught sporadically in other seasons in some years. Abundant from early May to mid-July and from mid-September to early October. Prominent from late May to early June; maximum readings were also recorded in this period. Source: chiefly pasture grasses in spring such as *Lolium multiflorum*, *Festuca rubra*, *Dactylis glomerata*; after summer, *Miscanthus sinensis*, *Digitaria ciliaris*, *Setaria faberi* etc.

Podocarpus. Season late May to early July, but not abundant. Catches in other seasons were sparse. Maximum reading from early to mid-June. Source: planted *P. macrophyllus*.

Mallotus. Season mid-June to late July, but not abundant. Catches in other seasons were rare. Maximum reading from mid-June to early July. Source: *M. japonicus*.

Compositae. This pollen type, other than *Artemisia*, was caught intermittently after June, from late July to late December continuously; catches in other seasons were sporadic. Abundant from August to November; prominent from late August to early September. Maximum readings were recorded between late August and early September. Because most of this pollen type were grains with short spines, the source seemed to be *Ambrosia artemisiaefolia* var. *elatior*. Observation of flowering time of this species supports this postulate. Probably pollen grains from common entomophilous weeds, e.g. *Solidago altissima*, *Conyza sumatrensis*, *Erigeron canadensis*, were less significant.

Artemisia. Season late August to late November; caught sporadically in other seasons in some years. Abundant from mid-September to early October; prominent in late September. Maximum reading from mid- to late September. Source: *A. princeps*, a common weed.

Humulus. Season late August to mid-November; catches in other seasons were rare. Abundant from mid-September to mid-October. Maximum reading from late September to early October. Source: *H. japonicus*.

Chenopodiaceae/Amaranthaceae. Season late August to mid-October; in some years, caught sporadically during a few weeks before and after this period, as well as in April, May and December. Maximum reading from late September to early October. Source: *Chenopodium album*, *Ambrina ambrosioides*, *Amaranthus patulus* etc.

2. Variation in the magnitude of the annual catch

The annual catches during the five years are summarized in Figs. 3, 4 and Table 2. The greatest total catch was 10848.8 in 1995, and the smallest 3301.2 in 1992. The coefficient of variation (CV) for the total catches among the years was 0.54. The values were 0.83 for total tree pollen; 0.16 for total non-tree pollen and 0.15 for total fern spores. Therefore the annual catch was most variable for total tree pollen. Among the tree pollen, highly variable pollen catches ($CV > 1.0$) were recorded for *Cryptomeria*, Cupressaceae-type, *Carpinus tschonoskii*, *Zelkova/Ulmus*, *Mallotus*, and *Sambucus*, while the variation was smallest for Gramineae (0.08).

Although atmospheric temperatures in a year or the previous year do not seem to control simply the annual pollen catch, alternations of high and low pollen catches were found for *Cryptomeria*, Cupressaceae-type, *Salix*, *Carpinus tschonoskii*, *Carpinus/Ostrya*, *Celtis/Aphananthe* and *Zelkova/Ulmus*. These pollen types were prolific in 1991, 1993 and 1995, whereas 1992 and 1994 were lean years. Although the annual pollen catch of many non-tree pollen types fell in 1995, the catch tended to grow in magnitude for Gramineae, *Artemisia* and *Typha/Sparganium* until 1994.

Discussion

The magnitude of the catch for tree pollen in this study would have been under-represented (Yonebayashi, 1994). Low position of the trap (Igarashi, 1979, 1987; Ikuse *et al.*, 1962; Yonebayashi, 1984) and relatively long-term exposure of sample slides (Sado, 1990) are responsible for under-representation. Despite this deficiency, not

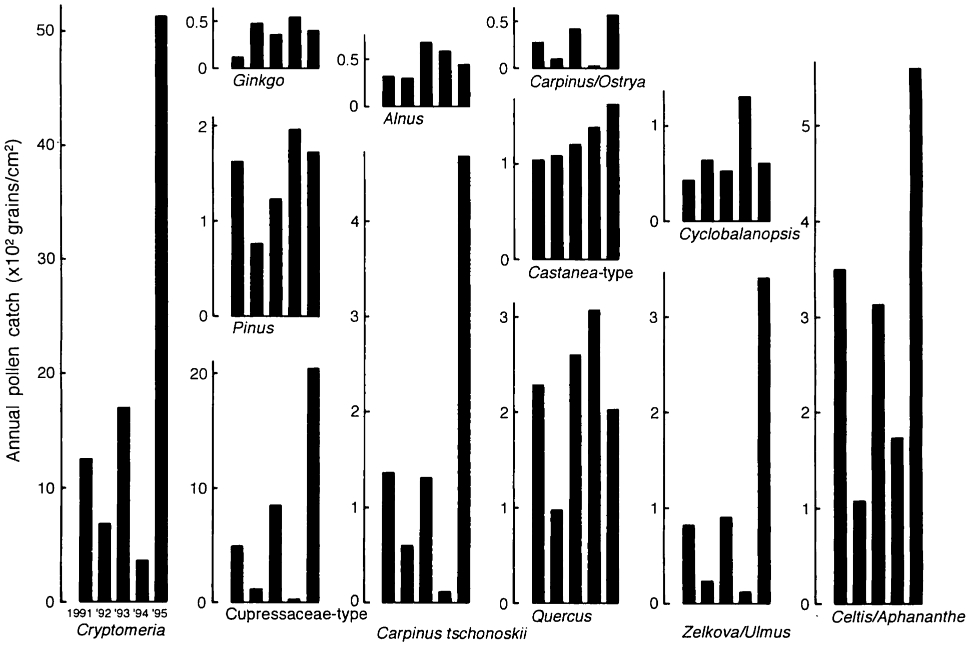

Fig. 3. Annual pollen catch in Chiba; year-to-year variation in 12 selected tree pollen types. Scales for *Cryptomeria* and Cupressaceae-type are different from others.

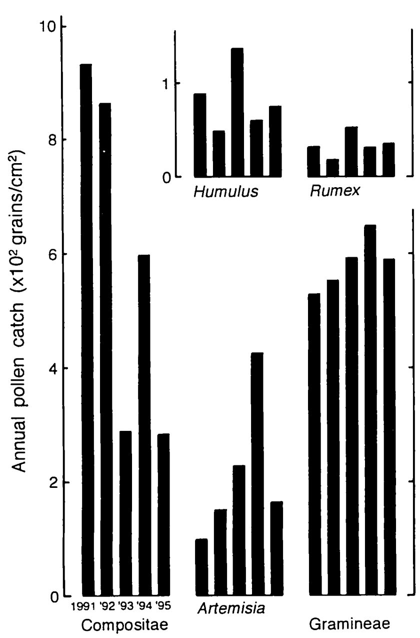

Fig. 4. Annual pollen catch in Chiba; year-to-year variation in 5 selected non-tree pollen types. Scales for *Humulus* and *Rumex* are different from others.

only the seasonal and year-to-year fluctuations are comparable at a site using the same methodology, but also the patterns of fluctuation are comparable among the sites. The seasonal and annual fluctuations obtained in this study will be discussed in comparison with those of other regions.

For many tree pollen types, dates of the maximum reading in spring tend to be earlier in Chiba than in Sendai, northern Japan, whereas those for autumn herbaceous pollen types are later in Chiba (Yonebayashi, 1994). Although sources of a pollen type frequently include some different species, and the species combination varies among regions, the lags between Chiba and Sendai are comparable for some pollen types whose main source is doubtless only one species. The lags were 19 days earlier for *Cryptomeria* (*japonica*) in Chiba; 18 days earlier for *Zelkova* (*serrata*) and 21days earlier for *Ginkgo* (*biloba*). For the autumn herbaceous pollen types, the lags were 9 days later for *Artemisia* (*princeps*) and 8 days later for *Humulus* (*japonicus*). A comprehensive study of Japanese phenology (Japan Meteorological Agency, 1988) supports these tendencies; the first flowering dates of trees (*Prunus mume, P.*×*yedoensis* and *Camellia japonica*) in spring were 15–49 days earlier in Tokyo than in Sendai, and 8 days later for an autumn grass (*Miscanthus* *sinensis*). Similar shifts in the timing of pollen phenology are also known in Europe (Bagni *et al.*, 1976; Spieksma, 1990; Spieksma *et al.*, 1980). The maximal values of grass pollen in spring shift from southern to northern Europe, taking more than a month; on the other hand, *Artemisia* pollen in summer to autumn reaches a maximum in central Europe about one month earlier than in the Mediterranean.

Since pollen grains caught by this method are the grains actually liberated from anthers, the pollen catch is a more effective indicator for evaluating the potential pollination efficiency of anemophilous plants than other figures such as male flower production measured by the litter trap method. In fact, Hyde (1952, 1963) has already suggested that bumper pollen years and good mast years frequently coincide with each other; a satisfactory correlation in *Fagus sylvatica* and *Fraxinus excelsior* and a less satisfactory one in *Betula verrucosa, B. pubescens, Pinus* spp., *Quercus robur* and *Q. petraea.* Synchronous production of male and female flowers has also been reported for *Cryptomeria japonica, Fagus crenata, Pseudotsuga menziesii* and *Taxus canadensis,* but not for three *Quercus* species (Tanaka, 1995).

The period of flower bud formation on many trees is spring or summer of the previous year. The weather during this formative period influences the pollen catch the following year (Andersen, 1974, 1980; Hyde, 1952). Holmsgaard and Olsen (1966) showed that high temperatures and low precipitation in June and July in the preceding year are particularly important for a high crop rating of *Fagus sylvatica* in mast years, and that high flower bud production can be induced by artificial drought in summer. A large pollen catch is expected in the season after a warm sunny spring or summer. The annual pollen catch after the warmest summer was largest in 1995, a bumper pollen year, and smallest in 1994 after a cool summer for many tree pollen types such as *Cryptomeria,* Cupressaceae-type, *Carpinus tschonoskii* and *Zelkova/Ulmus.* This relationship has been confirmed by long-term observation of *Cryptomeria japonica* pollen, the most serious pollen allergen in Japan. The magnitude of the annual catch of *C. japonica* correlates with global solar radiation and maximum temperature in the previous summer ($r^2=0.758$ and 0.552, respectively; after Sahashi *et al.*, 1995). Other studies of *C. japonica* pollen carried out at Niigata (1972–86; Fujisaki, 1988), Tokyo (1977–95; Saito, 1995), Funabashi (1979–95; Sahashi, 1991, 1994, 1995; Sahashi *et al.*, 1995) and Nishinomiya (1979–91; Ogasawara *et al.*, 1991), as well as this study, have shown that the year-to-year fluctuation patterns were highly synchronized among these sites, except for a decline at Nishinomiya (ca. 450 km west of Chiba) in 1985. Apart from *Cryptomeria* pollen, precipitation in April of the preceding year gives the best correlation (negative) with the annual pollen frequencies of *Betula* and *Alnus,* and those of *Quercus* and *Fagus* are best correlated with the average maximum temperature over the months from June to September of the preceding year in Denmark (Andersen, 1980).

In many tree pollen types such as *Cryptomeria,* Cupressaceae-type, *Salix, Carpinus tschonoskii, Carpinus/Ostrya, Celtis/Aphananthe,* and *Zelkova/Ulmus,* 2-year cycles of pollen catches were recognized in this study. Biennial flowering patterns have also been pointed out for *Betula* and *Fagus* in Cardiff, Wales (Hyde, 1952), and for *Betula, Alnus, Quercus* and *Fagus* in Draved Forest, southwestern Denmark (Andersen, 1980). At Ogawa, Ibaraki Prefecture, ca. 150 km north of Chiba, biennial synchronous production of reproductive organs has been suggested for four co-occurring *Carpinus* species (Shibata and Nakashizuka, 1995). The pattern, however, was interrupted by two subsequent years of low reproduction from 1991 to 1992 (H. Tanaka, *personal communication*). Andersen (1980) attributed an interruption by two consecutive years of high flowering to failed pollination in the first year, and two low flowering years in sequence to failed flowering in the second year. A 15-year observation of airborne pollen in Niigata, ca. 270 km NNW of Chiba, did not demonstrate 2-year pollen cycles for *Ginkgo,* Taxodiaceae, *Pinus,* Juglandaceae, *Alnus,* other Betulaceae, Fagaceae and Ulmaceae, the fluctuations being much more irregular (Fujisaki, 1988). The biennial pattern was also not dominant during a 4-year observation of trees (*Quercus, Betula, Alnus, Carpinus, Ulmus, Fraxinus, Cryptomeria* and *Fagus*) at four heights at Tomakomai, Hokkaido (Igarashi, 1987).

Since the coldest winter (the lowest mean and minimum temperatures in February among the five study years) occurred in 1995, it is possible that the low catches of herbaceous pollen types in this year were caused by "winter killing" (Hyde, 1952). This decline, however, may have been caused in part by lawn care in the nearly completed Aoba-no-mori Park. Andersen (1980) has pointed out that the pollen productivity of perennials is affected by the precipitation in June of the preceding year. It has been suggested that, in Europe, the pollen productivity of herbs is stimulated by good water supply before and during flowering, and by warmth in the early spring, whereas it is reduced by summer drought in the preceding year and coldness in the early spring (Andersen, 1980; Hyde, 1952).

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千葉市における5年間(1991–1995)の空中飛散花粉とその生態学的意味

米林　仲

千葉県立中央博物館
〒260 千葉市中央区青葉町 955-2

千葉市において，1991年1月4日から1996年1月4日の5年間にわたって，ダーハム型花粉採集装置を用いた空中飛散花粉調査を行ない，一般化した花粉カレンダーを作成した．その結果，季節的変化では，春の木本花粉のピークは，仙台市よりも千葉市で早く，夏から秋にかけての草本花粉のピークは千葉市で遅かった．年間捕獲量の変化では，木本花粉の多くで一年おきの増減がみられた．同様の増減パターンは，ヨーロッパ（カバノキ属，ハンノキ属，コナラ属，ブナ属）や日本（クマシデ属）で報告されているが，新潟市における15年間の調査では，一年おきの増減は一般的ではない．1995年に草本花粉の捕獲数が少なかったのは，冬期の寒さによる死亡の可能性が考えられた．