Annals of Agricultural and Environmental Medicine 2013, Vol 20, No 1, 36-47
www.aaem.pl

ORIGINAL ARTICLE

Forecasting of the selected features of Poaceae (R. Br.) Barnh., *Artemisia* L. and *Ambrosia* L. pollen season in Szczecin, north-western Poland, using Gumbel's distribution

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Puc M, Wolski T. Forecasting of the selected features of Poaceae (R. Br.) Barnh., *Artemisia* L. and *Ambrosia* L. pollen season in Szczecin (north-western Poland) using Gumbel`s distribution. Ann Agric Environ Med. 2013; 20(1): 36-47.

Abstract

Introduction and objectives. The allergenic pollen content of the atmosphere varies according to climate, biogeography and vegetation. Minimisation of the pollen allergy symptoms is related to the possibility of avoidance of large doses of the allergen. Measurements performed in Szczecin over a period of 13 years (2000-2012 inclusive) permitted prediction of theoretical maximum concentrations of pollen grains and their probability for the pollen season of Poaceae, *Artemisia* and *Ambrosia*. Moreover, the probabilities were determined of a given date as the beginning of the pollen season, the date of the maximum pollen count, Seasonal Pollen Index value and the number of days with pollen count above threshold values.

Materials and methods. Aerobiological monitoring was conducted using a Hirst volumetric trap (Lanzoni VPPS). Linear trend with determination coefficient (R^2) was calculated. Model for long-term forecasting was performed by the method based on Gumbel's distribution.

Results. A statistically significant negative correlation was determined between the duration of pollen season of Poaceae and *Artemisia* and the Seasonal Pollen Index value. Seasonal, total pollen counts of *Artemisia* and *Ambrosia* showed a strong and statistically significant decreasing tendency. On the basis of Gumbel's distribution, a model was proposed for Szczecin, allowing prediction of the probabilities of the maximum pollen count values that can appear once in e.g. 5, 10 or 100 years.

Conclusions. Short pollen seasons are characterised by a higher intensity of pollination than long ones. Prediction of the maximum pollen count values, dates of the pollen season beginning, and the number of days with pollen count above the threshold, on the basis of Gumbel's distribution, is expected to lead to improvement in the prophylaxis and therapy of persons allergic to pollen.

Key words

pollen count, Poaceae, *Artemisia, Ambrosia,* Gumbel's distribution, long-term forecast

INTRODUCTION

Pollen allergens of the Poaceae family (grass) and *Artemisia* spp. (mugwort) and *Ambrosia* spp. (ragweed) are among the most frequent and serious causes of pollinosis in many parts of the world. [1, 2, 3]. These plants are characterised by a huge production of small pollen grains which can be transported for several hundred or even thousands of kilometres by large air masses [4, 5, 6]. Moreover, the above taxa are involved in strong cross-reactions observed in patomechanism of allergy. With very few exceptions, all grass pollen types show a very high degree of cross-reactivity within the genera of the Poaceae family, and also with *Betula* and *Artemisia* pollen. Grass pollen can also cross-react with food, such as beans, peas, cereals, peanuts and fruit (melon, watermelon), as well as edible vegetables (carrots, tomatoes, celery) and flour. Cross-reactions are also possible between the allergens of grass, ragweed pollen and latex [7, 8, 9]. There is also significant cross-reactivity between ragweed species within the *Ambrosia* genus, as well as between the major allergens of *Ambrosia* and *Artemisia* [10, 11, 12].

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Received: 15 November 2012; accepted: 23 January 2013

Poaceae belong to one of the most abundant families in the world. Representatives of the grass are found in almost every habitat. From among more 300 species of grasses known from Poland, there are 160 species permanently established in natural habitats. They include 130 species native to Poland and more than 30 alien species [13]. The remainder represent widely-treated casuals or cultivated species. They are primarily components of non-forested communities, such as meadows, grasslands and marshes. Many species of grasses growing in Poland have distribution ranges that extend far to the north, indicating their tolerance of severe arctic climate [14]. Grasses are typical wind-pollinated plants. They form inconspicuous flowers that are reduced to bracts and scales. Their stamens have long, thin filaments and large anthers. The taxa of the Poaceae family are characterized with particularly high pollen productivity. Not all species of grasses are wind-pollinated; some taxa are autogamous, such as *Cynosurus, Bromus, Phalaris, Aira, Avena* and *Triticum*, whereas *Secale* and many other grasses have self-sterile flowers [15]. In periods of maximum pollen production, there are about 2,000 pollen grains in 1m^3 of air. The pollen season of grass, because of the large number of species involved, in Northern, Central and Eastern Europe lasts from the beginning of May to the end of July; in Southern Europe –

from April to June [1]. However, in Poland, Poaceae pollen occurs in the air until the second half of September [16, 17].

The genus *Artemisia* L. (mugwort) is found throughout almost the whole of Europe, from the Mediterranean zone in the south to the sub-Arctic zone in the north. The majority of European species of *Artemisia* grow in southern and south-eastern regions with continental climate. Occurrence of the *Artemisia* species is associated with dry or slightly moist habitats and full exposure to light, which are important components of the steppes [18]. In the inland saline habitats of eastern Europe, *A. maritima* is found. Some species of *Artemisia* are connected with the mountainous regions of southern and central Europe, e.g. *A. eriantha*. A number of species in Europe frequently occur in habitats transformed by human activities. There are about 50 native species of *Artemisia* altogether in Europe. Eighteen species grow in Poland, half of them are alien species naturalised in the native Polish flora. Of the nine other species, six are regarded as native (*A. absinthium* L. var. *calcigena, A. campestris* L., *A. eriantha* Ten., *A. pontica* L., *A. scoparia* Waldst. & Kit. and *A. vulgaris* L.), while another three species are cultivated. Only three native species of *Artemisia* are commonly found in Poland (*A. absinthium, A. campestris, A. vulgaris*) [13]. *Artemisia* pollen is present in the air for over 10 weeks, generally from mid-July until mid-September [16]. In central and northern Europe, the optimum of pollination falls in mid-August. *Artemisia* is one of the very few genera in the family Asteraceae comprising wind-pollinated plants. Despite wind dispersal and high pollen productivity (an individual plant produces thirty- eight million pollen grains), mugwort pollen is relatively poorly distributed. Much of the pollen does not rise higher than 3-10 m above ground level, which limits its wider distribution [16, 19, 20, 21].

In Europe, the occurrence of ragweed pollen is not uniform; its distribution covers the area of continental climate at medium latitude, and began its expansion from Hungary, Ukraine, Croatia and Italy. Its presence has been reported also from France, the Balkan countries, Switzerland, Austria, Slovakia and the Czech Republic [2, 6, 22, 23, 24, 25]. The genus *Ambrosia* comprises about 42 species of which only 5 have been noted in Europe. In Szczecin, the following three species have been noted since 1900: *Ambrosia psilostachya* DC. (=*A. coronopifolia* Torr. et A. Gray), *A. trifida* L. and *A. artemisiifolia* L. (=*A. elatior* L.) [16, 27]. Among the three species mentioned above, *A. artemisiifolia* is the most common in Poland, especially in the south-western region of the country [28]. The ragweed flowers are small, the female variety make capitulums, while the males make racemes. An individual plant in one season produces one hundred million pollen grains [19, 27]. In Europe, the majority of *Ambrosia* pollen grains are present in the air during August and September [24, 29].

A number of studies presented in the aerobiological literature have analyzed the threshold value of pollen count needed to provoke an allergic reaction. The intensity of clinical symptoms of allergy depends on individual reactivity, and show regional differences.

In Poland, the sensitised patients develop the first disease symptoms for grass pollen count more than 20 grains/m^3 [30]. In Finland, a count of less than 30 grass pollen grains/m^3 was significantly correlated with respiratory tract symptoms at the start of the Poaceae pollen season [31]. In the UK, the lowest concentration of grass pollen able to induce the appearance of hay fever symptoms was shown to be 10–50 grains/m^3 [32]. In Spain, the threshold value amounts to 25 grains/m^3 [33], and in Croatia, the first allergy symptoms were observed at 30 grains/m^3 [34]. For pollen grains of *Artemisia* in Poland the threshold value for pollinosis symptoms of sensitised patients is above 30 grains/m^3 [30]. While in Italy a pollen count of mugwort of above 12 grains/m^3 already causes the appearance of symptoms of allergy [35]. The threshold value for clinical symptoms for *Ambrosia* pollen grains for the majority of sensitised patients is below 20 grains/m^3 [11, 36], or is between 20-30 grains/m^3 [10, 37]. According to Laaidi & Laaidi [2], the first allergy symptoms can develop at a pollen count as low as 13 grains/m^3 of ragweed pollen.

The aim of the presented study is to propose a model for long-term forecasting of maximum values of pollen count, and the probability of its occurrence for selected taxa. The model should also be able to give a probability of a given date as the beginning of the pollen season, the date of maximum pollen count, Seasonal Pollen Index (SPI) value, and the number of days in a given season on which, after exceeding the threshold value, the first clinical symptoms will appear and on which such symptoms will appear in all patients with pollinosis. The calculations were performed by the method based on Gumbel's distribution, hitherto not applied in the area of aerobiology. Another interesting objective of this study was to determine the tendency of changes in pollen concentration on a regional scale. To this end, a trend analysis was conducted, which is a unique complement to the proposed forecasting model.

MATERIALS AND METHOD

Site and climate description. Szczecin is the capital of Western Pomerania, situated in the Northwest of Poland. The climate of the city is shaped by the morphological diversity of the surrounding area, the presence of watercourses and lakes, together with large forest complexes at the peripheries. Szczecin is distinguished by its rich greenery, with specific habitats of water vegetation, swamps and marshes, peat bogs, meadows, pastures, thickets and different types of forest. The green areas of the city also include numerous parks, lawns, graveyards, squares, street greenery and home gardens. Amongst them, parks cover the largest area (142.5 ha) [38]. The climate of the region is modified by the influence of Atlantic air masses and the proximity of the Baltic Sea. It has a mild climate, with January the coldest month (-1.1°C) and July the hottest (17.7°C). The average annual temperature is 8.4°C, annual mean relative humidity ranges between 70%-77%. Mean annual precipitation is 528 mm. The most unfavourable characteristics of the climate of Szczecin include strong and very strong winds, which are frequent especially, from November until March [39].

Aerobiological analyses. Analysis of daily average pollen counts was performed for Poaceae, *Artemisia and Ambrosia*. These taxa were chosen because of their allergy-producing properties and the availability of data on clinical determination of their pollen count threshold values at which allergy symptoms develop. Aerobiological measurement was conducted during 2000-2012 using a volumetric spore trap of the Hirst design [40] (Lanzoni VPPS-2000). The trap was set on a rooftop in the Śródmieście (central) district of Szczecin (53°26'26" N, 1432'50' E), at an elevation of 21m above ground level. The trap worked continuously taking samples of airborne particles at a flow rate of 10 L per min. The particles adhered to Melinex adhesive tape wrapped around a rotating drum. Pollen grains were stained with basic fuchsin. Every week, the Melinex tape was cut into 7 segments corresponding to 24-h periods. A microscope slide was made for each day of measurement. Pollen grains were counted along 4 longitudinal transects, which were divided into 2 mm (1 hourly) intervals; Pollen grains were identified and counted using a light microscope at magnification × 400. The daily average pollen concentration was expressed as grains/m^3 per 24 h.

The pollen season in particular years was defined as the period from which the sum of daily mean pollen concentration reached 1% of the total sum until the time when the sum reaches 99%, i.e. the time with 98% of the whole pollen count (98% method) [41].

The Seasonal Pollen Index (SPI) was calculated as the total of daily average pollen count in a given season [41].

On the basis of literature data, the number of days with a pollen count of the selected taxa exceeding the threshold values at which the consecutive allergy symptoms develop, were determined. Rapiejko et al. [30] have reported for Poland the following threshold values for Poaceae pollen count: the first clinical symptoms appear when the pollen count exceeds 20 grain/m^3 and the symptoms present in all patients at the pollen count above 50 grains/m^3; while for *Artemisia*: the analogous values were 30 grains/m^3 and above 55 grains/m^3. Laaidi and Laaidi [42] have found that in France the threshold value of *Ambrosia* pollen count for the appearance of the first allergy symptoms was 13 grains/m^3 However, in Italy, Mandrioli et al. [10] have reported that the allergy symptoms in all examined patients appeared at the threshold value of above 30 grains/m^3 for *Ambrosia*.

Statistical analyses. The degree of correlation between the length of pollen seasons and SPI values was analysed by non-parametric Spearman's correlations test. The distributions of the data were not normal (Shapiro-Wilk test), a statistical error risk was estimated at the significance level: α = 0.01 for Poaceae and α = 0.05 for *Artemisia*. Also, skewness and kurtosis ware calculated (Tab. 1). These analyses ware conducted using the Statistica ver. 10 [43]. A linear trend

Table 1. Descriptive statistics of Poaceae, *Artemisia* and *Ambrosia* pollen seasons in Szczecin (2000-2012)

Poaceae	Start	End	Length/days	SPI	Maximum	Date of maximum	*Days>20 grains/m^3 [30]	Skewness	Kurtosis
2000	30 IV	30 IX	154	3010	99	20 VI	32	2.23	4.50
2001	10 V	12 IX	126	5615	312	12 VII	58	2.41	6.19
2002	12 V	7 IX	119	6156	574	3 VI	72	4.11	23.53
2003	23 V	5 IX	105	5385	814	11 VI	54	5.64	42.04
2004	18 V	11 X	147	4371	171	8 VII	72	2.00	5.35
2005	22 V	13 IX	115	4620	186	18 VI	51	1.64	1.44
2006	21 V	25 IX	128	3409	196	1 VII	46	2.10	6.12
2007	6 V	9 IX	127	5074	435	10 VI	57	3.45	15.17
2008	18 V	22 IX	128	4026	233	8 VII	49	2.36	5.78
2009	18 V	7 X	143	3740	152	19 VII	44	1.82	2.34
2010	26 V	17 IX	115	6064	205	11 VII	59	1.83	3.38
2011	19 V	26 IX	133	4942	219	29 VI	69	1.68	3.40
2012	8 V	22 IX	140	3130	113	23 VI	50	1.95	3.52
Mean values 2000-2012	15 V	18 IX	129.2	4580.2	285.3	27 VI	54.8	2.555	9.443
Artemisia	Start	End	Length/days	SPI	Maximum	Date of maximum	*Days>30 grains/m^3 [30]	Skewness	Kurtosis
2000	7 VII	9 X	95	710	68	12 VIII	4	3.01	9.23
2001	7 VII	24 IX	80	955	145	2 VIII	9	3.62	16.35
2002	8 VII	15 IX	56	1420	187	31 VII	14	3.50	15.43
2003	4 VII	31 VIII	59	1809	129	31 VII	22	1.48	1.23
2004	19 VII	12 IX	56	1598	192	9 VIII	15	2.44	5.76
2005	9 VII	21 IX	75	706	67	15 VIII	5	1.83	3.42
2006	29 VI	9 IX	73	385	40	1 VIII	0	1.23	0.85
2007	18 VII	11 IX	56	817	99	6 VIII	9	2.30	5.43
2008	10 VII	1 X	84	390	33	27 VII	1	1.50	1.86
2009	14 VII	26 IX	75	811	127	7 VIII	10	3.26	13.85
2010	5 VII	28 IX	86	668	53	10 VIII	9	2.27	4.59
2011	11 VII	4 IX	56	1438	211	4 VIII	14	2.93	10.65
2012	12 VI	11 IX	92	598	42	7 VIII	7	1.23	0.48
Mean values 2000-2012	8 VII	17 IX	72.5	963.2	107.2	6 VIII	9.2	2.354	6.856
Ambrosia	Start	End	Length/days	SPI	Maximum	Date of maximum	*Days>13 grains/m^3 [42]	Skewness	Kurtosis
2000	20 VIII	14 IX	25	122	14	28 VIII	1	2.92	10.14
2001	22 VIII	19 IX	29	178	32	31 VIII	2	3.15	10.11
2002	22 VIII	12 IX	21	348	98	4 IX	6	3.59	13.57
2003	24 VIII	8 IX	15	96	17	31 VIII	2	1.43	1.32
2004	28 VIII	17 IX	21	112	17	12 IX	2	2.11	4.30
2005	23 VIII	22 IX	28	158	36	4 IX	6	2.83	9.15
2006	6 IX	18 IX	13	115	24	8 IX	2	2.35	5.86
2007	13 VIII	2 IX	22	85	13	22 VIII	1	2.14	5.25
2008	30 VIII	16.IX	18	83	15	1 IX	1	2.34	5.30
2009	25 VIII	10 IX	17	95	14	31 VIII	2	1.26	0.75
2010	1 IX	16 IX	16	114	31	5 IX	3	2.32	5.34
2011	2 IX	16 IX	15	117	23	5 IX	2	1.92	4.04
2012	28 VIII	17 IX	21	120	21	10 IX	3	1.36	1.86
Mean values 2000-2012	27 VIII	14 IX	20.1	134.1	27.4	3 IX	2.5	3.286	5.922

SPI – Seasonal Pollen Index. *- number of days with pollen count over a threshold value at which the first symptoms of allergy develop with determination coefficient (R^2) was calculated using the Excel (Office 2007), while the Spearman's correlations between linear trend and selected features of pollen season were calculated using Statistica ver. 10 [43].

The probabilities of the occurrence of maximum yearly pollen and other selected features of pollen season were determined by the most credible method using Gumbel's distribution (Matlab ver. R2012B, licence 871715). The Gumbel's distribution density function is based on the statistical distribution of extreme values which occur in certain large sets of values. The consistency between the assumed theoretical Gumbel's distribution and the empirical one was checked using the Kolmogorov test (α=95%). The confidence interval in which a given theoretical value was included with a certain probability assumed was P_α=95% [44].

The Gumbel's distribution density function is based on the statistical distributions of extreme values which occur in certain larger sets of values. The Gumbel's distribution density function is double exponential and described by the formula [45]:

$$f(x) = \frac{1}{\hat{a}} e\left[-\frac{x-\hat{b}}{\hat{a}} - e\left(-\frac{x-\hat{b}}{a} \right) \right]$$

where:

$\hat{a}$ – scale parameter (determines dispersion of the distribution along x-axis);

$\hat{b}$ – location parameter (determines the location of the distribution on x-axis);

e – Napierian base.

After finding logarithms and simplifying the above-given formula, the following was obtained:

$$X_{p\%} = \hat{b} - 1/\hat{a} * \ln[-\ln(1-f(x))]$$

The main point in estimation of the assumed distribution against given measurement data is to determine estimators of the distribution parameters $\hat{a}$ and $\hat{b}$, which was made by means of the maximum likelihood method. The thus obtained distribution parameters $\hat{a}$ and $\hat{b}$ were put in the formula for $X_{p\%}$ and theoretical values for selected quintiles of probability were calculated.

On the basis of Gumbel's distribution, the theoretical maximum pollen count levels, dates of the beginning of pollen seasons, SPI values and maximum value and number of days with pollen counts above the threshold value, were calculated by the method of the highest credibility for the taxa analysed.

RESULTS

Characterisation of pollen seasons and trend analysis. Throughout the 13 years of study it was observed that long pollen seasons of Poaceae and mugwort were characterised by a low SPI value, while short and compact pollen seasons of both taxa – by high seasonal total pollen counts (SPI) (Tab. 1). Thus, short pollen seasons are characterised by a higher intensity of pollination than long ones. This relation has been confirmed by analysis of Spearman's rank-correlation, which showed a negative, statistically significant correlation between duration of pollen season and SPI values for Poaceae (correlation coefficient -0.76, p<0.01) and for *Artemisia* (correlation coefficient -0.64, p<0.05). No such correlation was found for the pollen seasons of *Ambrosia*.

Poaceae. The beginning of the grass pollen season was noted on 30 April in 2000 at the earliest and 26 May in 2010 at the latest (Tab. 1). It was a rather weak (7% in 13 years), statistically significant tendency to the delayed appearance of pollen grains in the air in subsequent seasons. The percentage fitting between the linear trend equation (R^2´100) and the data was high and equal 12.8% (Tab. 2, Fig. 1). The length of the Poaceae pollen season varied considerably from 105-154 days, and lasted on average 129 days (Tab. 1). Throughout the whole period of the study, a very weak trend towards an increasing duration of the season (Tab. 2, Fig. 2) was noted. The values of linear trend showed a poor fit with the empirical data (0.12%).

Table 2. Trend analysis for Poaceae, *Artemisia* and *Ambrosia* pollen seasons in Szczecin (2000–2012)

Feature	Taxon	Spearman's correlation coefficient between the feature of pollen season and linear trend (p<0.05)	Determination coefficient R^2	Downward trend – Upward trend + [%]
Date of start of pollen season	Poaceae	0.56*	0.1284	7 +
	Artemisia	-0.04	0.0909	4.6 -
	Ambrosia	0.58*	0.1983	3.6+
Length of pollen season	Poaceae	0.11	0.0012	1.2 +
	Artemisia	0.07	0.0097	6.3 +
	Ambrosia	0.57*	0.2595	32.8 -
Number of days when the first allergy symptoms develop	Poaceae	-0.03	0.0057	5 +
	Artemisia	0.07	0.0169	23.5 -
	Ambrosia	-0.14	0.0081	17 -
Seasonal Pollen Index values	Poaceae	0.17	0.0267	11 -
	Artemisia	0.49*	0.0985	36.7 -
	Ambrosia	0.50*	0.1818	50.7 -

* – statistically significant correlation

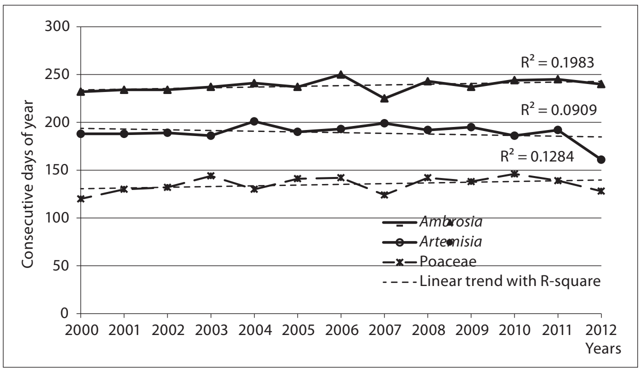

Figure 1. Comparison of beginnings of pollen seasons for the taxa analysed, including trends (2000-2012)
R^2 – determination coefficient

The number of days with over 20 grains/m^3 varied from 32-72 during the study period. The growing tendency of the number of days with pollen count above the threshold value was statistically insignificant (Tab. 2, Fig. 3).

Over the period of 13 years of study, the values of the SPI for Poaceae revealed an 11% decrease (decreasing tendency) (Tab. 2, Fig. 4), which can be a consequence of more frequent lawn-mowing in Polish cities.

Seasonal maximums of pollen count showed a great variety in the years of study and varied from 99-814 pollen grains/m^3

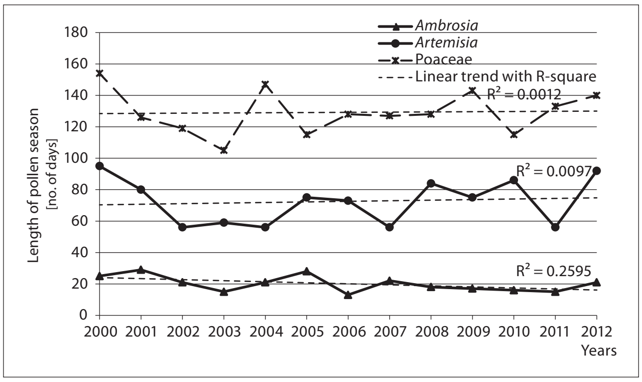

Figure 2. Length of pollen season for the taxa analysed, including trends (2000-2012).
R^2 – determination coefficient

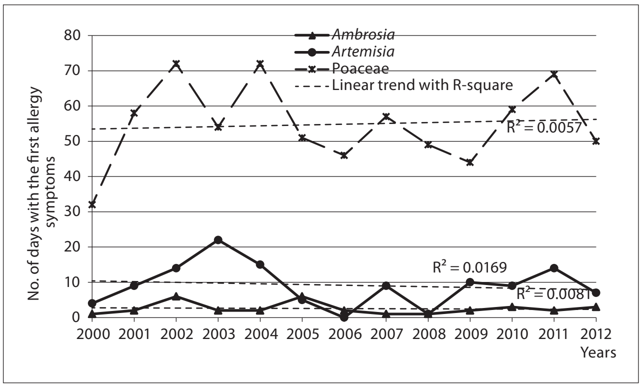

Figure 3. Number of days when first allergy symptoms developed for the taxa analysed, including trends (2000-2012).
R^2 – determination coefficient

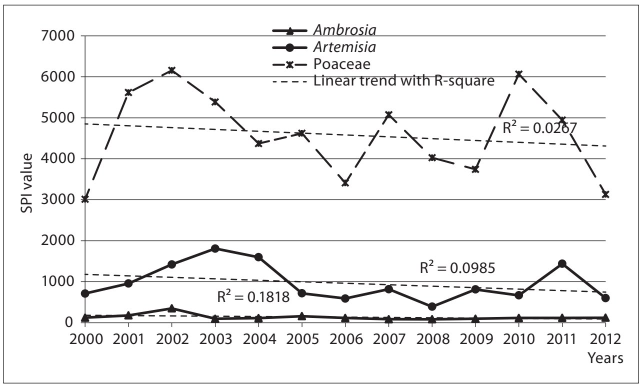

Figure 4. Seasonal Pollen Index values for the taxa analysed, including trends (2000-2012).
R^2 – determination coefficient

(Tab. 1). The distributions of grass pollen concentrations in individual seasons were asymmetric and strongly skewed to the right, which means a long-lasting presence of pollen grains in the air towards the end of the season. High values of kurtosis point to a slim shape of the curve of pollen concentration distribution.

Artemisia. The pollen season of mugwort started on average on 12 June and lasted until 11 September (Tab. 1). It was a very weak (4.6% in 13 years), statistically insignificant tendency to the earlier appearance of pollen grains in the air in subsequent years. The fit of linear trend equation to the empirical data was only of 9% (Tab. 2, Fig. 1).

The duration of mugwort seasons ranged from 56-95 days, to give an average of 72.5 days (Tab. 1). During the period of 13 years, a weak trend towards an increasing length of the pollen season (Tab. 2, Fig. 2) was deduced. The values of linear trend showed a very poor fit with empirical data (0.9%).

The number of days with over 30 grains/m^3 was 0-22 days in the study period. A distinct but statistically insignificant decrease in the number of days with pollen count above the threshold value at which the first allergy symptoms develop, by 23.5% in the 13 years of study, was found (Tab. 2, Fig. 3).

The total pollen count of *Artemisia* (SPI) recorded during the season varied annually. In 2003, the total sum of pollen was 1,809 grains, but in 2006 it was only 385 grains (Tab. 1). The decreasing trend in the annual sum of pollen of this taxon was statistically significant and a decrease in SPI was 36.7% in the study period (Tab. 2, Fig. 4).

The distributions of mugwort pollen concentrations in individual seasons were asymmetric and strongly skewed to the right, which – similar to Poaceae – indicates a higher concentration of pollen in the second half of the pollen season. The highest seasonal maximum in the 13 years of study was recorded in 2011, and equalled *nomen omen* 211 grains/m^3. Values of kurtosis were high, but the mean value of kurtosis for *Artemisia* was lower than for grass (Tab. 1).

Ambrosia. The start of the ragweed pollen season was noted between 13 July – 2 September (Tab. 1). A very weak (by 3.6% in 13 years), statistically significant tendency was observed to the delayed appearance of pollen grains in the air. The fit of the linear trend equation to the empirical data was estimated as 19% (Tab. 2, Fig. 1).

The pollen seasons of ragweed were relatively short. The longest pollen seasons were observed in 2001 and 2005 and lasted 29 and 28 days, respectively (Tab. 1). In the 13 years of study, there was a strong and statistically significant trend towards a decreasing length of pollen season by as much as 32.8% (Tab. 2, Fig. 2). The fit of the linear trend to the empirical data was also strong (25.9%). The period in which the ragweed pollen count exceeded the threshold value of 13 grains/m^3 showed a distinct decreasing tendency of 17% (Tab. 2, Fig. 3). The highest annual total sum of *Ambrosia* was observed in 2002 (348 grains), and the lowest annual sum occurred in 2008 (83 grains) (Tab. 1). The decreasing trend of the annual sum of pollen of this taxon was statistically significant and equal to 50.7% over the 13 years (Tab. 2, Fig. 4).

From among the 13 *Ambrosia* pollen periods analysed, the lowest peak value of 13 grains/m^3 was noted in 2007. The highest pollen concentration of 98 grains/m^3 occurred in 2002. The distributions of ragweed pollen counts in all seasons were asymmetric and strongly skewed to the right, which implies that the concentration of pollen was higher in the second half of the season. The mean value of kurtosis was the lowest from among the taxa analysed (Tab. 1).

Long-term probabilistic forecast. Theoretical values and their probabilities describing pollen seasons determined on the basis of Gumbel's distribution show the best fit to the multiannual observation series. For example, there is a 90% probability that the pollen season of Poaceae will begin on 4 May, and the maximum pollen count will reach 105.6 grains/m^3 on 8 June, the number of days with pollen count above 20 grains/m^3 (the first symptoms of allergy) will

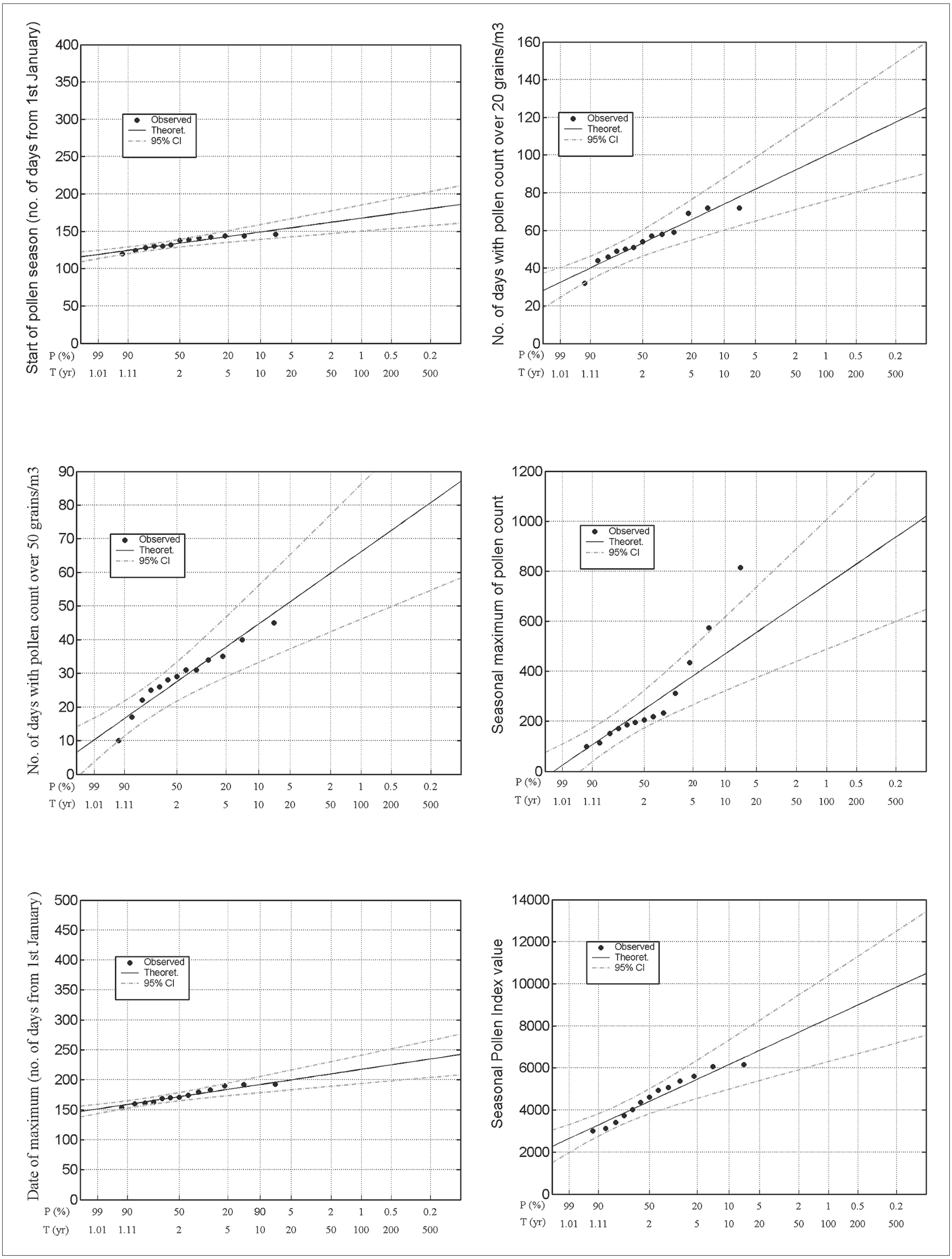

Figure 5. Probability of occurrence of selected features of Poaceae pollen season in Szczecin by Gumbel's distribution (dashed line – confidence interval for P_{α}=95%).

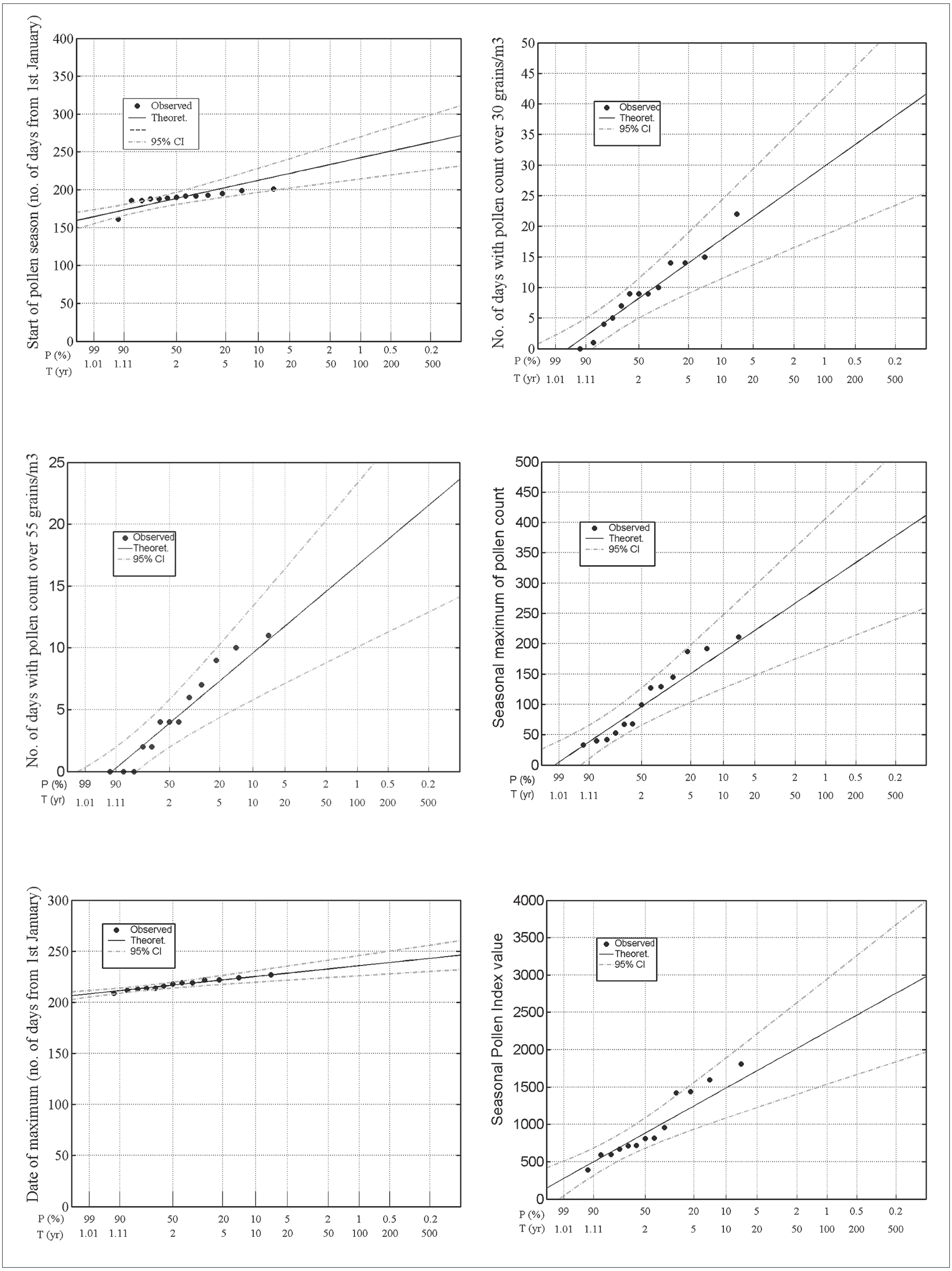

Figure 6. Probability of occurrence of selected features of *Artemisia* pollen season in Szczecin by Gumbel's distribution (dashed line – confidence interval for P_{α}=95%)

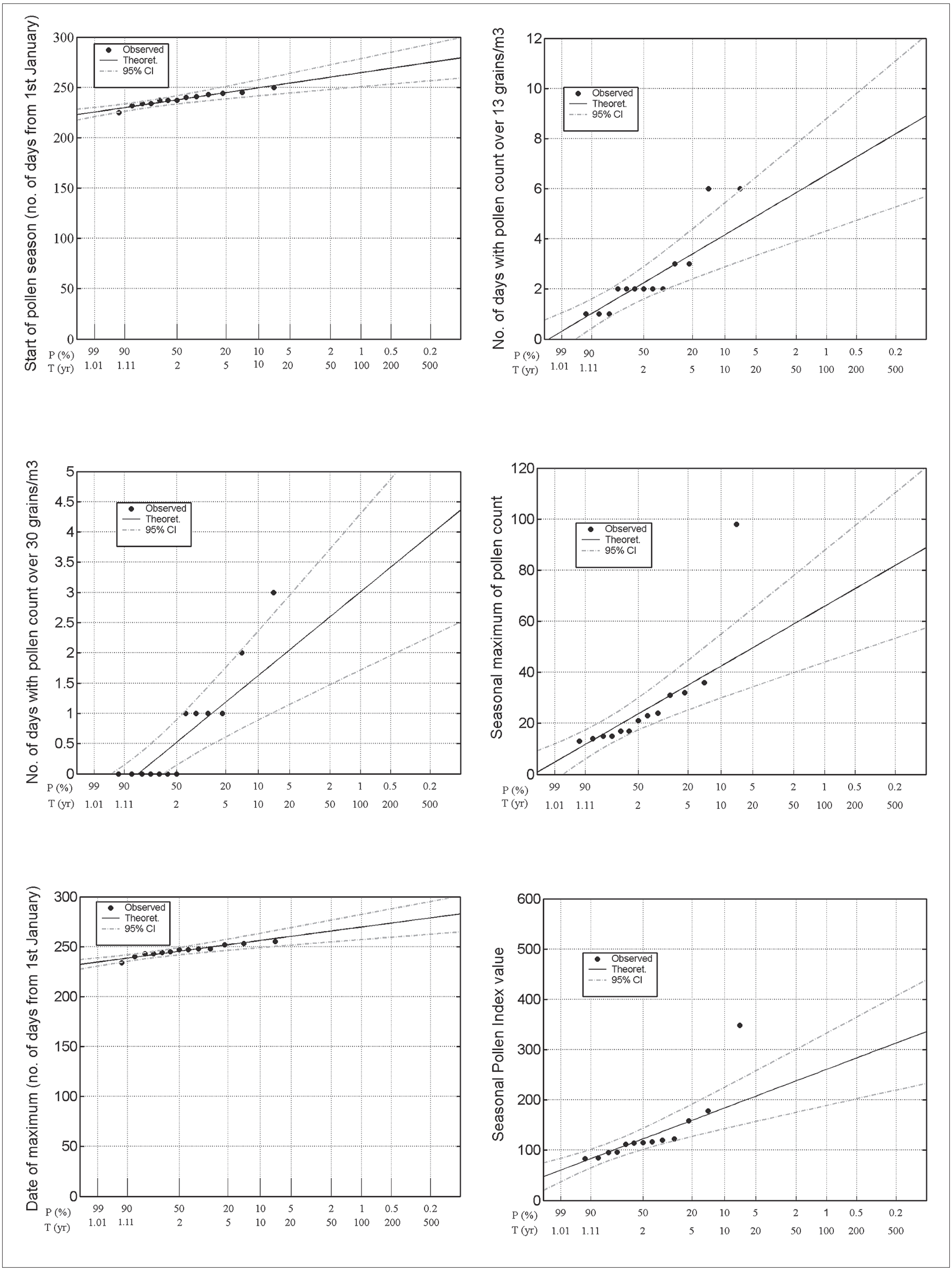

Figure 7. Probability of occurrence of selected features of *Ambrosia* pollen season in Szczecin by Gumbel's distribution (dashed line – confidence interval for P_{α}=95%).

Table 3. Theoretical values of selected features of the pollen season for grass (Poaceae) and their probabilities in the Gumbel's distribution Number of days with pollen count over the threshold value at which the first symptoms of allergy develop* and that at which the symptoms in all patients occur**

T [years]	Probability [%]	Start of pollen season (no. of days from 1st January/date)	*Days> 20 grains/m³ [30]	**Days>50 grains/m³ [30]	Maximum	Date of maximum (no. of days from 1st January/date)	SPI value
1000	0.1	185.96/5 VII	125.10	87.13	1018.96	242.31/30 VIII	10492.80
500	0.2	180.45/29 VI	117.49	80.79	937.16	234.82/23 VIII	9847.47
200	0.5	173.15/22 VI	107.41	72.42	828.93	224.92/13 VIII	8993.61
100	1	167.63/17 VI	99.77	66.08	746.89	217.42/4 VIII	8346.40
50	2	162.08/11 VI	92.10	59.71	664.55	209.89/29 VII	7696.83
20	5	154.68/4 VI	81.87	51.22	554.67	199.83/19 VII	6829.99
10	10	148.96/29 V	73.96	44.66	469.78	192.07/11 VII	6160.30
5	20	143.00/23 V	65.72	37.82	381.29	183.97/3 VII	5462.15
4	25	140.98/21 V	62.93	35.50	351.33	181.23/31 VI	5225.81
3.33	30	139.27/19 V	60.57	33.54	325.96	178.91/28 VI	5025.70
2	50	133.99/14 V	53.28	27.48	247.62	171.75/20 VI	4407.68
1.33	75	128.44/8 V	45.60	21.11	165.24	164.21/13 VI	3757.76
1.25	80	127.30/7 V	44.02	19.80	148.28	162.66/12 VI	3623.96
1.11	90	124.42/4 V	40.05	16.50	105.58	158.75/8 VI	3287.11
1.01	99	118.95/29 IV	32.48	10.22	24.30	151.32/31 V	2645.9

Table 4. Theoretical values of selected features of the pollen season for mugwort (*Artemisia*) and their probabilities in the Gumbel's distribution. Number of days with pollen count over the threshold value at which the first symptoms of allergy develop* and that at which the symptoms in all patients occur**

T [years]	Probability [%]	Start of pollen season (no. of days from 1st January/date)	*Days> 30 grains/m³ [30]	**Days>55 grains/m³ [30]	Maximum	Date of maximum (no. of days from 1st January/date)	SPI value
1000	0.1	271.49/28 IX	41.50	23.63	411.55	246.16/3 IX	2979.20
500	0.2	262.69/20 IX	38.03	21.53	378.10	243.03/31 VIII	2756.97
200	0.5	251.05/8 IX	33.35	18.76	333.83	238.93/26 VIII	2462.85
100	1	242.22/30 VIII	29.80	16.66	300.28	235.80/24 VIII	2239.91
50	2	233.37/21 VIII	26.24	14.56	266.61	232.67/21 VIII	2016.16
20	5	221.55/10 VIII	21.49	11.74	221.68	228.49/16 VIII	1717.57
10	10	212.41/31 VII	17.81	9.57	186.96	225.25/13 VIII	1486.90
5	20	202.89/22 VII	13.99	7.31	150.77	221.88/10 VIII	1246.41
4	25	199.67/19 VII	12.69	6.54	138.52	220.74/9 VIII	1165.00
3.33	30	196.94/16 VII	11.59	5.89	128.14	219.78/8 VIII	1096.07
2	50	188.51/8 VII	8.20	3.89	96.11	216.80/5 VIII	883.19
1.33	75	179.65/29 VI	4.64	1.78	62.42	213.66/2 VIII	659.32
1.25	80	177.83/27 VI	3.90	1.34	55.48	213.02/1 VIII	613.23
1.11	90	173.24/22 VI	2.06	0.25	38.02	211.39/20 VII	497.20
1.01	99	164.40/13 VI	NR	NR	4.78	208.29/27 VII	276.33

NR – lack of quintile value

be 40, and the number of days on which allergy symptoms will occur in all allergic persons (>50 grains/m³) will be 16.5, while the total annual pollen count will be 3,287 grains/m³ (Tab. 3, Fig. 5).

As far as the mugwort pollen season is concerned, there is a 90% probability that it will start on 22 June, the maximum pollen count will reach 38 grains/m³ on 20 July, the number of days with pollen count above 30 grains/m³ (the first allergy symptoms) will be more than 2, and the number of days on which allergy symptoms will appear in all allergic persons (>55 grains/m³) will be only 0.25, while the total annual pollen count will be 497 grains/m³ (Tab. 4, Fig. 6).

For *Ambrosia*, there is 90% probability that its pollen season will begin on 18 August, the maximum pollen count will reach 11.7 grains/m³ on 26 August, the number of days with pollen count above 13 grains/m³ (the first allergy symptoms) will be 1, and there will be no days with symptoms in all allergic persons (>50 grains/m³), and the total annual sum of pollen count will be 83 grains/m³ (Tab. 5, Fig. 7).

The above predictions, and in particular the prediction of the maximum pollen count, will help evaluation of the threat from pollen allergens and can improve the effectiveness of prophylactics and therapy in persons with pollinosis.

Table 5. Theoretical values of selected features of the pollen season for ragweed (*Ambrosia*) and their probabilities in the Gumbel's distribution. Number of days with pollen count over the threshold value at which the first symptoms of allergy develop* and that at which the symptoms in all patients occur**

T [years]	Probability [%]	Start of pollen season (no. of days from 1st January/date)	*Days> 13 grains/m^3 [42]	**Days> 30 grains/m^3 [10]	Maximum	Date of maximum (no. of days from 1st January/date)	SPI value
1000	0.1	279.33/6 X	8.90	4.36	88.78	282.83/10 X	335.90
500	0.2	274.89/2 X	8.20	3.95	81.87	278.85/6 X	313.32
200	0.5	269.03/26 IX	7.26	3.41	72.73	273.60/1 X	283.36
100	1	264.59/22 IX	6.55	3.01	65.81	269.61/26 IX	260.64
50	2	260.13/17 IX	5.84	2.60	58.85	265.62/23 IX	237.84
20	5	254.17/11 IX	4.89	2.05	49.58	260.28/17 IX	207.42
10	10	249.58/7 IX	4.16	1.62	42.41	256.16/13 IX	183.91
5	20	244.78/1 IX	3.40	1.18	34.94	251.86/9 IX	159.41
4	25	243.16/30 VIII	3.14	1.03	32.41	250.41/7 IX	151.11
3.33	30	241.79/29 VIII	2.92	0.91	30.26	249.18/6 IX	144.09
2	50	237.54/26 VIII	2.24	0.52	23.65	245.38/2 IX	122.40
1.33	75	233.08/21 VIII	1.53	0.11	16.69	241.38/29 VIII	99.59
1.25	80	232.16/20 VIII	1.38	0.02	15.26	240.55/29 VIII	94.89
1.11	90	229.85/18 VIII	1.01	NR	11.66	238.48/26 VIII	83.07
1.01	99	225.45/13 VIII	0.31	NR	4.80	234.53/23 VIII	60.56

NR – lack of quintile value

DISCUSSION

The variability in Poaceae, *Artemisia* and *Ambrosia* pollen seasons is related to a number of factors, including the resuspension of pollen grains, weather elements, phenology and vegetation, regional and long distance transport of pollen [5, 16, 46].

The Poaceae pollen is present abundantly over most of the area of Poland from mid-May – mid-August [16, 17]. The grass pollen season in Szczecin lasts for about 4 months, rarely 5 months, and the Poaceae pollen count is recorded from the end of May – mid-September. The dates of the beginning of the pollen seasons of grasses observed in subsequent years were different. In Szczecin, the number of days with a grass pollen count over 50 grains/m^3 was 11-32 days per year, whereas Jato et al. [47] noted 11-23 days in Spain in 2001-2003. In Croatia, a high variability was observed in the number of weeks when grass pollen concentration exceeded the threshold value of 30 grains/m^3, i.e. 1-5 weeks in 2002-2005 [34].

The pollen seasons of *Artemisia* were observed in a long span (72 days), from 8 July – 17 September. For most periods studied, the day of the maximum concentration occurred approximately in the middle of the season, between 27 July – 15 August. The *Artemisia* pollen count exceeded the threshold value (30 grains/m^3) in Szczecin for a period of 1-22 days. In Croatia [48], the peak daily concentration of mugwort did not exceed moderate levels. The largest amount of *Artemisia* pollen recorded in a season was 1,747 grains in Poznań, and 1,809 grains in Szczecin. The smallest amount was 105 grains in Sofia, Bulgaria [49].

The pollen of *Ambrosia* is noted in the air of Szczecin regularly in each pollen season, on average from 27 August – 15 September. Almost at the same time, the pollen of ragweed appears in the air in Lublin, while in Poznań a few days earlier [5, 29]. In the first days of September, the ragweed pollen count often exceeds the threshold value of 13 grains/m^3 at which the allergy symptoms begin to develop. The duration and character of the pollen seasons of *Ambrosia* and the percentage contribution to the total annual pollen sum is close in many regions of Poland, which means that *Ambrosia* pollen recorded there comes mostly from long range transport [3, 6, 23].

Many year aerobiological observations performed all over the world have revealed the tendencies in pollen count changes on a regional and macroregional scales. A growing trend of pollen count in subsequent seasons was observed for *Artemisia, Urtica* and Poaceae in Italy [35], in Sweden [50], while in Belgium the trend towards a decrease in pollen count of *Poaceae* was reported [51]. Growing trends of *Ambrosia* pollen count was observed e.g. in Austria [11] and in the Czech Republic [52]. In Switzerland, a significant trend towards an increase of pollen quantities was observed for *Ambrosia* and *Artemisia*. For Poaceae there was no major change in the abundance of pollen [53]. In Spain, in the 30 years of study, the trends towards lower annual total Poaceae pollen counts, lower peak values, and a smaller number of days on which counts exceeded 30, 50 and 100 pollen grains/m^3 were found [47]. Moreover, the survey noted a trend towards delayed onset and shorter duration of the pollen season. In Szczecin, a trend towards the lowering of annual total pollen count of grass, mugwort and ragweed was observed from 2000-2012, together with a strong trend towards a shortening of the *Ambrosia* pollen season A trend towards smaller number of days on which the concentration of *Ambrosia* and *Artemisia* pollen exceeded 13 and 30 pollen grains/m^3 was also noted.

A number of studies presented in the aerobiological literature have analyzed daily pollen concentrations using different statistical models, e.g. in France [2, 54], Germany [54], Switzerland [55], Italy [56], Spain [57] Denmark [58], the UK, Poland [17, 59, 60] and Argentina [61].

The objective of many techniques used for forecasting pollen in the air is to provide accurate information on airborne pollen to sensitive patients in order to help them optimize their treatment process. Castellano-Méndez et al. [62] proposed the use of neural networks as good methods for predicting the probability of threshold values of pollen concentrations, which is useful information for the population suffering from allergy. Many year aeropalinological observations performed in Szczecin permitted a long-term forecast of the maximum pollen count and other features of the pollen season. The forecasting model, developed on the basis of Gumbel's distribution, proposed to predict the probabilities of certain maximum values that can occur, e.g. once in 5, 10 or 100 years. One of values predicted by the model is the number of days with the pollen count above the threshold value, for Poaceae, *Artemisia* and *Ambrosia*, at which clinical symptoms of allergy can develop. Arizmendi et al. [61] have shown that a neural network technique, trained with measured values of pollen concentrations, was able to predict near future values. However, without the environmental parameters used in this approach, it was impossible to predict the start of the pollen season. This method could be used only after the beginning of the season. The Gumbel's distribution applied in this study permits prediction of the date on which the pollen season will begin, with a certain probability on the basis of many-year observation data. Laaidi [54] has proposed an approximate forecast of the duration of the main pollen season on the basis of multiple regression, relative humidity and maximum temperature. It is one of many forecasting models based on the use of meteorological elements. The authors of this work have been able to determine the probabilities of the duration of pollen seasons for three taxa without analysis of meteorological parameters. Kasprzyk and Walanus [17] have studied the relations between the Poaceae pollen season and the weather, using the bi-modal probability and Gaussian-weighed moving correlation coefficient. They showed that the pattern of successive flowering in grass species and meadow-cutting dates appear to be the factors which cause the characteristic bi-modal behaviour of grass pollen season.

Stach et al. [63] have constructed long-term and short-term forecasting models, employing linear and multiple regression analysis to predict certain characteristic of the grass pollen season in Poznań, such as start, peak day and end of pollen season. These features of the pollen season have also been predicted for Poaceae, *Artemisia* and *Ambrosia* analysed in the presented study.

CONCLUSION

A statistically significant, negative correlation was found between the duration of the pollen season of Poaceae and *Artemisia* and the Seasonal Pollen Index (SPI) value. Short pollen seasons are characterised by higher intensity of pollination than long ones.

In Szczecin, the pollen seasons of grass, ragweed and mugwort have shown a weak but statistically significant trend towards delayed onset. Although *Artemisia* pollen appears in the air earlier in subsequent seasons, this tendency is very weak and statistically insignificant. For *Ambrosia,* a distinct and statistically significant trend towards a shortening of pollen season has been noted.

The trend analysis has revealed a distinct but statistically insignificant tendency towards a decrease in the number of days on which the first clinical allergy symptoms develop for the pollen seasons of mugwort and ragweed. However, for Poaceae, the opposite tendency has been noted.

Total annual pollen count of all taxa studied shows a strong decreasing trend (11-50.7%). This tendency is statistically significant for *Artemisia* and *Ambrosia*

Prediction of the maximum concentrations of pollen in the air and other features of pollen season, on the basis of Gumbel's distribution, permits avoidance of increased doses of allergens of the taxa analysed and thus contributes to successful prophylaxis and treatment of people with allergy to pollen antigens. Long-term forecasts of selected features of pollen seasons are consistent (Kolmogorov test) with the observed values, which permits precise prediction of probable maximum values that can occur once in 5, 10 or 100 years, i.e. selected features of pollen seasons of Poaceae, *Artemisia* and *Ambrosia*.

Acknowledgements

This study was carried out within the framework of Project No. 2011/01/B/ST10/06470, financed by the National Science Centre.

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