Aus der Klinik für Dermatologie, Venerologie und Allergologie
der Medizinischen Fakultät Charité – Universitätsmedizin Berlin

DISSERTATION

Distribution of Allergenic Pollen in a Metropolitan Region

zur Erlangung des akademischen Grades

Doctor rerum medicinalium (Dr. rer. medic.)

vorgelegt der Medizinischen Fakultät
Charité – Universitätsmedizin Berlin

von

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Datum der Promotion:
21.06.2020

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1.1 ABSTRACT IN ENGLISH, ABSTRAKT IN DEUTSCH

Worldwide, approximately every fifth person suffers from allergic rhinitis, frequently caused by a reaction to pollen. Nowadays, more than half of the global population lives in urban areas. Nevertheless, large cities are often equipped with just one pollen trap to provide information about aerial pollen content. Therefore, there is still a lack of information about the spatial distribution of pollen on an intra-urban scale and the possible effects on human health. In order to widen the knowledge about pollen distribution in urban environments, allergenic pollen – birch (*Betula*), grass (Poaceae), and mugwort (*Artemisia*) – was monitored with a network of fourteen traps within the large city of Berlin, and birch and grass pollen were monitored with four pollen traps within the Berlin/Brandenburg Metropolitan Region in 2014. Further, the detected pollen data and anonymously reported, geographically localized, pollen-induced symptom data were used to study temporal and spatial relationships between these two variables in the Berlin/Brandenburg metropolitan region, in the city of Berlin, and for the first time in different areas of a city on the example of Berlin. The seasonal pollen courses of birch and grass exhibited significantly positive correlations between all possible combinations of the fourteen traps in Berlin. For mugwort, the correlations were only to some extent significantly positive. In contrast to those mainly temporal similarities, remarkable spatial variations in the pollen distribution within the city were demonstrated, with the highest differences occurring in mugwort. The correlations between detected pollen and symptom levels during corresponding pollen seasons in the city of Berlin, its different areas, and the metropolitan region were found to be to a large extent significantly positive, with the weakest correlations occurring in mugwort. Higher amounts of birch and grass pollen measured in the suburban area than in the city center of Berlin were followed by more severe symptoms reported from the suburban area during the birch and grass pollen seasons. For mugwort, no such a relationship was found.

The presented and discussed results of the study

- substantiate the large differences in the spatial distribution of important allergenic pollen taxa within a city,
- highlight the benefit of using further pollen traps to monitor pollen within large urban areas,
- emphasize the importance of pollen as an significant cause of allergenic rhinitis and allergenic asthma.

Considering the ongoing urbanization, it is necessary to expand further the knowledge about pollen exposure and pollen allergy in urban environments.

ABSTRAKT IN DEUTSCH

Weltweit leiden ca. 20 % der Bevölkerung an allergischer Rhinitis, die am häufigsten durch den Kontakt mit Pollen hervorgerufen wird. Gegenwärtig leben mehr als 50 % der Weltbevölkerung in Städten. Ungeachtet dessen verfügen selbst große Städte oftmals nur über eine Pollenfalle zur Bereitstellung von Informationen zur Pollenbelastung der Luft. Daher gibt es immer noch ungenügende Informationen über die räumliche Verbreitung von Pollen innerhalb einer Stadt und die möglichen Auswirkungen auf die Gesundheit der Einwohner. Zum besseren Verständnis der Verteilung von Pollen in urbanen Räumen wurde 2014 der Pollenflug der allergenen Arten Birke (*Betula*), Gräser (Poaceae) und Beifuß (*Artemisia*) mit einem Messnetz von 14 Pollenfallen in der Großstadt Berlin sowie der Flug von Birken- und Gräserpollen mit vier Pollenfallen im Großraum Berlin/Brandenburg gemessen. Darüber hinaus wurden die ermittelten Pollendaten und anonym übermittelte, ortsgebundene Daten zu polleninduzierten Symptomen dazu verwendet, zeitliche und räumliche Beziehungen zwischen diesen beiden Variablen im Großraum Berlin/Brandenburg, in der Stadt Berlin und erstmalig auch in Teilbereichen einer Stadt am Beispiel Berlins zu untersuchen. Die zeitlichen Verläufe der Birken- und Gräserpollensaison ergaben für alle möglichen Kombinationen der vierzehn Fallen in Berlin einen signifikant positiven Zusammenhang. Für Beifuß waren diese Zusammenhänge weniger stark ausgeprägt und nur teilweise signifikant. Entgegen diesen vorwiegend saisonalen Übereinstimmungen traten deutliche Abweichungen hinsichtlich der räumlichen Verteilung der Pollen innerhalb des Stadtgebietes zu Tage, wobei die Unterschiede beim Beifuß am größten waren. Die statistischen Beziehungen zwischen den ermittelten Pollenzahlen und den gemeldeten Symptomstärken während den entsprechenden Pollensaisons waren in der Stadt Berlin, in deren Teilbereichen und im Großraum Berlin-Brandenburg größtenteils signifikant positiv, wobei der schwächste Zusammenhang beim Beifuß auftrat. Die Zahl der Birken- und Gräserpollen war in den Randbezirken der Stadt höher als im Stadtzentrum. Damit einher gingen Unterschiede in der Symptomschwere zwischen Stadtrand und Stadtzentrum, wobei die gemeldeten Symptomstärken am Stadtrand im Mittel höher lagen als im Zentrum. Beim Beifuß zeigte sich kein solcher Zusammenhang.

Die vorgelegten und diskutierten Ergebnisse der Studie

- belegen die sehr unterschiedliche Verteilung wichtiger allergener Pollenarten innerhalb einer Großstadt,
- verdeutlichen den Vorteil des Einsatzes mehrerer Pollenfallen für das Monitoring von Pollen in Großstädten,
- unterstreichen die große Bedeutung von Pollen als wichtige Auslöser von allergischer Rhinokonjunktivitis und allergischem Asthma.

Die fortschreitende Urbanisierung verlangt nach einer noch eingehenderen Forschung zur Pollenexposition und Pollenallergie in Städten.

1.2 INTRODUCTION

Pollination is an important process in the life cycle of plants. On the other hand, pollen is an aeroallergen with a remarkably negative impact on human health.

Within the global population, about 10–30% of adults and 40% of children suffer from allergic rhinitis, commonly caused by a reaction to pollen [1]. Allergic rhinitis is a risk factor for asthma [1], and asthma itself can be induced by pollen as well [2]. Asthma afflicts approximately 300 million people worldwide [1]. In Germany, 14.8% of adults and 12.6% of children/adolescents are affected by medically diagnosed allergic rhinoconjunctivitis, and 8.6% of adults and 6.3% of children/adolescents suffer from asthma [3,4]. Negative influences on the quality of life, performances at school and work, and high costs for insufficiently treated patients are serious socio-economic consequences of allergies [5].

More than half of the global population lives in urban areas, a value estimated to reach 68% in 2050 [6]. Owing to that, large parts of the population are exposed to pollen released from urban flora within cities and the surroundings at the same time. On the one hand, urban green offers and fulfils important cultural and recreational functions and can reduce air pollution [7]. On the flip side, planting non-native plants introducing new allergens to the population (e.g. tree of heaven [*Ailanthus*] in Germany), plants releasing allergenic pollen (e.g. birch [*Betula*], hazel [*Corylus*]), or inappropriate maintenance of urban green (e.g. uncut grass [Poaceae] or ruderal vegetation of disturbed soils with plants carrying allergenic pollen [e.g. mugwort {*Artemisia*}]) are risk factors of urban green spaces for people suffering from pollen allergy [8-12]. Moreover, an increasing trend in the annual pollen sum, stronger in urban areas in comparison to semi-rural/rural areas, was detected for many taxa in Europe [13], and people growing up/living in urban areas were found to be more likely affected by pollen-induced diseases than people growing up/living in rural areas [14,15]. In addition, pollutants particularly associated with urban areas, e.g. particulate matter (PM), ozone (O_3), or nitrogen dioxide (NO_2), have a negative effect on respiratory health as reviewed by D'Amato [16].

In Germany, airborne pollen is monitored by the non-governmental German Pollen Information Service Foundation with a network of more than 30 pollen monitoring stations equipped with 7-day volumetric spore traps of the Hirst type used by the majority of monitoring stations worldwide [17-19]. Regardless of the size of a city as well as the topographical and biogeographical characteristics, there is often just one pollen trap per city [19]. Results of studies temporarily operating additional pollen traps per city showed certain spatial differences in pollen counts among the monitoring sites which were often linked with influences of local conditions [8,10,20-22]. Main limitations of those studies were (1) the low number of pollen traps, (2) sampling height inconsistencies, (3) monitoring being limited to a part of a city and/or (4) pollen data being collected during a limited number of days within a pollen season only.

The origin and development of pollen allergy is a complex issue caused and influenced by many factors on the human side (e.g. genetic predispositions, individual thresholds) as well as on the side of the environment (as mentioned earlier). Overall, it is established that the degree of exposure to an allergen affects the development and magnitude of allergic symptoms [23,24]. Therefore, pollen monitoring and follow-up pollen forecasts are important informative and preventive tools for individuals suffering from pollen allergy and those treating it [25]. Beside pollen information, there is a growing need to collect and study pollen-induced symptoms in order to answer the question as to the impact of pollen on human health [26-30] for the purpose of improving the overall quality of life of people suffering from pollen allergy.

The presented study aimed to gain information about pollen and the relationship between pollen and pollen-induced symptoms contributing towards improved allergy management with an emphasis on research in urban areas as main centers of population.

The first subject matter of the study was the observation of spatial distributions of allergenic pollen within a single city. The novelties of the screening network were the usage of (1) fourteen pollen traps located (2) at uniform heights (3) within one complete city and (4) pollen data collected on a weekly basis during a whole pollen season.

The second aim of the research was to study relationships between pollen counts and pollen-induced symptoms in a metropolitan region, in a city, and for the first time on an intra-urban scale of a city. Partial results of the presented work have been published in [31-33].

1.3 MATERIAL AND METHODS

1.3.1 STUDIED AREA

The area of interest was the Berlin/Brandenburg Metropolitan Region (BBMR) situated in the North German Plain in the northeast of Germany. The main part of the study was carried out in Berlin – the capital of Germany and at the same time the most populated (3.6 million inhabitants) and the largest (891 km^2) German city [34]. The complementary area of interest was Brandenburg – the region surrounding Berlin with an area of 29,654 km^2 and 2.5 million inhabitants [35].

1.3.2 POLLEN DATA

Pollen data were collected by passive and active pollen sampling methods in 2014.

1.3.2.1 Passive method

The passive (gravimetric) method utilizes the natural sedimentation of pollen from the air. Self-constructed gravimetric traps (GTs) inspired by a trap described by Durham [36] were used in the study. The GT was composed of two horizontal circular disks 13.5 cm apart from each other: the flat plastic upper disk, 22 cm in diameter, with a downward sloping rim and the flat stainless-steel lower disk, 18 cm in diameter. A microscopic slide covered with petroleum jelly placed on a horizontal holder 4 cm above the lower disk was used as the pollen-collecting tool. Fourteen of these traps were placed at street-level heights within the whole city of Berlin (table 1).

1.3.2.2 Active method

The active (volumetric) method relies on active air sampling. 7-day volumetric spore traps (7VSTs) [17], a standard for collecting pollen among aerobiologists and medical doctors, were used in the study. The trap sucks ambient air at a rate of 10 l/min through an orifice into the trap. The particle content of the air impacts on a trapping surface – a transparent tape (Melinex®) with an adhesive medium (petroleum jelly in the study) covering a drum moving with the rotation speed of 2 mm/hour. Pollen data were collected with three 7VSTs located at roof-top-level heights within the BBMR: Berlin (52°31'38.3"N 13°22'40.6"E), Potsdam (52°22'46.3"N 13°08'29.0"E), Treuenbrietzen (52°04'52.4"N 12°52'33.7"E), and one 7VST in the Mecklenburg-West Pomerania Region adjacent to the BBMR: Neustrelitz (53°21'40.8"N 13°03'32.1"E).

1.3.2.3 Pollen types

Three pollen types having the highest prevalence of sensitization (PS) in the adult German population within one of the three seasons of the year were chosen: birch (*Betula*) pollen as representative of the spring season with a PS of 17.4%, grass (Poaceae) pollen for the summer season with a PS of 18.1%, and mugwort (*Artemisia*) pollen for the late summer/autumn season with a PS of 9.0% [18,37].

1.3.3 POLLEN-INDUCED SYMPTOM DATA

Symptom data were reported anonymously and voluntarily via a web-based system – Patient's Hayfever Diary (PHD; www.pollendiary.com) [28,38]. Due to the anonymous nature of the reports, clinical diagnoses of the PHD users relating to pollen allergy and/or pollen-induced asthma and/or the responses to specific pollen type(s) were not known. The pollen-induced[1] symptom data were available on a daily basis and characterized by geographic location (geographic coordinates, postal codes, or regions).

1.3.4 ANALYSES

The statistical analyses and graphic presentations of the data were processed in Microsoft Office, CorelDRAW, Adobe Photoshop CS2, and IBM SPSS Statistics 23 and 24.

1.3.4.1 Pollen in the city of Berlin

Fourteen GTs were collecting pollen within the city of Berlin over a period of 33 weeks from 11 March until 28 October 2014. As the daily exchange of microscopic slides within the whole city of Berlin would be highly time-consuming, the exposed slides were changed weekly. The slides were stained in a mixture of safranin-colored Mowiol®, glycerol, and water and covered with a coverslip. Pollen within an area of 48 mm^2 centered on the slides was determined under a light

[1] Throughout the text, the term "pollen-induced symptom" is used following the expectation that most users of the diary suffer from some pollen-induced disease.

microscope at a magnification of 400× in accordance with the systematic by Beug [39]. Fifteen of 462 slides were not available for pollen analysis. The missing data were generated based on multiple inputs – the Markov Chain Monte Carlo (MCMC) method was used. The adapted definition from Jäger et al. [40], with "day" being replaced with "week" in the presented study, was applied to find the birch, grass, and mugwort pollen seasons. Kendall's Tau-b coefficient which is used for small data sets rather than Spearman's rank correlation coefficient [41] was chosen to calculate pairwise correlations between all fourteen seasonal[2] pollen curves of birch, grass, and mugwort.

1.3.4.2 Pollen and pollen-induced symptoms in the city of Berlin

Symptoms reported via the PHD from the Berlin area[3] during the birch, grass, and mugwort pollen seasons were used in the calculations. Every daily report of a user was expressed as Overall Total Symptom value (OTS). The daily OTS value of a user was calculated based on the severity of symptoms at three organs – eyes, nose, and lungs (bronchi). The severity was numerically quantified from "no problems" (0 points) to "severe problems" (3 points). Then, one point was added for each occurrence of specific symptoms at the three organs – eyes: itching, foreign body sensation, redness, watering; nose: itching, sneezing, running, blockage; and lungs: wheezing, shortness of breath, cough, asthma. This leads to an OTS between 0 and 21 points.

Taking the pollen data collected by GTs on a weekly basis into consideration, the daily OTSs of each PHD user were recalculated into weekly OTS values. During a specific pollen season, a weekly OTS value of a user was gained by averaging 4-7 daily OTS values reported from the same postal code in case of just one reporting week of the user or by averaging 3-7 daily OTS from the same postal code in case of two or more reporting weeks of a user. Afterwards, PHD users and the corresponding weekly OTSs characterized by postal codes were matched with the postal code of the nearest of the fourteen GTs to create fourteen groups. In addition, due to the insufficient number of users in these fourteen groups, the GTs, the corresponding PHD users, and the OTS values were merged into two larger groups sorted by distance of the GTs from the geographic center of the city: the "city center" group (7 GTs: BRÜCKE, CHU, FRANK, KA-MA, RING, SILBER, ZOO) and the "suburban" group (7 GTs: A100, BORN, CORR, J&W, LENG, MAR-DA, SCHI). The statistical analysis was performed using Kendall's Tau-b correlation coefficient.

1.3.4.3 Pollen and pollen-induced symptoms in the Berlin/Brandenburg Metropolitan Region

Pollen data were collected using four 7VSTs in 2014. The exposed tape, changed at least once per week, was cut into parts representing one day each, put on microscopic slides, stained in a mixture of safranin-colored Mowiol®, glycerol, and water, and covered with a coverslip. Pollen was

[2] Time between the beginning of the birch (grass, mugwort) pollen season and the end of the birch (grass, mugwort) pollen season.
[3] Additionally, symptoms reported by one user from a postal code area of the Brandenburg region adjacent to the postal code of the suburban GT "SCHI" were used.

determined in four horizontal lines, each of 250 µm, under a light microscope at a magnification of 400×. Pollen values were indicated as average daily concentrations (in pollen per cubic meter of air). A recently stated definition of the pollen season [42] was applied to determine the birch and grass pollen seasons. As the definition is not available for mugwort yet, this pollen type was excluded from that part of the study.

In order to evaluate the pollen/symptom relationship in the BBMR, the Total Nasal Symptom and Medication Score (TNSMS) was calculated on the basis of PHD symptom data reported from the area. The TNSMS is a sum of the Total Nasal Symptom Score (TNSS) and the Weighted Nasal Medication use Score (WNMS) and ranges from 0 to 9.05 points. The TNSS is calculated based on the severity of symptoms at the nose ("no problems" [0 points] to "severe problems" [3 points]) and the reported specific nasal symptom – itching, sneezing, running, or blockage (1 point for each of the symptoms). Thus, the TNSS ranges from 0 to 7 points. The WNMS can reach a maximum value of 2.05 points: 1 point for the reported usage of "Nose drops" or "Tablets" or both, 0.25 points for "Eye drops", 0.5 points for "Others", and 0.3 points for "Homeopathic" medication.

Daily pollen data from the four traps and daily symptom data were averaged, resulting in average daily pollen levels and average daily TNSMS for the BBMR. Spearman's rank correlation coefficient was applied to analyze the relationship between pollen and the TNSMS in the region.

1.4 RESULTS

1.4.1 POLLEN IN THE CITY OF BERLIN

In total, 32.701 birch, 6.794 grass, and 976 mugwort pollen grains were detected by fourteen GTs placed within Berlin during the whole monitoring period (fig. 1, tables 1–3). In 2014, the birch pollen season in Berlin lasted for 8 weeks from 11 March to 6 May, the grass pollen season lasted for 16 weeks from 15 April to 5 August, and the mugwort pollen season lasted for 12 weeks from 24 June to 16 September.

1.4.1.1 Birch pollen in Berlin

The comparison of the fourteen seasonal pollen curves (horizontal view: table 1) revealed positive and significant correlations for all the 91 possible pair combinations: ($p < 0.05$): $\tau = 0.643–1.000$ (average $\tau = 0.852$). However, there were differences in the pollen counts within individual weeks (vertical view: table 1) and in the total pollen sums (TPS) for the whole investigation period (fig. 1a; table 1). The highest TPS of birch was found in the suburban GT coded "LENG", the lowest TPS was detected in the city center GT "BRÜCKE" (fig. 1a; table 1), reaching 40.76% of the TPS at "LENG". The highest weekly pollen count for all fourteen GTs manifested during the same week of the birch pollen season: week 4 (table 1).

1.4.1.2 Grass pollen in Berlin

The seasonal pollen courses of grass (horizontal view: table 2) were positive and significantly correlated for all 91 pair combinations: ($p < 0.05$): $\tau = 0.569$–0.901 (average $\tau = 0.762$). Spatial differences in the weekly values and TPSs are presented in table 2 (vertical view) and figure 1b. The biggest grass pollen count occurred in the suburban GT "SCHI", and the smallest one in the suburban GT "CORR" (fig. 1b; table 2) reaching 32.68% of the TPS at "SCHI". Maximum weekly pollen values for individual GTs occurred in three different weeks over the course of the grass pollen season: weeks 6, 8, and 10 (table 2).

1.4.1.3 Mugwort pollen in Berlin

The comparison of the seasonal courses of mugwort (horizontal view: table 3) was positive and significant for 45 pair correlations ($p < 0.05$), positive for 45 different pair correlations, and negative for one pair correlation ("J&W"/"KA-MA"): $\tau = -0.097$–0.848 (average $\tau = 0.467$). The detected differences in the spatial distribution of mugwort pollen for individual weeks and the entire investigation period are shown in table 3 and figure 1c. The highest TPS of mugwort was detected in the city GT "BRÜCKE", the lowest one in the city center GT "KA-MA" (fig. 1c, table 3), reaching 5.1% of the TPS at "BRÜCKE". Maximum pollen values were measured by individual GTs in six different weeks – weeks 3, 5, 6, 7, 8, and 9 – of the twelve-week mugwort pollen season (table 3).

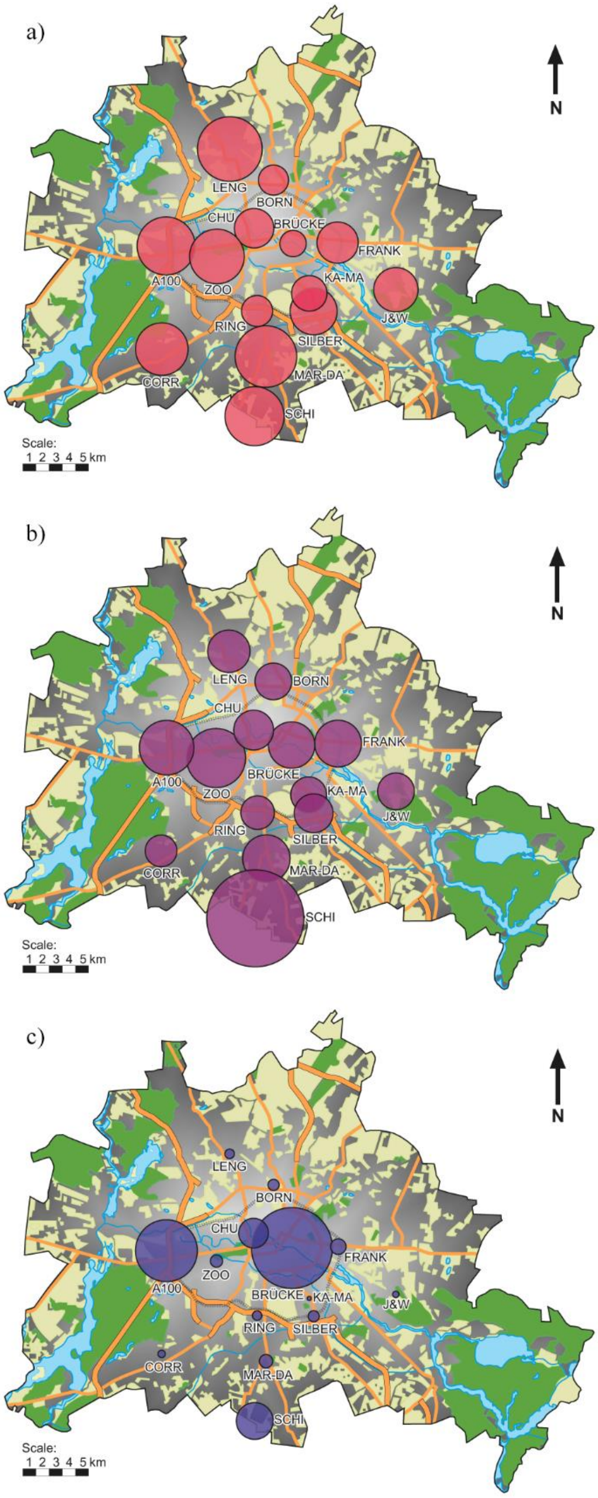

Figure 1 Total pollen sums (TPSs) of a) birch, b) grass, and c) mugwort from 14 gravimetric traps (GTs) located in Berlin from 11 March to 28 October 2014 (33 weeks)
The *circle size* corresponds to the observed TPS; *grey color* built-up areas; *light green* meadows, fields, gardens; *dark green* forests and tree-covered urban greens; *blue* bodies of water
Adapted and reprinted by permission from Springer Nature Customer Service Centre GmbH: Springer Nature, Environmental Monitoring and Assessment, Spatial distribution of allergenic pollen through a large metropolitan area, Werchan B, Werchan M, Mücke HG, Gauger U, Simoleit A, Zuberbier T, Bergmann KC, © 2017, advance online publication, 18 March 2017, doi: 10.1007/s10661-017-5876-8.Environ Monit Assess.

Table 1 Weekly, seasonal, and total pollen sums of birch (*Betula*) detected by fourteen gravimetric traps within Berlin during 33 weeks (2014) with information about the trap acronyms and locations; weekly birch pollen data displayed for 8 weeks of the birch pollen season

GT ↓	Coordinates (WGA 84) ↓	Height ↓	M → W → w →	March 1 1	 2 2	/ 3 3	 4 4	April 5 5	 6 6	/ 7 7	 8 8	SPS ↓	TPS ↓
BRÜCKE	52°30'48.8"N 13°25'08.0"E	2.5 m	City center	5	26	105	**647**	221	203	79	17	1303	1336
KA-MA	52°28'54.1"N 13°26'02.0"E	2.2 m	City center	1	24	124	**939**	353	216	63	19	1739	1798
CHU	52°31'38.4"N 13°22'40.7"E	2.5 m	City center	21	120	274	**1001**	256	210	69	24	1975	1998
RING	52°28'10.4"N 13°22'53.9"E	2.5 m	City center	3	11	172	**795**	229	226	58	33	1527	1574
SILBER	52°28'03.1"N 13°26'29.9"E	2.2 m	City center	5	26	210	**1191**	386	394	87	30	2329	2382
ZOO	52°30'23.8"N 13°19'58.7"E	2.5 m	City center	9	47	330	**1324**	520	320	105	43	2698	2769
FRANK	52°30'50.7"N 13°28'11.7"E	2.5 m	City center	7	76	110	**1085**	293	320	99	31	2021	2088
			Avg.	7	47	189	997	323	270	80	28	13592	13945
BORN	52°33'22.8"N 13°24'07.3"E	2.5 m	Suburban	4	37	138	**683**	257	209	122	23	1473	1523
MAR-DA	52°26'17.2"N 13°23'15.8"E	2.2 m	Suburban	1	31	358	**1832**	435	279	69	32	3037	3121
A100	52°30'59.8"N 13°17'01.9"E	3.5 m	Suburban	4	26	572	**1348**	354	403	109	41	2857	2939
J & W	52°29'06.9"N 13°31'46.1"E	2.5 m	Suburban	4	14	156	**1355**	311	275	48	14	2177	2244
LENG	52°34'59.2"N 13°20'55.3"E	2.5 m	Suburban	46	265	404	**1525**	563	275	110	16	3204	3278
CORR	52°26'43.1"N 13°17'08.1"E	2.0 m	Suburban	0	14	252	**1267**	805	164	43	17	2562	2659
SCHI	52°23'53.7"N 13°21'57.5"E	2.2 m	Suburban	0	10	394	**1760**	399	274	89	21	2947	2992
			Avg.	8	57	325	1396	446	268	84	23	18257	18756
											Total	31849	32701

GT gravimetric trap; *Height* sampling height in meters above ground level; *M* month; *W* week of the whole investigation period; *w* week of the birch pollen season; *SPS* seasonal pollen sum; *TPS* total pollen sum; *Avg.* average; *number in bold* maximum weekly value for an individual gravimetric trap

Table 2 Weekly, seasonal, and total pollen sums of grass (Poaceae) detected by fourteen gravimetric traps within Berlin during 33 weeks (2014); weekly grass pollen data displayed for 16 weeks of the grass pollen season

GT ↓	M → W → w →	April 6 1	 7 2	/ 8 3	May 9 4	 10 5	 11 6	/ 12 7	 13 8	June 14 9	 15 10	/ 16 11	 17 12	July 18 13	 19 14	 20 15	/ 21 16	SPS ↓	TPS ↓
BRÜCKE	City center	0	0	1	5	8	79	60	**138**	45	44	25	22	16	6	4	3	456	488
KA-MA	City center	0	0	1	15	11	65	51	**67**	35	30	23	31	15	5	14	1	364	376
CHU	City center	1	2	2	7	7	**101**	52	66	35	36	22	26	13	11	10	7	398	418
RING	City center	1	0	6	6	14	**80**	56	56	34	21	9	9	16	16	5	6	335	353
SILBER	City center	0	0	4	5	11	**94**	57	86	19	38	13	22	16	16	13	1	395	408
ZOO	City center	1	0	0	13	16	**114**	96	76	69	86	52	34	18	11	0	7	593	621
FRANK	City center	0	1	0	15	13	92	61	**102**	32	39	24	24	27	23	7	7	467	491
	Avg.	0	0	2	9	11	89	62	84	38	42	24	24	17	13	8	5	3008	3155
BORN	Suburban	1	1	2	26	6	**66**	53	48	49	30	12	23	18	18	12	6	370	385
MAR-DA	Suburban	3	2	5	30	27	**102**	52	82	59	34	20	28	13	8	11	3	479	498
A100	Suburban	1	0	1	8	36	101	111	**134**	51	63	11	0	10	15	7	0	549	573
J & W	Suburban	0	0	2	2	23	67	47	**76**	35	20	29	15	28	15	10	4	373	386
LENG	Suburban	0	3	2	9	15	**96**	70	67	28	36	39	30	17	9	5	4	430	445
CORR	Suburban	0	1	3	4	9	49	44	63	26	**77**	10	17	5	11	3	1	323	333
SCHI	Suburban	0	0	0	9	37	**305**	266	157	60	60	31	30	9	13	13	1	991	1019
	Avg.	1	1	2	13	22	112	92	90	44	46	22	20	14	13	9	3	3515	3639
																	Total	6524	6794

GT gravimetric trap; *M* month; *W* week of the whole investigation period; *w* week of the grass pollen season; *SPS* seasonal pollen sum; *TPS* total pollen sum; *Avg.* average; *number in bold* maximum weekly value for an individual gravimetric trap

Table 3 Weekly, seasonal, and total pollen sums of mugwort (*Artemisia*) detected by fourteen gravimetric traps within Berlin during 33 weeks (2014); weekly mugwort pollen data displayed for 12 weeks of the mugwort pollen season in Berlin

GT gravimetric trap; *M* month; *W* week of the whole investigation period; *w* week of mugwort pollen season; *SPS* seasonal pollen sum; *TPS* total pollen sum; *Avg.* average; *number in bold* maximum weekly value for an individual gravimetric trap

GT ↓		M →	/		July			/		August		/	September			
		W →	16	17	18	19	20	21	22	23	24	25	26	27	SPS	TPS
		w →	1	2	3	4	5	6	7	8	9	10	11	12		
BRÜCKE	City center		1	3	3	19	57	**67**	49	47	2	4	2	1	255	255
KA-MA	City center		0	0	0	2	**4**	0	2	2	0	2	0	0	12	13
CHU	City center		5	0	**31**	5	8	10	12	2	4	5	10	1	94	94
RING	City center		0	0	1	0	5	3	5	3	**9**	0	0	1	27	30
SILBER	City center		0	0	1	5	5	6	**10**	4	3	0	0	0	34	35
ZOO	City center		0	0	10	2	**12**	3	5	2	1	2	0	1	38	39
FRANK	City center		2	3	0	3	7	**10**	9	7	3	0	4	1	49	49
		Avg.	1	1	7	5	14	14	13	10	3	2	2	1	508	515
BORN	Suburban		0	0	1	2	4	**11**	10	3	0	0	1	4	35	35
MAR-DA	Suburban		0	0	0	2	3	**10**	13	7	1	0	1	3	40	42
A100	Suburban		0	3	23	10	35	14	**52**	41	12	2	1	1	194	195
J & W	Suburban		0	0	2	0	0	**8**	5	2	3	0	0	0	20	20
LENG	Suburban		0	0	0	3	4	4	**11**	4	2	0	0	1	29	30
CORR	Suburban		0	0	0	2	0	7	**8**	3	0	3	0	0	23	23
SCHI	Suburban		0	0	11	4	19	14	31	**32**	1	2	1	0	115	116
		Avg.	0	0	5	3	9	10	19	13	3	1	1	1	457	461
														Total	965	976

1.4.2 POLLEN AND POLLEN-INDUCED SYMPTOMS IN THE CITY OF BERLIN

Overall, 163 PHD users reported at least one applicable symptom week from at least one postal code during the birch pollen season, 149 PHD users (148 from Berlin, 1 from Brandenburg) during the grass pollen season, and 71 PHD users (70 from Berlin, 1 from Brandenburg) during the mugwort pollen season in 2014. Some of the OTS values were part of two pollen seasons (birch/grass or grass/mugwort) because of the overlap of the pollen seasons.

1.4.2.1 Birch pollen season in Berlin

The relationships between birch pollen levels detected by GTs and pollen-induced symptoms (OTS) during the birch pollen season in Berlin were mostly positive and significant (table 4). Birch pollen counts and OTS values were higher in the suburban area in contrast to the city center (table 5: Mean). The highest weekly OTS values were present during week 4 of the birch pollen season, with higher values for the suburban area (fig. 2).

1.4.2.2 Grass pollen season in Berlin

The correlations between grass pollen and OTS during the grass pollen season were mainly positive and significant (table 4). Grass pollen counts and OTS were higher for the suburban area in comparison to the city center (table 5: Mean). The maximum weekly OTS appeared between weeks 7 and 9 of the grass pollen season and were in all cases higher for the suburban area (fig. 2).

1.4.2.3 Mugwort pollen season in Berlin

Depending on the user category, positive and significant, positive, and negative relationships between mugwort pollen counts and OTS values were revealed during the 2014 mugwort pollen season in Berlin (table 4). More mugwort pollen was measured in the city center area than in the suburbs, but more severe symptoms occurred in the suburban area than in the city center (table 5: Mean). The highest weekly OTS levels appeared between weeks 3 and 10 of the mugwort pollen season (fig. 2).

Table 4 Kendall's Tau-b correlation coefficient (τ) between averaged weekly birch, grass, and mugwort pollen counts from GTs (Berlin: from 14 GTs, Berlin: city center area: from 7 city center GTs, Berlin: suburban area: from 7 suburban GTs) and averaged weekly Overall Total Symptom scores (OTS) of PHD users during the corresponding pollen seasons in Berlin and in both studied areas of the city together with the p value (two-sided)

	Birch pollen season			**Grass pollen season**			**Mugwort pollen season**		
Berlin	No. of users	τ	p	No. of users	τ	p	No. of users	τ	p
Avg. weekly OTS of all users	170	**0.643***	0.026	159	0.317	0.087	76	-0.290	0.192
Avg. weekly OTS of sign. positively (p<0.05) corr. users ≥ 3 weeks	14	**0.857****	0.003	15	**0.733****	0.000	1	**1.000***	
Avg. weekly OTS of sign. positively (p<0.05) & positively (p>0.05) corr. users ≥ 3 weeks	82	**0.857****	0.003	55	**0.700****	0.000	21	**0.595****	0.007
Berlin: city center area	No. of users	τ	p	No. of users	τ	p	No. of users	τ	p
Avg. weekly OTS of all users	90	0.429	0.138	79	**0.427***	0.022	43	-0.182	0.411
Avg. weekly OTS of sign. positively (p<0.05) corr. users ≥ 3 weeks	8	**0.929****	0.001	11	**0.678****	0.000	1	**1.000***	
Avg. weekly OTS of sign. positively (p<0.05) & positively (p>0.05) corr. users ≥ 3 weeks	40	**0.929****	0.001	31	**0.644****	0.001	14	0.394	0.075
Berlin: suburban area	No. of users	τ	p	No. of users	τ	p	No. of users	τ	p
Avg. weekly OTS of all users	81	**0.786****	0.006	80	0.183	0.322	33	-0.303	0.170
Avg. weekly OTS of sign. positively (p<0.05) corr. users ≥ 3 weeks	9	**0.714***	0.013	3	**0.633****	0.001	1	**1.000***	
Avg. weekly OTS of sign. positively (p<0.05) & positively (p>0.05) corr. users ≥ 3 weeks	45	**0.857****	0.003	26	**0.583****	0.002	7	0.333	0.131

τ Kendall's Tau-b correlation coefficient; *p* significance level; *denotes significance level of < 0.05 and **denotes significance level of < 0.01; *Avg.* averaged; *sign.* significantly; *corr.* correlated; *users ≥ 3 weeks* users with at least 3 weeks of available symptom data during the corresponding pollen season

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Table 5 Basic descriptive statistics for averaged weekly pollen counts from gravimetric traps (GTs) and averaged weekly overall total symptoms (OTS) during birch, grass, and mugwort pollen seasons for both studied areas of the city of Berlin

	Berlin: city center area				**Berlin: suburban area**			
	Min	Max	Mean	Std	Min	Max	Mean	Std
Birch pollen season								
Avg. weekly birch pollen counts	7.3	997.4	242.7	326.4	**8.4**	**1395.7**	**326.0**	**460.7**
Avg. weekly OTS of all users in the area	3.22	7.35	4.36	1.42	**3.83**	**8.10**	**5.13**	**1.43**
Avg. weekly OTS of sign. positively (p<0.05) corr. users ≥ 3 weeks	0.90	7.40	3.72	2.17	**2.14**	**10.69**	**4.87**	**2.61**
Avg. weekly OTS of sign. positively (p<0.05) & positively (p>0.05) corr. users ≥ 3 weeks	3.23	7.87	4.61	1.66	**3.93**	**8.83**	**5.27**	**1.71**
Grass pollen season								
Avg. weekly grass pollen counts	0.4	89.3	26.9	28.9	**0.7**	**112.3**	**31.4**	**35.9**
Avg. weekly OTS of all users	**2.55**	4.53	3.47	0.49	1.90	**5.70**	**3.87**	**1.09**
Avg. weekly OTS of sign. positively (p<0.05) corr. users ≥ 3 weeks	0.56	6.76	3.18	1.86	**0.57**	**13.39**	**6.22**	**3.34**
Avg. weekly OTS of sign. positively (p<0.05) & positively (p>0.05) corr. users ≥ 3 weeks	1.62	5.18	3.28	1.08	**1.90**	**6.87**	**4.41**	**1.54**
Mugwort pollen season								
Avg. weekly mugwort pollen counts	**0.7**	14.1	**6.1**	5.3	0.0	**18.5**	5.4	**6.0**
Avg. weekly OTS of all users	**2.26**	3.59	2.82	0.41	1.71	**3.68**	**2.93**	**0.71**
Avg. weekly OTS of sign. positively (p<0.05) corr. users ≥ 3 weeks	0.43	**6.25**	2.95	**2.48**	**1.71**	4.71	**3.50**	1.28
Avg. weekly OTS of sign. positively (p<0.05) & positively (p>0.05) corr. users ≥ 3 weeks	**2.62**	5.15	3.97	0.92	0.50	**8.26**	**4.59**	**2.23**

Min minimum; *Max* maximum; *Std* standard deviation; *Avg.* averaged; *sign.* significantly; *corr.* correlated; *users ≥ 3 weeks* users with at least 3 weeks of available symptom data during the corresponding pollen season; *number in bold* higher level when comparing both areas

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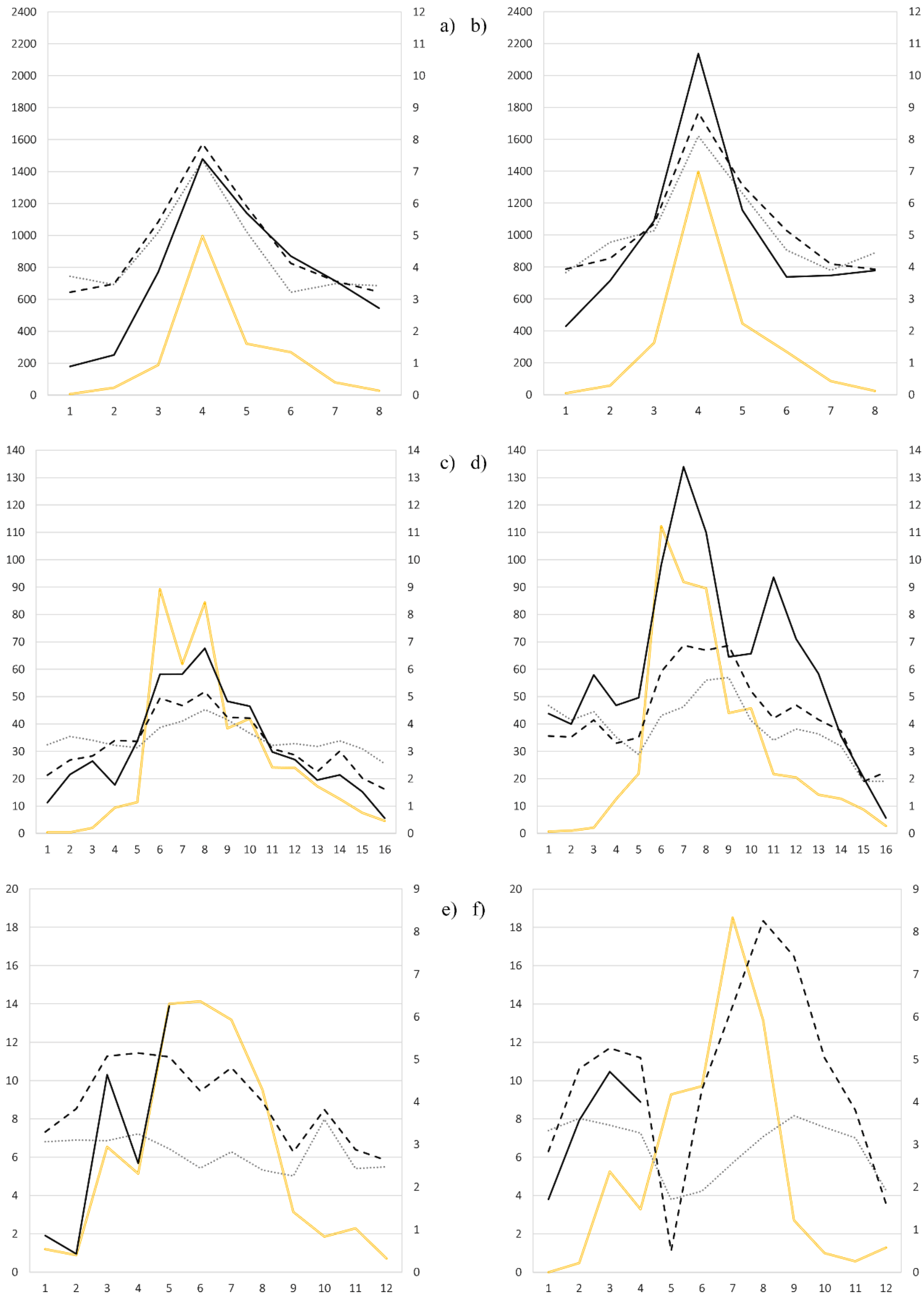

Figure 2 Averaged weekly overall total symptoms (OTS) and averaged weekly birch pollen counts for 8 weeks of the birch pollen season (a, b); averaged weekly overall total symptoms (OTS) and averaged weekly grass pollen for 16 weeks of the grass pollen season (c, d); averaged weekly overall total symptoms (OTS) and averaged weekly mugwort pollen for 12 weeks of the mugwort pollen season (e, f) in the city center area (a, c, e) and the suburban area (b, d, f) of the city of Berlin

Left y-axis pollen; *x-axis* week of the corresponding pollen season; *right y-axis* overall total symptoms (OTS) level; *yellow line* pollen; *grey dotted line* averaged weekly OTS of all users from the corresponding area; *black line* averaged weekly OTS of significantly positively ($p<0.05$) correlated users ≥ 3 weeks; *black dashed line* averaged weekly OTS of significantly positively ($p<0.05$) and positively ($p>0.05$) correlated users ≥ 3 weeks; *users ≥ 3 weeks* denotes users with at least 3 weeks of available symptom data during the corresponding pollen season

Figure 2 Continued *Adapted and reprinted by permission from Springer Nature Customer Service Centre GmbH: Springer Nature, Aerobiologia, Spatial distribution of pollen-induced symptoms within a large metropolitan area – Berlin, Germany, Werchan B, Werchan M, Mücke HG, Bergmann KC, © 2018, advance online publication, 19 July 2018, doi: 10.1007/s10453-018-9529-3.Aerobiologia.*

1.4.3 POLLEN AND POLLEN-INDUCED SYMPTOMS IN THE BERLIN/BRANDENBURG METROPOLITAN REGION

The birch pollen season lasted from 27 March until 5 May 2014, and the grass pollen season from 13 May until 27 July in the BBMR. Birch pollen levels and TNSMS levels during the birch pollen season were higher when compared to grass pollen levels and TNSMS levels during the grass pollen season (table 6).

Table 6 Basic descriptive statistics for averaged daily birch and grass pollen levels and Total Nasal Symptom and Medication Score (TNSMS) in the Berlin/Brandenburg Metropolitan Region during the 2014 birch and grass pollen seasons

	Min	Max	Mean	Std
Birch pollen	9.3	3042.0	570.8	877.0
Grass pollen	1.0	159.5	34.1	32.9
TNSMS – birch pollen season	1.4	3.0	2.1	0.5
TNSMS – grass pollen season	1.2	2.7	1.8	0.4

Min minimum; *Max* maximum; Std standard deviation; *TNSMS* Total Nasal Symptom and Medication Score

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The relationship between birch pollen levels and TNSMS during the birch pollen season and between grass pollen levels and TNSMS during the grass pollen season was positive and significant in the BBMR (table 7).

Table 7 Spearman's rank correlation coefficient (r) between the averaged daily Total Nasal Symptom and Medication Score (TNSMS) and the averaged daily birch and grass pollen count levels with the p value for a significance level of a = .001in the Berlin/Brandenburg Metropolitan Region (BBMR) during the 2014 birch and grass pollen seasons

	r	p
Birch pollen season	0.79	$2*10^{-9}$
Grass pollen season	0.80	$5*10^{-18}$

r Spearman's rank correlation coefficient; *p* significance level

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1.5 DISCUSSION

The study has presented results on the spatial distribution of allergenic pollen within a metropolitan area and the relationships between the detected pollen and the reported pollen-induced symptoms in the area. Based on the author's best knowledge, pollen monitoring via a network of fourteen weekly changed pollen traps placed at uniform height within a whole city during a pollen season and researching the relationship between the pollen and the symptoms on an intra-urban scale have not been undertaken before and are novelties of the study.

1.5.1 BIRCH POLLEN IN BERLIN

There were only very little temporal variations between the seasonal pollen curves of birch from all 14 GTs. However, certain differences in the spatial distribution of birch pollen within the city were presented (table 1). When comparing two different city areas, more birch pollen was detected in the suburban area (18.756 pollen grains) than in the city center area (13.945 pollen grains; table 1), similar as reported in another study from Berlin [10] and from Poznan, Poland [21]. The lower birch pollen values in the city center (fig. 1a) were likely caused by a gradual sedimentation and filtration of pollen coming from sources mostly located outside the city, e.g. woodlands with birch in the Brandenburg region [43] and/or long-range transport of pollen from more faraway sources [44]. Additionally, higher birch pollen amounts in the suburbs could also be caused by pollen released from sources located in the area, since less densely built-up areas often provide more space for planting trees with birch being a popular decorative tree [45] and/or spontaneous vegetation with birch being a frequent species [46].

1.5.2 GRASS POLLEN IN BERLIN

The seasonal grass pollen curves from 14 GTs were similar to each other. However, the variations exceeded those of birch. Also differing from birch characterized by the maximum pollen load for each of the 14 GTs simultaneously appearing in one week (table 1), the maximum grass pollen load from a number of the fourteen traps appeared as three peaks over a period of five weeks (table 2). With some rare exceptions, grass pollen can hardly ever be determined on the genus or species levels. Thus, the pollen type Poaceae [39] follows the botanical family Poaceae, including numerous grass species with a broad spectrum of ecological characteristics. Therefore, the manifested temporally different occurrences of the maximum grass pollen loads could be due to meteorological conditions [47] as well as different flowering seasons [30] of abundant pollen-producing grass species dominantly growing and flowering near monitoring sites and their surroundings. As was the case for birch pollen, more grass pollen was observed in the suburban area (3.639 pollen grains) than in the city center area (3.155 pollen grains; table 2). This coincides with the findings by Simoleit [10] in Berlin and Rodriguez-Rajo in Poznan [21]. However, the difference between the amounts of grass pollen in the suburban and city center areas was lower than that of birch pollen. Grass pollen grains are in general bigger [39] and have an approximately four times higher settling velocity than birch pollen grains [8,36], resulting in a shorter presence of grass pollen grains in the air and shorter distance transport [8]. Since in comparison to the GT "SCHI"[4], the remaining 13 traps showed lower and more similar TPSs without a gradual reduction of TPSs towards the city center, urban sources of grass pollen had to have a certain influence on enriching the Berlin air with grass pollen. The importance of urban-scale grass pollen sources for

[4]The GT "SCHI" was located on the very edge of the city and opened to the countryside (approx. 250 m to the south) with pastures and grasslands; this was clearly reflected in the pollen counts at the GT (table 2).

grass pollen loads within a city is indicated in a study by Skjøth [8] focusing on the city of Aarhus, Denmark.

1.5.3 Mugwort pollen in Berlin

The comparison of the seasonal courses of mugwort pollen mostly resulted in positive correlations between the sites. However, the averaged correlation was the weakest for the three observed pollen types. The differences in spatial distribution of mugwort pollen within Berlin were remarkable (fig. 1c). Earlier findings indicated that mugwort plants are flowering and releasing pollen during the morning when air convections are rather low [10,48]. Before air convections reach the daily maximum, facilitating lifting the pollen to the upper air layers for spreading, mugwort stops the daily pollen release. As a result, it is more probable to find a higher abundance of pollen nearer to the ground and in closer proximity of its sources [10,49]. When comparing both areas of Berlin, more mugwort pollen was detected in the city center (515 pollen grains) than in the suburban area (461 pollen grains; table 3). However, it disregards the fact that 49.51% of the TPS of the city center was collected by just one GT ("BRÜCKE"; table 3).

1.5.4 Pollen and pollen-induced symptoms in the Berlin/Brandenburg Metropolitan region and the city of Berlin

In the BBMR, the temporal variation of pollen-induced symptoms (TNSMS) reported by PHD users during the 2014 birch and grass pollen seasons was significantly influenced by birch and grass pollen levels (table 7). This coincides with and confirms other findings of pollen being one of the relevant determinants for developing allergy symptoms [23,26,28,30].

More severe symptoms in the BBMR (table 6: Mean) and in both areas of Berlin (table 4: Mean) were reported during the birch pollen season than during the grass pollen season, again confirming other studies [29,50].

With regard to this Berlin study, the relationship between allergenic pollen and pollen-induced symptoms within different areas of a single city was studied for the first time. Loads of allergenic birch and grass pollen during the birch and grass pollen seasons were found to be higher in the suburban area than in the city center. This pattern was followed by more severe pollen-induced symptoms (OTS) in the suburbs and weaker OTS in the city center area during the birch and grass pollen seasons (table 5, fig. 2). In contrast to that, the only other study comparing symptom levels among different areas of a single city indicated no variations in the symptom levels among three areas of the city of Vienna (Austria) during the birch and grass pollen seasons [50]. The remarkably uneven distribution of mugwort pollen within the city of Berlin, together with the limited number of users reporting symptoms during the mugwort pollen season (table 4), made the evaluation of the pollen-symptom relationship rather questionable.

In Berlin, the relationship between pollen loads and symptoms during corresponding pollen seasons was calculated for three categories of users (table 4). The correlation differences between the categories and the fact that the temporal development of symptoms did not exactly follow the temporal pollen season development (fig. 2) – mainly at the pollen season beginnings and ends – suggests that other factors played a certain role in the symptom development during the pollen seasons. For example, it could be a possible reaction of PHD users to other allergenic pollen types (e.g. to ash [*Fraxinus*] flowering during the birch pollen season [18]) and/or the presence of cross-reactions (e.g. between oak [*Quercus*] pollen and birch pollen at the end of the birch pollen season [51]). Allergy responses of purely monosensitized persons and the effects of other, more rarely studied allergenic pollen types on the symptom development are important issues for further research. Additionally, there are not just pollen grains carrying allergens, but also pollen allergens themselves in the form of small respirable particles that can be present in the air [52]. The recent study by Bastl [29] discussed and suggested that airborne allergen content could play a stronger role in symptom developments than pollen counts. Nevertheless, due to the high costs of allergen monitoring, there is still insufficient knowledge about the effects of airborne allergen content on human health which future studies should focus on.

1.5.5 REMARKS AND CONCLUSION

The presented and discussed results highlighted that the usage of additional pollen traps per city can provide new insights into the distribution of pollen and pollen-induced symptoms within a city and/or explanations that cannot be seen and/or clarified with just a single trap per city (fig. 2). In contrast to that, the only other study researching symptoms on an intra-urban scale considered no usage benefits of multiple pollen traps within a city since the symptom levels did not vary among different city areas [50]. However, this could be due to the approximately two times smaller size of the city (Vienna) in comparison to the city of Berlin. The limited amount of literature about the spatial distribution of pollen and symptoms within cities to some extent restricts the interpretation of the results of the study.

When it comes to designing future studies and assessing their results, it is worthwhile considering that every city has unique characteristics - geography, size, vegetation composition within the city and the surroundings - that are reflected in the pollen spectrum and distribution. Therefore, a similar temporary screening network with additional pollen traps within a city, running for more than one season in the best case, may validate/verify the power of a single pollen trap in the city or can provide a tool to determine site(s) for the installation of further permanent pollen traps. The use of 7VSTs (volumetric method) in an extended screening network, for example with 14 traps as presented in the study, would be expensive, include time-consuming analyses, require electric power for the traps, but would also provide more detailed pollen data in daily or bi-hourly resolution. In contrast to that, the usage of GTs (gravimetric method) was substantially cheaper as well as easier to establish and run. Despite the limitation of the weekly resolution of the GT pollen data instead of more detailed daily data from 7VSTs, the Berlin results provided important evidence and established a basis for future research in the fields of urban pollen distribution and the effects on human health. The results of this study underlined that a minimum of three pollen traps for the city of Berlin would be appropriate for reflecting the wide spectrum of differences in phenology, plant composition, and proportions of green spaces within the city. Beside the already running 7VST in the city center of Berlin, two other proposed locations for 7VSTs are the suburbs and the edge of the city, the transition zones from the town to open landscapes. Supplementing static pollen monitoring with portable personal pollen samplers [53] could bring more accurate pollen exposure results, especially with regard to pollen types exhibiting stronger dependencies on local conditions (examples for the Berlin area: mugwort [{*Artemisia*}; presented in the study], plane [*Platanus*], tree of heaven [*Ailanthus*], or cedar [*Cedrus*] [11]). Future studies should also target the field of self-reported symptoms (the subjectivity of symptom intensity, the extent of possibilities for recall bias [54], or the fluctuation of interest in reporting symptoms during a year) to bring further improvements to the understanding of symptom development.

The study showed that pollen has a noticeable impact on human health. However, some human activities may also have a certain impact on pollen occurrences. Therefore, it is recommended to respect the existing high number of people suffering from pollen allergy when planning and managing urban green spaces, e.g. by accurately selecting roadside and park trees as well as ornamental plants, regularly cutting lawns prior to flowering, preventing the growth of ruderal vegetation, e.g. mugwort. Plants frequently used in urban environments and the allergenicity are summarized and discussed by Bergmann [9] on the example of Berlin and in a review by Cariñanos [55].

In conclusion, differences in the spatial distribution of three allergologically relevant pollen types for Germany – birch (*Betula*), grass (Poaceae), and mugwort (*Artemisia*) – were detected within the single city of Berlin. The relationship between pollen and pollen-induced symptoms on an intra-urban scale was studied for the first time. Higher birch and grass pollen levels in the suburban area were followed by more severe symptoms in that area during birch and grass pollen seasons in comparison to weaker symptoms in the city center area.

The relationships between pollen and pollen-induced symptoms during the corresponding pollen seasons in the city of Berlin, in the two areas, and in the metropolitan region were mostly positive and significant.

Due to the growing importance of cities as global population centers and the health risks of urban areas, special attention should be paid to further research in pollen exposure and pollen-induced respiratory diseases in urban environments.

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2 EIDESSTATTLICHE VERSICHERUNG UND ANTEILSERKLÄRUNG AN DEN ERFOLGTEN PUBLIKATIONEN

2.1 EIDESSTATTLICHE VERSICHERUNG

„Ich, Barbora Werchan, versichere an Eides statt durch meine eigenhändige Unterschrift, dass ich die vorgelegte Dissertation mit dem Thema: *Distribution of Allergenic Pollen in a Metropolitan Region* selbstständig und ohne nicht offengelegte Hilfe Dritter verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel genutzt habe.
Alle Stellen, die wörtlich oder dem Sinne nach auf Publikationen oder Vorträgen anderer Autoren beruhen, sind als solche in korrekter Zitierung kenntlich gemacht. Die Abschnitte zu Methodik (insbesondere praktische Arbeiten, Laborbestimmungen, statistische Aufarbeitung) und Resultaten (insbesondere Abbildungen, Graphiken und Tabellen werden von mir verantwortet.

Meine Anteile an etwaigen Publikationen zu dieser Dissertation entsprechen denen, die in der untenstehenden gemeinsamen Erklärung mit dem Betreuer, angegeben sind. Für sämtliche im Rahmen der Dissertation entstandenen Publikationen wurden die Richtlinien des ICMJE (International Committee of Medical Journal Editors; www.icmje.og) zur Autorenschaft eingehalten. Ich erkläre ferner, dass mir die Satzung der Charité – Universitätsmedizin Berlin zur Sicherung Guter Wissenschaftlicher Praxis bekannt ist und ich mich zur Einhaltung dieser Satzung verpflichte.

Die Bedeutung dieser eidesstattlichen Versicherung und die strafrechtlichen Folgen einer unwahren eidesstattlichen Versicherung (§156,161 des Strafgesetzbuches) sind mir bekannt und bewusst.“

Datum

Unterschrift

2.2 ANTEILSERKLÄRUNG AN DEN ERFOLGTEN PUBLIKATIONEN
Declaration of own contribution to the published works

Barbora Werchan hatte folgenden Anteil an den folgenden Publikationen:
Barbora Werchan made the following contributions to the following publications:

Publikation 1: **Werchan B**, Werchan M, Mücke HG, Gauger U, Simoleit A, Zuberbier T, Bergmann KC, Spatial distribution of allergenic pollen through a large metropolitan area, Environ Monit Assess, 2017
Beitrag im Einzelnen:
Contributions in detail:

- led the design and planning stages of the study
- led building the gravimetric traps
- led the selection of locations for the gravimetric traps within the city of Berlin
- co-participated in the weekly exchange of microscopic slides in the gravimetric traps
- co-participated in the preparation of the slides for pollen analysis
- led the pollen analysis of the slides
- co-participated in the mapping of the vegetation around the traps
- led the analysis of the gathered pollen and vegetation data
- created table 1, fig. 3, fig. 6, fig. 8
- assisted in the creation of fig. 2, fig. 5, fig. 7, fig. 9
- led the interpretation of the results
- led the literature research
- led writing the publication as well as the revisions and corrections of the publication during the review process
- submitted the publication, corresponding author

Publikation 2: **Werchan B**, Werchan M, Mücke HG, Bergmann KC, Spatial distribution of pollen-induced symptoms within a large metropolitan area – Berlin, Germany, Aerobiologia, 2018
Beitrag im Einzelnen:
Contributions in detail:

- led the design and planning stages of the study
- led the preparation of the pollen data from fourteen gravimetric traps and one volumetric trap in Berlin for statistical analysis
- led the preparation of the symptoms for statistical evaluation
- co-participated in the analysis of pollen data and symptoms
- created table 1, fig. 4, fig. 5, fig. 6, table 2, table 3, table 4

- assisted in the creation of fig. 1, fig. 2, fig. 3
- led the interpretation of the results
- led the literature research
- led writing the publication as well as the revisions and corrections of the publication during the review process
- submitted the publication, corresponding author

Publikation 3: Karatzas K, Katsifarakis N, Riga M, **Werchan B**, Werchan M, Berger U, Pfaar O, Bergmann KC, New European Academy of Allergy and Clinical Immunology definition on pollen season mirrors symptom load for grass and birch pollen-induced allergic rhinitis, Allergy, 2018
Beitrag im Einzelnen:
Contributions in detail:

- led the preparation of the pollen data from four volumetric traps for the statistical analysis
- co-participated in the preparation of the symptom data for statistical evaluation
- co-participated in writing the publication as well as during the revisions and corrections of the publication during the review process

Unterschrift, Datum und Stempel des betreuenden Hochschullehrers
Signature, date, and stamp of the supervising university professor

---

Prof. Dr. med. Dr. h. c. Torsten Zuberbier

Unterschrift der Doktorandin
Signature of the doctoral candidate

Barbora Werchan

3 DRUCKEXEMPLARE DER AUSGEWÄHLTEN PUBLIKATIONEN

3.1 PUBLIKATION 1

Werchan B, Werchan M, Mücke HG, Gauger U, Simoleit A, Zuberbier T, Bergmann KC. Spatial distribution of allergenic pollen through a large metropolitan area. Environ Monit Assess [Internet]. 2017;189:169. Available from:
https://link.springer.com/article/10.1007%2Fs10661-017-5876-8

https://doi.org/10.1007/s10661-017-5876-8

3.2 PUBLIKATION 2

Werchan B, Werchan M, Mücke HG, Bergmann KC. Spatial distribution of pollen-induced symptoms within a large metropolitan area – Berlin, Germany. Aerobiologia. 2018;34(4):539-56.

https://doi.org/10.1007/s10453-018-9529-3

3.3 PUBLIKATION 3

Karatzas K, Katsifarakis N, Riga M, **Werchan B**, Werchan M, Berger U, Pfaar O, Bergmann KC. New European Academy of Allergy and Clinical Immunology definition on pollen season mirrors symptom load for grass and birch pollen-induced allergic rhinitis. Allergy. 2018;73(9):1851-9.

https://doi.org/10.1111/all.13487

4 LEBENSLAUF
Curriculum vitae

Mein Lebenslauf wird aus datenschutzrechtlichen Gründen in der elektronischen Version meiner Arbeit nicht veröffentlicht.

5 KOMPLETTE PUBLIKATIONSLISTE
Complete list of publications

Original articles	**Impact Factor**
Karatzas K, Papamanolis L, Katsifarakis N, Riga M, **Werchan B**, Werchan M, Berger U, Bergmann KC. Google Trends reflect allergic rhinitis symptoms related to birch and grass pollen seasons. Aerobiologia. 2018;34(4):437-44.	1.515[5]
Werchan B, Werchan M, Mücke HG, Bergmann, KC. Spatial distribution of pollen-induced symptoms within a large metropolitan area—Berlin, Germany. Aerobiologia. 2018;34(4):539-56.	1.515[6]
Karatzas K, Katsifarakis N, Riga M, **Werchan B**, Werchan M, Berger U, Pfaar O, Bergmann KC. New European Academy of Allergy and Clinical Immunology definition on pollen season mirrors symptom load for grass and birch pollen-induced allergic rhinitis. Allergy. 2018;73(9):1851-9.	6.048[7]
Bobek P, Svitavská Svobodová H, **Werchan B**, Švarcová MG, Kuneš P. Human-induced changes in fire regime and subsequent alteration of the sandstone landscape of Northern Bohemia (Czech Republic). Holocene. 2018;28(3):427-43.	2.419[8]
Werchan M, **Werchan B**, Bergmann KC. German pollen calendar 4.0 – update based on 2011-2016 pollen data. Allergo J Int. 2018;27(3):69-71.	-
- Werchan M, **Werchan B**, Bergmann KC. Deutscher Pollenflugkalender 4.0 –Update mit Messdaten von 2011 bis 2016. Allergo J. 2018;27(3):18-20.	-
Kmenta M, Bastl K, Berger U, Kramer MF, Heath MD, Pätsi S, Pessi AM, Saarto A, **Werchan B**, Werchan M, Zetter R, Bergmann KC. The grass pollen season 2015: a proof of concept multi-approach study in three different European cities. World Allergy Organ J [Internet]. 2017;10(1):31. Available from:	5.676[9]

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Werchan B, Werchan M, Mücke HG, Gauger U, Simoleit A, Zuberbier T, Bergmann KC (2017). Spatial distribution of allergenic pollen through a large metropolitan area. Environ Monit Assess [Internet]. 2017;189(4):169. Available from: https://link.springer.com/article/10.1007/s10661-017-5876-8 — 1.804[10]

Simoleit A, Werchan M, **Werchan B**, Mücke HG, Gauger U, Zuberbier T, Bergmann KC. Birch, grass, and mugwort pollen concentrations and intradiurnal patterns at two different urban sites in Berlin, Germany. Allergo J Int. 2017;26(5):155-64. — -

Simoleit A, Wachter R, Gauger U, Werchan M, **Werchan B**, Zuberbier T, Bergmann KC. Pollen season of European beech (*Fagus sylvatica* L.) and temperature trends at two German monitoring sites over a more than 30-year period. Aerobiologia. 2016;32(3):489-97. — 1.515[11]

Simoleit A, Gauger U, Mücke HG, Werchan M, **Obstová B**, Zuberbier T, Bergmann KC. Intradiurnal patterns of allergenic airborne pollen near a city motorway in Berlin, Germany. Aerobiologia. 2015;32(2):199-209. — 1.515[12]

Abstracts

Werchan B, Werchan M, Bergmann KC. Urban flora in the context of palynology and allergology. Poster session presented at: 11th International Congress of Aerobiology; 2018 Sep 3-7; Parma.

Werchan M, Zhi Y, Gu J, **Werchan B**, Bergmann KC. Sensitization against the native Tree-of-Heaven (*Ailanthus altissima* [Mill.] Swingle) in Beijing, China. Poster session presented at: 11th International Congress of Aerobiology; 2018 Sep 3-7; Parma.

Abraham V, Roleček J, Jamrichová E, Plesková Z, Vild O, **Werchan B**, Kuneš P. The relationship of pollen-floristic diversity in poor-species and rich-species regions of Czech Republic. Poster session presented at: 10th European Palaeobotany & Palynology Conference; 2018 Aug 12-17; Dublin.

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Vild O, Abraham V, Kuneš P, Jamrichová E, Plesková Z, **Werchan B**, Svitavská-Svobodová H, Roleček J. Comparison of floristic and pollen diversities for the reconstruction of Holocene vegetation changes. In: Minchin PR, Roberts DW, editors. Natural Ecosystems as Benchmarks for Vegetation Science. Proceedings of the International Association for Vegetation Science 61st Annual Symposium; 2018 Jul 22- 27; Bozeman. Bozeman: International Association for Vegetation Science (IAVS); 2018. p. 254.

Roleček J, Abraham V, Vild O, Plesková Z, Jamrichová E, Svitavská H, **Werchan B,** Kuneš P. Plant diversity: can we trace its history using pollen data? Poster session presented at: 27th Congress of the European Vegetation Survey; 2018 May 23-26; Wrocław.

Werchan B, Werchan M, Mücke HG, Bergmann KC. Spatial distribution of airborne pollen-induced health symptoms in Berlin. In: Sokhi RS, Gállego MJ, Tiwari PR, Arnau JMC, Guiu CC, Singh V, editors. Proceedings of Abstracts. Proceedings of the 11th International Conference on Air Quality – Science and Application; 2018 Mar 12-16; Barcelona. p. 215.

Werchan B, Werchan M, Bergmann KC. Entstehung, Wert und Nutzung der Pollenflugvorhersage. Allergo J Int. 2017;26:236.

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Kmenta M, Bastl K, Bergmann KC, Hewings SJ, Kramer MF, Pätsi S, Pessi AM, Saarto A, Skinner MA, **Werchan B**, Werchan M, Zetter R, Berger U. Grass pollen season 2015 in Vienna (Austria), Berlin (Germany) and Turku (Finland): spatial and temporal variation in pollination of different grass species and their impact on pollen allergy sufferers. Allergy. 2016;71(S102):217.

Werchan B, Werchan M, Mücke HG, Bergmann KC. Spatial distribution of non-regulated biogenic air pollutants (allergenic pollen) across Berlin, Germany In: Radice P, Finardi S, Farrow A, Chemel C, Medeiros JD, Singh V, Sokhi RS, editors. Proceedings of Abstracts.

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Bobek P, Svitavská Svobodová H, Švarcová MG, **Obstová B**, Šamonil P. Inter-regional comparison of the Holocene fire regimes in Bohemia (Czech Republic): spatio-temporal patterns and possible driving forces. In: Ludemann T, Nelle O. Congress-Guide, Abstract-Volume. Proceedings of the 6th International Anthracology Meeting – Local to global significance of charcoal science; 2015 Aug 30 – Sep 6; Freiburg. p. 33.

Obstová B. Pylový diář – novinka pylovým alergikům. Alergie. Suppl. 2013;1/2013:46.

Obstová B. Aerial pollen spectra in different city building patterns: seasonal dynamics and implications for allergology. Alergologia Immunologia. 2012;9(2-3):155.

6 DANKSAGUNG
Acknowledgement

The journey bringing this thesis into reality has been a marvelous experience of developing my scientific mind for future contributions in my chosen field of passion. This path would not have been possible without the generous dedication of exceptional individuals who gave their time, knowledge, and support to help me reach my dreams. To each and every one, I would like to express my heartfelt gratitude.

I would like to offer special thanks to the supervisors of my dissertation, Prof. Dr. med. Dr. h. c. Torsten Zuberbier and Prof. Dr. med. Karl-Christian Bergmann, for the excellent opportunity to take on this work and receive guidance during the thesis preparation.

Additionally, I want to express my wholehearted thanks to Prof. Dr. med. Karl-Christian Bergmann for giving me insights into the world of allergology as well as advice, constructive criticism, and valuable suggestions whenever needed and providing support throughout the entire course of the thesis work.

Many thanks go to Dr. Hans-Guido Mücke for the remarkable support, especially at the beginning of the thesis work.

I would also like to thank Frieder Hofmann † for the encouragement and professional advice.

I want to thank to Dr. oec. troph. Andrea Jahnen for the generous support with extra staff necessary to ensure the timely exchange of gravimetric trap slides.

Many sincere thanks go to Julius Giebel, Tim Philipp Müller, Matthias Werchan, and Jaron Zuberbier for the great help with changing gravimetric trap slides within the large city of Berlin during any weather conditions.

I would like to thank everyone who contributed to the development of the web-based pollen diary, in particular Uwe E. Berger. My thanks also go to Dr. rer. nat. Katharina Bastl, Maximilian Bastl Ph.D. and Christoph Jäger for their advice, and I appreciate all the anonymous users reporting their daily suffering from pollen allergy.

I am very thankful to Matthias Werchan for all the extraordinary time filled with pollen, botany, statistical discussions, and solving scientific challenges as well as all the exceptional support during all stages of the thesis work.

Many thanks go to Ingrid van Hofman, Jan Mrťka, and Alexander Pogede for the professional help with English during the entire course of the thesis work.

My sincere thanks go to my fellow doctoral candidates Dr. rer. medic. Anke Simoleit and Dr. med. Georg Bölke for the support and advice during the thesis preparation.

My special gratitude belongs to RNDr. Zdeňka Chocholoušková, Ph.D., Hana Jezlová, Věra Prokšová, and doc. RNDr. Antonín Pyšek, CSc. †, for teaching me a lot about biology and botany.

I would like to thank doc. MUDr. Ondřej Rybníček, Ph.D., for the interesting and enlightening conversations about allergic rhinitis which gave rise to my initial curiosity about pollen as a cause of this disease.

I also want to express my gratitude to prof. RNDr. Milan Chytrý, Ph.D., for supporting me in my chosen field of specialization and finding me the best mentor possible.

I would like to warmly thank RNDr. Eliška Rybníčková, DrSc. †, for many enchanting days spent together behind the microscope, showing me the fascinating world of pollen and teaching me a great deal about the microscopic world of plants.

I would also like to express my appreciation to PhDr. Helena Svitavská Svobodová, CSc., for giving me further insigts in palynology and teaching me more about pollen as well as non-pollen palynomorphs.

I greatly appreciate my colleagues, in particular Kim Eppert, Ingrid Erb, Julia Gildemeister, Ingrid van Hofman, Christiane Kehl, Hannah Löwe, Prof. Dr. med. Karl-Christian Bergmann, Dr. med. Georg Bölke, MPharm Martin K. Church, PhD DSc, André Ellrich, Kerim Fedai, Ben Müller, and Matthias Werchan, for the positive atmosphere in the office.

I would like to express my warm thanks to all my friends who have been supportive along the way of completing my thesis - special thanks go to Ria Becker, Eva Hudcová, Jaroslav Beránek, and Jan Mrťka.

I would also like to express my deep appreciation to Alexander Pogede for the extraordinary encouragement and giving me the strength to keep going.

The final and biggest thanks belong to my family for always believing in me and supporting me in my dreams with unconditional and endless love, encouragement, patience, and understanding. I dedicate this dissertation to them.