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• *Urban climate – Neophytes – Biodiversity – Surface radiation*

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Meso- and Micro-Climatic Aspects of Berlin's Urban Climate

Lokal- und mikroklimatische Aspekte des Berliner Stadtklimas

With 10 Figures and 6 Tables

As early as 1936, Father *Kratzer*, the founder of urban climatology in Germany, mentioned some climatic data from Berlin in his famous book. Subsequently *Hupfer* and *Chmielewski* (1990) dedicated a whole book to the urban climate of Berlin, Germany's largest city, mostly using data from the former East Berlin. *Malberg* (2002) included meteorology data predominantly from West Berlin. The new digital atlas by the Senate Department of Urban Development Berlin (http://www.stadtentwicklung. berlin.de/umwelt/umweltatlas/) offers instructive information about temperature, precipitation and human bioclimate for the reunited city. Nevertheless, new investigations on meso- and micro-scales are currently being conducted to further our understanding of the urban climate of Berlin. Such studies are necessary in the framework of urban ecology, for example to relate human well-being to local climate and to determine the thermal conditions for the establishment of neophytes and neozoes in urban environments. Big cities such as Berlin, with an area of about 892 km^2 and a population of 3.39 million inhabitants, show a mosaic of micro-scaling climates. The crucial factors are density and height of buildings, integration of open spaces, parks, forest and lakes and thermodynamic parameters of the different materials used in the city. They influence surface radiation by day and night, and thus the urban climate (both the ecoclimatological and biometeorological conditions). Nevertheless, this local climate is embedded in the regional one, and the large-scale macro-climate influences the local-scale meso-climate, too. Therefore, first the regional climatic framework conditions have to be described before developing the special urban details.

1. The Regional Climate

The regional climate of northeastern Germany is dominated by the high latitude westerlies, yet has some subcontinental features. High and low pressure systems, and the corresponding weather types, are only slightly modified by the gentle topography of moraine hills and plateaus (*Fig. 1*). *Hendl* (1969, 1991, 1996) and *Endlicher* (2000) as well as *Hendl* and *Endlicher* (2003) have described the leading atmospheric processes and climatic factors of Eastern Germany's regional climate.

Concerning thermal conditions, mean July temperature is 17.8°C for Berlin-Buch and 18.0°C for Berlin-Schönefeld. Slightly higher summer temperatures are found on the ground moraine plateaus and sand fans rather than in the lowlands, for example in Berlin-Spandau with 17.0°C, due to thermal inversion during clear nights. Mean January temperatures vary between -0.8°C (Berlin-Buch) and -1.1°C (Berlin-Schönefeld and Berlin-Spandau) (*Hendl* 2002). These differences are mostly due to local topography rather than urban effects.

Annual precipitation reaches about 550 mm (1951-1980, according to *Hendl* 1996, 2002), with a distinctive maximum during summer. Maximum summer precipitation is generally twice the winter precipitation. Ground and end moraines influence precipitation processes to some extent. Moraine flanks (80-100 m asl) directed to the Atlantic Ocean, show enhanced precipitation of about 580-600 mm/a; in contrast, leeward situated valleys (30-40 m asl) show a reduced amount of precipitation of 520-530 mm/a (*Hendl* 1996). The Berlin valley, open to the west, receives about the same amount of precipitation as the moraine plateaus of Barnim and Teltow to the north and the south of the city. It is only at the Oder valley farther east that annual precipitation decreases to the clearly subcontinental level of 450 mm. The Fläming moraine hills, south of Berlin, receive up to 650 mm due to orographic effects.

2. Remarks on the Urban Climate of Berlin-Dahlem

The effects of urban climate are often demonstrated in studies comparing data from stations outside and inside a city, avoiding, if possible, any orographic interferences. The School of Agriculture and Horticulture of Berlin's Humboldt Uni-

Fig. 1 The Berlin region, with investigation sites / *Die Region Berlin, mit Untersuchungsgebieten*

Tab. 1 Precipitation for four weather stations in and near Berlin for the period 1961-1990
Niederschlag an vier Klimastationen in und um Berlin (1961-1990)

Precipitation (1961-1990)	Berlin-Dahlem	Berge	Thyrow	Blumberg
Mean annual precipitation [mm]	544.6	506.9	496.1	586.9
Mean precipitation in spring (Mar.-May); [mm]	122.8	118.3	116.1	134.7
Mean precipitation in summer (Jun.-Aug.); [mm]	186.3	163.0	163.5	187.4
Mean precipitation in autumn (Sep.-Nov.); [mm]	121.9	113.5	116.8	135.4
Mean precipitation in winter (Dec.-Feb.); [mm]	113.5	113.7	104.3	128.2
Number of days with a precipitation of ? 0.1 mm	167.2	167.7	152.8	150.4
Number of days with a precipitation of ? 10.0 mm	11.2	9.9	10.1	12.8
Number of days with a precipitation of ? 50.0 mm	5.0	2.0	3.0	8.0

Data: Faculty of Agriculture and Horticulture – Agricultural Meteorology, Humboldt University of Berlin

versity has three weather stations outside Berlin (*Fig. 1*): Berge on the Nauen Plateau in the west (52° 73' N, 12° 74' E; 40 m asl), Thyrow in the Nuthe Valley in the south (52° 16' N, 13° 12' E; 40 m asl) and Blumberg on the Barnim Plateau in the north-east (52° 36' N, 13° 37' E; 80 m asl). The main measuring station of the School is situated in Berlin-Dahlem, in the southwestern, less densely populated, part of the city (52°28' N, 13°18' E; 51 m asl).

The comparison of the precipitation data (*Tab. 1*) reveals that Dahlem and Blumberg have the highest values for all parameters. Mean summer precipitation at both stations is about 20 mm higher than at Berge and Thyrow. The number of days

Tab. 2 Summer temperatures for four weather stations in and near Berlin for the period 1961-1990
Sommertemperaturen an vier Klimastationen in und um Berlin (1961-1990)

Summer temperatures (1961-1990)	Berlin-Dahlem	Berge	Thyrow	Blumberg
Mean sum of daily temperatures > 20°C (Jun.-Aug.) [K]	67.7	47.0	39.2	37.9
Warmest recorded temperature [°C]	35.8	36.0	36.4	39.0
Mean dates of the first and last occurence of a summer day; Tmax. > 25°C	13 May / 10 Sept.	13 May / 10 Sept.	9 May / 12 Sept.	13 May / 9 Sept.
Mean temperature of the warmest month [°C]	18.5	17.9	17.9	17.7
Mean number of annual summer days; Tmax. > 25°C	32.1	31.8	37.7	34.7
Mean number of annual hot days; Tmax. > 30°C	6.0	5.8	7.9	6.6

Data: Faculty of Agriculture and Horticulture – Agricultural Meteorology, Humboldt University of Berlin

Tab. 3 Winter temperatures for four weather stations in and near Berlin for the period 1961/62-1989/90
Wintertemperaturen an vier Klimastationen in und um Berlin (1961/62-1989/90)

Winter temperatures 1961/62-1989/90	**Berlin-Dahlem**	**Berge**	**Thyrow**	**Blumberg**
Mean sum of temperatures < 0°C (Dec.-Feb. [K])	139.7	163.2	184.5	204.7
Coldest recorded temperature [°C]	-19.9	-24.4	-26.8	-26.0
Mean dates of the first and last occurence of a frost day	5 Nov. / 16 Apr.	25 Oct. / 23 Apr.	18 Oct. / 30 Apr.	27 Oct. / 27 Apr.
Mean temperature of the coldest month [°C]	-0.1	-0.5	-1.1	-1.7
Mean annual number of ice days (Tmax. < 0°C)	26.2	25.7	25.2	33.0
Mean annual number of frost days (Tmin. < 0°C)	72.1	85.3	98.1	88.8

Data: Faculty of Agriculture and Horticulture – Agricultural Meteorology, Humboldt University of Berlin

with a precipitation amount of at least 50 mm (that means extremely high precipitation events) is greater (by 5 to 6 days) in Blumberg than in Thyrow and Berge, and greater (by 2 to 3 days) in Berlin-Dahlem than in Thyrow and Berge. This may be explained by the convective effects on cumulonimbus cells crossing the city mostly from west to east during the summer months.

The urban influence on air temperature, generally known as the urban heat island, is less evident in the Dahlem data and may be explained by the predominantly residential character of the area with its large gardens surrounding the weather station. However, the mean sum of daily temperatures higher than 20°C, from June to August, is 67.7 K at Dahlem, about 20 K higher than at the other stations. In addition, the mean temperature of the warmest month (July, 18.5°C) (*Tab. 2*) is higher at Dahlem than at the other stations. But Thyrow, with a warmest month of 17.9°C, has more summer days and hot days than Dahlem.

Tab. 4 Vegetation period at four weather stations in and near Berlin for the period 1961-1990
Vegetationsperiode an vier Klimastationen in und um Berlin (1961-1990)

Vegetation period (1961-1990)	**Berge**	**Berlin-Dahlem**	**Thyrow**	**Blumberg**
Mean duration in days	244	249	238	232
Mean beginning	20 March	16 March	19 March	23 March
Mean end	15 November	20 November	12 November	10 November
Mean sum of temperatures > 5°C [K]	3077.5	3264.7	3049.6	2979.8
Mean air temperature during the vegetation period [°C]	13.0	13.1	13.0	13.0

Data: Faculty of Agriculture and Horticulture – Agricultural Meteorology, Humboldt University of Berlin

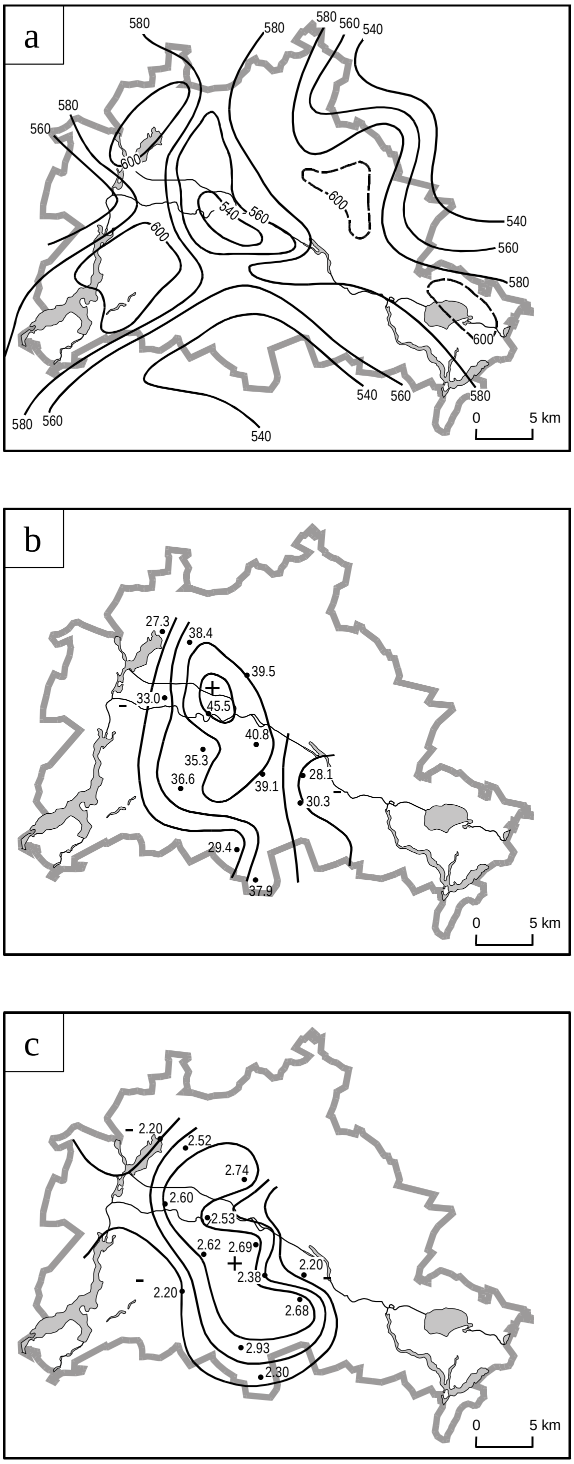

Fig. 2 Precipitation characteristics for Berlin:
a) Mean distribution of precipitation (mm) in Berlin during the period 1960/61-1989/90 (*Schlack* 1992, modified)
b) Mean frequency (%) of summer showers in West Berlin (*Malberg* 1994, modified)
c) Mean intensity (mm/10 min) of summerly showers in West Berlin (*Malberg* 1994, modified)

Niederschlagscharakteristik im Berliner Stadtgebiet:
a) Mittlere Niederschlagsverteilung (mm) in Berlin für die Periode 1960/61-1989/90 (Schlack 1992, verändert)
b) Mittlere Häufigkeit (%) sommerlicher Schauer im West-Berliner Stadtgebiet (Malberg 1994, verändert)
c) Mittlere Intensität (mm/10 min) sommerlicher Schauer im West-Berliner Stadtgebiet (Malberg 1994, verändert)

The urban heat island is more clearly represented in the data during winter time. The sum of winter coldness (daily temperatures lower than 0°C, from December to February) at Dahlem is 139.7 K, about 20 to 60 K less than at the other stations. The coldest temperature of -19.9°C and the highest mean number of frost days (72.1) have been recorded in Dahlem. Mean dates of first and last frost are very important for plant growth; in Dahlem the dates of November 5 and April 16 exceeded those at the other stations (*Tab. 3*). The consequences of the urban influence on the thermal conditions are shown in *Table 4*. The mean length of the vegetation period in Dahlem exceeds that in Berge, Thyrow and Blumberg by 5, 11 and 17 days respectively. Mean temperature degree sum over 5°C (sum of summer warmth) in Dahlem was 3,264.7 K, about 200 K higher than at the other stations.

3. Distribution of Annual Means of Precipitation and Urban Effects on Precipitation Structures

Since the well known METROMEX experiment carried out at St. Louis in the USA by *Changnon* et al. (1981), it is known that larger built-up areas generally enhance summer precipitation at the leeward side. The mean annual precipitation maps of Berlin drawn by *Schlaak* (1980, 1992; *Fig. 2a*) show a relative minimum lower than 540 mm in the city centre. The amount higher than 600 mm in the Grunewald area, east of the Havel River in the southeast, may be the result of orographic enhancement at the windward side of morainic hills. Thus, the central minimum of precipitation in the Berlin Valley may be seen as a leeward reduction during the dominant westerly circulation. However, the quite pronounced maximum of precipitation of 580-600 mm in eastern Berlin may be due not only to the orographic effect of the Barnim plateau, but also to extra convection in unstable shower cells crossing the central urban heat island (*Fig. 2a*). Mean frequencies of summer showers and their mean intensities (*Fig. 2b, 2c*), based only on West Berlin data, support this interpretation, according to *Malberg* (1995). The mean intensity is highest over the city centre and the northeastern section of Berlin. Regional and local, orographic and urban effects cannot always be distinguished properly (*Graf* 1979).

The more recent precipitation maps drawn by *Malberg* (2002) distinguish the precipitation falling during westerly and easterly winds. These maps show a northwest-southeast minimum across the city centre and higher values at the southwestern and northeastern city borders. The author points out that the mean precipitation inside of Berlin varies between 530 and 630 mm, which represents a difference of up to 100 l/m² over a small area with relatively little orographic influence.

4. Temperature Conditions and Neophyte Growth

4.1 Annual mean temperature

A map of the mean air temperature of Berlin developed by the city administration has recently been published by *Helbig* (2003). The mean temperature difference between the City centre (> 10.5°C) and the surrounding countryside (< 8.0°C) is about 2-3 K. However, the "heat islands" of the several densely built-up areas form a "heat archipelago". But the detailed distribution of air and surface temperature is even more complicated as the following microclimatic study shows.

4.2 Microclimatic experiment

In a field experiment, establishment and growth of neophytes in Berlin are investigated at three sites between the city centre, industrial outskirts of Berlin and the surrounding countryside (city centre, Oberschöneweide and Blossin respectively; *Fig. 1*). A detailed description of the experimental set-up is given by *Lanfer* (2003).

Of particular interest is the determination of which site-related environmental conditions allow neophytes to grow outside of their native distribution area (*Starfinger* et al. 1998 and *Kowarik* 2003). One of the best investigated trees in this regard is the Tree of heaven (*Ailanthus altissima*). This tree has been introduced from east Asia, and represents, in the (sub)continental European area, the early successional plant on ruderal sites (see also *Sukopp* in this issue). Furthermore, *A. altissima* is characterised as an urbanophil and thermophil plant (*Wittig* 1998). Floristic investigations on the inner-urban dispersal of Tree of heaven have been carried out by *Müller* (1987) in Augsburg, *Gutte* et al. (1987) in Leipzig and *Kowarik* and *Böcker* (1984) in Berlin. Dispersal and naturalisation of Tree of heaven is, according to *Kowarik* and *Böcker*'s (1984) hypothesis, a function of the urban heat island. But the simple correlation between the inner-urban growing area of *A. altissima* and the urban heat island (high values for mean air temperature and sum of summer warmth [mean sum of daily temperatures >20°C in the months of June-August] as well as longer vegetation period) is not sufficient to affirm the regular dispersal and functional coherences along a gradient from the city centre to the outskirts. The hypothesis about a causal connection between the inner-urban dispersal of *A. altissima* and the zonification of the urban heat island is controversial (*Adolphi* 1995).

Under these aspects, two closely related projects are integrated into the Research Training Group 780 "Perspectives on Urban Ecology – the Example of the European Metropolis of Berlin" (http://www.stadtoekologie-berlin.de). The two projects investigate establishment and growth of two non-native trees, *Ailanthus altissima* and *Acer negundo* (Box-elder, *Eschen-Ahorn*), as well as of the native tree *Acer platanoides* (Norway maple, *Spitzahorn*) along the urban-rural gradient described above. A partner project focuses on biological investigations (phenology, bud formation and break and biomass). The specific aim of the present investigation is determining micro-scaling thermal parameters that influence establishment and growth of non-native plants in Berlin. Initial results from the winter frost period of 2002/03 and the summer months of 2003 will be presented.

4.2.1 Air temperatures during the winter frost period

Mean air temperature in the densely populated city centre was 1.2°C, in the industrial outskirts of Oberschöneweide 0.7°C, and in the surrounding countryside of Blossin -1.0°C (*Fig. 3*). Thus, we recorded a mean difference of the average air temperature between the city centre and the surrounding countryside of about 2.2 K. The absolute air temperature maximum showed the same trend, with 10.3°C in the city centre, 9.1°C in Oberschöneweide and 7.3°C in Blossin. This resulted in a difference of 3.0 K between the city centre and the

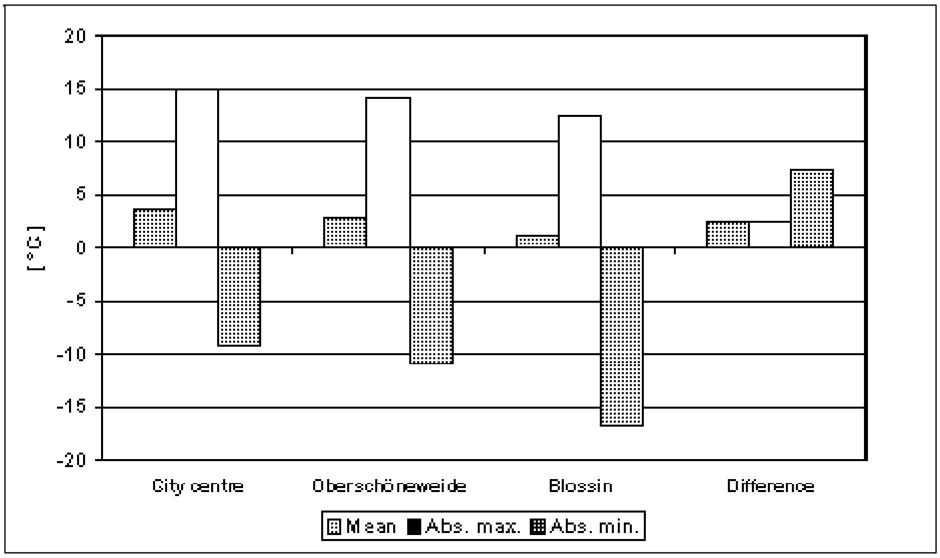

Fig. 3 Winter air temperature 20 cm above the canopy of the experimental plantings from the city centre to the surrounding countryside (11 December 2002 - 13 May 2003)
Winterliche Lufttemperatur 20 cm über dem Kronenbereich der Versuchsanordnung vom Stadtzentrum zum Stadtumland (11. Dezember 2002 - 13. Mai 2003)

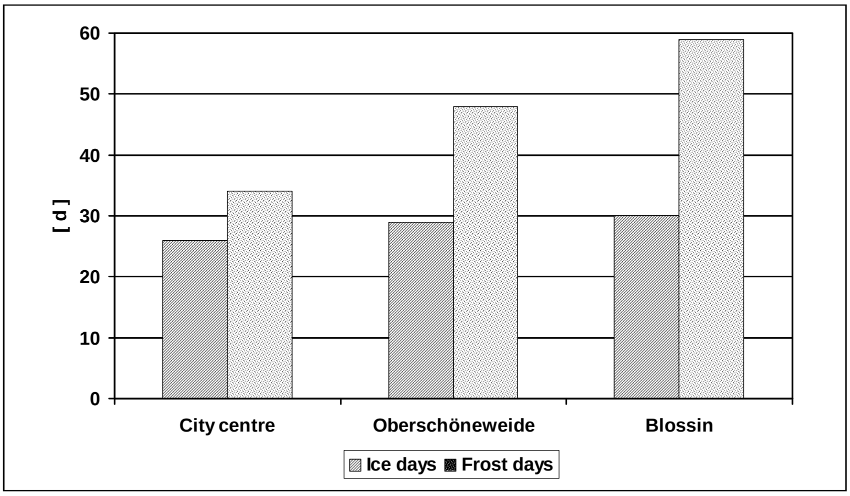

Fig. 4 Number of days with ice and frost (11 December 2002 - 13 May 2003)
Anzahl der Eis- und Frosttage (11. Dezember 2002 - 13. Mai 2003)

surrounding countryside. The absolute minimum air temperature showed the most marked difference with 7.5 K along the gradient city centre (-9.3°C) – Oberschöneweide (-10.9°C) – Blossin (-16.8°C).

Because *A. altissima* is a thermophil tree, climatic conditions during the winter period are expected to be most important for limiting establishment and growth. Relevant climatic parameters are the number of ice days (Tmax. # 0°C), number of frost days (Tmin. # 0°C), beginning and end of the frost period and the sum of coldness (sum of daily temperatures lower than 0°C). For winter 2002/03 we can give data for the number of ice days and number of frost days at the sampling sites. In contrast, data for the beginning and end of the frost period and sum of coldness cannot be given for our sites, because the measurements began on December 11, 2002, after the first day with frost. The number of ice days increases gradually from the city centre to the surrounding countryside: 26 in the city centre, 29 in Oberschöneweide and 30 in Blossin (*Fig. 4*). Regarding the number of frost days, a sharp increase along the gradient was registered: 34 in the city centre, 48 in the industrial area and 59 in the surrounding countryside.

At all experimental stations, February 20 was the last day with ice in 2003. In contrast, the last day with frost varied by about two weeks: In the city centre we recorded March 15 as the last day with frost, in Oberschöneweide March 25 and in the surrounding countryside at Blossin March 27. Thus, there is a difference of 12 days when frost stress can limit the establishment of *A. altissima* in the countryside.

4.2.2 Soil temperatures during the winter frost period

Soil temperature is an indicator for frost stress of the roots, whilst air temperature is related to bud formation and break. At both the city centre and Oberschöneweide sites, soil temperature sensors were installed in 9 flowerpots with standard potting compost. At Blossin, three were installed in pots with standard potting compost, three in sand and three in building rubble. Data for soil temperature in flowerpots with standard potting compost are presented (*Fig. 5*).

Soil temperature, as indicated by the mean, the mean absolute maximum and mean absolute

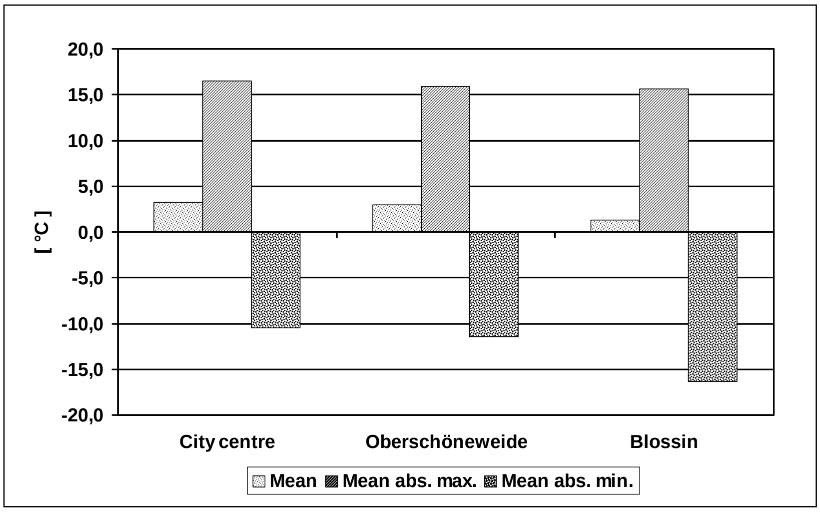

Fig. 5 Winter soil temperatures in flowerpots with standard potting compost (11 December 2002 - 13 May 2003)
Winterliche Bodentemperaturen in den Pflanztöpfen mit Standard-Blumentopferde (11. Dezember 2002 - 13. Mai 2003)

minimum, decreased from the city centre to the surrounding countryside. Although mean soil temperatures in the city centre (0.2°C) and Oberschöneweide (0.1°C) were similar, the recording at Blossin (-1.9°C) was markedly lower. Mean absolute maximum temperatures were also similar, 9.6°C (city centre), 8.4°C (Oberschöneweide) and 7.0°C (Blossin), and differed by 2.6 K between the city centre and the surrounding countryside. Mean absolute minimum temperatures showed the most marked difference; these differed between the city centre (-10.5°C) and the surrounding countryside (-16.3°C) by 5.8 K. This points out that the absolute minimum temperatures will be a main factor in determining the establishment of young neophytic seedlings.

Tab. 5 Summer temperatures in 2003 at three experimental sites in Berlin
Sommertemperaturen des Jahres 2003 an den drei experimentellen Stationen in Berlin

Climatological Parameters	**City centre**	**Ober-schöneweide**	**Blossin**
Mean sum of daily temperatures > 20°C (Jun.-Aug.) [K]	128.7	76.9	136.1
Warmest recorded temperature [°C]	35.2	35.5	37.7
Mean dates of the first and last occurrence of a summer day; Tmax. > 25°C	15 Apr. / 22 Sept.	5 May / 22 Sept.	5 May / 22 Sept.
Mean temperature of the warmest month [°C]	22.2	21.4	20.5
Mean number of annual summer days; Tmax. > 25°C	43	51	47
Mean number of annual hot days; Tmax. > 30°C	33	24	39

4.2.3 Air temperatures during the summer months

The summer of 2003 (*Tab. 5*) was extraordinary, compared to summer temperatures of 1961-1990 (*Tab. 2*). The sum of the daily temperatures >20°C was 128.7 K in the city centre, twice as high as in Berlin-Dahlem (67.7 K). In the surrounding countryside at Blossin we can schedule a three times higher sum of daily temperatures >20°C in the month of June, July and August, with 136.1 K, in comparison to the other stations in the Berlin countryside: Berge (47.0 K), Thyrow (39.2 K) and Blumenberg (37.9 K). The extraordinary summer of 2003 started with a very early date of the first summer day (*Tab. 5*). In the city centre this date was nearly four weeks earlier in 2003 than at Berlin-Dahlem in the years between 1961 and 1990 (*Tab. 2*). In Oberschöneweide this date was only eight days earlier in 2003 than in Berlin-Dahlem (1961-1990). In the surrounding countryside this date was four up to eight days earlier in 2003 than in Berge, Thyrow or Blumberg during the years 1961-1990. At all experimental stations the last occurence of a summer day in 2003 was 22 September, nearly two weeks later than in the years 1961-1990 (*Tab. 2*).

The mean temperature of the warmest month shows the same tendency as the mean sum of daily temperatures. The mean temperature of 22.2°C in the city centre is 3.7 K higher than the mean temperature in the warmest month in 1961-1990 in Berlin-Dahlem. In Blossin (20.5°C) the mean temperature of the warmest month is 2.6-2.8 K higher than in Berge, Thyrow and Blumberg.

The mean number of annual summer and hot days (*Tab. 5*) was markedly higher in 2003 than in 1961-1990. We recorded 5-6 times more days with a daily maximum temperature >30°C.

The only climatological summer parameter that did not show higher values in 2003 than in the years 1961-1990 was the warmest recorded temperature. At all three experimental stations we measured slightly lower temperatures.

4.2.4 Results

In *Table 6* we can see the percentage of seedlings of the three tree species surviving after the first winter period 2002/03. The non-native tree *A. altissima* did not survive at any location. The native tree *Acer platanoides* (Norway maple) survived only in the city centre and at Oberschöneweide. The non-antive tree *Acer negundo* (box elder) was the only one to survive in all three locations.

Of all planted seedlings, only 27.7% survived in the city centre, 14.0% in Oberschöneweide and 1.9% in Blossin. Despite of this, the die-off rate during the first winter was high at all locations. The influence of the urban heat island on the lower die-off rates in the city area as compared to those in the surrounding countryside could be clearly established.

Furthermore, we can point out:

- The relationship between establishment and growth of *A. altissima* in big cities of

Tab. 6 Percentage of tree seedlings surviving after the first winter 2002/03
Prozentuale Überlebensraten der Setzlinge nach dem Winter 2002/03

	City centre	Oberschöneweide	Blossin
Total	27.7	14.0	1.9
Ailanthus altissima	0.0	0.0	0.0
Acer negundo	30.3	23.3	5.5
Acer platanoides	50.0	20.0	0.0

northern Europe (for example Berlin) on the one hand and higher summer warmth and longer vegetation period in the cities than in the surrounding countryside on the other hand is not sufficient to explain their inner-urban spreading.

- The intensity and frequency of days with ice and frost, combined with the duration of the winter cold period, seems to be one of the most important factors limiting establishment and growth of young *A. altissima* seedlings (root stress, bud formation and break).

- Critical values of air and soil temperature associated with a die-off of all *A. altissima* seedlings in the city centre after the first winter period 2002/03 are not known yet.

- We do not know yet whether only one day or any other number of days with low minus degrees can be sufficient for the die-off of the seedlings.

5. Thermal Imagery as a Tool for Analysing Surface Radiation Temperatures

Airborne and spaceborne thermal imagery are useful tools to study day and night surface radiation temperatures in cities. The temperature information of the thermal images may, however, come from surfaces situated at different heights (such as streets,

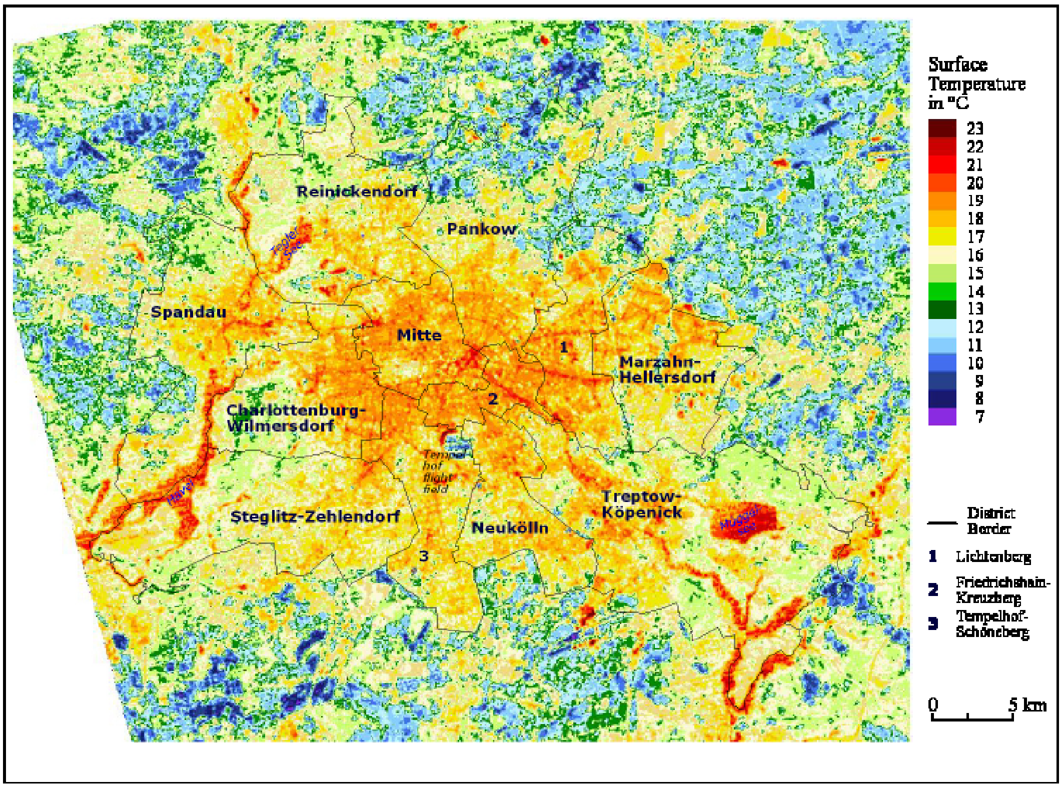

Fig. 6 EOS-AM1 Terra thermal image of Berlin; 26 June 2001, 21:57 CET, 90 m ground solution / *EOS-AM1 Terra Aster-Thermalbildszene von Berlin vom 26. Juni 2001, 21:57 MEZ, 90 m Bodenauflösung*

roofs, tree canopies, clumps of grass, walls and water surfaces), and this complicates the interpretation. Furthermore, radiation temperature data should not be interpretated in the same way as air temperature measurements, because the formation of local breezes due to different heating of urban surfaces has not yet been demonstrated by thermal imagery (*Zahnen* 2003). Thermal imagery cannot replace air temperature measurements or wind measurements. But remote sensing data cover large areas, such as the whole city of Berlin, and are quite informative, giving data about the location of the city's areas of maximum surface temperatures, sharp borders between extreme values and the extension of warming and cooling surfaces during day and night time.

5.1 Spaceborne night-time thermal image of Berlin

Figure 6 shows the AM-1 "Terra" ASTER satellite thermal image for June 29, 2001, 21:57 CET. The densely built-up and sealed area of the eastern central area of Berlin has the highest surface radiation temperatures as well as the water surfaces of the lakes. Lowest temperatures are recorded inside the city, at Tempelhof Airport, and along the southern and north-eastern borders, which are mostly grassland and crops. Forests and parks with tree stands have lower temperatures than buildings, but higher temperatures than grassland. The production of cool fresh air during clear summer nights may be more substantial there than over grassland, due to the larger amount of leaves.

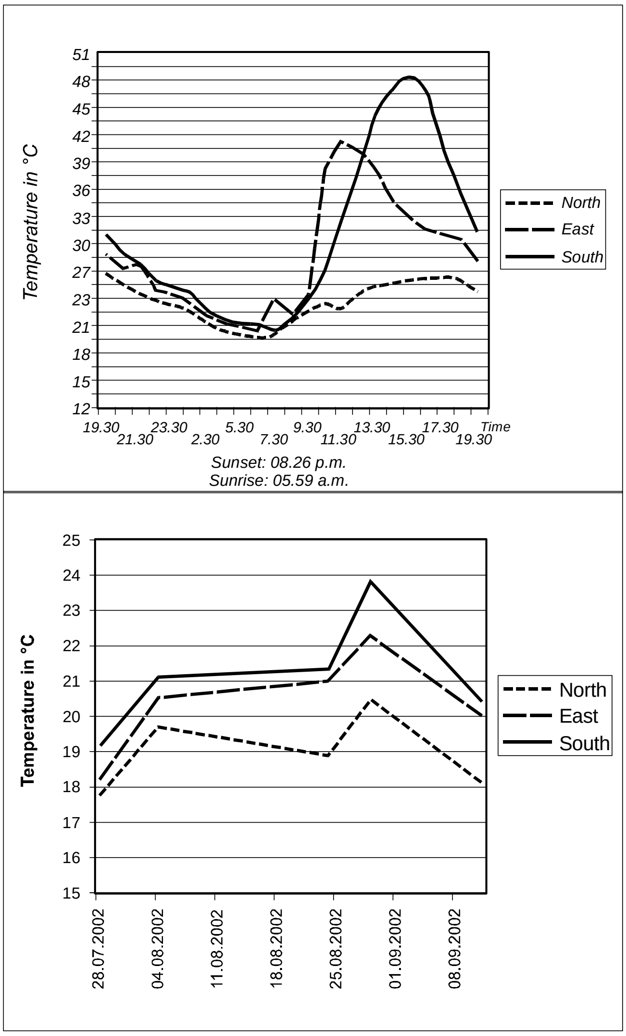

Fig. 7 Surface temperatures of house walls with different exposures: a) surface temperatures on 19 August 2002; b) minimum surface temperatures at 6:30 a.m. on seven different days; highest minimum temperatures on south exposed wall / *Oberflächentemperaturen von Hauswänden unterschiedlicher Exposition: a) Temperaturverlauf am 19. August 2002; b) Minima um 6:30 Uhr an sieben verschiedenen Messtagen; höchste Minima an südexponierter Hauswand*

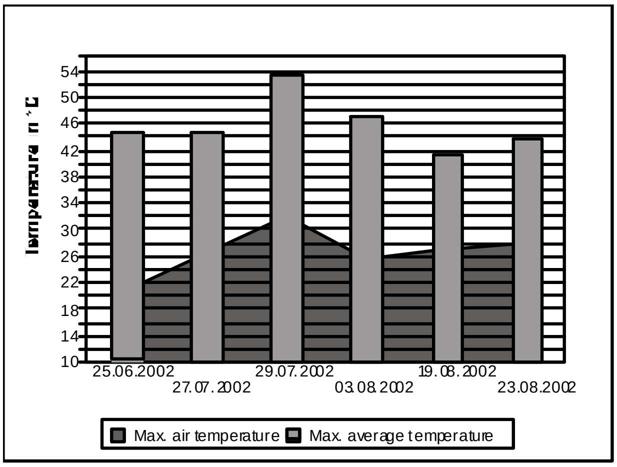

Fig. 8 Maximum air temperature and surface temperature of asphalt on seven different days / *Maximale Luft- und Asphalttemperaturen an sieben verschiedenen Messtagen*

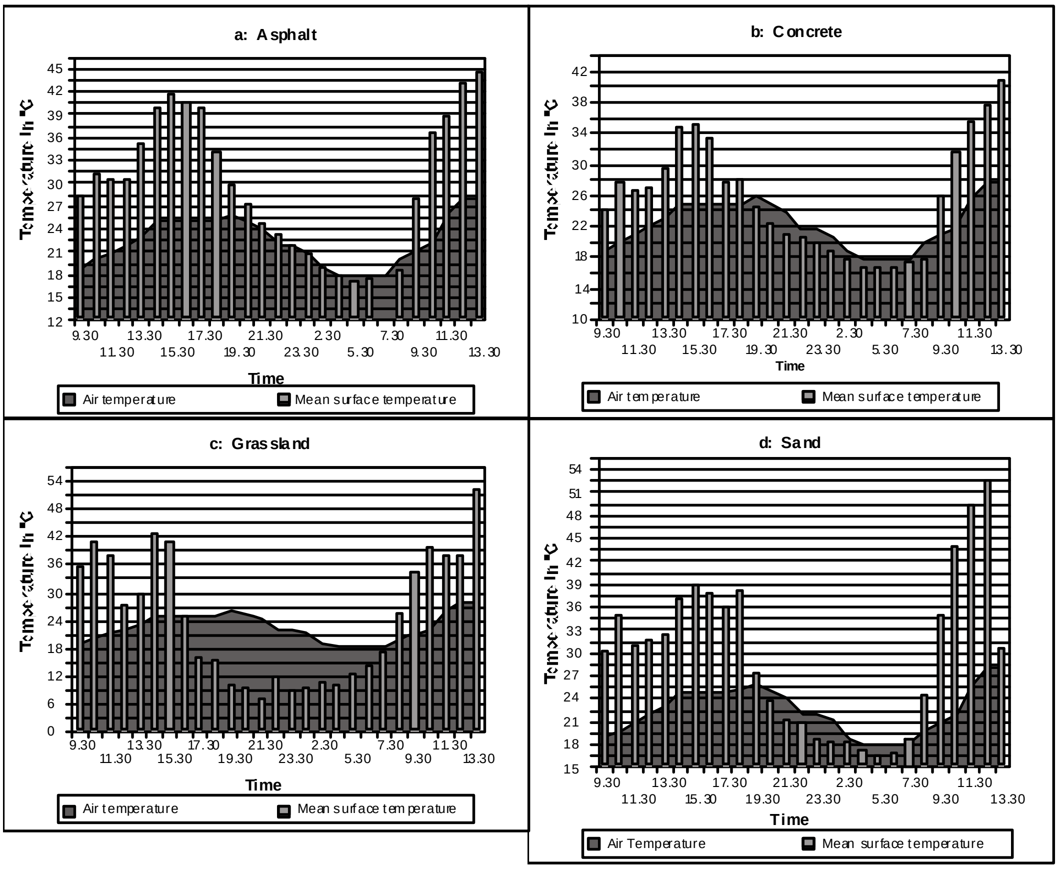

Fig. 9 Daily air and surface temperatures on 27 July 2002; different materials act as warming or cooling surfaces during the day / *Gang der Luft- und Oberflächentemperatur am 27. Juli 2002; je nach Material und Tageszeit wirken die Oberflächen als Heiz- oder Kühlflächen*

5.2 Terrestrial thermal imagery for microscale investigations of urban surfaces

Longwave emission from urban surfaces such as asphalt and walls of different material, colour and exposure to direct solar radiation are important for the environmental conditions of plants and animals on a micro-scale. The heat storage of urban surfaces is an important process, has practical applications and is useful in theoretical modelling (*Arndt* 1996).

Several measuring programmes using a hand-held thermal infrared camera were conducted at Berlin-Alexanderplatz in summer 2002 (*Fig. 1*). The daily range of the radiation temperature of walls of different exposure is shown in *Figure 7a*. Different minimum temperatures on seven different days, in relation to the exposure, are compared in *Figure 7b*. Possible maximum temperatures of asphalt in summer are represented in *Figure 8*. The temperature ranges of asphalt, concrete, grassland and a sand surface are given in *Figure 9a-d*. Finally, two thermal images of raster bricks on an urban lawn, one showing the maximum and one showing the minimum surface temperature, are given in *Figure 10a* and *10b*. All these examples show the important differences in longwave emission and surface temperatures between common urban surfaces during clear summer days. The thermal conditions on, under and near these materials are important for urban vegetation (see *Chapter 4.2*) and animals including human beings. Perhaps the most famous example of these special warm environments in Berlin are the vines in Sanssouci Park, planted in front of south exposed walls.

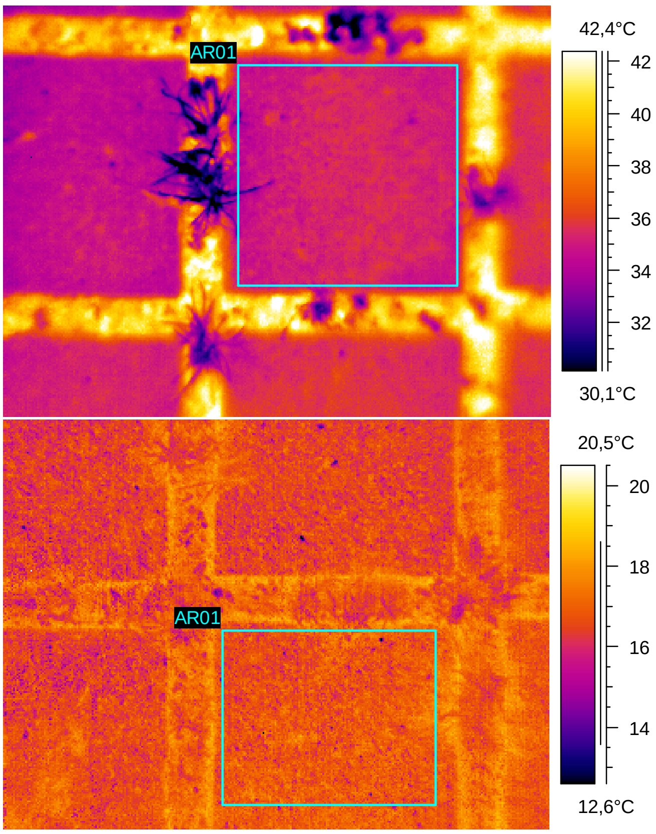

Fig. 10 Thermal images of concrete lattice bricks (edge length approx. 10 cm) on an urban lawn (27 July, 2002) with warming and cooling phases. The difference of surface radiation temperatures between concrete and vegetation are remarkably high. a) 15:30 CET; b) 06:30 CET
Thermalbild von Betongittersteinen (Kantenlänge ca. 10 cm) am 27. Juli 2002 mit Erwärmungs- und Abkühlungsphase. Bemerkenswert sind die hohen Unterschiede der Oberflächentemperatur von Beton und Vegetation. a) 15:30 MEZ; b) 06:30 MEZ

6. Conclusion

Through floristic studies there is a good knowledge about the spreading of non-native plants in big cities. The general relationship to mean air temperature, however, is not sufficient to explain the inner-urban spreading. Intensity and frequency of ice days and frost days may be major factors limiting the establishment and growth of *A. altissima* in Berlin. So far, the limiting critical value of air and ground temperatures remain unknown. Furthermore, it is uncertain if only a single day with low sub-zero temperatures after the first winter period is sufficient for the die-off of most of the young plants.

In general, the urban heat island leads to a higher and new biodiversity in big cities. In this context it would be interesting to know if a dependence exists between climatic zones, urban heat islands and biodiversity. A further question in this context is: Do urban heat islands in temperate latitudes lead to higher new biodiversity than in other climatic zones? With regard to a subsequent translation of our results to other large cities, spaceborne thermal imagery can be a useful tool for predictive studies about possible invasive neophytes. In order to get more reliable results, records from a longer measuring period are needed.

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Summary: Meso- and Microclimatic Aspects of Berlin's Urban Climate

Berlin shows a distinct urban climate as do all big cities, which is, in this case, only slightly influenced by the ground and end moraines and the Berlin valley. The description of the influence of urban climate on fauna and flora, and on the changing biodiversity associated with this effect, is, so far, based on assumptions. Thus, in an experiment, the thermal growth conditions of neophytes (for example *Ailanthus altissima*) along an urban-rural gradient are being investigated by the Research Training Group DFG-GRK 780. We can see a close connection between urban climate and the growth of *A. altissima*. Initial results show that there is a close relationship between the die-off of young seedlings and the intensity and frequency of days with frost and ice. However, nothing is known so far about the limiting critical values of air and ground temperature, and no data about the ecological range of the trees are available. An important question in relation to biodiversity studies is whether urban climate, especially urban heat islands, lead to a higher new biodiversity in our big cities due to the establishment of neophytes. Investigations using terrestrial thermal imagery of surface radiation temperatures from different horizontal surfaces (asphalt, concrete, grass and sand) and vertical house-walls show the important and different influence of these materials on urban climate. By means of spaceborne night-time ASTER thermal images the influence of all different surface radiations on the urban climate of Berlin can be detected on a mesoclimatic scale. Spaceborne images, however, can only give direct information about horizontal surfaces such as streets, places, parks and roofs. Terrestrial thermal imagery is needed to detect longwave radiation from vertical surfaces such as house-walls and the influence on human beings, fauna and flora. Finally, a combination of spaceborne and terrestrial thermal imagery is important.

Zusammenfassung: Lokal- und mikroklimatologische Aspekte des Berliner Stadtklimas

Wie alle Großstädte zeigt Berlin ein ausgeprägtes Stadtklima, das in leichter Form von der orographischen Situation Berlins mit dem Berliner Urstromtal in Verbindung mit den Grund- und Endmoränen beeinflusst wird. Die Darstellung des Einflusses des Stadtklimas auf Fauna und Flora und einer damit verbundenen Veränderung in der Biodiversität beruht oftmals auf nicht nachgewiesenen Annahmen. Daher wurde im Rahmen des Graduiertenkollegs DFG-GRK 780 ein Projekt implementiert, das sich mit den thermischen Rahmenbedingungen von Einbürgerung und Wachstum von Neophyten (insbesondere am Beispiel von *Ailanthus altissima*) in Berlin beschäftigt. Erste Resultate zeigen, dass eine enge Beziehung zwischen dem Absterben und der Intensität und Häufigkeit von Frost- und Eistagen besteht. Ein kritischer Grenzwert im Bereich der Luft- bzw. Bodentemperatur, der zum Absterben junger Setzlinge führt, kann jedoch bislang noch nicht angegeben werden. Weiterhin liegen keine Daten über die potentielle ökologische Spannweite der thermophilen und urbanophilen Baumart *Ailanthus altissima* vor. Eine wichtige Frage im Hinblick auf Biodiversitätsstudien ist, ob das Stadtklima und hier insbesondere die städtische Wärmeinsel zu einer neuen hohen Biodiversität, dominiert von wärmeliebenden Neophyten, führt. Untersuchungen zu den Oberflächentemperaturen unterschiedlicher Materialien (Asphalt, Beton, Wiese und Sand) zeigen den Einfluss dieser Materialien auf das Mikroklima und damit letztendlich auf das mesoskalige Stadtklima als Ganzes. Dabei ist eine Verknüpfung von Satellitenbildinformationen (z.B. ASTER) mit ambulanten Aufnahmen mittels einer Thermalbildkamera zu leisten. Jede Satellitenaufnahme gibt im Idealfall bei Nadirsituation eine Information über horizontale Oberflächen an (Straßen, Plätze, Parks, Dächer etc.), während die langwelligen Emissionen vertikaler Flächen (Hauswände und Mauern) und ihr Einfluss auf das Stadtklima und damit auf Mensch, Tier und Pflanze nur mit einer Thermalbildkamera erfasst werden können.

Résumé: Le climat urbain de Berlin et ses aspects micro- et mésoclimatiques.

Berlin possède – comme toutes les grandes villes – un climat urbain typique, cependant légèrement influencé par la situation orographique au centre d'une grande vallée et étendue sur des plaques morainiques. L'influence du climat urbain sur la faune et la flore comme sur la biodiversité en général est plus difficile à prouver. Voilà pourquoi on a commencé un projet de bioclimatologie pour connaître plus en détail acclimatisation et croissance des néophytes (*Ailanthus altissima*) à Berlin en relation avec le climat urbain. Les premiers résultats montrent qu'il existe un rapport étroit entre la mort de cette espèce et l'intensité et la fréquence des jours avec gel. Cependant, des valeurs critiques de la température du sol et de l'air entraînant la mort des ces espèces fraîchement plantés ne peuvent pas encore être determinées. En outre, il n'y a pas encore des données sur l'envergure écologique possible de l'espèce urbanophile *Ailanthus altissima*. Une question importante en rapport avec ces études de biodiversité est de savoir si le climat urbain et en particulier l'ilôt de chaleur urbain conduit à une nouvelle biodiversité dominée par des néophytes thermophiles. Des mesures de la température de surface de différents matériaux (asphalte, béton, gazon et sable) montrent des différences importantes attestant ainsi l'influence de ces matériaux sur le climat urbain à une échelle microclimatique. L'émission thermique des surfaces verticales (murs et façades des maisons) a pu être mesurée avec une caméra infrarouge. Une image infrarouge thermique nocturne à partir du satellite ASTER a donné des informations sur la température radiative des surfaces horizontales (rues, places, parcs, toits etc.) à une échelle moins détaillée.

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