A methodological framework for the assessment of regulating and recreational ecosystem services in urban parks under heat and drought conditions

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ABSTRACT
Climate change, urbanisation and demographic change affect urban areas and pose a range of health-related challenges to urban residents, including heat waves, drought periods, air pollution and densification processes. Urban green spaces provide ecosystem services that can help to mitigate the effects of these challenges. Urban green spaces such as parks, urban gardens and street trees regulate the microclimate and buffer noise as well as a variety of air pollutants. Parks promote physical activity, relaxation and social interaction. The potential to provide these services might be limited during extreme weather events such as heat waves and drought periods. With this experience-based perspective paper, we introduce an interdisciplinary project that consists of multi-method field campaigns to assess the potential of urban parks to provide regulating and recreational ecosystem services in the context of the 2018 and 2019 heat and drought periods in Germany. We highlight that multi-method field campaigns that combine sensor-based environmental measurements with social science approaches, including visitor observations, counts, and questionnaire surveys, are highly useful when urbanisation and climate change-related challenges must be effectively addressed in the context of the complex socio-ecological systems of a city. Based on our hands-on experiences, we provide recommendations for local urban green space planning and outline prospects for future research.
1. Introduction

Urban green spaces are key to mitigate the challenges from climate change and urbanisation. Vegetation regulates air temperature through shading and evapotranspiration (Bowler et al. 2010; Baró et al. 2014) and air quality through physical and chemical interactions with pollutants (Grote et al. 2016; Nowak et al. 2018). By combining natural and human-made elements, urban green spaces such as parks form essential spaces for providing recreational opportunities for people (Konijnendijk et al. 2013; Dickinson and Hobbs 2017) and thus benefit their health and wellbeing. Recently, during the COVID-19 pandemic, urban parks became extremely important when people were urged to engage in social distancing (Ugolini et al. 2020). The potential of parks to provide ecosystem services can, however, be limited by extreme heat and drought events (Kabisch and Haase 2018).

Given the complexity of urban environmental and socio-demographic conditions, little is known about the potential of urban parks of different origins and structures to continue to provide ecosystem services under heat and drought conditions. To address this knowledge gap, we conducted multi-method field campaigns in two inner-city parks in the city of Leipzig, Germany, during the recent heat and drought periods in 2018 and 2019 as part of the interdisciplinary GreenEquityHEALTH project (www.greenequityhealth.hu-berlin.de). Our goals were to:

(i) assess climate regulation and air quality regulation functions under drought and heat conditions in differently structured urban parks,
(ii) identify vegetation and infrastructural characteristics of urban parks that could increase their regulation functions and determine park visitation patterns under heat conditions,
(iii) integrate heterogeneous environmental, social and health data in an innovative and publicly accessible way, and
(iv) disseminate the results as research-informed recommendations to the city’s planning departments.

This experience-based perspective paper introduces an interdisciplinary project design as a framework of multi-method field campaigns at multiple temporal and spatial scales and provides initial results. We discuss how these results might be used in urban planning, critically discuss our approach and identify prospects for future research. We conclude that a multi-method approach is needed when urbanisation- and climate change-related challenges must be effectively addressed in the context of the socio-ecological system of a city.

2. Methods

2.1 Setting

The study was conducted in the city of Leipzig, Germany. Leipzig is one of the fastest growing cities in Germany, with a population projected to rise from currently approximately 600 to over 650 thousand residents in the upcoming decade (Heinemann et al. 2019). Unusual annual precipitation patterns (e.g. significantly lower summer precipitation and higher frequency and intensity of heavy rainfall events) were detected during the 2018 and 2019 drought periods; the total precipitation between April and July 2018 was only half of the long-term (since 1980) mean (Kabisch and Haase 2018). The study area comprises the combined area of two parks – Friedenspark and Lene-Voigt-Park – and their local neighbourhoods (Figure 1). Friedenspark is a long-standing green space that was initially developed as a cemetery in the mid-19th century. Hence, the park is rather extensive in size (17.5 ha) and is dominated by mature trees (61% coverage, mean height > 13 m) of considerable diversity (64 species) as well as a playground (cf. Figure 1). In addition, the Friedenspark hosts an extensive playground and some sports facility areas. Lene-Voigt-Park is a new green space developed on a former railway brownfield. The park was opened to the public in its full extent (ca. 6 ha) in 2004 and is located in a densely populated residential area (Figure 1). The vegetation cover at Lene-Voigt-Park is relatively sparse (78% total, 14% trees of 8 m mean height). The park contains, however, several playgrounds, sports facilities such as beach volleyball and table tennis courts, basketball/soccer fields and a high density of exclusively paved paths frequently used by skaters and cyclists.

2.2 Study design

To address our research questions, we applied various complementary survey methods and technologies during two field campaigns in two consecutive summer seasons in 2018 and 2019 (cf. timeline in Figure 2). An overview of these methods is provided in the following section, and details are provided in the supplement (Table S1, Supplementary Material Information on methods applied), including information about measured data, details about the measurement device and period, sources, and additional information about the methodology applied.

The multi-method campaigns included in-situ ground-based, stationary, and aerial (remote sensing-based) environmental measurements, mobile air quality measurements, and social science-informed surveys, namely, observations, visitor counting and a questionnaire survey.
The stationary meteorological measurements collected air temperature and air humidity data for a period of seven consecutive days in 2018. The data were collected at a total of 30 sites distributed across both parks and in nearby street areas, including two long-term measurement stations that began operating continuously in April 2018 (Figure 3, left). The ground-based measurements were complemented by two aerial...
surveys by a so-called gyrocopter recording high-resolution multi- and hyperspectral (short- to mid-wave) and thermal (long-wave) images (Figure 3, right).

For the identification of vegetation and infrastructure characteristics that potentially determine park visitation patterns and behaviour under heat and drought conditions, we also acquired detailed geospatial information that was publicly available (Banzhaf et al. 2018) or provided by the city administration and performed additional on-site validation mappings in both parks. The geodata were transferred into a web map application that consists of an extensive set of 33 indicators covering aspects of park quality that are relevant from a human perspective as well as ecological aspects (Kraemer and Kabisch 2021). The use of open-access (input) data allowed the possible reproduction of the study as well as the adaptation, extension and further improvement of the database.

The goal of the air quality campaign in 2019 was to assess how the air quality regulation function differs between the two differently structured parks and the local street environment, particularly under heat and drought conditions. Mobile air quality measurements were performed on five consecutive days in 2019 using portable sensors for particulate matter (PM) and black carbon (BC) placed in small backpacks. The backpacks were carried on routes through the parks and adjacent urban areas, including a heavily frequented street area (cf. map in Figure 4 depicting a typical route for Friedenspark). To collect robust reference data for the air quality campaign and due to repeated heat wave conditions, we performed the measurements of air temperature and humidity again in 2019 in the same way as in 2018’s meteorological campaign. In addition, to evaluate air flow conditions, one measurement station was equipped with a wind gauge that measured the wind speed and direction (Figure 4, left image).

Furthermore, we conducted social science-informed methods, including systematic observations, structured quantitative counting of park visitors in 2018 and a questionnaire survey in 2019 (for a detailed description of the 2018 campaign, see Kabisch and Kraemer 2020). We decided on this multi-method approach based on previous works on park field surveys (McCormack et al. 2014; Danford et al. 2018), our own site visits prior to the survey and discussions with external experts. Multiple methods complement each other (Balram and Dragićević 2005). In particular, we were interested in determining which park and what kind of characteristics attracted children with their families as well as older people during hot periods and what recommendations for urban planning and design could be derived from our findings.

Specifically, the observations of park visitors aimed to assess what groups of people were on the sites, what activities they were pursuing, where (in shaded or non-shaded spaces), when, and with what kind of equipment. Eight members of the research team carried out observations over a seven-day period from 18–24 July 2018, for 10 hours every day. The team used detailed observation sheets, followed a standardised protocol, and established dedicated observation zones (see Kabisch and Kraemer 2020).
for detailed information on the procedure, including the data extraction sheets).

The questionnaire survey took place in July 2019 to complement the observations and count data with direct ratings and opinions from park visitors (Kabisch et al. 2021).

2.3 Data management

For the purpose of openly providing the collected data for potential follow-up studies and subsequent use, an innovative data management approach was developed to synthesise the data and the results generated during the project duration. All datasets have been saved in suitable data storage systems. The collection, transmission, storage, and analysis of data; access to the data; and data reusability have been ensured in a sustainable manner according to the FAIR data policy so that the data are easily findable, openly accessible, interoperable and labelled with a clear user licence according to international standards (Wilkinson et al. 2016). For interoperable reuse, the data from each respective campaign (2018 and 2019) will be published online in a data repository along with this study protocol. The data will then be accessible via machine access (via an interface) to the long-term data records in the repositories.2

3. First results

In the following section, exemplary results from the different parts of the research approach are presented.

Figure 4. Details for the air quality campaign in 2019: Meteorological station with wind gauge (upper left), typical mobile measurement route for Friedenspark (map on the right), PM and BC sensor with a data-receiving smart phone (lower left, photos: GreenEquityHEALTH, TROPOS).
3.1 Air temperature

During the 2018 field campaign, which took place during the hottest period of the year, we observed gradually increasing daily maximum air temperatures for seven consecutive days, with a slight break in this increase due to cloudy conditions (Figure 5, see also for a detailed description Kabisch and Kraemer 2020). This trend illustrates the gradual heating-up of the urban landscape when incoming heat during the day cannot be completely released overnight. We observed the hottest day, with a maximum air temperature of 33.5°C at 2 m height and nearly 40°C above ground (0.1 m height), in the Lene-Voigt-Park. The mean air temperature (day and night) over all seven days at a height of 2 m was slightly higher in Lene-Voigt-Park (23.4°C versus 22.9°C for Friedenspark), which was driven mainly by the markedly higher daytime temperatures. These differences in air temperature values between the two parks might be attributable to their diverse structures of surface cover composed of a variety of vegetation and built elements. Friedenspark features a total vegetation cover of 96% dominated by mature trees (cf. Figure 1), which effectively moderate surface and air temperatures through shading during the day and evapotranspiration during the day and at night. Trees in Lene-Voigt-Park cover only approximately 15% of the park and the park has a considerable proportion of unvegetated open space (ca. 20%). Moreover, major grass areas in the park were lost due to the drought conditions coupled with intensive use by park visitors during the summer (see Figure 1). Nevertheless, the vast open space in Lene-Voigt-Park promotes vertical heat flux from the surface, allowing for better cooling overnight (cf. night-time values in Figure 5).

3.2 Air quality

The air quality measurements identified the PM$_{10}$ mass concentrations (or the calculated mean concentrations) as being mostly below 30 μg/m$^3$. For comparison, the European Commission recommends threshold daily and annual mean values of 50 μg/m$^3$ and 40 μg/m$^3$, respectively. The black carbon (BC) mass concentrations reached values of 5–10% of the PM$_{10}$ mass concentration, which is a typical fraction in urban areas with heavy traffic (Viidanoja et al. 2002). The results showed lower mass concentrations in the park areas than in the street areas. The mass concentrations were highest in areas near major street intersections (Figure 6). Comparing the two park areas, the mass concentrations were slightly higher in Lene-Voigt-Park, with peaks along the beach volleyball area and where a four-lane main road is adjacent in the western part. Additionally, other park structures, such as playgrounds and dusty paths can interfere with PM$_{10}$ measurements. Park vegetation affects the air pollutant distribution and its structure and composition determine whether it influences local air quality in a positive or rather negative way (Janhäll 2015; Barwise and Kumar 2020). The initial results indicated that the park areas with a higher coverage of large, old trees and a dense shrub layer along the park boundary (as in Friedenspark) had lower PM$_{10}$ and BC mass concentrations inside the park compared to park areas with lower vegetation cover (as in the Lene-Voigt-Park). Furthermore, higher vegetation density and net primary productivity are associated with lower dust emissions.

![Figure 5. Temperature trend at a height of 2 m in Friedenspark and Lene-Voigt-Park during the field campaign in July 2018. Note: Grey bars indicate data at night (22:00-6:00, adapted from Kabisch and Kraemer 2020).](image)
Figure 6. PM10 (a) and BC (b) distributions across parks during the weekday rush hour period between 7:30 and 8:30 in the morning in June 2019.
(Engelstaedter et al. 2003). Therefore, the loss of vegetation due to heat and drought, such as in the heat and drought periods of 2018 and 2019, may have intensified dust emissions and thereby PM$_{10}$ concentrations.

### 3.3 Structured observation and visitor counting in 2018

In July 2018, during the study period, we observed a total of 2280 visitor groups. Of those, approximately 80% in Friedenspark and 82.3% in the Lene-Voigt-Park were adults, while 13.1% and 8.9% were children, respectively. Older children or school children of an estimated age between 7 and 17 years were observed to make up 4.6% of the visitors to Lene-Voigt-Park and 3.8% of the visitors to Friedenspark. The observations indicated that particular park facilities seem to determine park uses. Passive activities such as sunbathing, relaxing or conversing were observed in groups located on lawn areas or on benches. In contrast, active physical activities such as beach volleyball or soccer took place in dedicated sports areas and mostly in Lene-Voigt-Park, where these spaces are more frequently available and better equipped than those in Friedenspark.

The counts of passing visitors at the counting points indicated variations in the number of visitors by temperature class and by park. Walking and cycling activities took place more often in the Lene-Voigt-Park during high-temperature periods for all age groups, which may be explained by the fact that the paths in this park are used mainly for transit and in the late afternoon/evening. Even at the highest temperatures, visitors may have passed through Lene-Voigt-Park on their way back from work or from school to home. In Friedenspark, the counted numbers of young children walking or cycling and of adults jogging decreased significantly at the hottest temperatures (29.5°C or higher). For detailed results, see Kabisch and Kraemer (2020).

### 3.4 Questionnaire survey 2019

The aim of the survey was to explore how extreme heat events with temperatures above 30°C affect the way people use urban parks and what role parks play in helping people cope with such extreme weather events. In total, 178 individuals answered the two-page survey in July 2019. The results showed that approximately half of the respondents in Friedenspark (51%) and approximately 40% in Lene-Voigt-Park do not change their frequency or way of park use under heat conditions (Kabisch et al. 2021). Approximately 20% responded that they would visit the park more often under heat, while approximately 15% used the parks less, and approximately 17% adapted their park use in terms of daytime or activity. Some stated that they visit the parks later in the evening or that they avoid active sports and relax in the shade instead. More than two-thirds of all respondents indicated that a visit to the park helps them to better tolerate summer heat conditions.

### 3.5 Project communication to urban planning departments

An important aim of the study was to communicate the results to local stakeholders in urban planning departments and provide them with applicable methods and research-informed recommendations for higher-quality urban green space planning, design and management. The City of Leipzig is currently developing a Masterplan Green 2030 (Stadt Leipzig 2018) and appreciates our project results and the resultant recommendations for future park design and management practices for strategic development. To provide the information in a condensed and maximally informative way, the dissemination and communication materials and efforts include:

- the development of project factsheets (Kabisch et al. 2018, 2020) that contain condensed information in an easy-to-understand and visually appealing way. Factsheets are available in German and English;
- participation in and the active presentation of results to the City’s Green Department Colloquium, in which the project team participated in January 2019 and 2020; and
- the development and presentation of the open city-wide GreenEquityHEALTH-Web-GIS application of green space qualities, available at https://arcg.is/0GXafX.

Thus far, the following detailed recommendations have been provided to the city planning departments:

- Aiming at equal access to urban parks as a resource for health and well-being, park usage barriers should be removed. This includes the installation and maintenance of toilets, adaptive lighting, drinking water fountains (Kabisch et al. 2021), and age-appropriate seating facilities/benches (Kabisch and Kraemer 2020).
- With regard to climate change-related challenges such as more frequently occurring heat waves and drought periods, older parks with high tree coverage should be preserved and maintained to maintain their regulating ecosystem services, such as cooling; at the same time, the demands for cultural ecosystem services such as natural experience and socializing should be respected.

Since we found that specific local environmental and sociocultural conditions influence park use
behaviour, future urban green space planning requires co-production processes in which ecosystem service provisioning and human demands are jointly considered in the planning, design and implementation processes (Fischer and Eastwood 2016). This is particularly relevant because increasing population densities in cities, heat and drought periods, and planetary health crises such as the COVID-19 pandemic have clearly shown the demand for and relevance of green urban environments for city residents. This calls for an increased appreciation and preservation of the green and natural elements our cities provide.

4. Critical reflection and prospects for future research

This study and its underlying interdisciplinary framework are among the pioneers of research on ecosystem service provisioning in urban systems with a particular focus on climate change-induced heat and drought conditions. The strength of the interdisciplinary approach lies in the integration of different methods and disciplinary expertise into one research design as well as the mutual learning between the various disciplines that enabled trust-building and partnership among the members of the research teams.

However, such a complex approach does not come without pitfalls and trade-offs in terms of methodology. Assumptions were used in the overall discussion of the results, e.g. in terms of ecosystem services provision. Although we can draw conclusions from the temperature reduction based on vegetation in the parks, our measurements were clearly spatially and temporally limited by focussing only on two parks and their vicinity over a period of one week which was mainly due to staff capacity constraints. Furthermore, we assume that green space qualities identified through counting and observation can be related to cultural ecosystem service provisioning for particular age groups. Through a follow-up questionnaire survey in 2019, we identified certain functions of urban green space related to the health and well-being of park visitors in high-temperature conditions (Kabisch et al. 2021). We related these functions to ecosystem service provisioning. This interpretation is, however, qualitative, and we may be primed in our role as experts to expect ecosystem services – park visitation relationships. These relationships, however, should not be considered as a given causality. Schröter et al. (2021) intensively discussed the assumptions made in ecosystem services research, e.g. with regard to representativeness and validity, that may contribute to uncertainty and biases (Schröter et al. 2021). We agree that these factors may influence final research outcomes. Rules of transparency were applied as major guiding principles for the research in our multi-method approach. This means, in our case, that we have been transparently communicating and discussing our applied methods with the project’s advisory board, with external experts at conferences, and with representatives from the local planning departments.

Furthermore, we acknowledge that the on-site field campaigns were restricted mostly to a limited time period. This included the field campaigns in July 2018 and in June/July 2019. These windows of time may limit any general conclusion about ecosystem service provisioning for parks (Willemen 2020). The air temperature measurement campaigns for the entire park were, however, extended, with two long-term measurement stations running continuously since spring 2018.

The time periods of the observations, counting and questionnaire surveys may have also led to the exclusion of some visitor groups that did not visit the parks in the particular study weeks and times (day-time). Here, we obviously faced staff capacity limitations. For future research, we suggest long-term (questionnaire) surveys that also focus on non-heat periods and surveys that include a higher number and variety of green spaces and thus cover more diverse neighbourhoods. Comparing the results of potentially additional city-wide, long-term surveys with the results of on-site surveys and validating them with the latter may be helpful to ensure a more comprehensive evaluation of adaptation behaviour to particular environmental conditions such as heat or drought periods. Another opportunity that might be efficient and cost-saving could be to use park visitation information derived from social media (Ilieva and McPhearson 2018). For example, Twitter data have already been used for park visit counting and assessments (Hamstead et al. 2018). Although they have many advantages, data from social media usually come with a number of limitations, such as issues in data security and bias in the representativeness of the sample. One additional option would be to combine different sources of user-generated data, including social media data, data from sports tracking systems and survey data (e.g. on-site questionnaire surveys or public-participation-GIS – PPGIS). Heikinheimo et al. (2020) comprehensively describe the potential benefits of different user-generated data sets. They show that tracking data (sports tracking apps or mobile phone data) are most relevant for identifying where and when people go to green spaces (Heikinheimo et al. 2020). In addition, PPGIS approaches and social media data can provide information about what people do and about who is doing what at the sites. However, no form of user-generated data can fully capture information about the actual intention of
visitor groups (the ‘why’), which also includes potential park visitation adaptation behaviour. Hence, the combinations of these user-generated data sets with social science-informed on-site surveys are recommended in order to obtain detailed information about visitor motives and their health and wellbeing (see Figure 7 for a visualisation of the applicability of different user-generated data sets).

Final, we acknowledge the importance of accounting for the general temporal dimension or evolution of ecosystem service delivery (Willemen 2020). The Lene-Voigt Park is a young park on a former railway brownfield site. It was opened as a park for public use in 2004. Tree plantings, infrastructure adjustments, and other implementations have taken place continuously since the park opened. We can thus assume that the provision of ecosystem services, particularly of regulating ecosystem services (e.g. cooling functions), will improve with time.

5. Conclusion

Based on our initial data assessments, we learned that environmental and social conditions in and around parks are complex, so are comprehensive assessments of regulating and cultural ecosystem services. Many parameters are spatially and/or temporally highly variable, including air temperature, air flow, surface materials and traffic conditions, and therefore require spatially and temporally dense and well-designed surveys. Combined with the assessment of recreational function, we found that a number of parameters seem to influence park use behaviour depending not only on air temperature or overall weather conditions but also on individual demographics, employment, social context, and living and health conditions. Thus, regarding the actual use of parks, a considerable influence of personal perceptions or demand for specific functions from parks and their services remains. Detailed environmental information as well as people’s individual perceptions and behaviour should be considered together to obtain more informed recommendations for urban green space planning.

Thus, as a key message of this experience-based perspective paper, we highlight that assessing the provision of, demand for and actual use of regulating or cultural ecosystem services in parks under global change requires detailed environmental and social science-based data that complement each other and, hence, need to be based on an interdisciplinary multimethod study design. Moreover, such a comprehensive approach requires the integration of a broad diversity of data based on thorough data management.

Notes

1. Please, note that Kabisch and Kraemer (2020) is referred to by Kabisch, Kreamer and Brenck (2020b).
2. Both relational databases (SQL-based for csv files) and file-based data storage (cloud-based file server for raster data) were used to store the data according to standards for accessible systems. The data presented here are available via public repository under Kabisch et al. (2021b) via 10.5281/zenodo.5148571 (except for uncalibrated air quality data). For any questions regarding data please contact the authors.

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