Proposal of indicators regarding the provision and accessibility of green spaces for assessing the ecosystem service “recreation in the city” in Germany

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ABSTRACT
The paper summarises the multiple benefits of urban green spaces for city dwellers and provides an overview of proximity approaches and common key parameters for green-space quantification in cities. We propose indicators for the assessment of the ecosystem service ‘recreation in the city’ on a national scale. The calculation procedure, which takes into account the best available data sets in Germany, is explained. The determination of threshold values regarding green-space standards comprising type, size and distance is crucial to such studies. The results, the degree of provision with public green spaces in all German cities with more than 50,000 inhabitants (n = 182) and their accessibility, are presented. In total, green spaces are accessible for daily recreation for 74.3% of the inhabitants in German cities, which means that underprovision affects 8.1 million city dwellers. Some indicator details are shown for the examples of Wiesbaden and Stuttgart. Finally, we discuss the approach and values of the proposed and quantified indicators in a German and European context.

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1. Introduction
In Target 2, Action 5, the EU Biodiversity Strategy stipulates that the member states will map and assess the state of the ecosystems and their services and promote the integration of these values into the accounting and reporting systems at the EU and national level by 2020. This also includes urban ecosystems with their range of services, as a large number of consumers, users or beneficiaries of ecosystem services (ESs) are concentrated here (Maes et al. 2014).

The possibilities of capturing the ESs in Germany and examining them with respect to their relevance and representability at the federal level are currently being studied in the framework of research projects (Albert et al. 2015; Grunewald et al. 2016). Indicators for capturing and assessing ES are required as an essential instrument of operationalisation and for measuring success. They are intended to provide information on existing ES (including supply and demand) and on development trends as selected, readily comprehensible parameters. Monitoring with indicators involves representing temporal developments. However, this requires the databases to be reliably available in comparable quality on a national scale. This significantly restricts the selection of computable indicators.

Urban ecosystems, whether they are closer to nature or more artificial, contribute to essential aspects of the quality of life in cities. They fulfil urban ecological functions, provide urban ES and allow city dwellers to be in touch with urban nature (Barbosa 2007; Kabisch & Haase 2013; Elmqvist et al. 2015; Kabisch et al. 2015; Lee et al. 2015).

The term ‘urban green’ is often used to focus on urban green spaces used by human beings. Following the German Greenbook ‘Green in the City’, urban green includes all forms of green urban open spaces and vegetated buildings as parks, cemeteries, allotments, brownfields, areas for sports and playing, street vegetation and street trees, vegetation around public buildings, areas of nature protection, woodlands and forests, private gardens, urban agricultural areas, green roofs and green walls as well as other open spaces (BMUB 2015). Following this, ‘urban green spaces’ are normally understood as spaces, which are directly used for active or passive recreation, or indirectly used by virtue of their positive influence on the urban environment, accessible to citizens, serving the diverse needs of citizens and thus enhancing the quality of life in cities (URGE-Team 2004; GreenKeys Team 2008). Urban green spaces are essential providers of ESs and can be regarded as service-providing units for urban residents (Wruster & Artmann 2014). Waterbodies and their nearshore environment (sometimes called blue infrastructure) such as streams, lakes, ponds, artificial swales and storm water retention ponds are part of the green infrastructure (European Commission 2011) and are included in our ‘green spaces’ concept as well.

The shape, habitat and vegetation structure of green spaces, their species composition and their
utilisation can differ widely. Generally, the term refers to public spaces, i.e. public properties or spaces in the responsibility of public authorities. By contrast, private gardens and the greenery of apartment blocks are not included, nor are small business premises such as landfills or mines, though they may be covered with vegetation. In Germany, e.g. the use of allotments and schoolyards is semipublic or restricted to selected population groups; thus, these areas have not been considered as green spaces in this study.

With ongoing urbanisation, the paradigm of the compact city, as an immediate antidote to the sprawling city, still cannot be fully substantiated (Uhel 2008). The effectiveness of compaction, as well as centralisation and concentration, have been thoroughly examined, including the various ways in which compaction can be achieved including intensification, new high-density development, traditional neighbourhood development, etc. In core cities, open spaces are a scarce good. Section 1 (6) of the German Federal Nature Conservation Act (BNatSchG) requires open spaces, including their components and individual biotopes, to be preserved also in settled areas and to be created or re-established where they do not exist to a sufficient extent. Many municipalities and initiatives aim to increase the provision of green spaces in the cities. Germany’s National Urban Development Policy also stresses this strategy (BMUB 2015). Quantifications at the city and federal level are necessary in order to derive and pinpoint urban planning and nature conservation requirements in this context. Developing indicator values through a monitoring process can serve as a basis for the competition of the German cities for an urban development that is ‘green’, i.e. ecologically sustainable and oriented towards the well-being of all citizens.

Against this background, it is the aim of this paper to propose and discuss indicators regarding the provision and accessibility of green spaces for assessing the ES ‘recreation in the city’ on a national scale for Germany. In general, we are following the method proposed for the federal ES indicators in the framework of the project ‘Implementation of Action 5 of the EU Biodiversity Strategy: Development and implementation of a methodology for capturing and assessing ecosystem services at the federal level in the context of the implementation of Target 2 and Action 5 of the EU Biodiversity Strategy for 2020’ (2014–2016, IOER Dresden/ifuplan München, Grunewald et al. 2016).

First, we summarise the multiple benefits of urban green spaces for city dwellers and give an overview of proximity approaches and common key parameters for the quantification of green spaces in cities. Second, we propose indicators for the assessment of the ES ‘recreation in the city’ on a national scale based on the first results. The calculation procedure, which takes into account the best available data sets in Germany, is explained. The determination of threshold values regarding green-space standards comprising size and distance is crucial to this study. The results, the degree of provision with public green spaces in all German cities with more than 50,000 inhabitants \((n = 182)\) and their accessibility, will be presented. Finally, we discuss the approach and values of the proposed and quantified indicators in a German and European context.

2. Description of the ES ‘recreation in the city’

Urban ecosystems, such as forests, parks, bodies of water and adjacent embankments, deliver services for the residents regarding the experience of nature, recreational activities and aesthetics (Barbosa 2007; Kabisch & Haase 2013; Elmqvist et al. 2015; Lee et al. 2015). In the following, we will refer to these as the ES ‘recreation in the city’. In a narrower sense, it mainly comprises ‘daily or leisure-time recreation’ and ‘recreation in the residential environment’.

According to the EU’s Common International Classification of Ecosystem Services classification (Haines-Young & Potschin 2013), the ES ‘recreation in the city’ belongs mainly to the classes ‘Experiential use of animals, plants and land-/seascapes in different environmental settings’ and ‘Physical use of land-/seascapes in different environmental settings’ in the group ‘Physical and experiential interactions’. It is part of the division ‘Physical and intellectual interactions with biota, ecosystems and land-/seascapes in different environmental settings’ and the section of cultural services. However, other classes of cultural ES are concerned as well (e.g. aesthetic). Furthermore, green spaces are important for many other ESs, such as habitat services, air purification, water regulation and provision or microclimate regulation (e.g. Bastian et al. 2012; Elmqvist et al. 2015). They are multifunctional and provide multiple benefits. For instance, biodiversity can improve the appreciation of the time in green spaces (Carrus et al. 2015). However, in our study, we focus on access possibilities to outdoor recreation in cities.

Proximity of green spaces results in better physical and psychological health of city dwellers in a long-term perspective and makes the city more beautiful (Maas et al. 2006; Van Den Berg et al. 2010). People can strengthen their immune system and maintain their performance. The health system is less strained; labour productivity is maintained or enhanced. The beneficial health effects of experiential interaction with nature have been demonstrated in various studies (Hartig et al. 2003; Health Council of the Netherlands and Dutch advisory council for research on spatial planning, nature and environment 2004; BMU 2010; Irvine et al. 2013; White et al. 2013; Lee et al. 2015; Shanahan et al. 2015; etc.). Low share of
green space is positively correlated with higher mortality (Gascon et al. 2016).

In considering the provision of the population with recreational areas, their reachability (pedestrian distance) and public accessibility are important factors, in addition to their percentage of the area (referred to the entire city area or to the inhabitants) and quality (Comber et al. 2008; Kabisch & Haase 2014; Wolch et al. 2014; Haaland & Van Den Bosch 2015).

In Europe, recently 73% of its population is living in urban areas and it is expected to be over 80% by 2050 (EU 2016). Close to two-thirds of Europe’s urban dwellers live in small urban places today (UN – United Nations 2014). In Germany, three quarters of the population reside in urban areas, of which one-third lives in big cities with more than 100,000 inhabitants (BMVBS 2015). The proximity of green spaces is a key criterion for choosing a place of residence (Naturkapital Deutschland – TEEB DE 2016). Recreational opportunities in public settlement areas are the key to improving the quality of life for people without a motor vehicle of their own and especially for population groups of lesser mobility such as the elderly, the disabled and children. The accessibility of recreational spaces for all population groups is in particular also relevant for social justice (Panduro & Veie 2013; Kabisch & Haase 2014; Wüstemann et al. 2016).

We therefore postulate as a goal for the ES ‘recreation in the city’ that publicly accessible green spaces should be reachable in the neighbourhood for every resident. Availability of green space can be understood as the amount of green area at a certain defined distance from where urban residents live (Kabisch et al. 2016).

Important measurable parameters that describe the ES ‘recreation in the city’ are as follows:

- Share of green spaces in the settlement area with the potential to provide recreation (supply in the sense of ‘provision by nature’), degree of provision and quality of green spaces (e.g. condition/maintenance, safety, cleanliness and equipment with benches);
- Settlement areas with residential use, inhabitant data, distances between residential areas and proximate green spaces (for estimation of demand aspects).

A systematic selection of key measurable indicators for the evaluation of urban green spaces is shown in Table 1. Many cities use such parameters to assess the amount of green space quantitatively. In Germany, 39% of the cities currently use benchmarks to assess green spaces qualitatively (Kühnau et al. 2016). These are based mainly on the ‘Guideline Values of the Standing Conference of Municipal Gardens and Park Heads’ in Germany (Gartenamtsleiterkonferenz – GALK 1973 quoted in Ermer et al. 1996), which define for the provision of German cities with public green areas at least 20 m²/inh. including at least 7 m²/inh. district parks with area of not less than 10 ha and 6 m²/inh. small parks. The value of the characteristic quantities can vary widely depending on the database used (source and selection of land use types, census) and the thresholds set (e.g. distances, areal requirements).

### 3. Proposal of indicators regarding green-space provision and accessibility and calculation steps

A quantitative approach to the topic provision of green spaces and the availability of public green space can be taken in different ways. Traditionally, the indication of an absolute size, e.g. green spaces per inhabitant in square metres at the city level (Table 1), serves as a value for rough orientation or comparisons (Haase et al. 2012; Dobbs et al. 2014). However, this indicator does not contain much information on the distribution and accessibility of green spaces for recreational purposes. The link between the size of individual green spaces and a path distance which the user can be expected to cover in order to visit this green space is comparable to accessibility indicators, e.g. from traffic planning (Schwarze 2005). A distance which is not far beyond the living environment and is manageable for all population groups will be classified in various planning disciplines as ‘within walking distance’ (BMVBS – Bundesministerium für Verkehr, Bau und Stadtentwicklung 2013; Neumeier 2013). Specifications from the immediate neighbourhood to the entire city level are common (Van Herzele & Wiedemann 2003; Haaland & Van Den Bosch 2015).

In response to this and based on previous work in Europe and Germany (e.g. Kabisch & Haase 2013; Maes et al. 2014; Simoens et al. 2014; Albert et al. 2015) and in consultation with national experts and authorities, we propose for the evaluation of urban recreation as a sociocultural ES on the federal level in Germany the development and implementation of the following indicators:

- Accessibility of green spaces (main indicator – M)
- Green-space provision per inhabitant related to green spaces within walking distance to residential areas (supplementary indicator – S1)
- Green-space provision per inhabitant related to total amount of green space (supplementary indicator – S2)

Indicator M contains compressed information on the provision of the population with green spaces in cities in close proximity to the residence on the basis of census data. Indicators S1 and S2 provide additional information on the proportion of green spaces for a
Table 1. Indicators for description and assessment of urban green space (according to Dosch & Neubauer 2016, slightly changed).

| Indicator                        | Characteristic                                                                 | Recording method                                                                 | Assessment goal                                      |
|----------------------------------|-----------------------------------------------------------------------------|---------------------------------------------------------------------------------|----------------------------------------------------|
| Green-space accessibility        | Average distance for the population to the nearest public green space        | Determining the average distance of the residents to the nearest green space (m) | Indicator to evaluate the residential and living quality |
|                                  | Proportion of population with accessible public green spaces with defined minimum size in near distance⁴ | Estimating the mean population density across the city structure types          |                                                    |
| Green-space provision            | Green space per capita in a defined commuter belt⁵                          | Quotient of the total green space and population in a defined commuter belt (m²/inh.) | Indicator to evaluate the residential and living quality, recreational quality, health promotion and site quality (image) |
|                                  | Provision of residents with urban green space in a defined commuter belt     | Quotient of population of commuter belt within pedestrian distance of green space and the total number of inhabitants, multiplied by 100 (%) |                                                    |
|                                  | Supply requirements: Total urban supply situation of the residents with green spaces based on city-specific quantitative benchmarks⁵ | Computerised, quantitative, benchmark-oriented analyses (m²/inh.)               |                                                    |
| Green-space supply               | Proportion of green space                                                   | Percentage of green space of the total area of the city (%)                      | Indicator to describe the amount of green in the urban area (quantity) |
| Green-space volume               | Volume of urban green                                                        | Vegetation height (m) per square meter                                           | Indicator to determine the ecological and in particular the climatological capacity of existing city structures (quality) |

⁴Corresponds to proposed indicator (M).
⁵Corresponds to proposed indicator (S1).
⁶Corresponds to proposed indicator (S2).

city and verify changes of the indicator M in the case of strong increase or decrease in green-space provision or changes through shifts in population density. Both supplementary indicators are less complex approaches that can be applied without high-resolution data on the population distribution.

In particular, the indicators have the function of displaying a target achievement and its changes over time. For the results, the frameworks are crucial, which we discuss in the following section.

3.1. Determination of the relevant recreational areas (in terms of green spaces)

(a) Database: AKTIS Basic-DLM
The AKTIS Basic-DLM is the first choice in Germany for a map base on land use with a high thematic and spatial resolution and quality (Krüger et al. 2013; Schorcht et al. 2016). The research project mentioned earlier agreed on using it as a database (Grunewald et al. 2016). For the land use types, the lower limit of data acquisition is 1 ha, but some of them are acquired completely (e.g. sports and leisure facilities, game parks). The update is carried out cyclically for all areas after at most 3–5 years, using aerial photography and a multitude of thematic details. Individual ATKIS object types, e.g. from the traffic domain, are even subject to a priority update of less than 1 year.

In the Basic-DLM, there is no distinction between settlement areas with a high or low degree of greening, i.e. green spaces between row developments or within a block-edge development are not represented due to modelling rules (block-building rule). For this reason, it is impossible to examine private green spaces or spacing green in the context of the residential accessibility of areas relevant for recreation. A database for including private green areas in a nationwide monitoring is currently not available because comprehensive and cyclically updated data are lacking.

The land use data of the European Urban Atlas (EUA) represent an alternative to the Basic-DLM (www.eea.europa.eu/data-and-maps/data/urban-atlas). They are particularly suitable for European comparisons (e.g. Kabisch & Haase 2013). The data are published by the European Environment Agency (EEA) for more than 300 European urban regions and are publicly available. The EUA includes categories relevant to the indicators to be calculated (‘Forest’, ‘Water’), but also some highly aggregated categories such as ‘Green urban areas’ or ‘Agricultural’. For example, the ‘Green urban areas’ include the zoo facilities with limited public access, and the category ‘Agricultural’ comprises grassland relevant for recreation as well as less relevant arable land. A number of big cities in Germany such as Münster, Mannheim or Chemnitz (data set 2006) or Dresden, Magdeburg (data set 2012) are not represented in the
EUA. For these reasons, but also because the Basic-DLM has a higher thematic and temporal resolution, the ATKIS Basic-DLM is preferred for the development of indicators in Germany (Grunewald et al. 2016; Schorcht et al. 2016).

(b) Selection and justification of the relevant categories (land use types) from the ATKIS Basic-DLM

The object types that represent the stock of green spaces were chosen with regard to the recreation on offer and public accessibility in general (Table 2). The categories ‘park’, ‘green area’, ‘forest’ and ‘wood’ are relatively indisputable. They make a huge contribution to recreation of city dwellers. Opportunities for recreation are sportive activities (walking, cycling, jogging), pick-nicking, enjoying the aesthetics and clean, fresh air to recover from daily stress by strengthen mental and physical health (Tyrväinen et al. 2005; Brown et al. 2014).

‘Waterbodies’ are included because they can serve for a variety of recreational activities at, on and in the water (e.g. bathing, boating, fishing, ice skating), sometimes include green embankment areas and are usually also accessible to the public. Water as a landscape element has a positive effect on the visual quality of landscape (Polat & Akay 2015) and recreation (Ulrich et al. 1991; Laumann et al. 2003).

Accessibility and usability for recreational purposes are also the decisive criteria for the selection of open spaces so that ‘grassland’ and ‘orchard meadow’ are included, but not arable land (cf. Table 2). Grassland (meadows or grazing land with natural elements) is attributed *inter alia* with a restoration effect (Hartig et al. 2003; Laumann et al. 2003). Orchard meadows are comparable to open, managed green spaces and areas with a low density of wood and can mostly be walked on.

On the basis of controversial discussions with experts in Germany, ‘cemeteries’ were explicitly included in our study as part of the publicly accessible system of the green infrastructure, as they exhibit important recreational functions (in this case particularly regarding recreation oriented towards silence) and are often used for walks (e.g. Korda 2005). But we know that in a lot of cases cemeteries have a time for the accesses and are limited by fences.

Further object types with a high percentage of greenery (e.g. zoo, game park, sports facilities and allotments) modelled in the Basic-DLM were not included, as public access to them is limited by entrance fees or fences commonly.

(c) Central reference quantities of the ES demand

Inhabitants are taken into account as potential consumers of the ES ‘recreation in the city’, drawing on census data or the municipal directory information system. In addition, geometries are required as reference points for the calculation of indicators in the geographic information system (GIS):

– Administrative city boundaries (municipal boundaries): administrative boundary geometry

| Topic | Land use type according ATKIS Basic-DLM | Green space with recreation functions and mostly accessible for the public |
|-------|----------------------------------------|--------------------------------------------------|
| Settlement | Sports, leisure and recreational area*: | |
| | – Sports facility | |
| | – Golf course | |
| | – Zoo/wildlife park | |
| | – Swimming bath | |
| | – Campsite | |
| | – Green area | x |
| | – Park | x |
| | – Allotment | |
| | Cemetery | x |
| Traffic | Road traffic | |
| | – Roadside area | |
| | Railway side area | |
| Vegetation | Agriculture: | |
| | – Arable land | |
| | – Hop growing area | |
| | – Grassland | x |
| | – Orchard meadow | |
| | – Garden land | x |
| | – Tree nursery | |
| | – Vineyard | |
| | Forest | x |
| | Woods | |
| | Heath | |
| | Moor | |
| | Marsh | |
| | Unproductive area | |
| Waterbodies | Flowing body of water | x |
| | Standing body of water | x |

* Land use types of less relevance as leisure park, open air theatre, weekend house area or model airfield are not listed.
VG25, source: Federal Agency for Cartography and Geodesy (Bundesamt für Kartographie und Geodäsie, BKG)
- Polygon features of basic raster geometries (INSPIRE grid 100 m), source: IOER, own calculations
- Population raster of the 2011 census, size of raster cells 100 m, source: Federal Statistical Office (Statistisches Bundesamt, DESTATIS)
- The municipal directory information system (Gemeindeverzeichnis-Informationssystem), source: Federal Statistical Office (Statistisches Bundesamt, DESTATIS)

3.2. Definition of threshold values for distance from the residential environment and minimum area sizes

The determination of threshold values is based on literature that considers green spaces in the context of everyday and local recreation (European Commission 2001; EEA 2002; English Nature 2003; Senatsverwaltung für Stadtentwicklung und Umwelt 2013; Richter et al. 2016; Van Den Bosch et al. 2016). For instance, the study in Flanders uses 400/800 m linear distances (Simoens et al. 2014), while in the UK, urban dwellers should have access to 2 ha of green spaces within a 300 m straight-line distance from the place of residence (Handley et al. 2003).

An overview with reference values from German cities for different types of open/green spaces can be found in DRL (2006). In coordination with the German environmental authorities, the following determinations have been agreed:

(a) Accessibility of nearby green spaces
The minimum size of nearby green spaces is determined as 1 ha by the lower limit of acquisition in the AKTIS Basic-DLM. All the aforementioned sources assume a value of 300–500 m distance to green spaces for everyday recreation. Therefore, we count a recreational area as reachable or near-residential if it is at a path distance of at most 500 m, or 10–15 min by foot, from the residential area. With routing (e.g. streets, railways) and barrier effects taken into account, this amounts to approximately 300 m straight-line distance, which we calculate from the area boundary of the selected ATKIS object types/values (Table 2).

The representation of a pedestrian distance of 500 m to a green space by a straight-line distance of 300 m is confirmed on average by Richter et al. (2016) using a network analysis with path data. In the indicator calculation carried out there, comparable results for the investigated cities are obtained on the basis of straight-line distances and existing paths.

(b) Accessibility of larger green spaces at a medium distance
According to the DRL (2006) evaluation, near-settlement areas relevant for local recreation include areas with a minimum size of 10 ha and a maximum path distance of 1000 m or 20 min walking distance. Here, too, the specified path distance does not correspond to the straight-line distance. For the implementation of accessibility of larger green spaces in the main indicator, we thus assume a straight-line distance of approximately 700 m, taking barrier effects into account.

After evaluating the national and international literature, we have defined areas bigger than 1 ha to be at walking distance (300 m straight-line distance, approx. 500 m path distance, around 10–15 min by foot) for recreation in the nearby residential environment, and areas bigger than 10 ha to be at medium walking distance (700 m straight-line distance, approx. 1000 m path distance, around 20 min by foot) for recreation in the wider residential environment. The representation of a pedestrian distance of 500 m to green spaces by a straight-line distance of 300 m is confirmed on average by Richter et al. (2016) using a network analysis with path data. In the indicator calculation carried out there, comparable results for the investigated cities are obtained on the basis of straight-line distances and existing paths.

3.3. Short description of calculation and analysis steps

The indicators to be developed are particularly relevant in larger settlement units such as conurbations or big cities, since in rural areas the demand for public green spaces is largely substituted by recreation in the open countryside (Panduro & Veie 2013; Kabisch et al. 2015). According to the typology of municipalities and cities of the Federal Institute for Research on Building, Urban Affairs and Spatial Development (Bundesinstitut für Bau-, Stadt- und Raumforschung, BBSR), cities with at least 100,000 inhabitants are considered big cities (BBSR 2013). The indicators presented here are calculated for all cities above 50,000 inhabitants, as we assume that beginning with this order of magnitude (at the distances mentioned earlier) cities may exhibit restricted accessibility of the open landscape.

Indicator (M) captures the population that can reach both green spaces >1 ha within walking distance (accessibility of nearby green spaces) and green spaces >10 ha at medium distance (accessibility of larger green spaces at a medium distance) and places them in relation to the total population (Box 1).

The method of the secondary indicator 'green-space provision per inhabitant related to urban green spaces nearby to residential areas' (S1) was developed in the IOER Monitor of Settlement and Open Space
Development (www.ioer-monitor.de/home/?L=1), a permanent scientific service of the Leibniz Institute of Ecological Urban and Regional Development. It captures all green spaces (without consideration of municipal borders) in the vicinity of predominantly inhabited and contiguously built-up areas and relates them to the number of inhabitants of the respective municipality. In view of multifunctionality, this also takes into account areas with little sealing and predominant greening, including green spaces adjacent to traffic and arable land. This and the calculation steps of the second supplementary indicator ‘green-space provision per inhabitant related to total amount of green space’ (S2) are summarized in Box 1. It should be noted that in this study only public green areas with recreational functions are considered. S2 measures the total amount of green space with recreational functions within the municipal boundary and relates them to the number of inhabitants of the respective municipality.

### Box 1. Calculation steps of the indicators in the GIS.

#### (M) Accessibility of green spaces

**Step 1:** The object types listed in Table 2 are merged into a new data set ‘areas relevant for recreation’. It is impossible to distinguish between the different qualities and functions of the area types. That is to say, we assume for simplicity that all of them offer the same services.

**Step 2:** Buffer polygons with a distance of 300 and 700 m are created for those areas relevant for recreation, which are larger than 1 and 10 ha, respectively. The overlapping areas of the created buffer polygons are exported into a new data set ‘supplied areas’.

**Step 3:** Every raster cell derived from the INSPIRE grid 100 m2 is stored as a polygon and receives information regarding population density (inhabitants per hectare) from the census raster map. Subsequently, these are intersected with the ‘supplied areas’.

**Step 4:** In order to approximately derive the number of inhabitants at walking distance to green spaces and water areas, the inhabitant values in the vicinity of areas relevant for recreation are summed with weights. The weighting is carried out using the polygon area remaining after the intersection (area weighting). For example, half of the population of the original polygon is located in the buffer zone of the green space or water area. Thus, the population figure of this cell is multiplied by a weighting factor of 0.5. Finally, the weighted inhabitant values are summed and divided by the total number of inhabitants in the respective municipality.

#### (S1) Green-space provision per inhabitant related to urban green spaces within walking distance to residential areas

**Step 1:** Same as (M)

**Step 2:** Buffer polygons with a distance of 300 m are created for contiguously built-up and predominantly inhabited settlement areas.

**Step 3:** The area of urban green spaces within the buffer polygons are summed up.

**Step 4:** The quotient of the calculated sum and the number of inhabitants in the respective municipality is created.

#### (S2) Green-space provision per inhabitant related to total amount of urban green spaces

**Step 1:** Same as (M)

**Step 2:** The area of urban green spaces within the municipal borders are summed up.

**Step 3:** The quotient of the calculated sum and the number of inhabitants in the respective municipality is created.

The average degree of accessibility of green spaces in the German cities is relatively high (Table 3). This shows that the efforts to provide cities with green spaces, which were formulated more than 100 years ago and became more of a focal point due to a conference of heads of municipal park departments in the 1970s (Wiegand 1970), were not in vain. However, first, further efforts for improvement are required, especially in cities below the average or far from the 100% target (means every dweller should have access to nearby urban green, BMU/B 2015). The deviation from the objective is measurable based on the indicators (Figure 2). Second, it must be ensured that the provision with green spaces relevant for recreation in the residential environment does not decrease when measures for qualitative internal densification are taken, particularly in growing big cities.

Also the average values of the additional indicators S1 (2013: 101.6 m²/inh.) and S2 (2013: 273.7 m²/inh.) are at a relative high level. A classification of the large German cities according to the number of their inhabitants shows that for all three indicators the mean and the range increase with decreasing city size (population) (Table 3). This means that larger cities have more problems to ensure the provision and accessibility of green spaces. Nevertheless, there are also smaller cities with comparatively low values for the provision and accessibility of green spaces. However, there is no statistically significant correlation between indicator values and municipal area or between indicator values and population. The Pearson’s correlation coefficient between the values of all indicators and the municipal area is not less than −0.2 or greater than 0.2. The correlation coefficient between indicator results and population lies in the same range.

An analysis of indicator values has been carried out for three dates; it shows a decrease (Table 4). The changes
between 2008 and 2013 have to be taken with a grain of salt, because in this period, a change in the modelling of the database (ATKIS Basic-DLM) has occurred. Therefore, a portion of the calculated indicator value changes are not due to real changes in land use, but to changes in land use allocations. Since 2013, Basic-DLM data in Germany are available in a unified modelling scheme (Schorcht et al. 2016). Therefore, the indicator value for 2015 was calculated in order to obtain a more robust assessment of first trends. More reliable results will

Figure 1. Overview on the calculated indicators M and S2 on federal level in 2013.

Table 3. Results of indicator calculation for the German cities, structured by city sizes (inh.) in 2013.

| City class (No.) | M (%) | S1 (m²/inh.) | S2 (m²/inh.) |
|-----------------|-------|--------------|--------------|
| ≥1 Mio (4)      | 67.1  | 55.1         | 100.9        |
| ≥0.5–1 Mio (9)  | 69.0  | 68.9         | 105.0        |
| ≥0.25–0.5 Mio (13) | 77.7   | 86.6         | 152.6        |
| ≥0.1–0.25 Mio (51) | 78.7    | 119.4        | 261.4        |
| ≥0.05–0.1 Mio (105) | 80.5    | 163.3        | 443.2        |
| All (182)       | 74.3  | 101.6        | 273.7        |

Figure 2. Proportion of cities/dwellers with access to urban green space near to residence (indicator M in 2013).
be calculated after the update cycle of 5 years in 2018 when the land use data (ATKIS Basic-DLM) have been completed for the entire country. The census data are updated only every 10 years so that the same values were used in the three analyses of \( M \).

The indicators allow a nationwide assessment of the accessibility of green spaces for the residential population in the cities. However, it is worthwhile having a closer look at cities regarded as ‘green’ while exhibiting a below-average degree of accessibility of green spaces in the residential environment and vice versa (Section 5, Figure 3).

### 5. Discussion

With the ES indicator development, we are pursuing the goal of carrying out a reproducible assessment for all larger German cities. The indicators are rather simple, robust and reproducible measures. They exhibit an average value for Germany or on the level of the federal states, but also allow for simple nationwide comparisons between the cities. The proposed indicator \( (M) \) is easy to interpret, since the closer the degree of provision comes to 100%, the higher the welfare effect of recreation activities (Krekel et al. 2015). This target value is easier to justify, to compare and to communicate than the green-space provision (area per inhabitant – \( S1 \) and \( S2 \)). The number of inhabitants is more useful as a reference quantity for examining the accessibility of green spaces than the municipal area, since a concentration of population has a stronger influence on the indicator, which therefore exhibits a closer relation to the people looking for rest and recreation.

In 2013, nationwide, 74.3% of the inhabitants of the cities studied are able to reach at least green spaces (>1 ha) at a linear distance of no more than 300 m (=500 m walking distance) and larger green spaces (>10 ha) at a maximum linear distance of 700 m (=1000 m walking distance). The distances are stipulated/chosen by the authors and planners which may be different in other countries or studies (see Section 3.2).

One of the lowest degrees of accessibility of green spaces for the residential population \( (M = 53\%) \) was calculated for Wiesbaden, although the city has a relatively high value of urban green space with.

### Table 4. First trends overview for calculated indicators for all cities ≥50,000 inhabitants.

| Indicator | 2008 | 2013 | 2015 |
|-----------|------|------|------|
| \( M \) (%) | 79.4 | 74.3 | 74.1 |
| \( S1 \) \( (m^2/\text{inh.}) \) | 104.0 | 101.6 | 99.7 |
| \( S2 \) \( (m^2/\text{inh.}) \) | 279.6 | 273.7 | 266.7 |

### Figure 3.
Spatial distribution of green-space provision within the examples of the cities Wiesbaden and Stuttgart (for location, see Figure 1).
recreation function per inhabitant \((S_2 = 302 \, \text{m}^2/\text{inh.})\). The reason for the calculated below-average degree of accessibility lies in the low number of recreational spaces in the city centre with a high population density (Figure 3).

On the other hand, e.g. the values of 80% for the accessibility of green spaces for the residential population in the big city of Stuttgart stand out, although the area of green spaces per inhabitant is relatively low \((S_2 = 116 \, \text{m}^2/\text{inh.})\). The public parks in the densely populated core city and the remaining green spaces on the adjoining slopes as well as high population densities in the centres surrounded by forest areas outside the city centre are among the special features in Stuttgart (Figure 3).

Comparisons with other national and international assessments show that the results are plausible. However, it only makes sense to compare numbers if they have been calculated with similar methodology and comparable databases. This is particularly evident regarding the ‘simpler’ additional indicators that may vary more widely, depending on the selection of reference parameters (selection of type and area size of green spaces, city area, etc.). Wüstemann et al. (2016) used the EUA and not ATKIS as a database for assessing German cities. They estimated that 93% of the German households have access to green spaces within 500 m and 74.1% within 300 m linear distance around the location. The green-space provision for major German cities was calculated to be 8.1 \, \text{m}^2 per capita (median). Kabisch et al. (2016) show that the share of the population in European cities living within a 500 m linear distance from green and forest areas with a minimum size of 2 ha ranges from 11% to 98%. For the city of Berlin, Germany, they found that 30% of the population lives within a 300 m and 68% within a 500 m distance. Additionally, they found that on the basis of municipal data 58.7% of the population have access to urban green space within 300 m distance. The latter value is slightly below our result for Berlin \((M = 61.4\%)\). Possible reasons for a higher indicator value might include a broader definition of green spaces relevant to recreation (additionally considered: water area, orchard meadow, cemetery) as well as the inclusion of green spaces outside the municipality under consideration.

The main indicator \((M)\) is comparable in terms of approach, implementation and results with the studies in Flanders (Simoens et al. 2014). Thus, the share of population near green spaces (2011) is 84.1% in Antwerp, 78.4% in Ghent and 73.0% in Bruges. Barbosa (2007) analysed access to green spaces in Sheffield (UK) and found that 64% of the households fail to meet the recommendation of the regulatory agency English Nature, which states that people should live no further than 300 m from their nearest green spaces. Moreover, they found that distances of households to green spaces vary greatly across Sheffield with a mean distance to public green space of 416 m. We did not consider implementing an approach based on the mean distance to the closest green space, as it would require reliable-free georeferenced data per household across Germany. Moreover, an implementation based on the 100 m population raster of the 2011 census is problematic, as the distance between population and green space can be modelled either based on the centre or the boundary of the raster. The differences between these two approaches could be significant. In our approach, we were able to circumvent this problem by modelling the proportion of a raster cell proximate to the green space and using this to determine the population count.

In the French city of Nantes, which won the title of European Green Capital in 2013, 100% of the population lives within 300 m from green spaces (Nantes Métropole 2012). The first Environmental Assessment for Europe showed significant differences in green-space provision between European cities ranging from Brussels, Copenhagen and Paris, where all citizens live within 15 min walking distance from public green, and Venice and Kiev, where the corresponding figure is 63% and 47% of the population, respectively (Stanners & Bourdeau 1995).

Cities should provide at least 20–30% or 9 \, \text{m}^2 per capita green spaces as recommended by the World Health Organisation (WHO, Kuchelmeister 1998). According to analyses of the BMUB (2015), there are \(46 \, \text{m}^2\) of green spaces per inhabitant in big German cities; in small cities, the value is nearly twice as high. As a general rule, the authors state that the bigger the cities, the less green space is available per inhabitant. Accordingly, cities such as Berlin or Leipzig have developed corresponding normative goals for providing the inhabitants with green spaces (e.g. 6 \, \text{m}^2/\text{inh.} in Berlin, Senatsverwaltung für Stadtentwicklung und Umwelt 2013). This approach may be suitable for a comparison within the municipality, but it distorts the comparative picture between places, since, on average, cities with a high population density are placed at a disadvantage, e.g. compared to cities which have incorporated sparsely populated surrounding areas.

Of course, green-space coverage can be calculated in a variety of ways leading to different results or rankings (Fuller & Gaston 2009). The supplementary indicator \((S_1)\) proposed by us primarily captures green spaces in the surroundings of inhabited settlement areas and refers them to the number of inhabitants of a municipality. For German cities (>100,000 inhabitants), the value is approx. 81.4 \, \text{m}^2/\text{inh.}, and thus lies significantly above the previously mentioned 46 \, \text{m}^2 green spaces per capita. Differences between the two approaches also lie in a broader definition of
green spaces (e.g. additionally taking into account grassland and water areas) and the spatial relationship of green spaces to settlement areas (also beyond municipal boundaries). The inclusion of green spaces in the surroundings of inhabited settlement areas leads to a modified value, as it is not merely a summation of green spaces within municipal boundaries.

The discussion shows that the indicators put forward cannot represent all aspects of the recreation services in cities. The result of the indicator calculation decisively depends on the databases used, the land uses (object types) classified as relevant for recreation and the choice of threshold values. Quality and accessibility are important for the recreational use of land (Arlt et al. 2005). However, a user-specific nationwide acquisition of the quality and accessibility of potential recreational areas is currently unachievable. In this respect, only an approximation is possible.

Green areas, parks, cemeteries, grassland, orchard meadows, forests, woods as well as surface waters are regarded as green spaces in our calculation (Section 3.1; Table 2). As an example, we have analysed how object types such as water areas and cemetery spaces influence the indicator value. In the German average, the corresponding value changes are in the lower single-digit range.

Allotments were excluded from the calculation, because they are not open for the public. But one could them make in some cases accessible. The addition of this category would lead to a nationwide additional supply of 1.8 million people (5.7%) for indicator (M) and impressively demonstrates the potential of allotments for improved green-space accessibility in the residential environment. Therefore, allotments should be more included in green-space planning which implies that in districts with deficits in public green spaces the accessibility to allotments for the general public should be assured.

The assessment on the basis of population figures from a recent high-resolution census (raster maps with 100 m raster resolution) regarding indicator (M) allows a more differentiated analysis of the ES demand compared to the supplementary indicators (S1, S2). However, the census raster data are only collected every 10 years, which restricts the update frequency.

6. Conclusion

Key parameters of the quality of green spaces in urban areas are important for pointing out reference values for municipal practice. In this context, empirical data and action goals for ‘Green in the City’ based on indicators regarding the accessibility and provision of green spaces for assessing the ES ‘recreation in the city’ represent a basis for the pursuit of a more sustainable urban development, as green infrastructure has been stressed as an important factor for health and constitutes much of the quality of life in cities. Three indicators were proposed and applied in a large number of German cities (n = 182) and are thus quite comprehensive. In total, green spaces are accessible for daily recreation for 74.3% of the inhabitants in large German cities. Underprovision affects 25.7% of the city population and thus 8.1 million inhabitants. The green area in the surroundings of inhabited settlement areas per inhabitant in the German cities amounts to 102 m² on average for the year 2013. The indicator values are updatable, but the recent trend (slight decrease) is yet uncertain.

Green-space provision has often been expressed in terms of size per inhabitant, which is not really sufficient (large variation between different parts of the settlement, influenced much by where the outer border is drawn). The combination of the sizes of green spaces with distances allows for relatively simple modelling of the accessibility of green spaces and represents an effective methodology for a nationwide application. Deficits and trends can be pointed out, and comparisons between cities are possible, also internationally if the methodology is comparable. However, such nationwide calculations can only give an overview. Therefore, it is possible for cities which have higher-resolution data available to carry out more complex analyses in order to underpin the determined quantitative values by respective site-specific quality requirements for municipal planning of green spaces.

The proposed indicators have been accepted by the German environmental authorities but are still being coordinated at the political level. On the one hand, they contribute to the implementation of Target 2, Action 5 of the EU Biodiversity Strategy 2020 (reporting obligations of Germany). On the other hand, the main indicator (M) is also proposed for the German National Strategy on Biological Diversity (Nationale Strategie zur Biologischen Vielfalt, NBS).

The ES indicator can underpin this NBS target as a measurement and monitor quantities. The indicator is selected to address the aims of increasing the percentage of green areas and structures, linking them and pursuing a qualified brownfield development of settlements as well as reducing land use (BMU 2010). By 2020, the greening of the near-residential open spaces is to be increased significantly, and publicly accessible green spaces with varying qualities and functions are to be available within walking distance. This is not only important for human health reasons (Section 2) but also because a good accessibility and interconnection of green spaces is critical to their usability and enhances the attractiveness of inner cities. It helps to stop the land-intensive migration into the surroundings and contributes to reducing the volume of traffic.
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No potential conflict of interest was reported by the authors.

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