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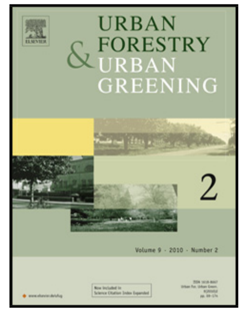

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Challenges of urban green space management in the face of using inadequate data

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Highlights

- Urban authorities often focus on a fraction of urban green spaces
- They refer to those for which they are formally responsible
- Agricultural land, private and informal green spaces are left out of their scope
- Meanwhile all green spaces count in light of green infrastructure and ecosystem services concepts
- Many datasets which provide a more complex picture are freely accessible to public institutions

Abstract

Effective urban planning, and urban green space management in particular, require proper data on urban green spaces. The potential of urban green spaces to provide benefits to urban inhabitants (ecosystem services) depends on whether they are managed as a comprehensive system of urban green infrastructure, or as isolated islands falling under the responsibility of different stakeholders. Meanwhile, different urban green space datasets are based on different definitions, data sources, sampling techniques, time periods and scales, which poses important challenges to urban green infrastructure planning, management and research. Using the case study of Lodz, the third largest city in Poland, and an additional analysis of 17 other Polish cities, we compare data from five publicly available sources: 1) public statistics, 2) the national land surveying agency, 3) satellite imagery (Landsat data), 4) the Urban Atlas, 5) the Open Street Map. The results reveal large differences in the total amount of urban green spaces in the cities as depicted in different datasets. In Lodz, the narrowly interpreted public statistics data, which are aspatial, suggest that green spaces account for only 12.8% of city area, while the most comprehensive dataset from the national land surveying agency reveals the figure of 61.2%. The former dataset, which excludes many types of green spaces (such as arable land, private and informal green spaces), is still the most commonly used. The analysis of the 17 other cities confirms the same pattern. This results in broader institutional failures related to urban green infrastructure planning, management, and research, including a lack of awareness of green space needs (e.g. connectivity) and benefits (ecosystem services), and the related political disregard for urban green spaces. Our comparison suggests that a better understanding of green space data sources is necessary in urban planning, and especially when planning urban green infrastructure.

Keywords: urban green space; urban planning; green space availability; urban green space data; green space classification; informal green spaces; Lodz

1. Introduction

Urban green spaces have already been the subject of extensive research, largely meant to support green space planning and management (e.g., Hansen et al., 2015; Kabisch, 2015; Rall et al., 2015). However, many of the relevant discussions, and especially formal planning documents, tend to overlook some green space types and overemphasize some others. This is related to the fact that the definitions and classifications available to date seem not to have ended the debates on what is an urban green space, and how the different green space types and categories are related to each other (Cvejić et al., 2015; Taylor and Hochuli, 2017). To make things even more complicated, different green spaces are managed by different stakeholders (public vs. non-public, city vs. districts), and they are characterized by different degrees of accessibility by the public, and many other different administrative features (Kabisch et al., 2016).

Formal planning documents in cities often focus on the formal and most broadly recognized flagship categories of urban green spaces, such as parks, forests, allotment gardens, cemeteries, and street greenery. These green spaces have also been the focus of much research because they are clearly demarcated and depicted in reliable, official inventory databases (Feltynowski, 2015; Schipperijn et al., 2010). This is mainly because these green spaces are primarily managed by formal institutions and they are located on public land. Meanwhile, many forms of urban green spaces elude formal classifications, either because they are located on private land or they are not perceived as green spaces through the dominant lens of recreational potential (e.g., arable land or urban brownfields), or because of their small spatial scale, temporal and transitory character as interim or brownfield sites, as well as the uncertainty of land tenure and changing governance settings. Such informal green spaces have been defined by Rupprecht and Byrne (2014) as those covered with vegetation, usually neither designated nor recognized by governing institutions or owners as spaces for use by the inhabitants.

As a result, and in addition to the above fundamental challenges, different urban green space datasets are prepared based on different sources of information and definitions, and they are often neither consistent nor compatible (cf. Kabisch et al. 2016). This is also the case in Poland, where the predominantly used green space dataset is derived from public statistics and captures only a small fraction of all green spaces.

Our objective in this article is to analyse the differences between several urban green space datasets, including formal green space data collected for the purposes of public statistics, and the broadly used land use and land cover data. Based on our analysis, we highlight the challenges related to these differences from the point of view of urban green space planning, management, and research. Ultimately, our analysis is meant to support the planning and management of green infrastructure by indicating which green space data sources are the most adequate and reliable.

In the following section, we briefly present the most important sources of information on urban green spaces. We provide brief information on urban green space governance in our case study city – Lodz (Łódź) – as an illustration of the broader urban green space management patterns in Poland and as the background for the comparison of urban green space data sources. We then test if the data for 17 other major cities in Poland follow a similar pattern. Subsequently, we discuss the results of our comparison in the context of the challenges arising from the use of inadequate data. In the end we offer conclusions on which sources of data seem to be the most relevant in the context of urban green space planning, management, and research, as well as urban planning in general.

2. Materials and methods

2.1. An overview on urban green space data and an illustration of the broader situation in Polish cities

There exists a range of different spatially explicit datasets for the management, monitoring and study of urban green spaces (Table 1). Some of them are based on remotely sensed images, others on field inventories and mapping, and still others on obligatory reporting to various public bodies. The different datasets are used for different purposes. Data based on remote sensing material are often used for cross-country comparisons because they are prepared based on identical methods and therefore ensure comparability. For example, for comparisons between European cities where only relatively rough data is available for many urban areas, researchers tend to use CORINE land cover data (Fuller and Gaston, 2009; Kabisch and Haase, 2013; Larondelle and Haase, 2013). For more detailed information, researchers often reach out to resources characterized by higher resolution, such as Urban Atlas data and orthophotomaps, or perhaps less frequently, high resolution satellite images and aerial photographs. For example, Nowak and Greenfield (2012) used aerial photographs to study changes in tree, impervious, and other land cover types in 20 U.S. cities. Badiu et al. (2016) compared aerial photographs and Urban Atlas data, along with public statistics datasets, to compare urban green spaces in 38 cities in Romania. Researchers from the European Commission’s Joint Research Centre, the developer of the European Settlement Map, indicated that their resource can also be successfully used to study urban green spaces (Pafi et al., 2016).

For analyses which focus on the local level, such as a single city, local green space datasets are often preferred because of their high resolution and accuracy (Kabisch and Haase, 2014). In many countries, the local datasets most commonly used in urban planning are prepared by land surveying agencies. In different European countries, these databases include largely compatible categories of land cover/land use data, and they are detailed and constantly updated (Burckhardt, 2015; Medyńska-Gulij, 2013; Morar et al., 2014). Examples include ATKIS (Amtliche Topographisch-Kartographische Informationssystem) in Germany, BD TOPO® in France, and BDOT (Baza Danych Obiektów Topograficznych) in Poland.

Particularly detailed and yet automated inventories of trees and shrubs can be based on LiDAR, an information acquisition technique based on laser technology and modelling (Caynes et al., 2016; Chen et al., 2015; He et al., 2013). LiDAR data can be combined with further sources of information, such as orthophotomaps, fieldwork, and other data sources to study tree aggregations, individual trees, and other detailed green space characteristics (Guan et al., 2013; MacFaden et al., 2012; Yan et al., 2015). Some cities have much more detailed data on urban green spaces, including tree inventories (Nielsen et al., 2014). Still, there are cities where local databases are either not available or not accurate enough, and then – even for local analyses – researchers may be forced or prefer to use sources such as CORINE or Urban Atlas (Mrozik, 2016; Petrisor, 2015), or OpenStreetMap (Wuestman, 2015).

Data on urban green spaces are also collected for the purposes of public statistics, which however often depict only the most remarkable green space categories. Although these data are widely used because of their availability and because their interpretation does not require the use of GIS tools (cf. Szymańska et al., 2015), they neglect the spatial dimension of green space distribution and many other types of green spaces which do not fit into the basic categories of, e.g., public green spaces. Similarly, there are specific analyses available for different cities based on their own green space classifications and data, often available from the local planning agencies. For example, a recent green infrastructure strategy for Warsaw included diverse land use categories derived from the local register (Szulczewska, 2016).

Furthermore, when formal, standardized data on urban green spaces are not available or when one needs to complement the official data with additional information based on the inhabitants' perception of green spaces, participatory GIS methods can be used (Kyttä et al., 2010, 2013; Pietrzyk-Kaszyńska et al., 2017). This is particularly useful when one decides to collect additional information on green spaces for management purposes, such as concerning their functions or deficiencies. Indeed, one more reason for relying on such complementary sources of information is that urban inhabitants often do not distinguish between formal green spaces created and maintained by the city office, and informal ones, which may be seen by city authorities as reserve land for investment purposes (Danford et al., in press; Kremer et al., 2013; Pietrzyk-Kaszyńska et al., 2017; Rupprecht and Byrne, 2014).

In addition to the above, new tools to collect information on urban green spaces keep being developed to support green space management and research. These include various citizen science initiatives, which focus for example on inventorying urban trees (Paulos et al., 2009; Vogt and Fischer, 2016), and tools which collect readily available information from other Internet resources. The latter include an application developed by Li et al. (2015) which analyses greenery captured by Google Street View. A similar approach has also been tested for other online street view services (Long and Liu, 2017).

A combination of different datasets may be necessary for comparisons within longer time frames, especially to include information on green spaces from the time before satellite images or aerial photographs became available. For example, Madureira et al. (2011) compared ortophotomaps with old topographic maps and spatial planning documents (as well as supporting information underlying those planning documents) to study changes in green spaces in Porto throughout the 20th century.

In general, the selection of a green space dataset depends on the specific needs and their availability. However, insufficient knowledge of which data is available, or poor data availability, may pose significant challenges to green space analysis and management.

In the case of Lodz, similar to other Polish cities, the data on urban green spaces referred to in planning documents, academic monographs, and research papers is most often based on public statistics (City of Lodz Office, 2013; Kaczmarek et al., 2006; Marszał, 2006). The most commonly used spatially explicit data are also based on the main categories distinguished for the purposes of public statistics (e.g. Czembrowski and Kronenberg, 2016).

This is possible because using data from the land surveying agencies allows us to spatially represent the public statistics data. The reasons for using this dataset may be related not only to the specific purposes of the different studies, but also to the fact that this interpretation mirrors the official thinking about green spaces in Poland (as reflected in various political and public discussions, in which green spaces are reduced to these key categories).

2.2. Data used in our analysis

For our analysis of urban green spaces in Lodz, we selected the following datasets, adjusting the green space categories to make them comparable:

- Open Street Map (2015).
- BDOT 1:10,000 (2015);
- Urban Atlas (2006 and 2012);
- Landsat multispectral satellite images (2006 and 2013);
- Two versions of public statistics data – one following the narrow official definition of urban green spaces, and the other a broader interpretation of what is an urban green space (2006 and 2012).

Having tested the above five sources of data in Lodz, we moved to the next step, that of comparing BDOT, Urban Atlas and the narrowly interpreted public statistics data for 17 other regional capital cities in Poland. The aim of this broader analysis was to explore whether the challenges related to urban green space data availability and the interpretations observed for Lodz are unique, or whether they illustrate common problems. The narrower selection of data sources for this comparison was motivated by the results from the first step (i.e. the overall consistency between Urban Atlas and Landsat, and the relatively low usefulness of OSM).

Some of the analysed datasets feature data which are collected periodically and thus represent a situation at selected moments in time, while others are permanently updated and only the most up-to-date version is provided (hence they are not available for historical comparisons). The former include Urban Atlas, satellite imagery, and data collected for the purposes of public statistics. The latter are represented by the Open Street Map (OSM), and the BDOT datasets available from the land surveying agencies (the Head Office of Geodesy and Cartography in the case of the BDOT 1:10,000 used in our analyses). The selection of 2006 and 2012 as reference years resulted from the fact that these are the years for which the Urban Atlas data are available. Because clouds in Landsat satellite images from 2012 partly obscured Lodz, we selected an image from 2013. In the case of OSM and BDOT, we used the versions from the end of 2015, which were the only available ones when we started our analysis.

As already indicated, the datasets used in our study differ in many respects. They are based on different green space classifications, which made it necessary to follow an individual approach in analysing the data. Table 2 presents green space categories from each of the analysed datasets considered in our study.

We compared the four spatially explicit datasets with the most broadly used data collected for the purposes of public statistics. Data collected for the purposes of public statistics are comprehensive, but they are most often narrowly interpreted. According to the Central Statistical Office of Poland (CSO), urban green spaces consist of parks, municipal forests, green squares, residential green spaces, street greenery, zoological and botanical gardens, and cemeteries. The key to selecting these types of green spaces is that they are managed by municipal authorities.

In the case of public statistics, we used two variants:

- the basic one, which reflects the most common approach and focuses on the most elementary formal categories recognized by the CSO definition; and
- the broader one, which is comparable in terms of the underlying green space categories with the other databases we considered – broadening the narrow interpretation of green spaces used for the purposes of public statistics by other categories which we understand as urban green spaces but which are not treated as such for the purposes of public statistics (such as arable land, meadows, pastures, horticulture, private gardens, and brownfields/vacant lots located within city boundaries).

Our analyses were performed with the use of QGIS, and involved the use of geoprocessing functions such as the 'union' of overlapping areas. In the case of OSM, we selected all categories corresponding with green spaces identified in other sources (Table 2). In the case of the BDOT 1:10,000 dataset, only one column featured all categories of the 'biologically active areas' which we associate with green spaces. Urban Atlas data on urban green spaces for 2006 and 2012 were identified based on the descriptions provided in the relevant mapping guides (European Union, 2016, 2011): for 2012 we included 27 land cover classes, and for 2006 we included 20 land cover classes.

The analysis of raw satellite imagery started with the selection of the most appropriate images in terms of best representing green spaces in our case study city. We used Landsat 7 ETM+ and Landsat 8 pictures, respectively, from July 2006 and June 2013. The blind spots in the 2006 pictures resulted from the Scan Line Corrector failure and had to be partly corrected manually with the use of the 2005 orthophotomap of Lodz (in which each pixel represented 1 m). The Landsat 8 picture was free from such failures. In both cases, green spaces were identified with the use of QGIS Semi-Automatic Classification Plugin (SCP), which is useful for generating training areas (Regions Of Interest). We used the Spectral Angle Mapping method, which is one of the three built-in satellite imagery classification methods in the SCP plugin. This algorithm is based on an assumption that a single pixel can be attributed to one class only, and the most relevant class is selected based on the angle between different spectres (Khaleghi et al., 2014; Kruse et al., 1993; Rashmi et al., 2014).

3. Results

We compared the share of green spaces in Lodz as a percentage of the total city area in the different datasets (Figure 1). Of these, the narrowly interpreted public statistics data yielded the lowest result – 12.2% in 2006, and 12.8% in 2012 (the difference results primarily from changes in the interpretation of street greenery). Out of spatially explicit datasets, OSM yielded the lowest result – 32.3%. Conversely, the BDOT data turned out to be the most comprehensive, indicating 61.2% of green spaces in the city. Landsat satellite images and Urban Atlas data provided highly consistent results, and these results were also close to the broadened version of public statistics data – yielding around 52% of green space in the city.

The time dynamic analysis is possible only for those datasets which are collected and made available periodically, i.e. – in the case of those used in our analysis – public statistics, Urban Atlas, and satellite imagery. According to the broadened version of public statistics, the share of green spaces has gone down by 1.9 percentage points between 2006 and 2012, while Urban Atlas and satellite images indicated a decrease of 0.2 and 0.3 percentage points, respectively. The latter changes are too small to indicate any trend as they may well result from minor problems with the underlying images.

The analysis of maps presented in Figure 1 indicates that while the BDOT data are the most comprehensive, they still do not include some smaller green spaces depicted in the other datasets, especially in the city centre. The OSM dataset features green space components which have not been depicted in other datasets, especially in the city centre. This is probably because there are more active OSM users in the city centre. Conversely, BDOT includes areas adjacent to the airport runway, which were not included as green spaces in either the Urban Atlas or satellite images we analysed. In Figure 2, we overlaid the BDOT data with other data sources to identify these differences.

Each of these sources adds more green spaces to the picture. However, to some extent this is related to the fact that BDOT contains the most recent data, and some areas captured as green spaces in 2012 have already been developed for residential, transport or commercial use. The most visible example is the motorway and its access roads in the east of the city, which opened in 2016 yet are still depicted as green spaces in the Urban Atlas. Similarly, the OSM green space dataset is not sufficiently updated, as indicated by the fact that it also includes parts of the motorway and its access roads, even though they are already marked as roads and not green spaces in BDOT from the same period (Figure 2b). This indicates that we cannot simply combine information from different sources (which would yield 68.9% of the area in Lodz as green space, Figure 2d) because some data have already become out of date.

Complementing the analysis done for Lodz, we used the three most characteristic sources of data on urban green spaces (public statistics, Urban Atlas and BDOT) to compare the results for 17 additional cities in Poland – all regional capitals. The results indicate a consistent pattern (Table 3) – with BDOT always the most comprehensive, while the public statistics dataset is always the least comprehensive in terms of representing urban green space cover. The analysis performed for all 18 cities indicates a correlation between the BDOT and Urban Atlas data (correlation coefficient 0.702), but no correlation between public statistics and the other two sources of data. This indicates a general weakness of the public statistics dataset.

4. Discussion

The most commonly used source of information on urban green spaces in Polish city administrations (narrowly interpreted public statistics) largely distorts the picture of what urban green spaces are and where they are. Even though these data are of limited use for detailed and comprehensive urban green space planning, analysis and monitoring, they are used as a basis for all types of policy and strategic documents, including environmental protection programmes, development strategies, and masterplans and their underlying baseline studies.

Local land surveying agencies provide the most comprehensive datasets. However, none of the datasets is fully comprehensive, as each includes some green spaces which have not been included in some others. In the case of satellite and aerial imagery, the quality of the derived information depends on the resolution of the underlying images, and even if their analysis is laborious, they do not provide the most accurate data. The OSM data are often considered less accurate, although – as also identified in other studies – OSM tends to overrepresent some well-recognized land use/land cover categories (Haklay, 2010; Mooney et al., 2010).

In the following sections, we discuss particular needs in terms of improving data on urban green spaces.

4.1. The need for a more comprehensive urban green space definition in public statistics

The narrow interpretation of green spaces given by CSO guides the reporting of local authorities, and – at least to some extent – the broader recognition (in Poland) of what an urban green space is. The narrow interpretation is also followed by local authorities and other institutions, which use these data for operational purposes. This interpretation excludes many other categories of green spaces present in cities, such as arable land, and private and informal green spaces. Although data on the latter are also available in public statistics (and we used them as the broadened version of public statistics data in our analysis), in practice they are not associated with urban green spaces because of the narrow definition adopted by CSO (the lock-in problem). Our broadened version of public statistics is largely compatible with Urban Atlas and satellite imagery, and only OSM and BDOT – based on a similarly inclusive understanding of green spaces – yield significantly different results. This indicates that external resources, such as Urban Atlas and satellite images, provide meaningful, spatially explicit counterparts of the broader variant of the public statistics dataset, at least in terms of the share of green spaces in the city.

Although we recognize that the selection of specific data depends on the specific purposes for which they are used, the selection of any narrow set of green spaces, such as the one determined by CSO, must be the result of a well-thought-out decision on the purposes of such an analysis, and not from the lack of awareness of the fact that urban green spaces are much more diverse and that their spatial location counts. A narrower selection of green spaces implies that some green spaces (or actually *most* of them in the case of Polish cities) are not treated as such, and the potential for understanding them as parts of a green infrastructure framework is missed (cf. European Commission, 2013). In addition, any narrower selection of green spaces fails to reflect the numerous ecosystem services provided by urban green spaces (Gómez-Baggethun et al., 2013).

Although our analysis focuses on Polish cities, this issue is also relevant in other countries. There are only few examples of urban authorities attempting to address green spaces which fall outside of their formal scope of responsibility, such as private gardens (Green et al., 2016), although many more address multiple green space categories as part of urban green infrastructure planning (Davies et al., 2015).

4.2. Need for more compatibility between different datasets

Another challenge is that the data presented in different datasets are not compatible. Different green space categories considered in the different datasets do not necessarily overlap, and even the understanding of what falls within the different categories may not necessarily be consistent. This makes it impossible to compare information on specific types of green spaces derived from the different datasets, not to mention identifying information on additional types of green spaces which are not covered in some or any of the datasets. For example, in none of the considered datasets are forests distinguished between private and public, although there are both types in Lodz, and it might be necessary to distinguish between them for the purposes of specific analyses (interestingly, the public statistics dataset only includes public forests). To derive such information, one might need to reach out to further sources, such as maps identifying ownership.

The compatibility of green space data is also limited because the classification used for the purposes of public statistics has changed several times and data from different periods are inconsistent. Even city boundaries change, in some cases resulting in dramatic changes in the share of green space within city boundaries. This poses particular challenges for urban planning and urban green space governance, especially when it results in a sudden increase of the share of urban green spaces in a city. In such a situation, it may lead to an unexpected fulfillment of some green space availability targets (if present), or simply to a false complacency on the part of some stakeholders that there are (too) many green spaces in a city and that some of them can be developed (even when official green space availability targets are not present). Finally, the understanding of green spaces in different cities differs, even if they are meant to comply with the general definitions used by CSO (Pietrzyk-Kaszyńska et al., 2017).

The fact that many green spaces present in cities, such as arable land and private and informal green spaces, are not included in urban green space planning and governance, and that cities often lack comprehensive inventory data on urban green spaces, as well as that green space classifications are not consistent in different datasets and even among cities, poses important challenges in terms of urban sustainability and resilience. This indicates the need to use land use or land cover classes as indicators of what is a green space, and – in consequence – of the related ecosystem services. However, as revealed by recent research in the area of urban ecosystem services, even such an approach has its own limitations for comparative research in urban areas, due to the differences in urban morphologies and urban heterogeneity (Kremer et al., 2016). As a result, studies on urban ecosystem services provide meaningful information only on areas where local or regional measurements have been acquired (Haase et al., 2014). Nevertheless, the use of land use or land cover classes provides a much more meaningful information on urban green spaces than the use of formal green space classifications. Furthermore, the public statistics green space data are collected only for municipalities or equivalent units (LAU level 2, formerly NUTS level 5, according to the Eurostat classification), and cannot be disaggregated into lower administrative units, while green space data are particularly relevant at the local scale. Meanwhile, spatially explicit data can be aggregated and disaggregated, down to the level of a single property.

Other researchers have also compared different sources of information on urban green spaces and came to similar conclusions. For example, Badiu et al. (2016) compared aerial photographs with the Romanian national statistics, local green space data from Environmental Protection Agencies, and the Urban Atlas, and identified significant differences between these different datasets. Interestingly, in the case of Romanian cities, formal statistical data overstated green space area when compared to the most accurate aerial photographs. Furthermore, a comparison of different sources of green space data in Berlin and Lodz (Kabisch et al., 2016) indicated that in Berlin the local database was more accurate than the Urban Atlas, and in Lodz – the opposite. Again, this was related to the fact that the local database in Lodz only included those green spaces which the city treats as such, i.e. which are formally managed by the city, and which follow the narrow classification used for the purposes of public statistics. The authors concluded that more consistent approaches towards green space reporting across the European Union would be helpful, and we subscribe to this conclusion.

4.3. Need for a comprehensive urban green space dataset (further research)

The search for a comprehensive urban green space dataset resembles the quest for the Holy Grail, and no dataset is comprehensive enough to include everything that is included in other sources (Ekkel and de Vries, 2017). Still, we can suggest what other information could be provided in a comprehensive urban green space dataset.

To facilitate green space management and research, further development of urban green space datasets should incorporate information on who manages each space. Typically, different municipal institutions are mostly interested only in those green spaces for which they are formally responsible, and – in light of the poor collaboration between different stakeholders – they neglect other green spaces and the connections between them (Kronenberg et al., 2016). Further research should also focus on measuring the accessibility of different green spaces and their related ecosystem services to different socio-economic groups of urban inhabitants (Baró et al., 2015; Kabisch et al., 2016). In this context, it is necessary to look into further attributes of urban green spaces, such as their physical accessibility (e.g. whether they are fenced) and whether they are socially hospitable. Ecological analyses (such as trait analyses) would require additional information on species composition. Climate adaptation plans would benefit from information on canopy cover and volume, not only green space area on the ground. Finally, such maps should be as broadly accessible as possible, in particular through collaboration with the Open Geospatial Consortium, which would warrant their easy use within major GIS software packages. Unfortunately, there are cases where public data is not being made available for public use, as is the case in many German cities and states. A particularly promising source of information on urban green spaces is the new and upcoming Sentinel data, which will greatly increase our ability to monitor land cover change.

4.4. Implications for urban green space planning and monitoring

The limited expertise of GIS tools, spatial analysis methods and processing of sensor data, in addition to the limited financial resources for software, staff and time seem to be the main restricting factors when it comes to the lack of use of spatially explicit data in various spheres of municipal management in Poland (Zagajewski, 2013; Zwirowicz-Rutkowska and Michalik, 2016). As a result, local authorities tend to use the public statistics dataset, which is not spatially explicit and neglects a large portion of urban green spaces. Furthermore, owing to path dependency if spatially explicit information was not used before and 'everything worked fine', there are few incentives to change this situation and start using it now. For these reasons, green space management strategies followed by the authorities of Polish cities usually neglect the spatial dimension and this has become part of the 'planning culture' (Figure 3). Owing to similar lock-in problems, the same incomprehensive data are also typically used by researchers in Poland (cf. Szymańska et al., 2015).

To manage green spaces more effectively, local authorities should strive to diversify and aggregate their sources of information, and obtain additional data on urban green spaces. Indeed, different qualities of urban green spaces need to be assessed using different methods. For example, remote sensing data does not capture the character and qualities of green spaces which can only be depicted with ground level analyses (Yang et al., 2009). Additional sources might include information on the public perception of green spaces, e.g. through a participatory GIS, and specialist inventories of different green space components. However, even when available, these sources of information are barely used in Polish cities (participatory GIS was used in Lodz, Krakow and Poznan (Pietrzyk-Kaszyńska et al., 2017), and regular tree inventory programs have only been established in the two largest cities, i.e. Warsaw and Krakow).

This illustrates the broader problem of insufficient collaboration between different institutions which collect and use data (Zagajewski, 2013), which is also typical of the broader problem of lack of collaboration between different stakeholders involved in urban green space management (Kronenberg et al., 2016). Eventually, this perpetuates the situation where different stakeholders only focus on those green spaces which fall within their responsibility. This causes further marginalization of private and informal green spaces in urban management and planning. Meanwhile, the uncertainty of land tenure and uncertain or dispersed management authority are key characteristics of informal green spaces (Pietrzyk-Kaszyńska et al., 2017). At the same time, stakeholders from around the world advocate formalizing such informal green spaces which would ensure their preservation as part of the relevant green infrastructure networks (Kremer and Hamstead, 2015).

The narrow interpretation of urban green spaces poses challenges for local authorities and researchers alike. A particular example here is the massive removal of trees in Polish cities triggered by the relaxation of the relevant legal restrictions introduced in the beginning of 2017. Property owners were no longer required to seek consent from local authorities to remove trees from their properties, and they were neither required to pay any fees or charges for removing trees, nor were they obliged to replace the removed trees with new ones. This has further aggravated the already difficult situation of urban green spaces, and especially of urban trees, in Poland (Kronenberg, 2015). Without a proper inventory of urban trees for the whole city, it is not possible to assess the losses related to the new law. Another example is linked to research: when a study was performed in Lodz in 2011 to assess the value of street trees in the city centre, to overcome problems with the availability of spatially explicit tree data, researchers had to choose a resource-intensive method which was independent of previously collected data (Giergiczny and Kronenberg, 2014). Indeed, data availability is one of the crucial factors influencing the selection of a valuation method (Larson and Perrings, 2013), and valuation is an increasingly popular tool meant to support urban green space management.

To conclude, the above challenges related to the use of inadequate urban green space data reflect and add to the broader barriers to urban greening and preservation of existing green spaces in Polish cities, such as insufficient funding, the priorities given to other, conflicting interests, the poor understanding of the importance of urban green spaces, and the related poor legal protection of urban nature (Kronenberg, 2015).

5. Conclusions

The fact that most discussions on urban green spaces in Polish cities are based on a narrow classification used for the purposes of public statistics makes it difficult to promote the broader concept of an interconnected system of urban green infrastructure. The narrow classification focuses on formal green spaces which are managed by public authorities. Meanwhile, various types of green spaces, which are still used by the inhabitants for recreational purposes and which provide many other ecosystem services, are not formally recognized as green spaces by local authorities. More broadly, these green spaces are not treated as such in the dominant classification used for the purposes of public statistics. Hence appropriate, consistent, and comprehensive urban green space data are essential for urban planning.

Better data are available – and reveal that green spaces account for a significantly larger share of our case study city area (12.8% vs. 61.2%), but they are barely used in Polish cities, at least not for the purposes of urban green space planning and monitoring. This is partly related to problems such as a lack of GIS skills, poor collaboration between the different institutions responsible for data collection and use, and in particular between different institutions responsible for urban green space management, and finally the 'tradition' of following the narrow interpretation of urban green spaces. A broader awareness of the availability of remote sensing datasets is necessary for better planning and research, but the first and easiest step would be to broaden the traditional categories of green spaces to cover other types of 'biologically active areas' and to understand that their spatial distribution is important.

Our results show a lock-in problem related to the dominant use of the narrow definition of urban green spaces imposed by the CSO, which nevertheless fits well into existing institutional arrangements related to urban green space management (only capturing those green spaces for which formal institutions are directly responsible). These findings are relevant for further discussions on the delineation of green spaces in cities, in particular from the point of view of urban planning and managing urban green spaces for the delivery of ecosystem services, as well as from the point of view of studying and ensuring urban green space availability and accessibility.

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References

Badiu, D.L., Iojă, C.I., Pătroescu, M., Breuste, J., Artmann, M., Niță, M.R., Grădinaru, S.R., Hossu, C.A., Onose, D.A., 2016. Is urban green space per capita a valuable target to achieve cities' sustainability goals? Romania as a case study. Ecological Indicators 70, 53–66. doi:10.1016/j.ecolind.2016.05.044

Baró, F., Haase, D., Gómez-Baggethun, E., Frantzeskaki, N., 2015. Mismatches between ecosystem services supply and demand in urban areas: A quantitative assessment in five European cities. Ecological Indicators 55, 146–158. doi:10.1016/j.ecolind.2015.03.013

Burckhardt, M., 2015. Erstellung eines differenzierten Gebäudebestandes auf Grundlage des ATKIS-Basis-DLM und Daten örtlicher Bauleitplanung. Kartographische Nachrichten 194–201.

Caynes, R.J.C., Mitchell, M.G.E., Wu, D.S., Johansen, K., Rhodes, J.R., 2016. Using high-resolution LiDAR data to quantify the three-dimensional structure of vegetation in urban green space. Urban Ecosyst 19, 1749–1765. doi:10.1007/s11252-016-0571-z

Chen, Z., Xu, B., Gao, B., 2015. Assessing visual green effects of individual urban trees using airborne Lidar data. Science of The Total Environment 536, 232–244. doi:10.1016/j.scitotenv.2015.06.142

City of Lodz Office, 2013. Polityka komunalna i ochrony środowiska Miasta Łodzi 2020+. City of Lodz Office, Lodz.

Cvejić, R., Eler, K., Pintar, M., Železnikar, Š., Haase, D., Kabisch, N., Strohbach, M.W., 2015. A typology of urban green spaces, ecosystem services provisioning and demands. Report of the GREEN SURGE project, Ljubljana and Berlin.

Czembrowski, P., Kronenberg, J., 2016. Hedonic pricing and different urban green space types and sizes: Insights into the discussion on valuing ecosystem services. Landscape and Urban Planning 146, 11–19. doi:10.1016/j.landurbplan.2015.10.005

Danford, R.S., Strohbach, M.W., Warren, P.S., Ryan, R.L., in press. Active Greening or Rewilding the city: How does the intention behind small pockets of urban green affect use? Urban Forestry & Urban Greening.

Davies, C., Hansen, R., Rall, E., Pauleit, S., Lafortezza, R., DeBellis, Y., Santos, A., Tosics, I., 2015. Green infrastructure planning and implementation: The status of European green space planning and implementation based on an analysis of selected European city-regions. Report of the GREEN SURGE project, Copehnagen.

Ekkel, E.D., de Vries, S., 2017. Nearby green space and human health: Evaluating accessibility metrics. Landscape and Urban Planning 157, 214–220. doi:10.1016/j.landurbplan.2016.06.008

European Commission, 2013. Green Infrastructure (GI) — Enhancing Europe's Natural Capital. Communication from the Commission to the European Parliament, The Council, the European Economic and Social Committee and the Committee of the Regions (COM(2013) 249 final), Brussels.

European Union, 2016. Mapping guide for a European Urban Atlas. European Commission, Brussels.

European Union, 2011. Mapping guide for a European Urban Atlas. European Commission, Brussels.

Feltynowski, M., 2015. Miejscowe plany zagospodarowania przestrzennego a zmiana przeznaczenia gruntów leśnych w gminach miejskich w Polsce. Sylwan 159, 252–258.

Fuller, R.A., Gaston, K.J., 2009. The scaling of green space coverage in European cities. Biology Letters 5, 352–355. doi:10.1098/rsbl.2009.0010

Giergiczny, M., Kronenberg, J., 2014. From valuation to governance: using choice experiment to value street trees. AMBIO 43, 492–501. doi:10.1007/s13280-014-0516-9

Gómez-Baggethun, E., Gren, Å., Barton, D.N., Langemeyer, J., McPhearson, T., O'Farrell, P., Andersson, E., Hamstead, Z., Kremer, P., 2013. Urban ecosystem services, in: Elmqvist, T., Fragkias, M., Goodness, J., Güneralp, B., Marcotullio, P.J., McDonald, R.I., Parnell, S., Schewenius, M., Sendstad, M., Seto, K.C., Wilkinson, C. (Eds.), Urbanization, Biodiversity and Ecosystem Services: Challenges and Opportunities. Springer, Dordrecht, pp. 175–251.

Green, T.L., Kronenberg, J., Andersson, E., Elmqvist, T., Gómez-Baggethun, E., 2016. Insurance value of green infrastructure in and around cities. Ecosystems 19, 1051–1063. doi:10.1007/s10021-016-9986-x

Guan, H., Li, J., Chapman, M., Deng, F., Ji, Z., Yang, X., 2013. Integration of orthoimagery and lidar data for object-based urban thematic mapping using random forests. International Journal of Remote Sensing 34, 5166–5186. doi:10.1080/01431161.2013.788261

Haase, D., Larondelle, N., Andersson, E., Artmann, M., Borgström, S., Breuste, J., Gomez-Baggethun, E., Gren, Å., Hamstead, Z., Hansen, R., Kabisch, N., Kremer, P., Langemeyer, J., Rall, E.L., McPhearson, T., Pauleit, S., Qureshi, S., Schwarz, N., Voigt, A., Wurster, D., Elmqvist, T., 2014. A quantitative review of urban ecosystem service assessments: Concepts, models, and implementation. AMBIO 43, 413–433. doi:10.1007/s13280-014-0504-0

Haklay, M., 2010. How good is volunteered geographical information? A comparative study of OpenStreetMap and Ordnance Survey datasets. Environment and Planning B: Planning and Design 37, 682–703. doi:10.1068/b35097

Hansen, R., Frantzeskaki, N., McPhearson, T., Rall, E., Kabisch, N., Kaczorowska, A., Kain, J.-H., Artmann, M., Pauleit, S., 2015. The uptake of the ecosystem services concept in planning discourses of European and American cities. Ecosystem Services 12, 228–246. doi:10.1016/j.ecoser.2014.11.013

He, C., Convertino, M., Feng, Z., Zhang, S., 2013. Using LiDAR data to measure the 3D green biomass of Beijing urban forest in China. PLOS ONE 8, e75920. doi:10.1371/journal.pone.0075920

Kabisch, N., 2015. Ecosystem service implementation and governance challenges in urban green space planning—The case of Berlin, Germany. Land Use Policy 42, 557–567. doi:10.1016/j.landusepol.2014.09.005

Kabisch, N., Haase, D., 2014. Green justice or just green? Provision of urban green spaces in Berlin, Germany. Landscape and Urban Planning 122, 129–139. doi:10.1016/j.landurbplan.2013.11.016

Kabisch, N., Haase, D., 2013. Green spaces of European cities revisited for 1990–2006. Landscape and Urban Planning 110, 113–122. doi:10.1016/j.landurbplan.2012.10.017

Kabisch, N., Strohbach, M., Haase, D., Kronenberg, J., 2016. Urban green space availability in European cities. Ecological Indicators 70, 586–596. doi:10.1016/j.ecolind.2016.02.029

Kaczmarek, J., Liszewski, S., Włodarczyk, B., 2006. Strategia rozwoju turystyki w Łodzi. Łódzkie Towarzystwo Naukowe, Łódź.

Khaleghi, M., Ranjbar, H., Shahabpour, J., Honarmand, M., 2014. Spectral angle mapping, spectral information divergence, and principal component analysis of the ASTER

SWIR data for exploration of porphyry copper mineralization in the Sarduiyeh area, Kerman province, Iran. Appl Geomat 6, 49–58. doi:10.1007/s12518-014-0125-0
Kremer, P., Hamstead, Z., 2015. Transformation of urban vacant lots for the common good: an introduction to the special issue. Cities and the Environment (CATE) 8, art.1.
Kremer, P., Hamstead, Z., Haase, D., McPhearson, T., Frantzeskaki, N., Andersson, E., Kabisch, N., Larondelle, N., Rall, E.L., Voigt, A., Baró, F., Bertram, C., Gómez-Baggethun, E., Hansen, R., Kaczorowska, A., Kain, J.-H., Kronenberg, J., Langemeyer, J., Pauleit, S., Rehdanz, K., Schewenius, M., van Ham, C., Wurster, D., Elmqvist, T., 2016. Key insights for the future of urban ecosystem services research. Ecology and Society 21, art. 21. doi:10.5751/ES-08445-210229
Kremer, P., Hamstead, Z., McPhearson, T., 2013. A social–ecological assessment of vacant lots in New York City. Landscape and Urban Planning 120, 218–233. doi:10.1016/j.landurbplan.2013.05.003
Kronenberg, J., 2015. Why not to green a city? Institutional barriers to preserving urban ecosystem services. Ecosystem Services 12, 218–227. doi:10.1016/j.ecoser.2014.07.002
Kronenberg, J., Pietrzyk-Kaszyńska, A., Zbieg, A., Żak, B., 2016. Wasting collaboration potential: a study in urban green space governance in a post-transition country. Environmental Science & Policy 62, 69–78. doi:10.1016/j.envsci.2015.06.018
Kruse, F.A., Lefkoff, A.B., Boardman, J.W., Heidebrecht, K.B., Shapiro, A.T., Barloon, P.J., Goetz, A.F.H., 1993. The spectral image processing system (SIPS)—interactive visualization and analysis of imaging spectrometer data. Remote Sensing of Environment 44, 145–163. doi:10.1016/0034-4257(93)90013-N
Kyttä, M., Broberg, A., Tzoulas, T., Snabb, K., 2013. Towards contextually sensitive urban densification: Location-based softGIS knowledge revealing perceived residential environmental quality. Landscape and Urban Planning 113, 30–46. doi:10.1016/j.landurbplan.2013.01.008
Kyttä, M., Kahila, M., Broberg, A., 2010. Perceived environmental quality as an input to urban infill policy-making. Urban Design International 16, 19–35.
Larondelle, N., Haase, D., 2013. Urban ecosystem services assessment along a rural–urban gradient: A cross-analysis of European cities. Ecological Indicators 29, 179–190. doi:10.1016/j.ecolind.2012.12.022
Larson, E.K., Perrings, C., 2013. The value of water-related amenities in an arid city: The case of the Phoenix Metropolitan Area. Landscape and Urban Planning 109, 45–55. doi:10.1016/j.landurbplan.2012.10.008
Li, X., Zhang, C., Li, W., Ricard, R., Meng, Q., Zhang, W., 2015. Assessing street-level urban greenery using Google Street View and a modified green view index. Urban Forestry & Urban Greening 14, 675–685. doi:10.1016/j.ufug.2015.06.006
Long, Y., Liu, L., 2017. How green are the streets? An analysis for central areas of Chinese cities using Tencent Street View. PLOS ONE 12, e0171110. doi:10.1371/journal.pone.0171110
MacFaden, S.W., O'Neil-Dunne, J.P.M., Royar, A.R., Lu, J.W.T., Rundle, A.G., 2012. High-resolution tree canopy mapping for New York City using LIDAR and object-based image analysis. J. Appl. Remote Sens 6, 063567-1. doi:10.1117/1.JRS.6.063567
Madureira, H., Andresen, T., Monteiro, A., 2011. Green structure and planning evolution in Porto. Urban Forestry & Urban Greening 10, 141–149. doi:10.1016/j.ufug.2010.12.004
Marszał, T., 2006. Łódź: wybrane zagadnienia zagospodarowania przestrzennego. Wydawnictwo Uniwersytetu Łódzkiego.

Medyńska-Gulij, B., 2013. Database of topographical objects as a ground for creation the spatial development study in polish communes. Geoinformatica Polonica 12, 45–52. doi:10.2478/v10300-012-0012-3
Mooney, P., Corcoran, P., Winstanley, A.C., 2010. A study of data representation of natural features in openstreetmap, in: Proceedings of the 6th GIScience International Conference on Geographic Information Science. Zurich, Switzerland, p. 150.
Morar, T., Radoslav, R., Spiridon, L.C., Păcurar, L., 2014. Assessing pedestrian accessibility to green space using GIS. Transylvanian Review of Administrative Sciences 10, 116–139.
Mrozik, K., 2016. Assessment of retention potential changes as an element of suburbanization monitoring on example of an ungauged catchment in Poznań Metropolitan Area (Poland). Rocznik Ochrona Środowiska 18, 188–200.
MSWiA, 2011. Rozporządzenie Ministra Spraw Wewnętrznych i Administracji z dnia 17 listopada 2011 r. w sprawie bazy danych obiektów topograficznych oraz bazy danych obiektów ogólnogeograficznych, a także standardowych opracowań kartograficznych. Dziennik Ustaw 279, 16096–16099.
Nielsen, A.B., Östberg, J., Delshammar, T., 2014. Review of urban tree inventory methods used to collect data at single-tree level. Arboricult Urban For 40, 96–111.
Nowak, D.J., Greenfield, E.J., 2012. Tree and impervious cover change in U.S. cities. Urban Forestry & Urban Greening 11, 21–30. doi:10.1016/j.ufug.2011.11.005
Pafi, M., Siragusa, A., Ferri, S., Halkia, M., 2016. Measuring the accessibility of urban green areas. A comparison of the Green ESM with other datasets in four European cities. Publications Office of the European Union, Luxembourg.
Paulos, E., Honicky, R., Hooker, B., 2009. Citizen science: enabling participatory urbanism, in: Foth, M. (Ed.), Handbook of Research on Urban Informatics: The Practice and Promise of the Real-Time City. IGI Global, Hershey, Pa., pp. 414–436.
Petrisor, A.-I., 2015. Assessment of the green infrastructure of Bucharest using CORINE and Urban Atlas data. Urbanism. Arhitectura. Constructii 6, 19–24.
Pietrzyk-Kaszyńska, A., Czepkiewicz, M., Kronenberg, J., 2017. Eliciting non-monetary values of formal and informal urban green spaces using public participation GIS. Landscape and Urban Planning 160, 85–95. doi:10.1016/j.landurbplan.2016.12.012
Rall, E.L., Kabisch, N., Hansen, R., 2015. A comparative exploration of uptake and potential application of ecosystem services in urban planning. Ecosystem Services 16, 230–242. doi:10.1016/j.ecoser.2015.10.005
Rashmi, S., Addamani, S., Ravikiran, S., 2014. Spectral angle mapper algorithm for remote sensing image classification. IJISET–International Journal of Innovative Science, Engineering & Technology 50, 201–205.
Rupprecht, C.D.D., Byrne, J.A., 2014. Informal urban greenspace: A typology and trilingual systematic review of its role for urban residents and trends in the literature. Urban Forestry & Urban Greening 13, 597–611. doi:10.1016/j.ufug.2014.09.002
Schipperijn, J., Stigsdotter, U.K., Randrup, T.B., Troelsen, J., 2010. Influences on the use of urban green space – A case study in Odense, Denmark. Urban Forestry & Urban Greening 9, 25–32. doi:10.1016/j.ufug.2009.09.002
Szulczewska, B. (Ed.), 2016. Potencjał do kształtowania zielonej infrastruktury w Warszawie. Urząd Miasta Stołecznego Warszawa, Warszawa.
Szymańska, D., Lewandowska, A., Rogatka, K., 2015. Temporal trend of green areas in Poland between 2004 and 2012. Urban Forestry & Urban Greening 14, 1009–1016. doi:10.1016/j.ufug.2015.09.008

Taylor, L., Hochuli, D.F., 2017. Defining greenspace: Multiple uses across multiple disciplines. Landscape and Urban Planning 158, 25–38. doi:10.1016/j.landurbplan.2016.09.024

Vogt, J.M., Fischer, B.C., 2016. A protocol for citizen science monitoring of recently-planted urban trees. Cities and the Environment (CATE) 7, art. 4.

Wuestman, M.L., 2015. Neighbourhood green space and health-seeking behaviour in the Netherlands: a multilevel analysis using open data. Technische Universiteit Eindhoven, Eindhoven.

Yan, W.Y., Shaker, A., El-Ashmawy, N., 2015. Urban land cover classification using airborne LiDAR data: A review. Remote Sensing of Environment 158, 295–310. doi:10.1016/j.rse.2014.11.001

Yang, J., Zhao, L., Mcbride, J., Gong, P., 2009. Can you see green? Assessing the visibility of urban forests in cities. Landscape and Urban Planning 91, 97–104. doi:10.1016/j.landurbplan.2008.12.004

Zagajewski, B., 2013. Zastosowanie teledetekcji do oceny stanu zagospodarowania przestrzennego w Polsce. Biuletyn Komitetu Przestrzennego Zagospodarowania Kraju 252, 13–29.

Zwirowicz-Rutkowska, A., Michalik, A., 2016. The use of spatial data infrastructure in environmental management: an example from the spatial planning practice in Poland. Environmental Management 58, 619–635. doi:10.1007/s00267-016-0732-0

Figures and tables

Figure 1. Green spaces in Lodz according to the different sources of data

Figure 2. Comparison of the most comprehensive BDOT dataset with other sources of data on urban green spaces in Lodz (BDOT data are marked in green and additions to BDOT from different sources are marked in red).

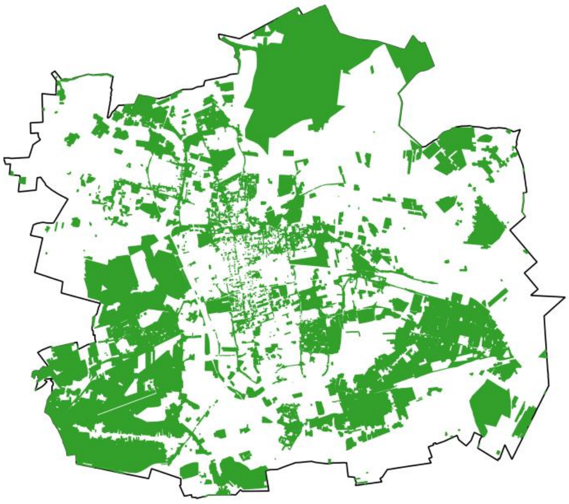
Figure 3. Key relations between the institutional context of green space planning and monitoring with the selection of the relevant definition and data on green spaces

Table 1. Resources typically used to create spatial datasets of urban green spaces

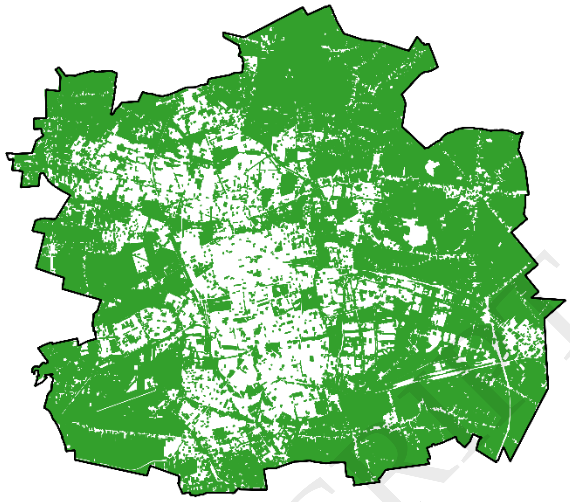
Table 2. Green space categories identified in each of the analysed datasets used to calculate the area of urban green spaces in Lodz – based on the categories defined in the relevant resource descriptions (CSO, 2016; European Union, 2016, 2011; MSWiA, 2011; https://www.openstreetmap.org)

Table 3. Green spaces in regional capitals in Poland according to the different sources of data

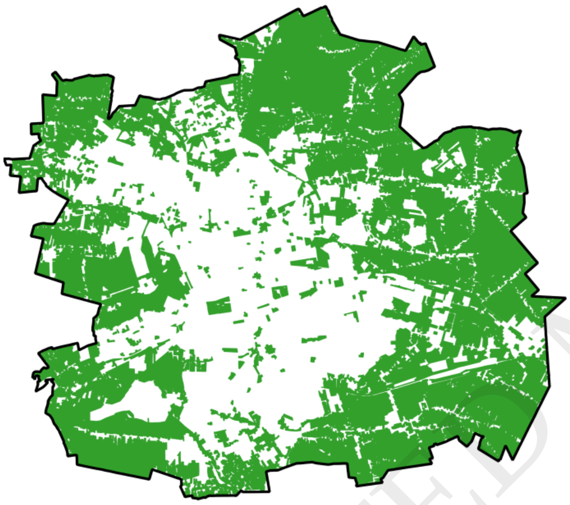
Figure 1. Green spaces in Lodz according to the different sources of data



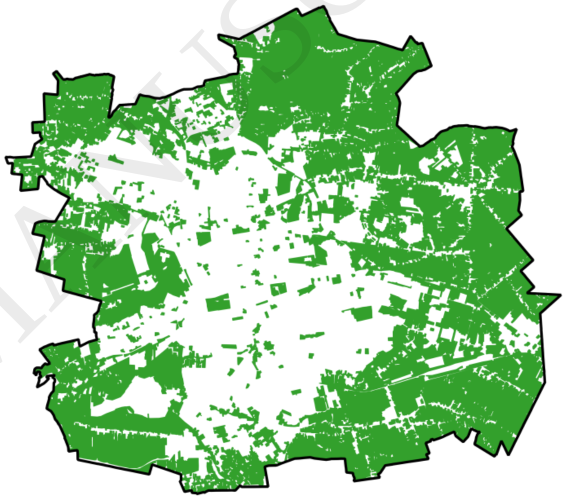
(a) Open Street Map 2015 – the second lowest share of green space in the city area; 32.3%



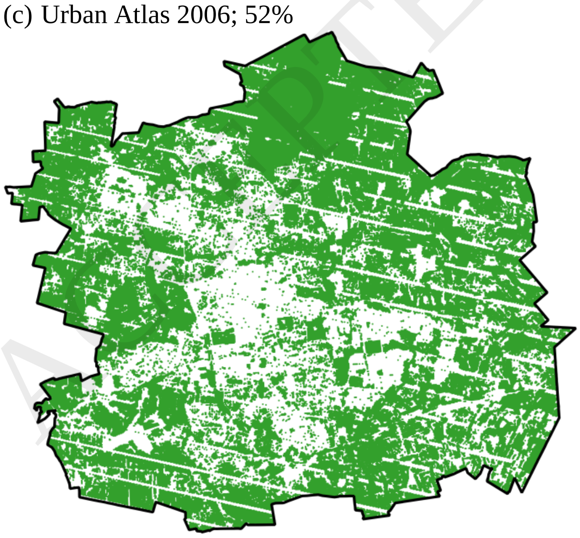
(b) BDOT 2015 – the highest share of green space in the city area; 61.2%



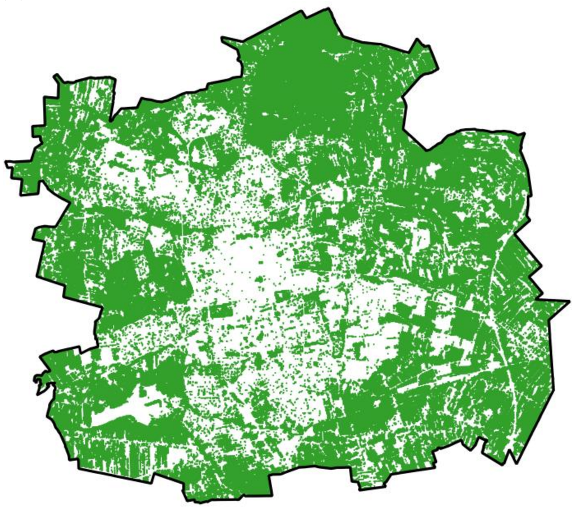
(c) Urban Atlas 2006; 52%



(d) Urban Atlas 2012; 51.8%



(e) Landsat 7 2006; 52.2%

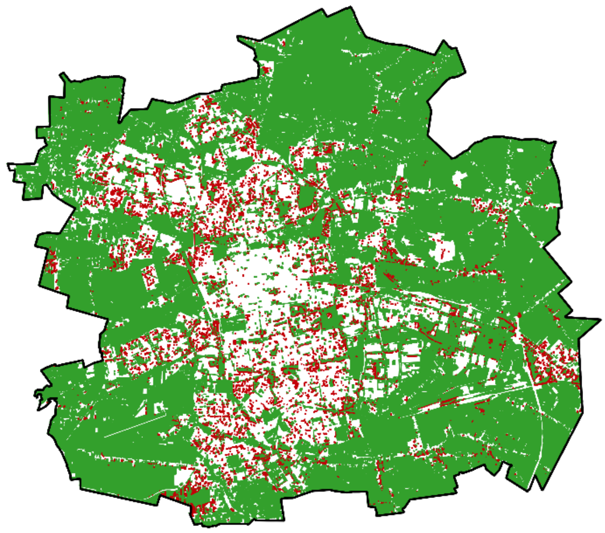


(f) Landsat 8 2013; 51.9%

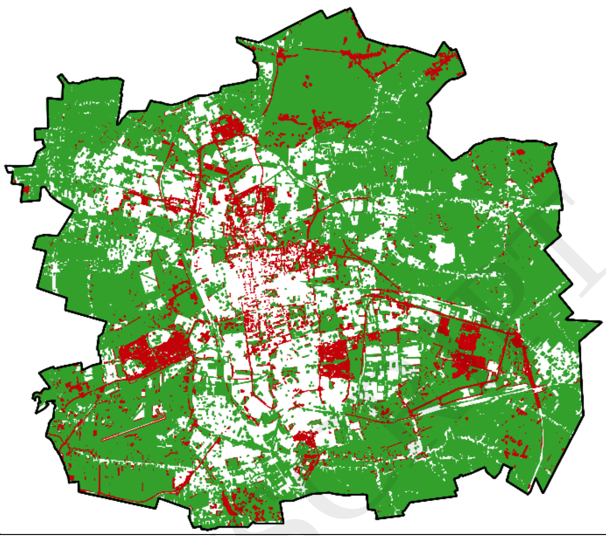
Narrowly interpreted public statistics 2006; 12.2%
Broadly interpreted public statistics 2006; 53.3%

Narrowly interpreted public statistics 2012; 12.8%
Broadly interpreted public statistics 2012; 51.4%

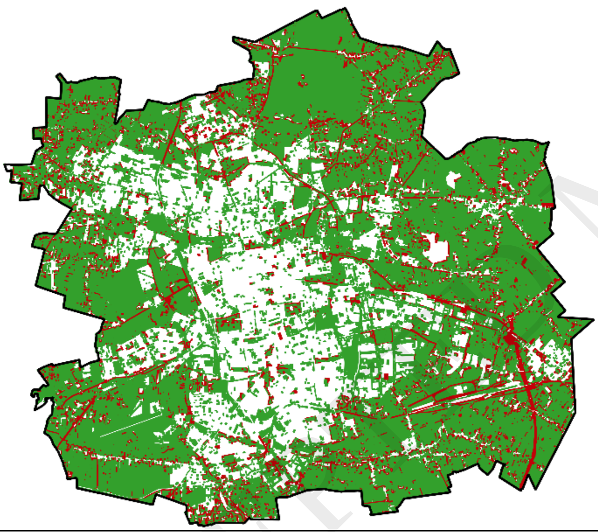
Figure 2. Comparison of the most comprehensive BDOT dataset with other sources of data on urban green spaces in Lodz (BDOT data are marked in green and additions to BDOT from different sources are marked in red).



(a) BDOT plus Landsat 2013 – addition of 2.57 percentage points



(b) BDOT plus OSM – addition of 3.55 percentage points



(c) BDOT plus Urban Atlas – addition of 3.21 percentage points (larger green space area in the Urban Atlas partly results from the construction of a motorway in what was still a green space in 2012)

(d) Sum of all layers of urban green spaces in Lodz – green spaces occupying 68.9% of city area

Figure 3. Key relations between the institutional context of green space planning and monitoring with the selection of the relevant definition and data on green spaces

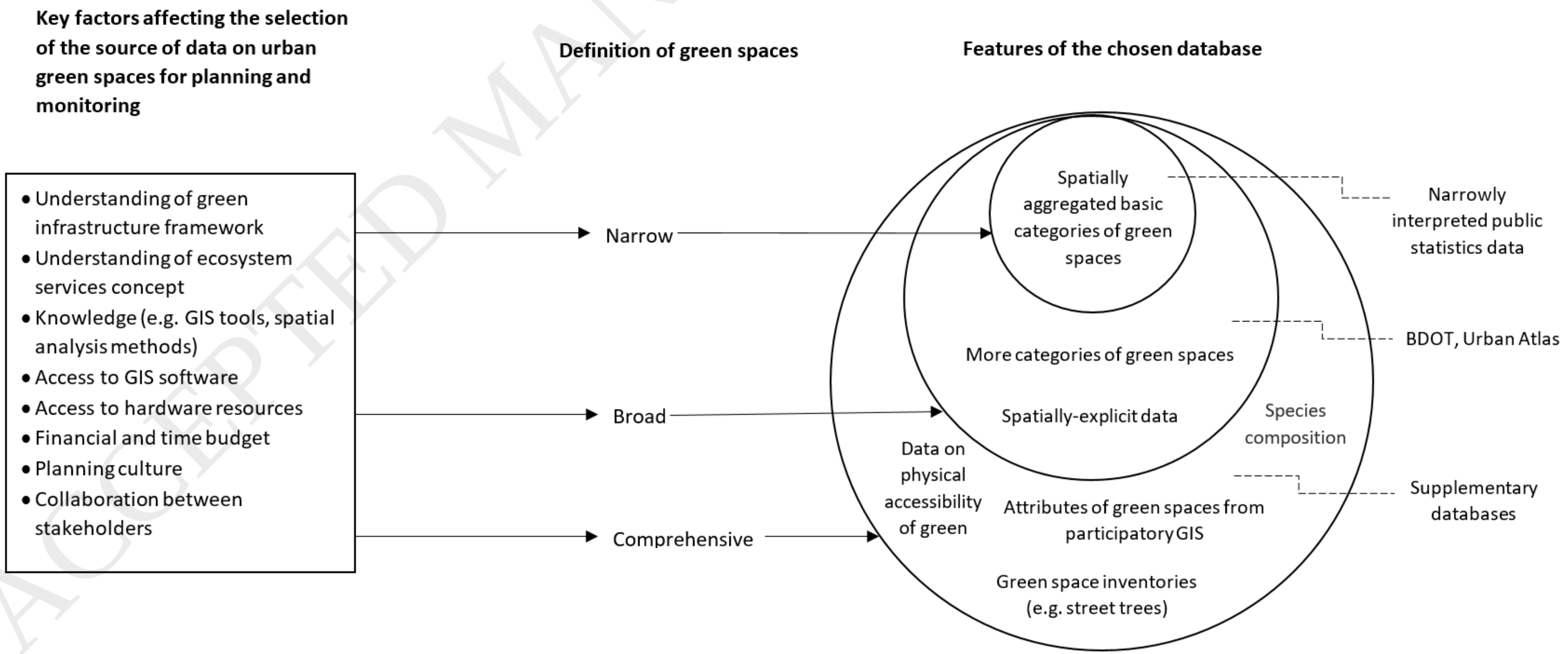


Table 1. Resources typically used to create spatial datasets of urban green spaces

Type	Name	Key characteristics (geographical and time scale, data availability, responsible agency)
Primary data	OpenStreetMap (OSM)	Data available for the whole world, although with different degrees of accuracy. A project which allows the community of Internet users to continuously update open and publicly available resources. Data can be used in compliance with the OSM license. Database maintained by the OpenStreetMap Foundation. Vector data available at different scales and standardized into a few land cover categories.
	Satellite imagery – Landsat	Data available for the whole world. Images taken in 16-day intervals by Landsat 7 and Landsat 8 satellites. Images available from the United States Geological Survey (USGS) based on NASA and USGS resources. Data resolution is 30 meters and it can be standardized according to user-specific classifications.
	Satellite imagery – Sentinel	Data available for the whole world with major focus on Europe. Images taken in 5-day intervals. Images will be available from Copernicus Land Monitoring Service. Data resolutions is 10 meters (4 bands), 20 meters (6 bands) and 60 meters (3 bands).
	Satellite imagery – RapidEye	Data available for the whole world. Images taken in 5.5-day intervals. Commercial services of Planet Labs. Data resolution is 5 meters and it can be standardized according to user-specific classifications.
	Orthophotomap	Data available for different locations. Data collected systematically or *ad hoc*, depending on specific needs, based on aerial and satellite imagery. If available, data can be obtained upon individual request. Data collection coordinated by public authorities. Data standardized according to user-specific classifications, defined when the map is created (resolution depends on the source of images and increases over time, in newer maps the resolution is 0.05 m).
	Datasets created by local land surveying agencies	Local authorities may be formally required to produce different datasets for the purposes of public statistics and land management, including with respect to urban green spaces. Data collected systematically or periodically, depending on formal requirements and local possibilities and approaches.

		Data available upon request. Data collection coordinated by local and regional public agencies responsible for land surveying. Data resolution and categories specified in the relevant legal documents, often available as vector data.
	Green space inventories	Data typically collected locally, in response to specific needs. Data reflects the specific situation in a given moment of analysis, although it can be used as a basis for long-term, periodically updated green space management system (especially in the case of tree inventories). Green space inventories are performed by specialized entities and supervised by those who order data. Data can be standardized according to user-specific classifications (potentially the most detailed information).
	Light Detection and Ranging (LiDAR)	Data typically collected locally, in response to specific needs, such as the identification of urban trees and vegetation heights. Data reflects the specific situation in a given moment of analysis. Each LiDAR study is performed by specialized entities and supervised by those who order data. Data takes the form of a 3D point cloud model, which is then used to create the digital terrain model and/or the digital surface model.
	Participatory GIS	Data typically collected locally, in response to specific needs, such as the identification of people's preferences towards green spaces or consulting on spatial planning options. Data reflects the specific situation in a given moment of analysis. Each participatory GIS study is performed by specialized entities and supervised by those who order data. Data can be standardized according to user-specific classifications – the objective of a study determines questions asked to respondents.
Secondary data	Data based on satellite imagery – Urban Atlas	Data available for functional urban areas larger than 100,000 inhabitants in the European Economic Area. Data prepared periodically, currently based on satellite images from 2006 and 2012. Data available free of charge from the website of Copernicus Land Monitoring Service (CLMS). Project coordinated by the European Environment Agency (EEA). The scale of Urban Atlas maps is 1:10,000, and they feature objects which cover 0.25 ha. Data standardized into 20 and 27 land cover categories for 2006 and 2012, respectively.
	Data based on satellite	Data available for 36 member and collaborating

	imagery – CORINE (CO-oRdination of INformation on the Environment)	countries of the EEA. Data prepared periodically, currently based on satellite images from 1990, 2000, 2006 and 2012. Data available free of charge from the website of CLMS. Project coordinated by the EEA. The scale of CORINE Land Cover maps is 1:100,000. Data standardized into 44 land cover categories consistently used for all years.
	Data based on satellite imagery – European Settlement Map	Data available for human settlements in most countries in Europe. Data prepared periodically, based on SPOT5 and SPOT6 satellite images from 2014 and 2016. Data available free of charge from the European Commission, Joint Research Centre. Data resolution is 10 m, standardized into seven categories indicating percentage of built-up land, green spaces, and water bodies.
	Data from local spatial planning documents	Local authorities collect additional data when preparing local spatial planning documents. Data collected before preparing the planning document. Data available upon request, although not always in numerical format and especially as vector files. Data collection coordinated by local and regional planning authorities. Data standardized according to local zoning classifications.

Table 2. Green space categories identified in each of the analysed datasets used to calculate the area of urban green spaces in Lodz – based on categories defined in the relevant resource descriptions (CSO, 2016; European Union, 2016, 2011; MSWiA, 2011; https://www.openstreetmap.org)

Open Street Map	**BDOT**	**Urban Atlas**		**Satellite imagery**	**Public statistics**	
		2006	**2012**		**Narrow interpretation**	**Broad interpretation**
– Allotments – Cemetery – Farmland/ farmyard – Forest/wood – Garden – Grassland – Greenfield – Greenhouse horticulture – Meadow – Nature reserve – Orchard – Park – Plant nursery – Scrub – Trees – Village green – Wetland	– Allotments (PTUT01) – Arable land (PTTR02) – Decorative plants plantation (PTUT05) – Forest (PTLZ01) – Grassland (PTTR01) – Orchards (PTUT03) – Plantation (PTUT02) – Scrub (PTRK02) – Shrubbery (PTLZ02) – Tree cover (PTLZ03) – Cemetary (KUSC1) – Mountain pine (PTRK01)* – Forest nursery (PTUT04)*	– Agricultural areas, semi-natural areas and wetlands (Code 20000) – Forests (Code 30000) – Green urban areas (Code 14100)	– Arable land (annual crops) (Code 21000) – Green urban areas (Code 14100) – Forests (Code 31000) – Pastures (Code 23000) – Permanent crops (Code 22000) – Wetlands (Code 40000) – Complex and mixed cultivation patterns (Code 24000)* – Orchards (Code 25000)*	Urban green spaces were identified with the use of supervised classification based on the representative samples for the different green space types in the digital image	– Parks – Municipal forests – Green squares – Residential green spaces – Street greenery – Zoological and botanical gardens – Cemeteries	– Parks – Municipal forests – Green squares – Residential green spaces – Street greenery – Zoological and botanical gardens – Cemeteries – Arable land – Other forests – Lawns – Orchards – Permanent meadow – Permanent pastures – Street greenery – Allotment gardens

* These land cover classes are potentially relevant when analysing Urban Atlas data, but they were not identified in Lodz.

Table 3. Green spaces in regional capitals in Poland according to the different sources of data

City	Share of urban green spaces in city area [in %] according to different sources of data			
	Narrowly interpreted public statistics (2012)	Broadly interpreted public statistics (2012)	Urban Atlas (2012)	BDOT (2015)
Bialystok	9.4	37.8	44.6	58.6
Bydgoszcz	10.8	27.2	57.1	67.1
Gdansk	8.0	41.0	55.0	68.9
Gorzow Wielkopolski	5.6	56.2	56.6	74.0
Katowice	7.2	17.2	59.9	66.2
Kielce	5.5	40.3	56.2	68.8
Krakow	9.4	54.8	51.6	63.4
Lublin	8.8	44.5	51.0	67.5
Lodz	12.9	51.4	51.8	61.2
Warsaw	9.4	31.8	41.3	55.3
Olsztyn	21.0	42.6	55.0	63.8
Opole	6.5	52.6	60.3	66.7
Poznan	14.4	46.6	49.2	65.7
Rzeszow	6.0	64.1	56.0	67.9
Szczecin	11.4	31.7	45.9	56.1
Torun	8.8	28.0	48.3	68.4
Wroclaw	10.0	50.7	51.4	69.3
Zielona Gora	15.2	24.3	54.7	69.2