SMART GREEN INFRASTRUCTURE IN A SMART CITY – THE CASE STUDY OF ECOSYSTEM SERVICES EVALUATION IN KRAKOW BASED ON I-TREE ECO SOFTWARE

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ABSTRACT

It is a common perception that urban greenery does not bring any rational benefits, while profits from real estates are obvious. Therefore, the cities green infrastructure (urban forests, parks, trees, lawns, meadows, etc.) are constantly threatened with housing and development. However, urban greenery plays a substantial role in improving the quality of urbanites' life, which is particularly significant in terms of predicted 70% urbanization rate by 2050. Healthy and well managed city green infrastructure can improve air quality, remove particulate matters (PM) and CO_2 sequestrate carbon, cool down temperature or protect against winds. These functions of vegetation are known as ecosystem services (ES).

Recognizing the value of ES provided by green infrastructure is crucial for urban planning and management in terms of assuring sustainable urban development. In our study we used the i-Tree Eco (USDA Forest Service) software, which quantifies vegetation structure, environmental effects and values of ES. The i-Tree Eco model is based on air pollution and local meteorological data along with the field data from inventory of city vegetation. Requiring easy to collect (e.g. based on LiDAR 3D point clouds) input data and having user-friendly interface, the i-Tree Eco has a potential of becoming a very useful tool for planners and managers in their everyday work.

In this paper we present a case study of ES evaluation for the "Krakowski Park" in Krakow (582 trees on 4.77 hectares, with domination of *Fraxinus excelsior, Ulmus laevis* and *Betula pendula*). For the analysed 2015 year, the Krakowski Park trees stored in total 441.59 t of carbon, removed 184 kg of air pollutants and contributed to 220 m^3 of avoided runoff. Total value of ecosystem services provided by the Krakowski Park in year 2015 was EUR 5.096 (EUR 8.76 tree/year). In our further work we intend to expand the ES evaluation on other green areas in Krakow and on a wider range of ES.

Keywords: urban greenery, urban management and planning, air pollution, carbon sequestration, GIS

1 INTRODUCTION

The expansion of urbanization is really rapid in the world. Economic and social changes affect the amount of inhabited areas and these days it does not concern only urban spaces, but also rural ones. This trend becomes more marked – it can be seen through an increase in the number of residential blocks or free-standing houses with corresponding communication and service facilities [1]. The human population is predicted to grow from 7 billion to over 9 billion by 2050 – almost 70% of people will be city dwellers and at least 25% will be over 65 years old (against today's 15%) [2].

Given the circumstances of increasing urbanisation, we need to lower the detriments and enhance the benefits of it. One of the ways is implementation of "a smart city" concept, which is broad and emergent term – smart infrastructure, transportation, environment, services, governance, people, living, economy – subsumed under a smart city definition [3]. In a holistic approach it can be said that a smart city extensively uses modern, intelligent and innovative solutions, increasing the functionality and reducing resource consumption, and thereby improves human well-being. The use of ecosystem services (ES) is a case in point.

ES can be defined as benefits which people acquire from the natural environment. They can be divided into four groups: supporting (the basis on which other three groups continue to provide services, nutrient cycling, soil formation, primary production etc.); provisioning (e.g. fresh water, food, raw materials supply); regulation (e.g. purification of water and air, climate regulation, mitigation of environmental disturbances) and cultural services (possibilities for recreational, cultural, educational activities and spiritual experiences) [4].

One should not forget that urban green infrastructure brings to humans not only benefits, but also nuisances. These are called ecological disservices (ED). ED relevant in urban areas are: damage to physical structure, harmful species, maintenance problems caused by tall trees, diverse direct and indirect costs, as well as security and health issues [5].

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In this paper, we present a case study of ES (and ED) assessment, conducted for Krakowski Park (Krakow, Poland) using i-Tree Eco software.

2 STUDY AREA

Krakow has 793.2 ha of parks, which amounts to 2.43% of the city's area [6]. Krakowski Park (4.77 ha) is one of the most popular parks in Krakow. It is located in the middle-east part of the city, approximately 1 km from the Main Square. The park is surrounded by a high street and side streets, as well as residential and service buildings (mainly houses). A large fountain pond is located in the park. In 2017/2018 the Krakowski Park was revitalised.

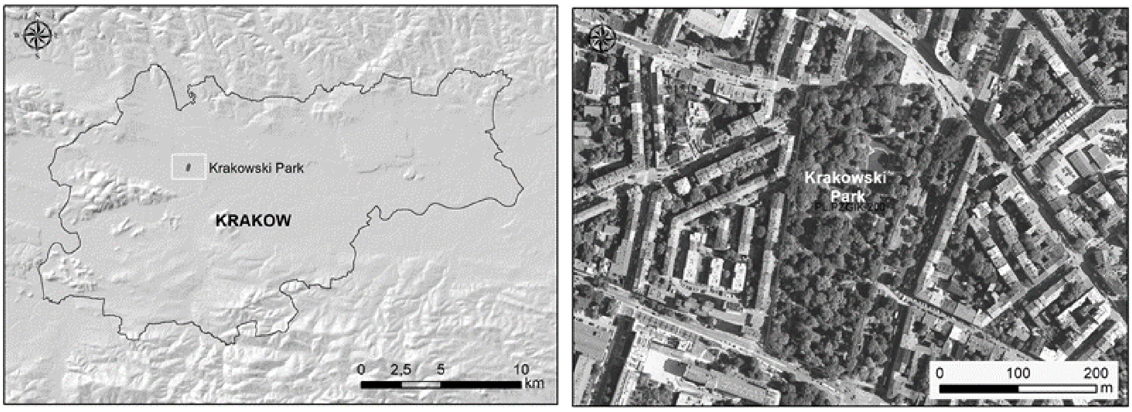

Figure 1. Location of the study area - Krakowski Park (Digital Terrain Model of Krakow and orthophotomap of Krakowski Park - www.geoportal.gov.pl).

3 METHODS

Complete tree inventory data of the study area of Krakowski Park were collected by Urban Greenery Authority of Krakow in 2018, within MonitAir Project "Integrated monitoring system of spatial data to improve air quality in Kraków" (co-financed from the European Economic Area Financial Mechanism 2009-2014). For the purpose of this work, the data originally stored in R3Trees system (R3GIS), were exported to a spreadsheet. The software used for ES analyses was i-Tree Eco (USDA Forest Service), which is a peer-reviewed computer program developed upon UFORE model [7]. As stated by Nowak and Crane (2000) [7], i-Tree Eco was "designed to use standardized field data and local hourly air pollution and meteorological data to quantify urban forest structure and its numerous effects". More detailed information on i-Tree Eco is available in the official documentation of the software.

The dataset consisted of 583 records. The data were checked for completeness. One tree, lacking species name, was removed from the dataset, resulting in the final number of 582 trees, resulting in 582 alive trees and 1 dead tree. The original data were conformed to meet i-Tree Eco requirements, redundant fields were removed, and several fields not included in the dataset were added.

The modelling was based on the following data: species, DBH, height, land use (park), ownership (public), height above ground of DBH measurements (in our case all trees were measured at 1.3 m) and condition.

Species names were checked to match the species database of i-Tree Eco. In one case a name of variety not covered by i-Tree was simplified to a species level, and in three cases a name of a variety was added to a species for there was no species name alone in the database. In all necessary cases, names of taxons were changed to their synonyms used in the i-Tree database.

Original trunk circumference measurements were converted to diameter and rounded to 0.1 cm. Trees with multiple trunks were separated to different columns (DBH). In the original dataset, the height of trees was recorded in 5.0 m intervals. Therefore, their mid-points (2.5 m for >5 m height, 7.5 m for 5-10 m interval etc.) were assigned to all trees.

The parameter "condition" was added to the dataset, with 0 value for the dead tree and 87% value for all other trees. Otherwise, the program would assign condition parameter of 87% to all trees in a dataset, resulting in overestimated ES value due to the presence of dead trees.

The newest weather and pollution data (from 2015) were chosen for the project. Same year data of population (761 069; Report on the state of the city 2015), as well as dollar and euro mean annual exchange rate (3.77 and 4.18 PLN respectively) were used. The nearest weather station was chosen for the project. The dataset was imported to i-Tree and submitted for the analysis. Value of ecosystem services was changed from PLN to euro

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(using 2015 mean exchange rate). The time in minutes was measured for 3 steps of the work: data adjustment, creating a project, and data processing.

4 RESULTS

Among 582 trees of Krakowski Park, the most common species were *Fraxinus excelsior, Ulmus laevis* and *Betula pendula* (38.8 % of trees). Other 61.2% of trees belonged to 50 different species (R3Trees; [6]. The tree cover was determined as 3.1 hectares and provided 14.23 ha of leaf area and 11.20 tonnes of leaf biomass. The population of Krakowski Park's trees is characterised by high percentage of trees wider than 60 cm in diameter (31%). 21.8% of trees does not exceed 15.2 cm at breast height.

The amount of ecosystem services as well as their monetary value, modelled by i-Tree Eco, are shown in Table 1. The value of one modelled ED, which was VOCs (volatile organic compounds) emission, was equal to 20 kg per year. The ecosystem services value of individual trees is shown in Figure 2.

Table 1. Summary of ecosystem services provided by Krakowski Park in Krakow, derived from i-Tree Eco.

Ecosystem service	Unit	Value / amount
Structural Value	EUR	1505501.44
Carbon Storage	kg	441591
Carbon Storage	EUR	73217.46
Gross Carbon Sequestration	kg/yr	8733
Gross Carbon Sequestration	EUR/yr	1448.09
Avoided Runoff	m^3/yr	220
Avoided Runoff	EUR/yr	416.51
Pollution Removal	g/yr	184314
Pollution Removal	EUR/yr	3231.10
Total Annual Benefits	EUR/yr	5095.69

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Figure 2. The map of Krakowski Park's trees with the value of ecological services provided by them annually

The time needed for adjustment of the dataset was 15 minutes. Setting a new project and importing the data needed 6 minutes. Processing time (since the data submission to the notification of reports being ready) was 32 minutes.

5 DISCUSSION

Aiming at sustainable development of our cities, urban planning and management should consider ecosystem services (ES) provided by green infrastructure. Proper addressing of ES in the planning process may have a strong influence on their protection [8].

The process of assessing ES is a complex issue, which requires taking into consideration numerous aspects: spatial and temporal scale, choice of ES and their indicators, costs of an operation, data availability, required accuracy, etc. Bagstad et al. (2013) [9] indicated that in order to become a common practice, ES assessments should be "quantifiable, replicable, credible, flexible, and affordable". The feature that is often pointed out as very important for practical use of ES assessments is the cost and time efficiency of methods [9, 10].

There are numerous solutions and tools to assess ecosystem services. They vary significantly in many terms: costs, time-consumption, required expertise of staff [9, 11]. One of the advantages of i-Tree Eco is a relatively short time needed for its operation, once data are available. In our case study, the total time from obtaining a raw datafile to receiving the results was less than 1 hour. The credible comparison is difficult to carry on due to different scales other programs operate on, but just to give a rough idea, the time required for other ES assessing tools, provided in the literature differed from 2.5 h/hectare (1h/acre), 25 h for 1 variable, 200 to 300 h for a dataset [11] to 10 to 800 hours for a dataset [9]. What is important is the fact that i-Tree software is freely available to users.

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Other advantage of i-Tree Eco as a tool for ES assessment is an integration of the third dimension, the need of which was pointed out by [12]. The model employs such tree's parameters as tree height, crown parameters and crown condition, which allows for extension of the ES study beyond typical two-dimension approach.

Urban green areas are mostly separated from each other, which causes discontinuous distribution of urban ES they provide [13]. Therefore, alongside complex ES evaluations for an entire city area, ES assessments of individual green infrastructure are justified. Moreover, in urban areas, where every tree matters, detailed studies are important. Most of the programs for ES assessment apply to the scale varying from site and watershed to landscape [9, 11]. I-Tree Eco enables ES assessments based on data on every tree in a study area, which suites very well the needs of urban ES surveys.

Important matter in ES assessments is the choice of ES, which vary between different studies. Based on the ES most relevant in the urban sphere, the urban ES that have played a role in decision making in New York City and data availability, Kremer, et al. (2016) [13] chose five ecosystem services – stormwater absorption, carbon storage, air pollution removal, local climate regulation and recreation. Elmqvist et al. (2015) [14] analyzed the following ES: pollution removal, carbon sequestration, carbon storage, stormwater reduction and energy savings. In the work of Sieber and Pons (2015) [15], air quality regulation, recreation and aesthetic quality were analyzed. Plieninger et al. (2013) [16] focused on selected cultural ecosystem services and disservices. I-Tree Eco models energy savings, gross carbon sequestration and carbon storage (including CO_2 equivalent), pollution removal, oxygen production and hydrology effects (potential evapotranspiration, evaporation, transpiration, water intercepted, avoided runoff).

Much of the research focuses solely on ES and neglect ecosystem disservices, which is often pointed out as misleading [5]. In this regard, i-Tree Eco model has an advantage of taking into account also ED, namely emission of volatile organic compounds and costs of maintenance. It is important to remember, however, that the number of other disservices, such as health and security issues, indirect economic costs, are omitted. Also, i-Tree Eco does not cover the full range of ES, focusing on chosen ecological effects only.

Woodruff and BenDor (2016) [8] indicated that "plans should consider multiple types of data such as surveys, focus groups, and public input in addition to ecological data". Under that reasoning, i-Tree Eco can serve as one of the tools of ES assessment for urban management. Nevertheless, since it does not cover all aspects important in the context of a smart city concept and urban planning and management, other sources of information are needed too.

The ES values obtained in this case study are just a model-based estimation and inevitably several limitations can be indicated. In the lack of crown parameters data, the ES values were calculated for model trees, without taking into account actual crown parameters of the trees, which lowered their accuracy to a certain extend. However, our calculations represent well the most common situation, as the very specific methodology of crown parameters for i-Tree Eco causes that they are not available from standard tree inventory. For ES assessments based on existing tree inventories, which can be expected to be a very common situation, the crown parameters as specified in i-Tree Eco will not be available. The scope of parameters available from park tree inventories may somewhat vary between datasets, as they are not standardized. The species and DBH, which are the only obligatory data to be provided for i-Tree Eco project, can be expected in every inventory. The total tree height variable should be present in most cases. In case of data from Krakow, however, height measurements are registered in 5 m intervals, which lowers the accuracy of the data. In general, traditional terrestrial measurements of tree height are likely to be inaccurate. One possible solution to tackle that issue is to derive tree heights from aerial laser scanning data if available. Good quality laser scanning data, for example integrated ALS and TLS point clouds could even allow obtaining DBH and crown parameters for i-Tree Eco. Provided that adequate remote sensing data are available, the acquisition of tree parameters would be faster, cheaper and more accurate that traditional measurements.

ALS data become more and more available, as numerous countries decide to free ALS data. So far the precision of such data is too low for the implementation in ES assessments, but expected improvement of data quality should widen the possibilities of such remote sensing based approach to gathering input data for ES surveys. Many projects analyze entire cities for their total ecosystem services value. This approach is necessary but for an average person not very informative (and we want people to be involved, engaged and aware). Thus, an approach analysing individual urban forests alone are also necessary as they allow to create a bond and recognize values of areas people feel attached to.

This tool can be used to create such map as this of New York, with every single tree - very informative for people, as we tend to have more feelings for objects we can identify. Detailed approach to ES assessments, as allowed by i-Tree Eco, enables initiatives such as New York City Street Tree Map which includes every street tree in New York City and provides information on ecological benefits served by each of them.

The assessments of ES (and ED) are still relatively scarce. Therefore, relevant comparison of ES values is not always possible, as previous studies often differ in terms of methodology, geographical location and characteristics of a study area, of study area, scope of ES and so on Rogers et al. (2015) [17] provided a collation of ES assessed with i-Tree Eco for 19 cities in USA, Canada and Europe. In order to compare them with the results from Krakowski Park, presented values were converted to values per 1000 trees (see Table 2).

Table 2. The amount of selected ecosystem services per 1000 trees, provided by urban greenery in 19 cities (according to [17]), compared with Krakowski Park in Krakow

City	Country	Carbon storage (tonnes/1000 trees)	Carbon sequestration (tonnes/year/1000 trees)	Pollution removal (tonnes/year/1000 trees)
Toronto	Canada	107.85	4.58	0.14
London	UK	281.08	9.17	0.27
New York	US	259.02	8.12	0.32
Chicago	US	181.18	6.38	0.22
Glasgow	UK	91.50	4.50	0.14
Oakville	Canada	11.58	3.16	0.09
Barcelona	Spain	79.90	3.82	0.21
Torbay	UK	119.93	4.05	0.06
San Francisco	US	290.42	7.63	0.21
Morgantown	US	141.34	4.39	0.11
Edinburgh	UK	242.69	7.87	0.17
Moorestown	US	200.69	6.45	0.20
Providence	US	271.06	8.81	0.20
Wrexham	UK	181.32	3.57	0.16
Las Cruces	US	62.83	5.58	0.32
Udine	Italy	117.90	5.48	0.49
Jersey City	US	154.41	6.54	0.30
Casper	US	272.89	8.85	0.37
Freehold	US	416.67	11.35	0.46
Krakowski Park, Krakow	Poland	758.76	15.01	0.32

The high values of carbon storage and sequestration, exceeding any other results, might stem from different DBH distribution - in most of the other surveys, the young and thin trees dominated. The pollution removal by Krakowski Park's trees was high, but not the highest among studied cases.

In the paper by [14], the value of 5 urban ES (pollution removal, C sequestration, C storage, stormwater reduction, energy savings) for 25 urban areas from USA, Canada and China was found to range between USD 3212 and 17 772 of benefits per ha per year. The total value of analyzed ES served by Krakowski Park's trees was EUR 16 730 (USD 18.550) per ha per year. I-Tree Eco calculates ES values taking into account weather conditions and pollution in a study area, which can be a cause for the differences between ES values in the analyzed cities. Moreover, results for a given location would differ among different study years for the same reason.

6 CONCLUSIONS

According to i-Tree model, in the study year 2015 Krakowski Park provided ecosystem services worth EUR 79.804 in total (gross carbon sequestration, carbon storage, pollution removal, avoided runoff) or EUR 16.730 per ha. Besides distinct characteristics of vegetation, lower values per ha in other cities cited in literature may result from differences in methodology and in weather and pollution condition in the analyzed locations.

Across numerous tools for ES assessment, i-Tree Eco has advantages of being free, easy and quick in usage and operating at single tree level, which suits needs of urban planning and management. Therefore, it can be recommended as one of the tools in application associated with the concept of smart cities.

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