Marta **SYLLA**

MAPPING AND ASSESSMENT OF THE POTENTIAL TO SUPPLY SELECTED ECOSYSTEM SERVICES AT A SUB-REGIONAL SCALE. THE EXAMPLE OF WROCLAW AND ITS SURROUNDING MUNICIPALITIES

Marta **Sylla**, MSc – *Wroclaw University of Environmental and Life Sciences, Poland*

Correspondence address:
Department of Spatial Economy
Grunwaldzka 55, 50–357 Wrocław
e-mail: marta.sylla@up.wroc.pl

MAPOWANIE I OCENA POTENCJAŁU ŚWIADCZENIA USŁUG EKOSYSTEMÓW W SKALI SUB-REGIONALNEJ NA PRZYKŁADZIE WROCŁAWIA I GMIN OŚCIENNYCH

STRESZCZENIE: Usługi ekosystemów przyczyniają się do podnoszenia jakości życia mieszkańców miast i obszarów suburbialnych, co sprawia, że ich kwantyfikacja i przestrzenne rozmieszczenie jest istotne z punktu widzenia planowania przestrzennego. W pracy przedstawiono wyniki kartowania potencjału dostarczania dwóch wybranych usług ekosystemów dla skali sub-regionalnej na przykładzie miasta Wrocławia i gmin ościennych. Badanie dotyczy usług ekosystemów zaopatrujących (dostarczanie pożywienia) oraz regulacyjnych (regulacja klimatu globalnego poprzez zmniejszenie koncentracji gazów cieplarnianych).

SŁOWA KLUCZOWE: usługi ekosystemów, kartowanie za pomocą narzędzi GIS, obszary podmiejskie

Introduction

The urban and suburban areas undergo increased human pressure due to urbanisation processes[1]. In Europe about 75% of population lives in urbanised areas[2]. In Poland about 60 percent of population consists of urban dwellers[3]. Cities host daily activities of their inhabitants; they are also important academic and business centres that attract people from rural surroundings. Transportation infrastructure and built up areas constitute a great share of cities' surfaces, leaving green infrastructure fragmented and under constant pressure of pollution[4]. The condition of living in cities affects human health[5]. Climate change is going to increase the negative effects of air pollution, traffic noise, and urban heat island to our health[6]. The ecosystems provide us with benefits that can reduce the risks to human health and wellbeing[7]. The benefits provided by ecosystems are captured by the ecosystem service (ES) concept. The ecosystem service concept can serve as a comprehensive approach in understanding the dynamic feedbacks between human and environmental components of the urban systems[8]. Ecosystem services in cities are mainly provided by green infrastructure within the city boundaries[9]. However, urban dwellers also take direct advantage of ecosystem services provided in the surrounding areas[10]. The aim of the study is to assess spatial changes in Wroclaw and its suburban municipalities in terms of the potential of ecosystems to provide selected ecosystem services.

---

1 T. Elmqvist et al., *History of Urbanization and the Missing Ecology,* in: *Urbanization, biodiversity and ecosystem services: challenges and opportunities. A Global Assessment*, Dordrecht, Heidelberg, New York, London 2013, p. 14.

2 *Urban Environment*, www.eea.europa.eu [01-09–2016].

3 www.stat.gov.pl [01-09–2016].

4 E. Andersson et al., *Reconnecting Cities to the Biosphere: Stewardship of Green Infrastructure and Urban Ecosystem Services*, "AMBIO" 2014 no. 43, p. 445–453.

5 I. Douglas, *Urban ecology and urban ecosystems: understanding the links to human health and well-being*, "Current Opinion in Environmental Sustainability" 2012 no. 4(4), p. 385–392.

6 *Urban adaptation to climate change in Europe 2016*. EEA Report No 12/2016.

7 T. McPhearson et al., *Resilience of and through urban ecosystem services*, "Ecosystem Services" 2014 no. 12, p. 152–156.

8 T. McPhearson et al., Advancing Urban Ecology toward a Science of Cities, "BioScience" 2016 no. XX(X), p. 1–15.

9 J. Langemeyer et al., *Contrasting values of cultural ecosystem services in urban areas: The case of park Montjuïc in Barcelona*, "Ecosystem Services" 2014, p. 1–9.

10 D. Łowicki, *Land prices as an indicator of the recreational services of ecosystems*, "Ekonomia i Środowisko" 2012 no. 2(42), p. 167–175.

Study area

The case study area consists of the city of Wroclaw and its suburban municipalities (figure 1). The suburban municipalities (i.e. Kostomłoty, Miękinia, Oborniki Śląskie, Wisznia Mała, Czernica, Długołęka, Kąty Wrocławskie, Kobierzyce, Sobótka, Święta Katarzyna /Siechnice, Żórawina) cover the area of 1430 km^2. Together with the city of Wroclaw (293 km^2) they constitute a major part of the Wroclaw Metropolitan area. The case study area is located in the Lower Silesia region in the west-south part of Poland. The climate of this area belongs to the temperate group of climates and in detail is described as transitional between maritime and continental. Average annual precipitation is 590 mm of rainfall and the annual average temperature is 9,3°C[11]. These parameters together with high quality soils constitute highly favourable agriclimate.

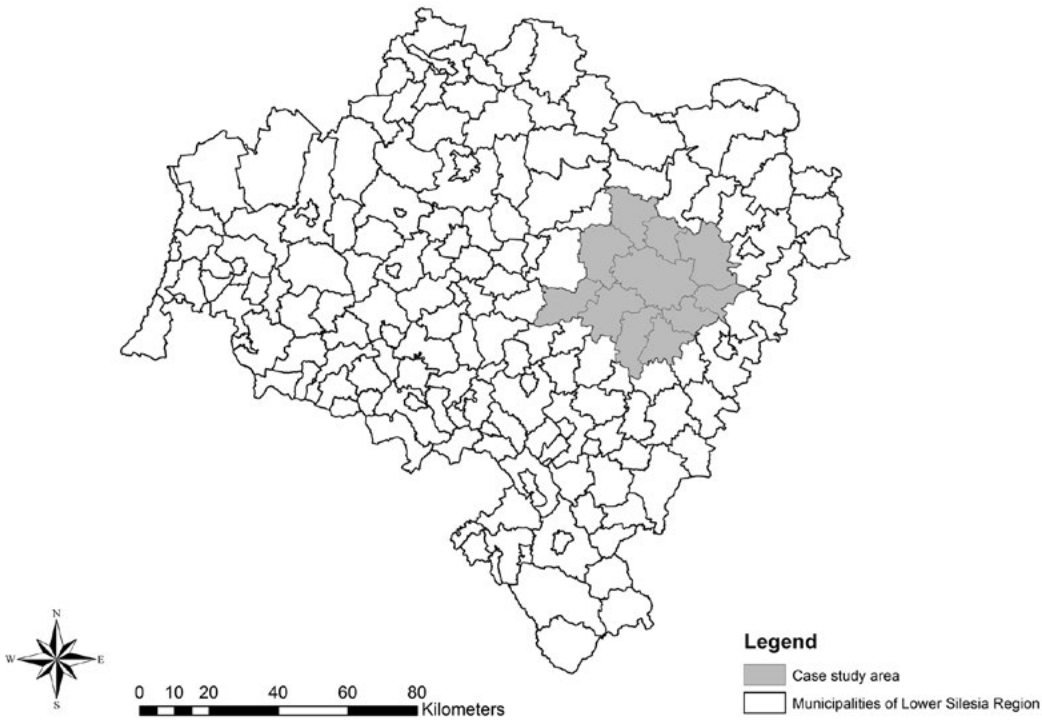

Figure 1. The case study area

[11] *Stan i zmiany właściwości gleb użytkowanych rolniczo w województwie dolnośląskim w latach 2000–2005*, Puławy Wrocław 2007, p. 19–20.

The study area was chosen based on land use change and the results of the study on every day commuting to work of the inhabitants of Wroclaw and surrounding municipalities[12]. The surrounding municipalities undergo intensive processes of suburbanisation. The land cover patterns of the main CORINE land cover classes for Wroclaw and suburban municipalities proves main challenges that the suburban area is facing. The biggest losses in terms of land cover are of non-irrigated arable lands and biggest gains in the urbanised areas. The urbanised areas have increased by 3 times, when arable land has decreased by 12%. The previous studies concerning this area prove the increasing land use changes into urbanised areas are supported and enhanced by the spatial planning documents[13]. The spatial policies are designed to enlarge urban area to host 2,600,000 inhabitants, which is more than three time the current number of citizens[14].

Materials and methods

The author analyses spatial distribution of two ecosystem services representing the two main types of ES distinguished in CICES 4.3 over the course of years 1990–2012. Food provision and global climate regulation by reduction of greenhouse gas concentrations were approached according to different quantification methods (table 1). The mapping activity was based on Corine Land Cover (CLC) data sets provided by the European Environment Agency for years 1990, 2000, 2006, and 2012. Therefore, unlike Urban Atlas, the use of CLC enabled the comparisons between different time spans. The spatial resolution of CLC is enough for setting the policy guidelines at sub-regional scale[15]. At the local level, though, the use of CLC may lead to overestimation of ecosystem service provision[16].

12 *Dojazdy do Pracy*. Narodowy Spis powszechny Ludności i Mieszkań 2011, Warszawa 2014, p. 170.

13 J. Kazak, Sz. Szewrański, J. Sasik, *Gospodarowanie zasobami przestrzennymi w strefie podmiejskiej Wrocławia* (Spatial Resource Management in the Suburban Area of Wroclaw), Studia Komitetu Przestrzennego Zagospodarowania Kraju PAN (Studies of Committee for Spatial Economy and Regional Planning of Polish Academy of Science) 2013 vol. 22, no. 1, p. 185–197.

14 J. Kazak, Sz. Szewrański, P. Decewicz, *Holistic Assessment of Spatial Policies for Sustainable Management: Case Study of Wroclaw Larger Urban Zone (Poland),* in: D. Lee, E. Dias, H.J. Scholten (eds), *Geodesign by Integrating Design and Geospatial Sciences*, Springer 2014.

15 F. Kroll, et al., *Rural-urban gradient analysis of ecosystem services supply and demand dynamics*, “Land Use Policy” 2012 no. 29(3), p. 521–535.

16 M. Kandziora, B. Burkhard, F. Müller, *Mapping provisioning ecosystem services at the local scale using data of varying spatial and temporal resolution*, “Ecosystem Services” 2013 no. 4, p. 47–59.

Table 1. Overview of ES indicators and quantification methods used in the assessment

Ecosystem Service		Method	Description	Unit	Relevant ecosystem type
Provisioning services					
Food supply	Crops production	Proxy-based method	The capacity of ecosystem to provide winter wheat crop service	[t/ha/yr]	Agricultural land
Regulating services					
Global climate regulation	Reduction of greenhouse gas concentrations	Benefit transfer	The capacity of ecosystem to store carbon in the above- and below-ground part of living plant material	[tC/ha/yr]	Forest and urban

Food provision

Food provision is a providing ecosystem service defined as "the capacity of agro-ecosystems to provide crop services"[17]. Food provision can be quantified using different methods. Egoh et al[18] classified the quantification methods into three categories:

- collection of primary data through direct observations;
- proxy methods in which a single or combined indicators are used to define ES, such as composite indicators;
- process models in which indicators are used as variables in the equation.

Food provision, as the ecosystem service that is soil and climate dependant, is spatially explicit. The most common data used for mapping food provision is land cover/land use maps, soil data and vegetation types. MAES 2nd Technical Report[19] suggests two indicators for the food supply quantification: as the volume of yields of food and feed crops in t/ha [ton dry matter/ha, or MJ/ha] and food and feed crop area [ha].

In this study, the food supply is defined as the potential of agro-ecosystems to provide crop services. The potential depends on various environmental factors related to soil quality and its type, agriclimate, water relations, topography and human induced factors such as agrotechnique, machinery and grains type, time of seeding, etc. In the case study region, the agricultural production consists mainly of cereals (71% of total farmland), among which

17 J. Maes, M.L. Paracchini, G. Zulian, *A European assessment of the provision of ecosystem services. Towards an atlas of ecosystem services,* European Union 2011.

18 B. Egoh, et al., *Indicators for mapping ecosystem services: a review*, European Union 2012.

19 *Mapping and Assessment of Ecosystems and their Services*, Indicators for ecosystem assessments under Action 5 of the EU Biodiversity Strategy to 2020, 2nd Report – Final, European Union 2014, s. 42.

the wheat production has the greatest share (36% of total farmland[20]). Therefore, in the food provision wheat production is taken as a proxy of food supply. The composite indicator for evaluation of agricultural production area is used for describing the ecological potential for food provision. The indicator consists of four elements: soil quality and type suitability for agricultural production, agroclimate, water relations (soil moisture) and topography[21]. The case study areas is 1430 km^2 of similar topography and agriclimate. Therefore, it is the soil type and class that have the biggest effect on changes in the agricultural production for this case study area. The potential wheat harvest in the case study areas is explained using two main variables: soil classes suitable for agricultural production and field study data on harvest with the use of basic agrotechnique (table 2).

Table 2. Soil classes suitable for agricultural production and field study data on harvest

Soil class number	Soil class description	Harvest volumes of winter wheat with basic agrotechnique (a1) –averages for 1999–2013 [t/ha]
1	Wheat very good	8,3
2	Wheat good	7,8
3	Wheat defective	5,8
4	Rye very good (wheat-rye)	7,0
5	Rye good	5,6

Source: *Stan i zmiany właściwości gleb użytkowanych rolniczo w województwie dolnośląskim w latach 2000–2005*, Puławy Wrocław 2007; Polish Official Variety Testing. Variety Testing Experimental Station database.

Global climate regulation

Global climate regulation by reduction of greenhouse gas concentrations is a regulating ecosystem service. The main greenhouse gas that is considered in prevailing studies on mapping and assessment of this service is carbon dioxide. The IPCC 2006[22] distinguishes five carbon pools: above- and below-ground biomass, deadwood, litter and soil organic carbon. These pools

20 *Podstawowe informacje według podregionów, powiatów i gmin województwa dolnośląskiego,* Powszechny Spis Rolny 2010, Wrocław 2012.

21 *Stan i zmiany właściwości…*, op. cit., s. 19–20.

22 IPCC 2006 Guidelines for National Greenhouse Gas Inventories, www.ipcc-nggip.iges.or.jp [08-08–2016].

are ecosystems that can store and sequester carbon. Carbon sequestration can be estimated by physically measured gas exchange, expressed in the ecosystem productivity indicators[23], or same as carbon storage, by applying different equations, the most of which include biomass expansion factor, carbon fraction of dry matter or net annual increment. Due to data limitation, the final values of carbon storage of different ecosystem were transferred to the case study area. Each land use class of CLC was attributed with the possible carbon storage capacity in hectares per year based on literature review and default numbers provided in the IPCC Guidelines for National Greenhouse Gas Inventories 2006. The benefit transfer of tonnes of carbon stored in the above- and below-ground parts of living plant material per year is applied to different land use classes. The main criteria for benefit transfer were climatic zone, geolocation of the study site, and year of publication of results.

Carbon storage is equated with the net removal of CO_2 and therefore any land use/cover classes that have no net accumulation of biomass carbon stocks within the year are excluded from the analysis. These are: agricultural areas, complex cultivation patterns and pastures, construction sites and mineral extraction sites.

The spatial distribution of the above- and below-ground carbon stored in living plant material is presented. The carbon storage is estimated for the following ecosystems and land use types: forest, settlements and woody plantations (table 3).

Table 3. Default and literature review values for carbon stored in biomass

Land Cover Class	[tC/ha/yr]	Source
Broad-leaved forest	123,17	IPCC 2006, Forest data bank
Coniferous forest	133,84	IPCC 2006, Forest data bank
Mixed forest and fruit trees and berries	119,73	IPCC 2006, Forest data bank
Green urban areas and transitional woodland shrub	69,7	Literature review[a)]
Discontinuous urban fabric and transport, sport and leisure facilities	12,5	Literature review[a)]
Continuous urban fabric	10	Literature review[b)]

a) T. Elmqvist et al., *Benefits of restoring ecosystem services in urban areas*. "Current Opinion in Environmental Sustainability" 2015 no. 14, p. 101–108.
b) M.W. Strohbach, D. Haase, *Above-ground carbon storage by urban trees in Leipzig, Germany : Analysis of patterns in a European city*, "Landscape and Urban Planning" 2012 no. 104(1), p. 95–104.

23 A. Danielewska, M. Urbaniak, J. Olejnik, *Growing season length as a key factor of cumulative net ecosystem exchange over the pine forest ecosystems in Europe*, "International Agrophysics" 2015 no. 29, p. 129–135.

Results

Food provision

The results show changes in the proxy-based estimated capacity of the ecosystem to provide food supply ecosystem service and in the possible harvest of winter wheat according to the assumptions taken. The main differences between two referencing years are caused by land use change taking place taken place on the soils that have the biggest ecological potential for food provision. The harvest area shrank by 2,75% which constitutes 668 ha (figure 2).

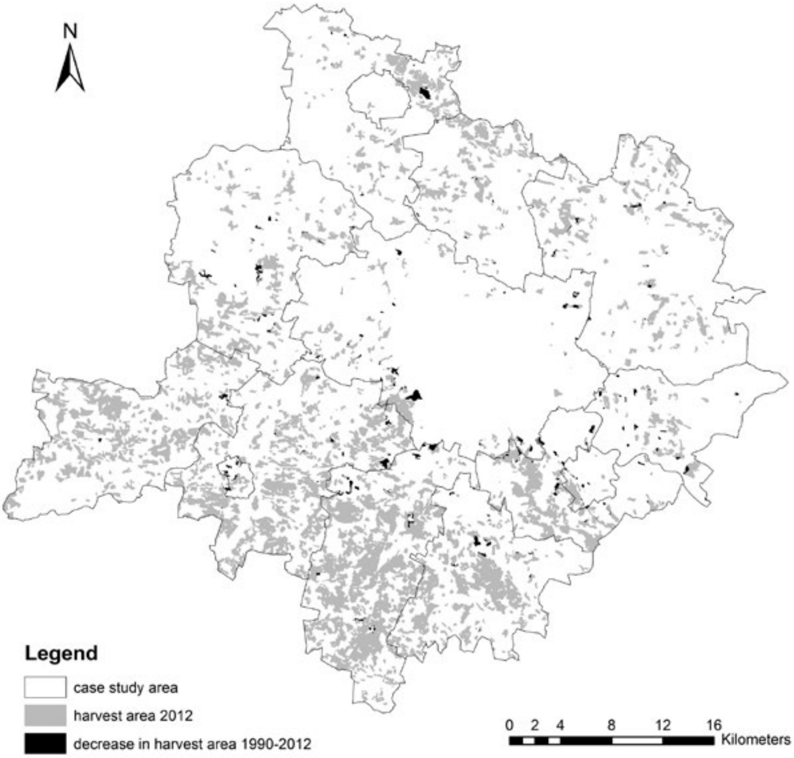

Figure 2. The spatial distribution of food supply service in 2012 and decrease in harvest area between 1990–2012

The loss in the harvest area could lead to the possible loss of 5271,6 t of harvested winter wheat. Almost 48% of land use changes resulted of the conversion from agricultural areas with high quality soils to discontinuous urban fabric. Next most often directions of land use changes were into industrial or commercial units (8%) and pastures (7%).

Global climate regulation

The potential of the ecosystems to provide global climate regulation vary between the 1990 and 2012 in the case study area (figure 3 and 4). The change in the potential provision is mainly due to the land use change between these years. The change from agricultural land (with no net accumulation of biomass carbon stocks) into discontinuous urban fabric, meaning mostly single-family housing estates in the suburbs, cause increase in the carbon storage potential by 4,89%. That is 170212,8 tC more in 2012 than compared to the year 1990. The biggest increase occurred between the years 2000 and 2006. Especially after 2004, the year of access of Poland to the European Union, the real estate market was at its boom[24].

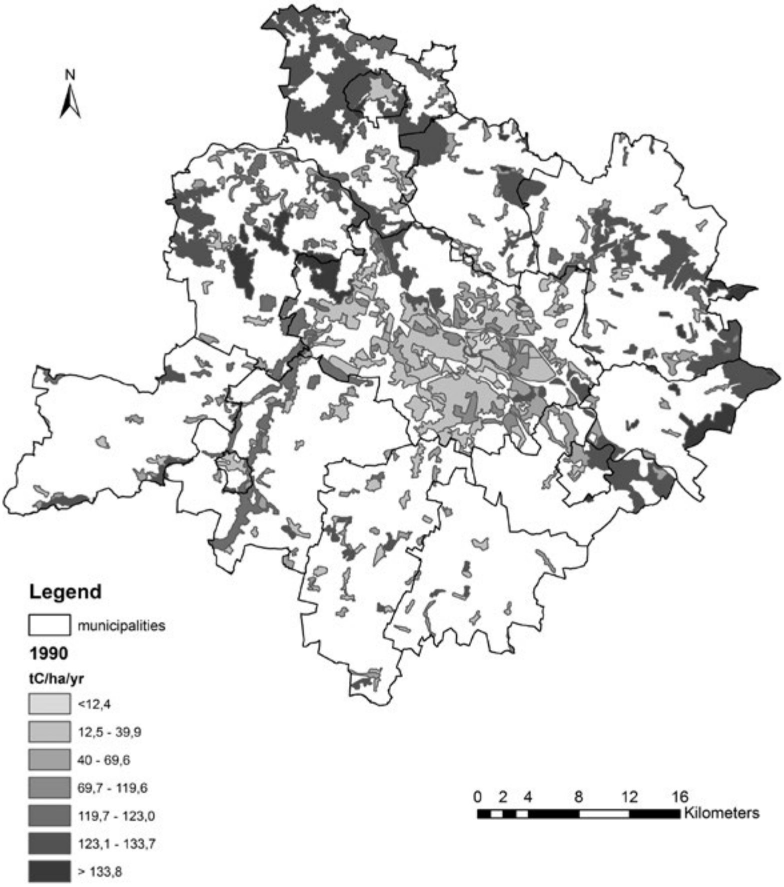

Figure 3. The spatial distribution of global climate regulation service in 1990

[24] E. Sawiłow, *Zmiany cen na wrocławskim rynku nieruchomości po wejściu Polski do Unii Europejskiej*, "Studia i Materiały Towarzystwa Naukowego Nieruchomości" 2007 vol. 15, no. 1–2, p. 149–157.

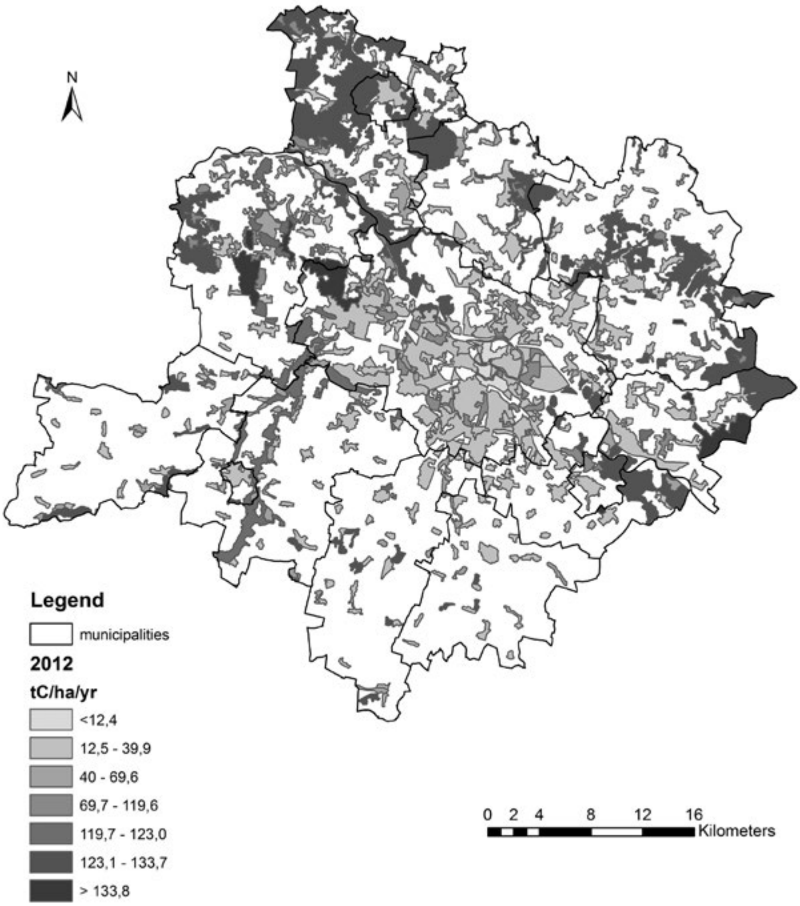

Figure 4. The spatial distribution of global climate regulation service in 2012

Conclusions, limitations and challenges

The study presents the use of two methods to assess and map two different ecosystem services in the suburban case study area of Wroclaw. The results show the proxy-based method as well as benefit transfer can be used at the subregional scale for assessment of the selected ecosystem services for the decision-support purpose. The results enable to provide the relative change of the potential provision of the assessed ecosystem services. The potential provision of carbon storage has increased while the food provision has decreased. Even though the ecosystem services were assessed with the use of different methods, results of both methods are closely linked to the land use/cover change in the case study area. The use of CLC enabled the comparability of the case study area between different time frames.

The considerable limitation to the study is the lack of the ecosystem service condition assessment. That could be overcome by either enlarging the set of indicators describing ecosystem condition or by applying a different method. Other limitations are closely related to the use of the selected methods. The benefit transfer could be improved by the use of benefit function transfer or meta analysis method. The proxy-based method used to assess the crop provision could be exchanged for process-based modelling. The use of more sophisticated methods is, however, limited by the time and capacity. Another important limitation is the unassessed level of uncertainty of the results of this case study. The benefit transfer method imposes a high degree of uncertainty involved in the quantification of the carbon storage due to the use default and literature review values. For the case of spatial planning, the uncertainties should be explained to the stakeholders so that the expectations about the accurateness of results are met.

The main challenge to the ecosystem service assessment that has come out of this case study is the data availability. The data on crop harvest disaggregated to the local scale is not freely available for the first ecosystem service of this case study. In the assessment of the second ecosystem service, the main challenge was the data on carbon storage in this particular area. The data on Polish National Gas Inventory is not freely available. The use of the benefit transfer method was mainly the outcome of the data limitations. The possible way to overcome this challenge would be to do field sampling and laboratory measurements.

Literature

Andersson E. et al., *Reconnecting Cities to the Biosphere: Stewardship of Green Infrastructure and Urban Ecosystem Services*, "AMBIO" 2014 no. 43, p. 445–453

Danielewska A., Urbaniak M., Olejnik J., *Growing season length as a key factor of cumulative net ecosystem exchange over the pine forest ecosystems in Europe*, "International Agrophysics" 2015 no. 29, p. 129–135

Dojazdy do Pracy. Narodowy Spis powszechny Ludności i Mieszkań 2011, Warszawa 2014

Douglas I., *Urban ecology and urban ecosystems: understanding the links to human health and well-being*, "Current Opinion in Environmental Sustainability" 2012 no. 4(4), p. 385–392

Egoh B. et al., *Indicators for mapping ecosystem services: a review*, European Union 2012

Elmqvist T. et al., *Benefits of restoring ecosystem services in urban areas*. "Current Opinion in Environmental Sustainability" 2015 no. 14, p. 101–108

Elmqvist T. et al., *History of Urbanization and the Missing Ecology,* in: *Urbanization, biodiversity and ecosystem services: challenges and opportunities. A Global Assessment*, Dordrecht, Heidelberg, New York, London 2013

IPCC 2006 Guidelines for National Greenhouse Gas Inventories, www.ipcc-nggip.iges.or.jp

Kandziora M., Burkhard B., Müller F., *Mapping provisioning ecosystem services at the local scale using data of varying spatial and temporal resolution*, "Ecosystem Services" 2013 no. 4, p. 47–59

Kazak J., Szewrański Sz., Decewicz P., *Holistic Assessment of Spatial Policies for Sustainable Management: Case Study of Wroclaw Larger Urban Zone (Poland),* in: D. Lee, E. Dias, H.J. Scholten (eds), *Geodesign by Integrating Design and Geospatial Sciences*, Springer 2014

Kazak J., Szewrański Sz., Sasik J., *Gospodarowanie zasobami przestrzennymi w strefie podmiejskiej Wrocławia* (Spatial Resource Management in the Suburban Area of Wroclaw), Studia Komitetu Przestrzennego Zagospodarowania Kraju PAN (Studies of Committee for Spatial Economy and Regional Planning of Polish Academy of Science) 2013 vol. 22, no. 1, p. 185–197

Kroll F. et al., *Rural-urban gradient analysis of ecosystem services supply and demand dynamics*, "Land Use Policy" 2012 no. 29(3), p. 521–535

Langemeyer J. et al., *Contrasting values of cultural ecosystem services in urban areas: The case of park Montjuïc in Barcelona*, "Ecosystem Services" 2014, p. 1–9

Łowicki D., *Land prices as an indicator of the recreational services of ecosystems*, "Ekonomia i Środowisko" 2012 no. 2(42), p. 167–175

Maes J., Paracchini M.L., Zulian G., *A European assessment of the provision of ecosystem services. Towards an atlas of ecosystem services,* European Union 2011

Mapping and Assessment of Ecosystems and their Services, Indicators for ecosystem assessments under Action 5 of the EU Biodiversity Strategy to 2020, 2nd Report – Final, European Union 2014

McPhearson T. et al., Advancing Urban Ecology toward a Science of Cities, "BioScience" 2016 no. XX(X), p. 1–15

McPhearson T. et al., *Resilience of and through urban ecosystem services*, "Ecosystem Services" 2014 no. 12, p. 152–156

Podstawowe informacje według podregionów, powiatów i gmin województwa dolnośląskiego, Powszechny Spis Rolny 2010, Wrocław 2012

Sawiłow E., *Zmiany cen na wrocławskim rynku nieruchomości po wejściu Polski do Unii Europejskiej*, "Studia i Materiały Towarzystwa Naukowego Nieruchomości" 2007 vol. 15, no. 1–2, p. 149–157

Stan i zmiany właściwości gleb użytkowanych rolniczo w województwie dolnośląskim w latach 2000–2005, Puławy Wrocław 2007

Strohbach M.W., Haase D., *Above-ground carbon storage by urban trees in Leipzig, Germany : Analysis of patterns in a European city*, "Landscape and Urban Planning" 2012 no. 104(1), p. 95–104

Urban adaptation to climate change in Europe 2016. EEA Report No 12/2016

Urban Environment, www.eea.europa.eu

www.stat.gov.pl