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Summary Report

Development of vector maps showing selected and important services of urban ecosystems on a national scale

Raport sporządzony dla Koordynatora Projektu – Uniwersytet im. Adama Mickiewicza w Poznaniu

Usługi świadczone przez główne typy ekosystemów w Polsce – Podejście Stosowane
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Warszawa, 30.09.2021

1. Introduction

The aim of the second stage of the task concerning urban ecosystems under the project "Services provided by main types of ecosystems in Poland - an applied approach", which this report concerns, was to develop vector maps showing selected and important services of urban ecosystems on the national scale. Ecosystem services (ES) indicators were selected from the set of 78 indicators proposed by IGiPZ PAN in the first stage of the project, supplemented by new proposals, the implementation of which became possible due to the current availability of data. They constitute an original and innovative approach in the assessment of ES in cities, as well as an extension of the set of indicators proposed earlier by I. Zwierzchowska and A. Mizgajski (2019) related to the abundance and spatial distribution of green infrastructure in the largest agglomerations of our country.

The ten new indicators developed by IGiPZ PAN refer to provisioning services (use of agricultural space in metropolitan areas to meet nutritional purposes), regulation and maintenance services (regulation of hydrological cycle, including flood control; regulation of air temperature and humidity; air purification from particulate matter; regulation of the chemical composition of the atmosphere; maintenance of nursery populations of living organisms) and cultural services (the possibility of recreation and recuperation in nature). The selection of services and the indicators describing them was based on their significance for the well-being of urban residents. The indicators refer to ES potential, use or unmet demand, as suggested by Maes et al. (2020). Most of the proposed indicators may refer to more than one service, as it is often the case that services appear together repeatedly in time and/or space, forming so called ES bundles. The indicators were calculated for all 20 functional urban areas (FUA) in Poland with the status of a metropolitan area (FUA250), i.e. those with a population of over 250,000, according to the OECD classification and delimitation (2021). Calculations were carried out for the entire FUA, as well as for its urban centre and commuting zone (Fig. 1). Raw indicator values for each service were reclassified to 1-5 rank scale to show the relative ES use, potential or unmet demand and to facilitate comparisons among FUAs.

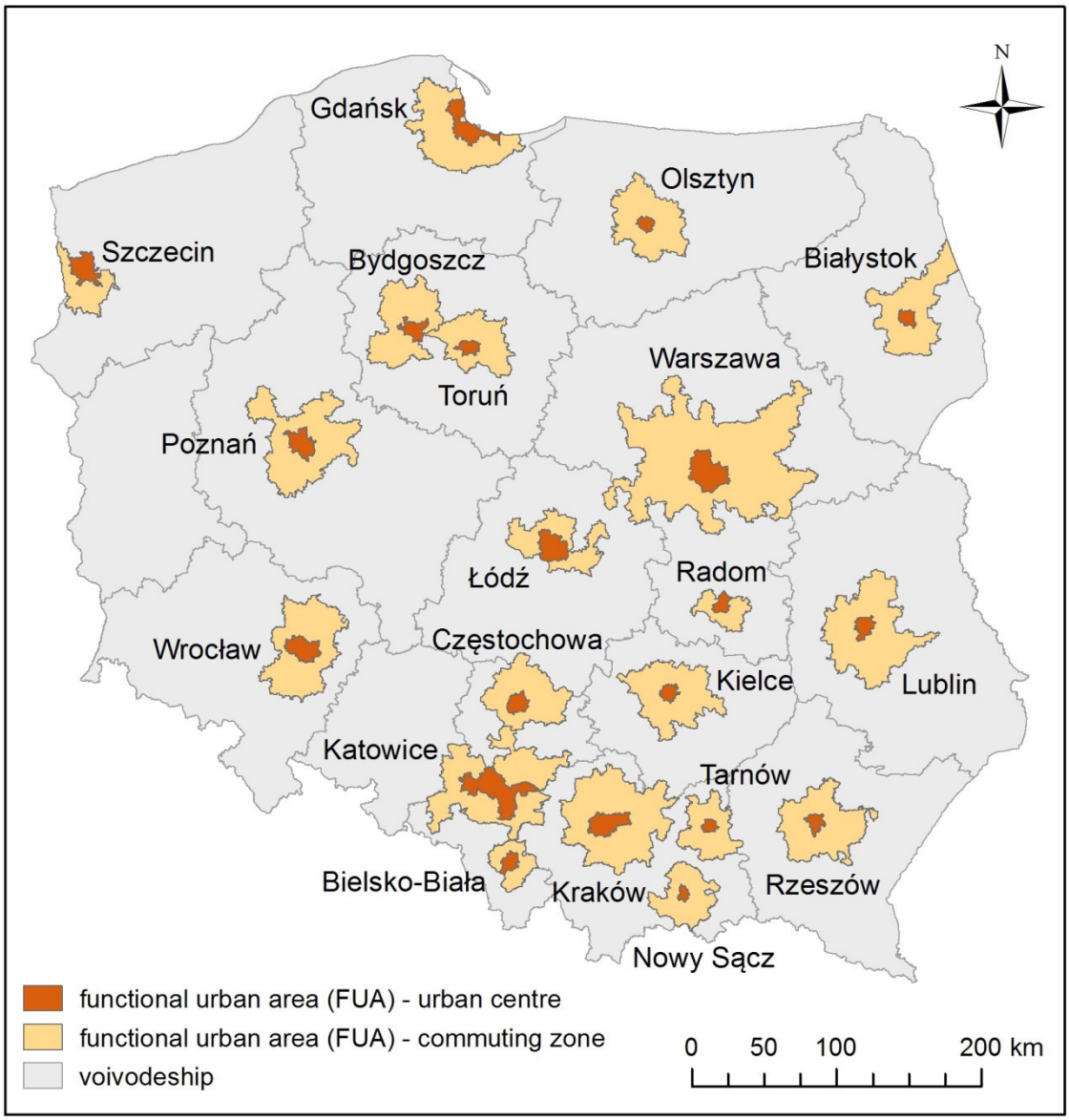

Fig. 1. Functional urban areas (FUA) with the status of a metropolitan area (FUA250) in Poland according to OECD (2021)

2. Ecosystem Services

2.1. Provisioning Services

2.1.1. Potential use of agricultural land in the metropolitan area for nutritional purposes

Ecosystem service: Provision of food

Section: Provisioning; division: Biomass; group: Cultivated terrestrial plants for nutrition, materials or energy; Class: Cultivated terrestrial plants (including fungi, algae) grown for nutritional purposes (code: 1.1.1.1).

The subject of the measurement is the potential use of agricultural land in the metropolitan area for nutritional needs. A service “Provision of food” is determined indirectly, based on the soil resource of metropolitan areas for their potential use for cultivated terrestrial plants grown for nutritional purposes. In the literature, total and per capita agricultural area is treated as one of the most important elements of the production potential of agriculture in Poland (Ziętara, 2017).

Two indirect indicators were proposed to assess the potential of this service:

– land resources for cultivated terrestrial plant per capita (Fig. 2). The indicator was constructed as the quotient of the sum of the area of arable land, orchards and permanent grassland of a given unit divided by the population of that unit (are per capita)

– share of land for cultivated terrestrial plant (Fig. 3). The indicator was constructed as the share of the area of arable land, orchards and permanent grassland defined for the FUA, urban centres and commuting zones, in the area of these units (%).

For both indicators, statistical data were obtained from the "Local Data Bank" of the Central Statistical Office (data available for selected years).

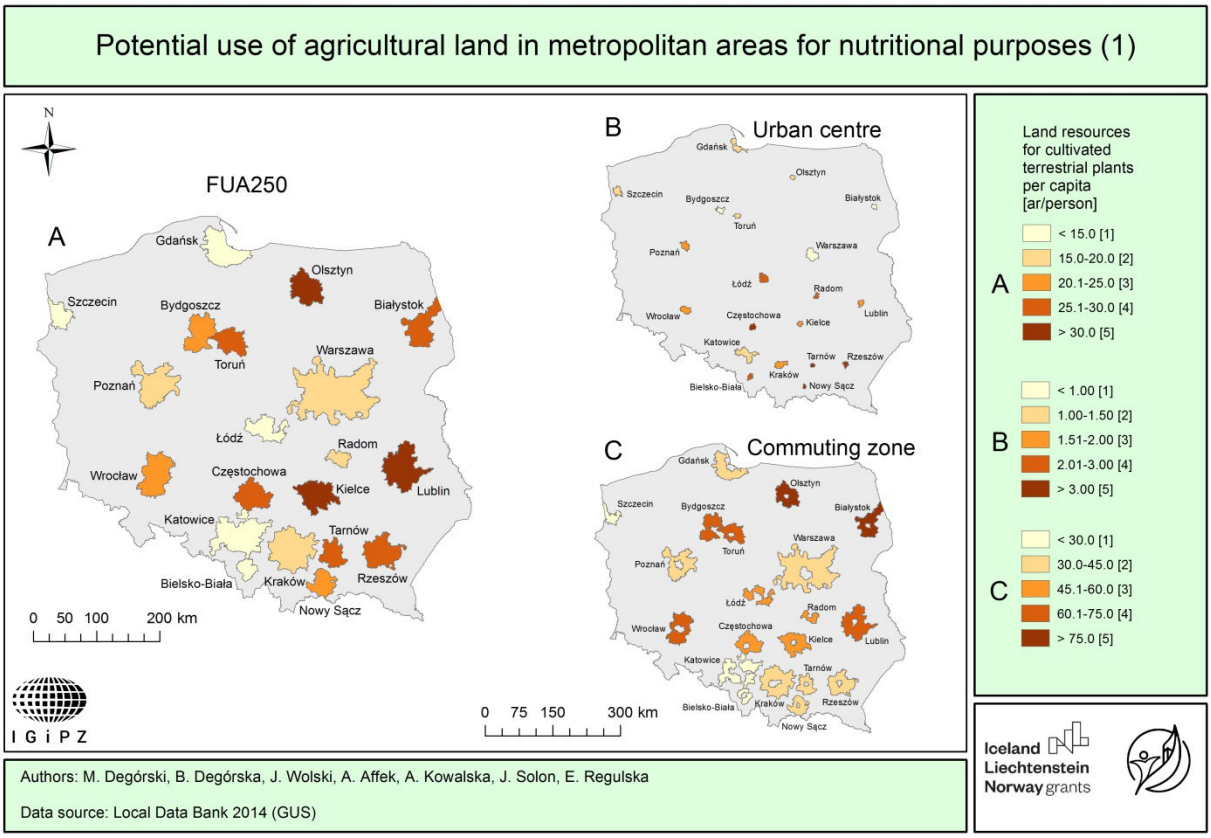

Fig 2. Potential use of agricultural land in metropolitan areas for nutritional purposes (1)

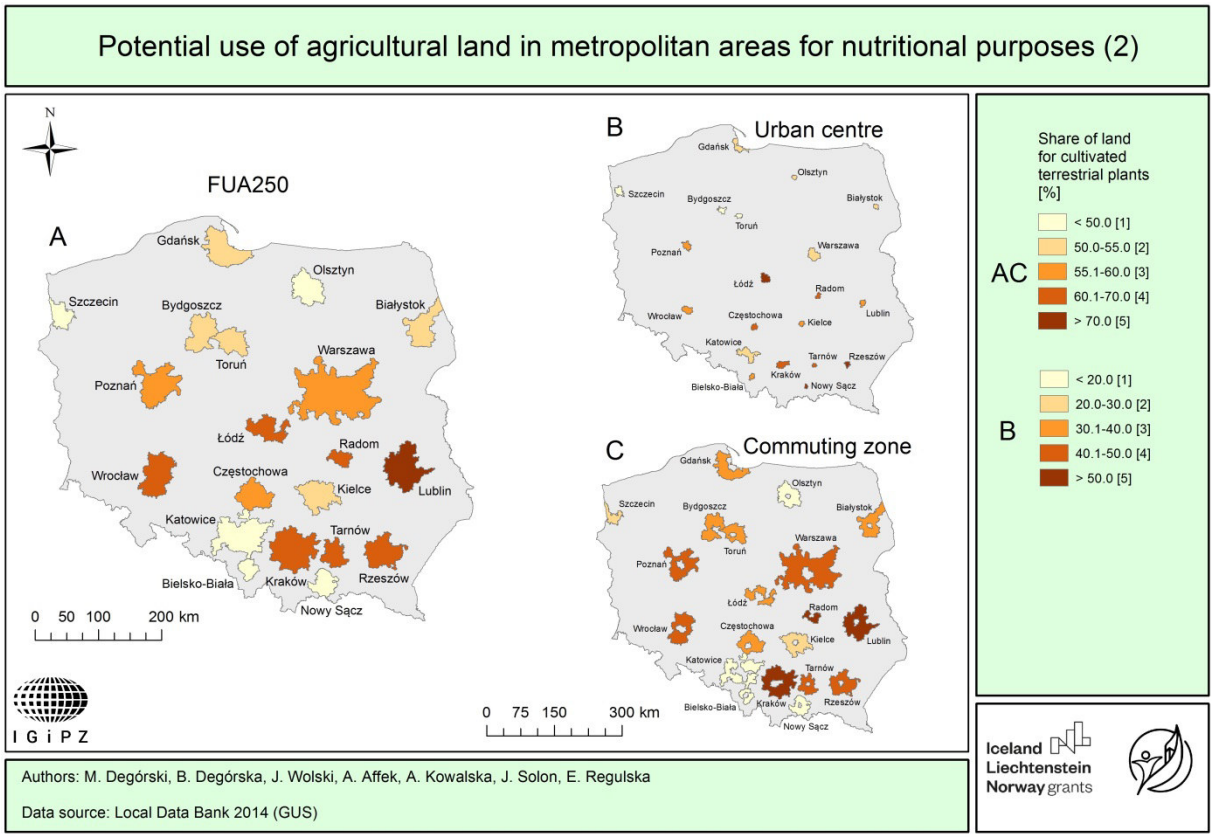

Fig. 3. Potential use of agricultural land in metropolitan areas for nutritional purposes (2)

The need to maintain strategic soil resources for agricultural production is of great importance, including to residents of metropolitan areas. Despite the globalised food market, food self-sufficiency is gaining importance, especially in crises. This is in line with EU policy *From farm to fork*. There is also a partial change in the consumption model, leading to an increase in the demand for healthy food and local products. In addition, it has an impact on eliminating unnecessary transport due to short supply chains to large urban centres. In addition to provisioning services, other related services, both cultural and regulating, can also contribute to the increasing importance of FUAs agriculture. Nevertheless, in addition to human benefits, agriculture also generates risks, e.g. to water and soil quality, which can be described as disservices.

2.2. Regulation and Maintenance Services

2.2.1. Key regulating services provided by trees in metropolitan areas

In an urban environment, we face a number of processes that negatively affect people's well-being. They include, among others pollution of air, soil and water, rapid rainwater runoff and risk of flooding, urban heat island and summer heatwaves (Livesley et al., 2016). It has long been known that trees are an integral part of the environmental quality of cities around the. At the same time, there is a growing awareness of the value of ecosystem services that urban trees and forests can provide to the world (Turner-Skoff and Cavender, 2019). Below, we

present indicators of the use of three regulating services provided by trees, which are essential for urban environment.

2.2.1.1. Hydrological cycle and water flow regulation, including flood control

This service belongs to *Regulation and Maintenance* section and *Regulation of physical, chemical, biological conditions* division in CICES V5.1. It can be further described as the regulation of water flows by virtue of the chemical and physical properties or characteristics of ecosystems that assists people in managing and using hydrological systems, and mitigates or prevents potential damage to human use, health or safety. The subject of measurement is the use of trees to regulate the hydrological cycle, including flood control, in metropolitan areas, and the tree cover is the indicator. As source data we used the high-resolution (10 × 10 m) Copernicus layer *Tree cover density* valid for 2018. Each raster cell contains information on the percentage of the Earth's surface covered by tree crowns. Tree cover (in %) for FUAs, their urban centres and commuting zones were obtained by calculating the mean of all cells in a given spatial unit using the *Zonal Statistics as Table* function in ArcGIS 10.2. The obtained indicator values ranges from 14% to 42% for the entire metropolitan areas, 10-29% for urban centres, and 14-43% for commuting zones (Fig. 4). The tree cover in the urban centres is significantly lower compared to the commuting zones, on average by 5.3% (t = -3.11; p = 0.006).

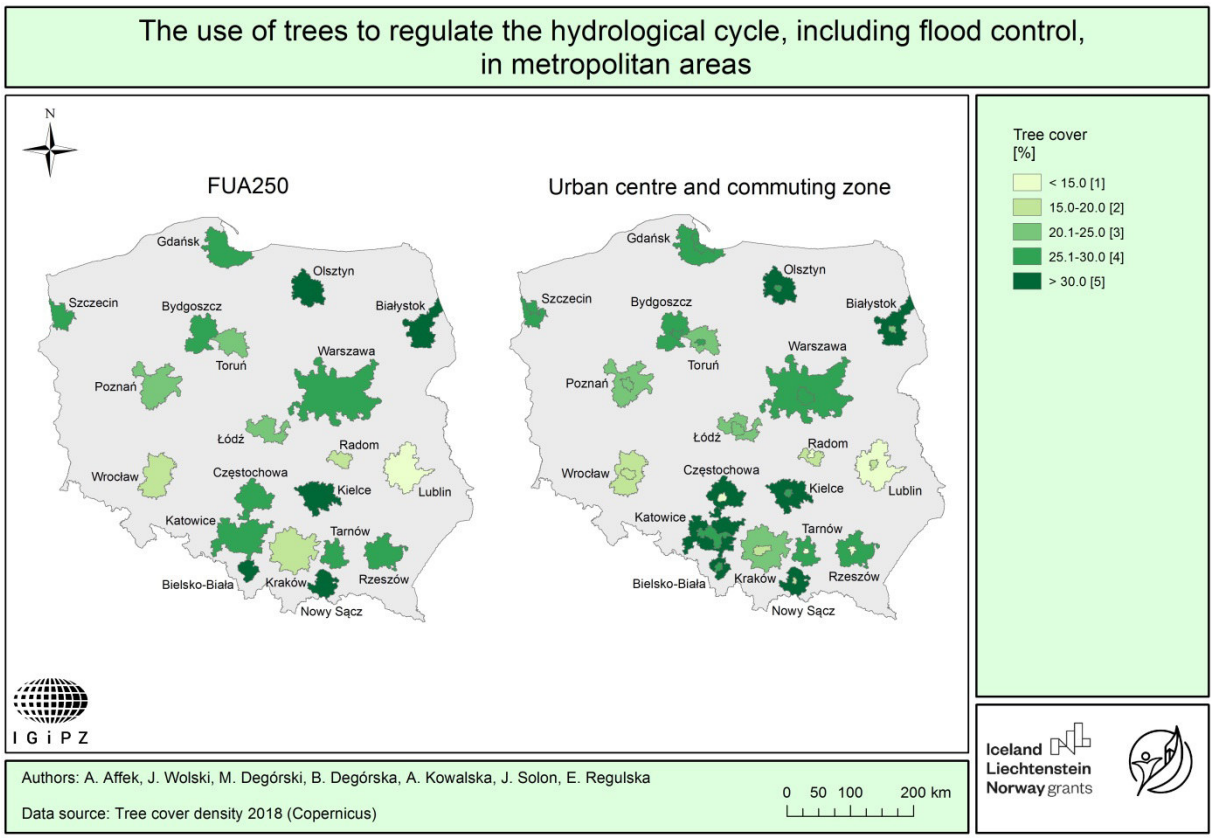

Fig. 4. The use of trees to regulate the hydrological cycle, including flood control, in metropolitan areas

2.2.1.2. Regulation of air temperature and humidity

This service belongs to *Regulation and Maintenance* section and *Regulation of physical, chemical, biological conditions* division in CICES V5.1. It can be further described as the mediation of ambient atmospheric conditions (including micro- and mesoscale climates) by virtue of presence of plants that improves living conditions for people. The subject of measurement is the use of trees to regulate air temperature and humidity in residential areas of metropolitan areas, and the tree cover in residential areas is the indicator. As source data we used the high-resolution (10 × 10 m) Copernicus layer *Tree cover density* valid for 2018, and CORINE Land Cover data for 2018. Tree cover (in %) for FUAs, their urban centres and commuting zones were obtained by calculating the mean of all cells in residential areas (CLC class *Urban fabric*) in a given spatial unit using the *Zonal Statistics as Table* function in ArcGIS 10.2. The obtained indicator values ranges from 6% to 16% for the metropolitan areas, 6-15% for urban centres, and 5-16% for commuting zones (Fig. 5). The capital city FUA (Warsaw) reached maximum values for each reference unit (FUA, urban centre and commuting zone). Interestingly, tree cover in residential areas of the urban centres is significantly higher compared to residential areas of the commuting zone, although on average only by 1.1% ($t = 2.62$, $p = 0.017$).

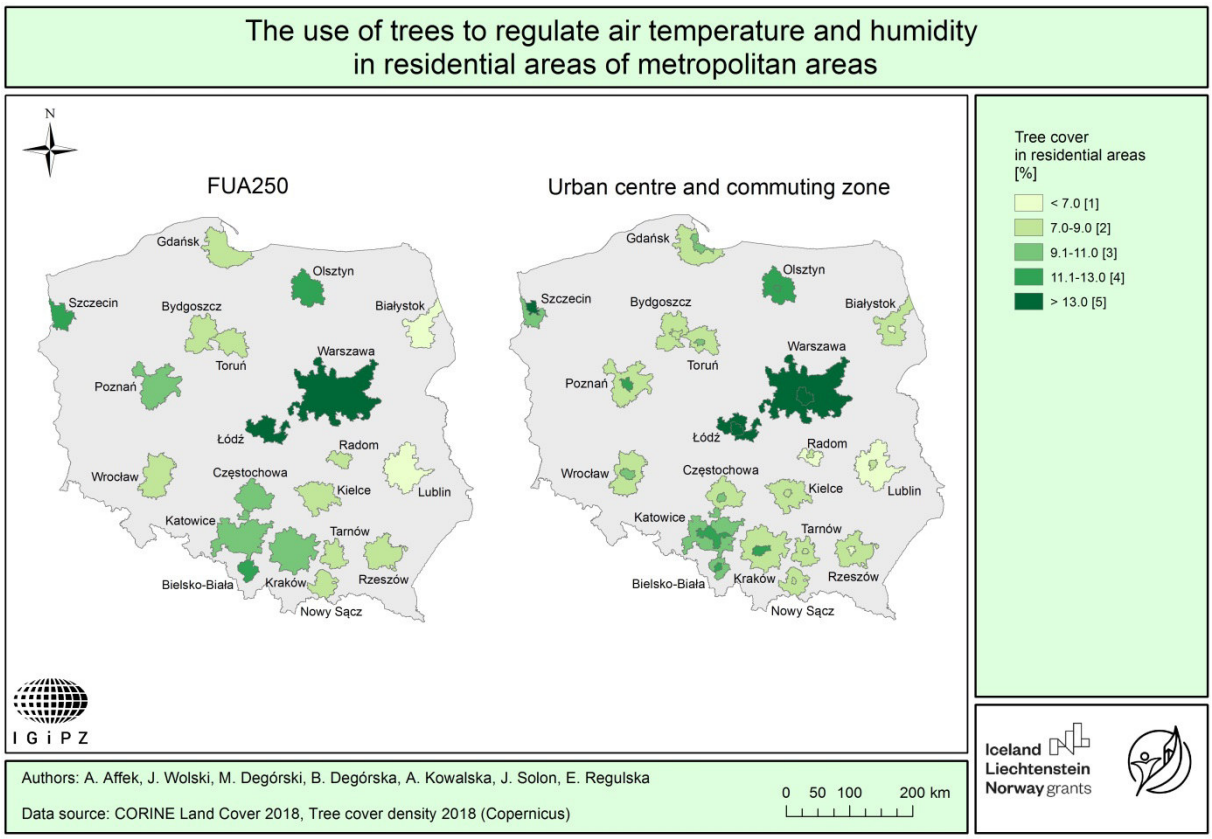

Fig. 5. The use of trees to regulate air temperature and humidity in residential areas of metropolitan areas

2.2.1.3. Purification of the air from particulate matter

This service belongs to *Regulation and Maintenance* section and *Transformation of biochemical or physical inputs to ecosystems* division in CICES V5.1. It can be further described as the fixing and storage of atmospheric aerosols (particulate matter, including PM2.5 and PM10) by a species of plant, animal, bacteria, fungi or algae that mitigates its harmful effects and reduces the costs of disposal by other means. The subject of measurement is the use of trees to reduce particulate matter air pollution from anthropogenic sources in metropolitan areas, and the number of trees per person is the indicator. As source data we used the high-resolution (10 × 10 m) Copernicus layer *Tree cover density* valid for 2018. Tree cover (in %) for FUAs, their urban centres and commuting zones were obtained by calculating the mean of all cells in a given spatial unit using the *Zonal Statistics as Table* function in ArcGIS 10.2. After correction due to different input data, the average crown size of 18.8 m^2 derived from the Map of Tree Crowns for Warsaw (http://zzw.waw.pl/2021/02/26/miliony-warszawskich-drzew-na-jednej-mapie/) was adopted for all FUAs for the transformation of tree cover into the number of trees. Then, the number of trees obtained in the reference unit was divided by the population obtained from the Local Data Bank of the Central Statistical Office, valid as of December 31, 2020. The obtained indicator values ranges from 21 to 157 for the metropolitan areas, 3-12 for urban centres, and 48-440 for commuting zones (Fig. 6). The number of trees per person is much lower in urban centres compared to the commuting zones, on average by as many as 123 trees per person ($t = -5.89$, $p < 0.0001$).

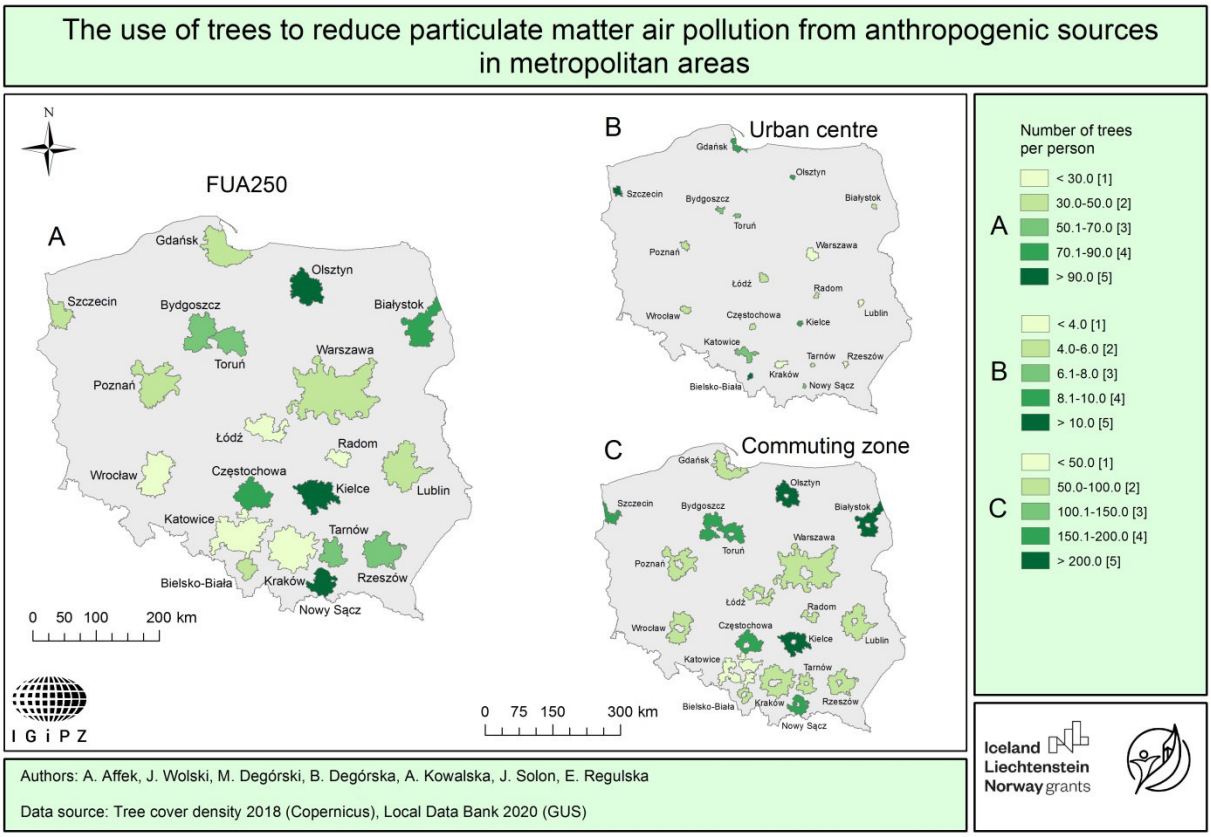

Fig. 6. The use of trees to reduce particulate matter air pollution from anthropogenic sources in metropolitan areas

2.2.2. Regulation of the chemical composition of the atmosphere

This service belongs to *Regulation and Maintenance* section and *Regulation of physical, chemical, biological conditions* division in CICES V5.1. It can be further described as the regulation of the concentrations of gases in the atmosphere that impact on global climate. The subject of measurement is the use of vegetation in metropolitan areas to regulate the chemical composition of the atmosphere, and the indicator is the average total productivity in the growing season. As source data we used the newly published (August 31, 2021) high-resolution (10 × 10 m) Copernicus layer *Total Productivity Season 1* valid for 2020, representing the total gross primary production in the main growing season. Total Productivity (in PPI × day, where PPI is the value of the plant phenology index (Jin and Eklundh, 2014) for FUAs, their urban centres and commuting zones were obtained by calculating the mean of all cells in a given spatial unit using the *Zonal Statistics as Table* function in ArcGIS 10.2. The obtained indicator values ranges from 1081 to 1400 for the metropolitan areas, 839-1340 for urban centres, and 1092-1440 for commuting zones (Fig. 7). The average total productivity in the urban centres is significantly lower compared to the commuting zones, on average by 187 PPI × day, i.e. 15% ($t = -8.82$; $p < 0.001$).

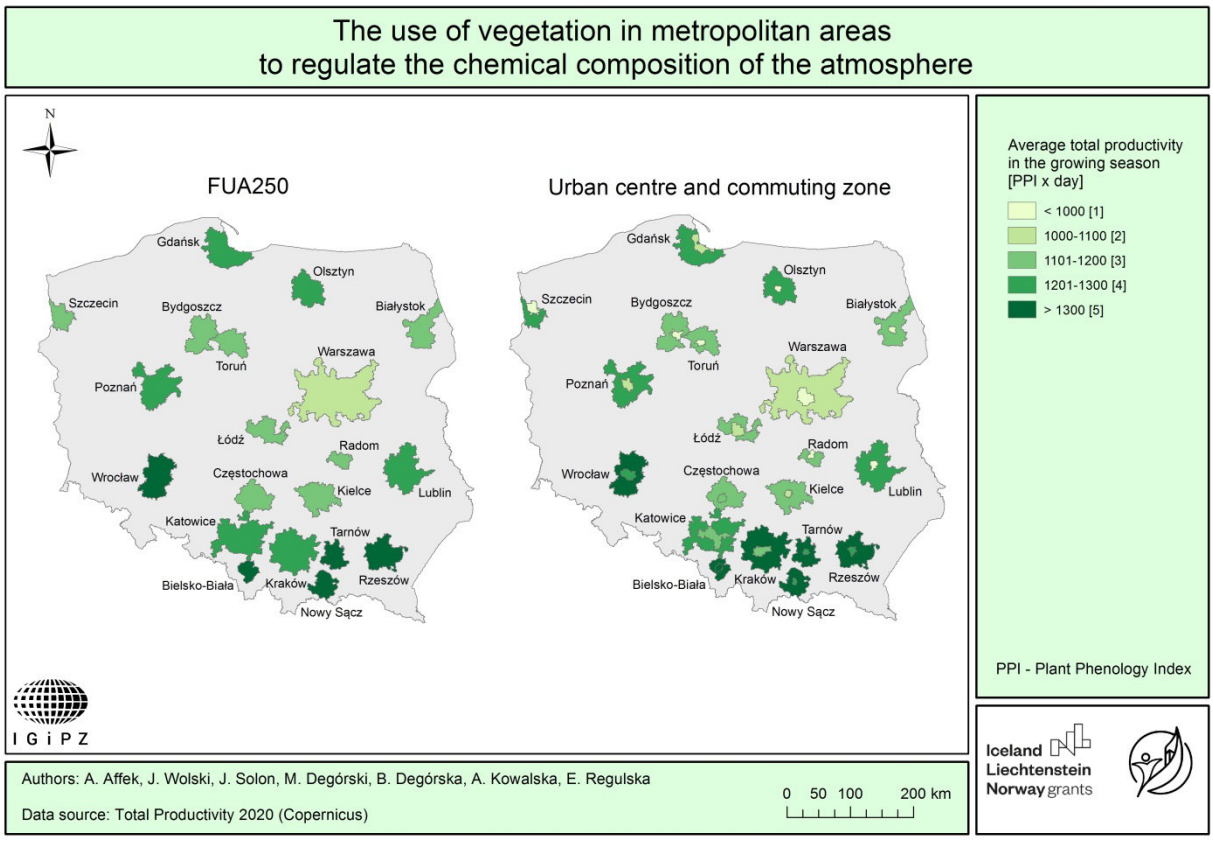

Fig. 7. The use of vegetation in metropolitan areas to regulate the chemical composition of the atmosphere

2.2.3. Lifecycle maintenance, habitat and gene pool protection

The particular services included in the class *Maintaining nursery populations and habitats (Including gene pool protection)* in CICES v5.1 can be handled very differently, according to

the thematic scope of these services, as they may concern, for example: (a) all or only selected groups of species, (b) habitats essential for all life processes or only species reproduction, (c) individual habitats or habitats and the ecological corridors connecting them (compare: Affek et al., 2020). Without going into more detailed considerations, we present sample indicators representing two different approaches to the issue.

2.2.3.1. Maintaining nursery populations of species

This service belongs to *Regulation and Maintenance* section and *Regulation of physical, chemical, biological conditions* division in CICES V5.1. It involves providing conditions for the sustained occurrence and reproduction of species populations, while maintaining appropriate levels of genetic diversity. The object of measurement is the presence of potential habitat and breeding sites for local native species in well-developed ecosystems of high biodiversity, and an indicator of the potential of this service is the area share of specific categories of protected areas. The service was assessed by means of two indicators:

A. Total share of national parks, landscape parks and nature reserves in the reference area (OCHRONA1)
B. Total share of national parks, landscape parks, nature reserves and NATURA2000 sites in the reference area (OCHRONA2)

Spatial data on the distribution, names and type of protected areas of the following categories: national parks, reserves, NATURA2000 sites (Special Protection Areas – SPAs – for birds, Special Areas of Conservation – SACs – for species other than birds, and for habitat types), landscape parks were derived from the official datasets of the General Directorate for Environmental Protection (in shp format). The values of both indicators were calculated for the three types of reference plots: the FUA urban centre, FUA commuting zone and the entire FUA.

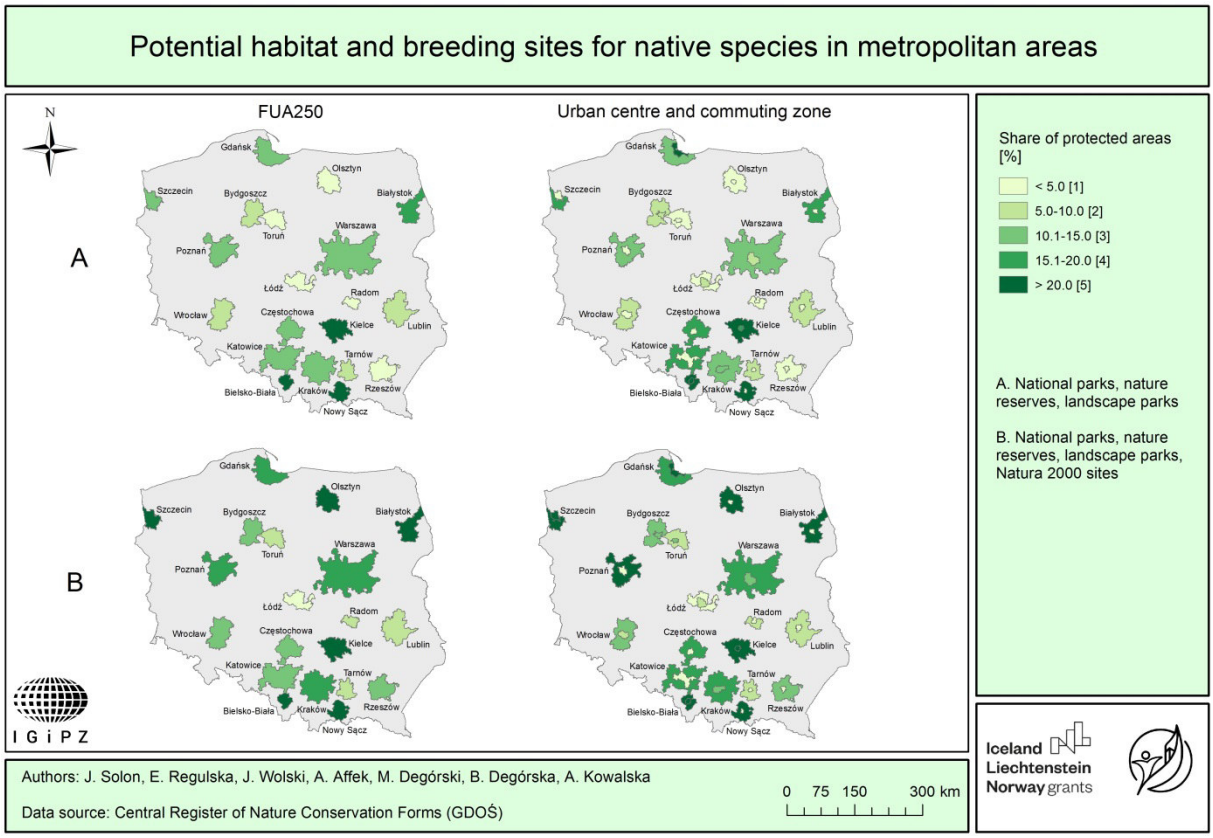

Fig. 8. Potential habitat and breeding sites for native species in metropolitan areas

The obtained indicator values of OCHRONA1 ranges from 0.2 to 30% for the metropolitan areas, 0-23% for urban centres, and 0.1-31% for commuting zones, while the obtained indicator values of OCHRONA2 ranges from 5 to 41% for the metropolitan areas, 0.2-39% for urban centres, and 4-45% for commuting zones (Fig. 8).

2.2.3.2. Maintaining ecological connectivity between populations and habitats

This service belongs to *Regulation and Maintenance* section and *Regulation of physical, chemical, biological conditions* division in CICES V5.1. It involves providing conditions for movement of individuals of particular species between locations suitable for reproduction and safe foraging. The object of measurement is the potential for movement and gene pool exchange between populations of large forest mammals in metropolitan areas, and the indicator is the calculated numerical characteristics of the shortest path between the most distant forest patches within the FUA. This service was assessed by means of two indicators:

A. Relative resistance of the shortest path (ŚCIEŻKA1)

B. Relative number of steps of the shortest path (ŚCIEŻKA2)

The base material was 2018 CORINE Land Cover data. It was assumed that land cover diversity corresponds - in simplified terms - to ecosystem diversity. In the first step of the procedure, two patches of forest within each metropolitan area (FUA) were selected that were as far apart as possible, but within the reference unit. The Euclidean distance (in km) between the boundaries of these forest patches was then determined from the map. This

distance was used to create relative index values. In the next step, the path of least resistance was defined in GraphScape.

GraphScape software uses a vector map representing discrete spatial units for analysis. The basis of the analyses is a complete graph of connections (boundaries) between all patches. The basic task of the program is to define such a path between two patches (defined as the sequence of patch boundaries to be crossed and measured by the number of these boundaries) that has the least resistance. The path resistance is defined as the sum of the resistances of crossing (transfer resistance), staying (patch class resistance) and leaving (individual patch resistance). Patch class resistance is determined by the suitability of the patch for the species, process, or phenomenon being analyzed. In practice, suitability is not determined for individual patches separately, but for patch classes. The relevant data are entered as a separate table. Resistance to stay is not an intrinsic value of the map, but depends on the issue being analyzed. Transfer resistance depends on structural, habitat and functional similarity between adjacent patches (the more similar the patches, the lower the transfer resistance). The data are entered as an additional cross table (matrix) where the users define the similarity/resistance values themselves. Passage resistance is a characteristic of the patch types depicted on the map and does not depend on the detailed task analyzed in the program (Pomianowski and Solon, 2020). For the purpose of determining the indicators, only the variation of stay and passage resistance was taken into account.

The resulting paths (represented as a polyline connecting the centroids of the patches through which it passes) were characterized by two numerical values. The first was the total path resistance and the second was the number of patch boundaries crossed. Due to the different size of FUAs, direct comparison of values for different FUAs can be misleading. Therefore, relative metrics, related to the 10 km direct distance between patches (rather than path length), were used for comparison purposes. The obtained indicator values of ŚCIEŻKA1 ranges from 0.357 to 1.610 for the metropolitan areas, while values of ŚCIEŻKA2 ranges from 2.375 to 7.357 (Fig. 9).

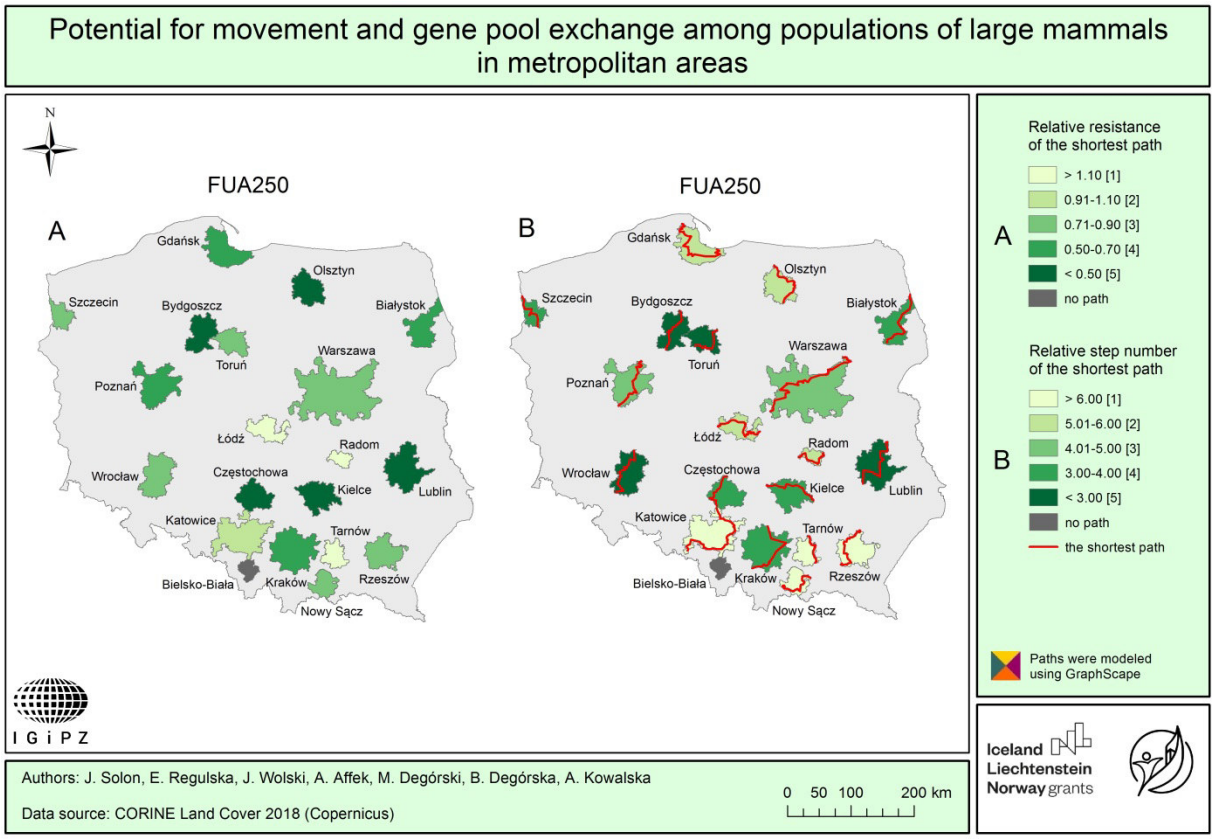

Fig. 9. Potential for movement and gene pool exchange among populations of large mammals in metropolitan areas

2.3. Cultural Services

2.3.1. Recreation and recuperation in nature

Recreation and recuperation in nature is of great importance for physical and mental well-being of urban residents (Geary et al., 2021). It is ensured by green urban spaces, which are more and more valued (increasing the attractiveness of the place of residence) and protected, but often lose out in the competition for land as the share of the population living in urban areas continues to rise. Not only the area of green spaces is important, but also their even spatial distribution in the city, which makes them accessible to all residents. The potential of metropolitan areas for recreation in nature was estimated through the share of spaces dedicated to the provision of recreation services, whereas the unmet demand - through the proportion of residential areas beyond the 300/1000 m buffer from spaces dedicated to recreation in nature.

After a detailed analysis of the 2018 Urban Atlas database, six classes were selected (14100 – urban green areas, 14200 – sports and leisure facilities, 31000 – forests, 32000 - herbaceous vegetation, 40000 – wetlands and 50000 – water) as those providing good conditions for direct, in-situ and outdoor interactions with living systems in cities and offering the possibility of recreation and recuperation in nature. The share of these classes in the FUA urban centre and commuting zone was calculated and used as an indicator of ES potential.

Accessibility to green spaces offering the possibility of recreation and recuperation in nature was determined on two scales: local and supralocal. For the local scale, a distance of 300 m was adopted, measured in a straight line from the green spaces, corresponding to 5-6 min walk; for a supralocal scale, a distance of 1000 m and a minimum area of 2 ha (see Zwierzchowska and Mizgajski, 2019; *Studium uwarunkowań* …, 2020). The demand for recreational services was related to the residential areas corresponding to the five categories of the Urban Atlas: 11100 – continuous urban fabric (S.L. >80%), 11210 – discontinuous dense urban fabric (S.L.: 50-80%), 11220 – discontinuous medium density urban fabric (S.L.: 30-50%), 11230 – discontinuous low density urban fabric (S.L.: 10-30%), 11240 – discontinuous very low density urban fabric (S.L. <10%). The proportion of residential areas beyond 300/1000 m buffers to all residential areas within the FUA urban centre and commuting zone was than calculated and used as an indicator of ES unmet demand.

For the 20 selected FUAs (metropolitan areas), the share of green spaces dedicated to the provision of recreation services ranges from 12% to 58% in urban centres and from 15% to 50% in their surroundings (commuting zones) (Fig. 10).

The percentage of residential areas beyond the 300 m buffer from spaces dedicated to recreation in nature in all residential areas ranges from 6% to 42 % in urban centres and from 18% to 55% in their surroundings (commuting zones) (Fig. 11). High values of this indicator show a high level of unmet demand for recreation in nature, i.e., low share of green spaces in urban centres/FUAs and their low availability at a distance of 300 m from the place of residence. All values greater than 0 mean an unfavourable state, as they indicate unmet demand of even a small group of residents. Better availability of green areas in the urban centres was reported at the supralocal scale (1000 m buffer). The indicator ranges from 0% to 12%. However, in the commuting zones access to green spaces at a distance of 1000 m from the residential areas is smaller compared to urban centres, the indicator ranges from 1% to 51% (Fig. 11).

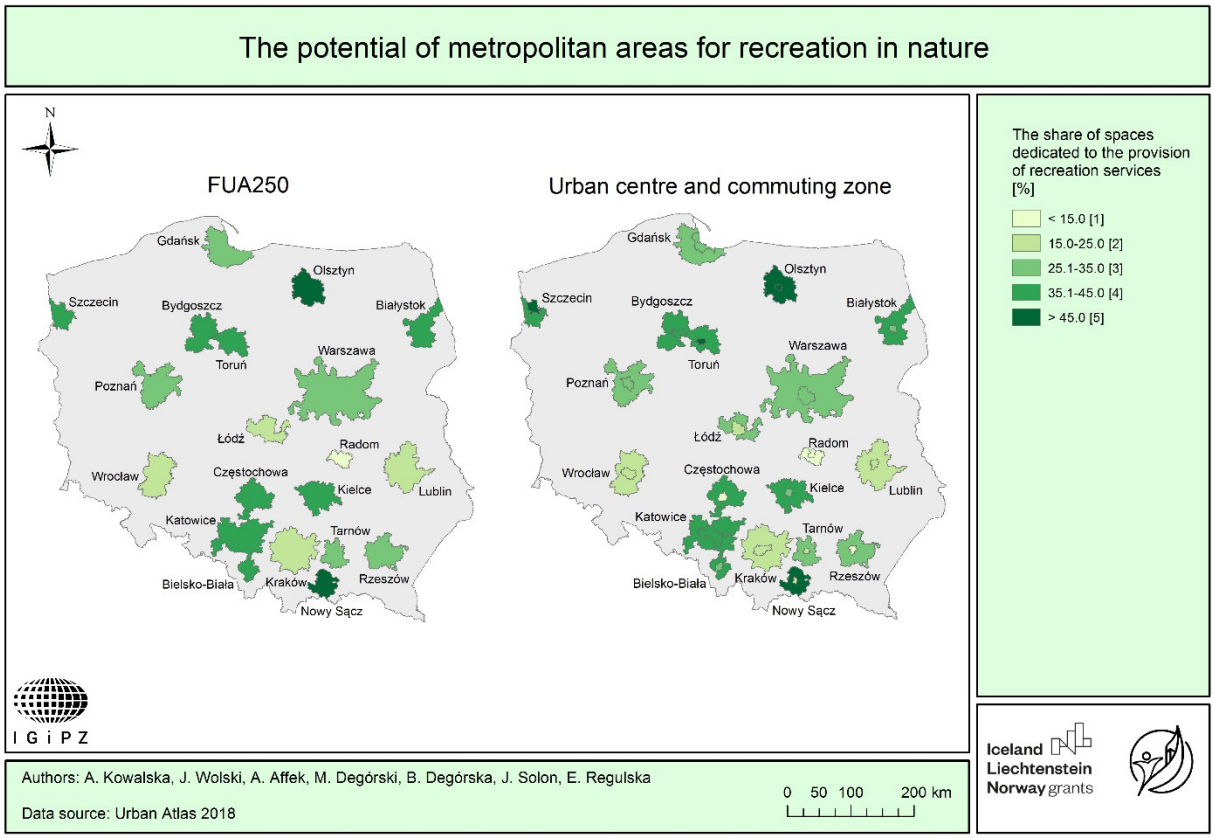

Fig. 10. The potential of metropolitan areas for recreation in nature

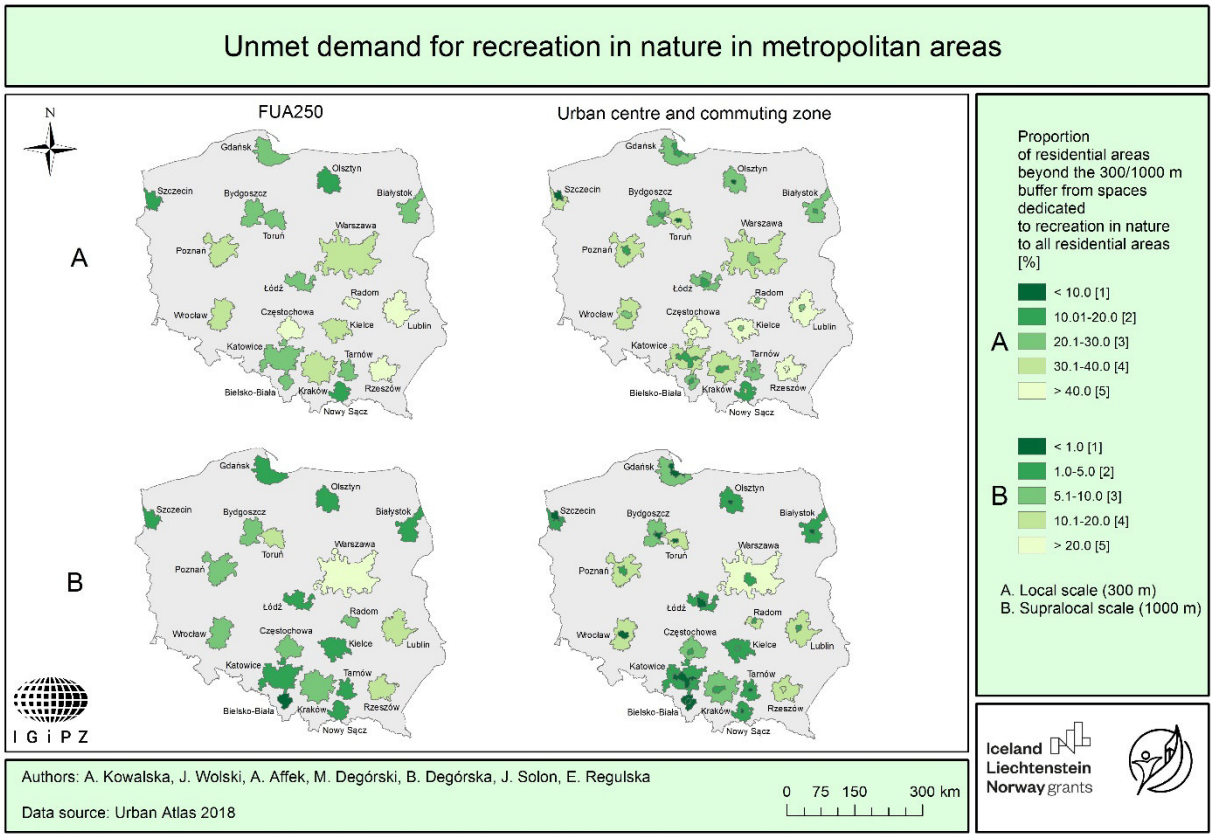

Fig. 11. Unmet demand for recreation in nature in metropolitan areas

References

Affek, A.N., Degórski, M., Wolski, J., Solon, J., Kowalska, A., Roo-Zielińska, E., Grabińska, B., Kruczkowska, B., 2020. *Ecosystem service potentials and their indicators in postglacial landscapes: Assessment and mapping*. Amsterdam, Oxford, Cambridge: Elsevier.

Geary, R.S., Wheeler, B., Lovell, R., Jepson, R., Hunter, R., Rodgers, S., 2021. *A call to action: Improving urban green spaces to reduce health inequalities exacerbated by COVID-19*. Preventive Medicine, 145: 106425.

Jin, H., Eklundh, L., 2014. *A physically based vegetation index for improved monitoring of plant phenology*. Remote Sensing of Environment, 152: 512-525.

Livesley, S.J., McPherson, E.G., Calfapietra, C., 2016. T*he Urban Forest and Ecosystem Services: Impacts on Urban Water, Heat, and Pollution Cycles at the Tree, Street, and City Scale*. Journal of Environmental Quality, 45:119-24.

Maes, J., Teller, A., Erhard, M., Condé, S., Vallecillo, S., Barredo, J.I., Paracchini, M.L., Abdul Malak, D., Trombetti, M., Vigiak, O., Zulian, G., Addamo, A.M., Grizzetti, B., Somma, F., Hagyo, A., Vogt, P., Polce, C., Jones, A., Marin, A.I., Ivits, E., Mauri, A., Rega, C., Czúcz, B., Ceccherini, G., Pisoni, E., Ceglar, A., De Palma, P., Cerrani, I., Meroni, M., Caudullo, G., Lugato, E., Vogt, J.V., Spinoni, J., Cammalleri, C., Bastrup-Birk, A., San Miguel, J., San Román, S., Kristensen, P., Christiansen, T., Zal, N., de Roo, A., Cardoso, A.C., Pistocchi, A., Del Barrio Alvarellos, I., Tsiamis, K., Gervasini, E., Deriu, I., La Notte, A., Abad Viñas, R., Vizzarri, M., Camia, A., Robert, N., Kakoulaki, G., Garcia Bendito, E., Panagos, P., Ballabio, C., Scarpa, S., Montanarella, L., Orgiazzi, A., Fernandez Ugalde, O., Santos-Martín, F., 2020, *Mapping and Assessment of Ecosystems and their Services: An EU ecosystem assessment*, EUR 30161 EN, Ispra:.Publications Office of the European Union.

OECD, 2021. Functional urban areas by country. Pobrane z https://www.oecd.org/regional/regional-statistics/functional-urban-areas.htm (20.09.2021)

Pomianowski, W., Solon, J., 2020. *Modelling patch mosaic connectivity and ecological corridors with GraphScape*. Environmental Modelling & Software, 134: 104757.

Studium Uwarunkowań i Kierunków Zagospodarowania Przestrzennego m.st. Warszawy. Uwarunkowania. Miejska Pracownia Planowania Przestrzennego i Strategii Rozwoju. Warszawa, 2020, maszynopis.

Turner-Skoff, J.B., Cavender, N., 2019. *The benefits of trees for livable and sustainable communities*. Plants People Planet, 1: 323-335.

Ziętara, W., 2017. *Polskie gospodarstwa rolnicze na tle tendencji w Unii Europejskiej*. Materiały konferencyjne, Przysiek 12 grudnia 2017: 2-13. Pobrane z: https://www.kpodr.pl/wp-content/uploads/2017/12/materialy_konferencyjne.pdf (15.09.2021).

Zwierzchowska, I., Mizgajski, A., 2019. *Potencjał zielonej infrastruktury w dużych polskich miastach do świadczenia usług ekosystemowych*. Rozwój Regionalny i Polityka Regionalna, 47: 21-37.