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MAPPING ECOSYSTEM SERVICES – A NEW REGIONAL-SCALE APPROACH

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Abstract

Identifying the potential of ecosystems to provide ecosystem services (ES) is largely dependent on the detail and completeness of the base ecosystem map. The existing guidelines for the construction of this type of map include only a few basic types of ecosystems that work only at a national or international scale and are insufficient to identify the full potential of ecosystem services at local or regional scales. The aim of the study was to develop a comprehensive map of ecosystem types for mapping ecosystem services at a local and regional scale in three selected communes located within young glacial landscape (NE Poland). As a result, a detailed map of ecosystems has been constructed containing 42 ecosystem types including age and habitat categories. This original map is the first detailed cartographic work that can be successfully used to determine the potential for ecosystem services to be provided by areas analysed in large scales. The proposed approach has a universal character and can be also applied to any area analysed at similar spatial scales.

Key words

ecosystem services • ecosystem • mapping • GIS • Poland

Introduction

Awareness of the benefits that ecosystems bring to society, which has been increasing over the last few decades, has contributed to the development of the concept of ecosystem services (ES). Ecosystem services are broadly defined as a set of products (e.g. wood, forest fruits, wild game) and ecosystem functions (e.g. water and air treatment, oxygen production, recreation areas) used by society (Costanza et al. 1997). In recent years, numerous proposals have been made to organize the terminology and classification of ecosystem services, the most important of which have included the Millenium Ecosystem Assessment – MEA (MEA 2005), the Economics of Ecosystems and Biodiversity – TEEB (TEEB 2010) and the Common International Classification of Ecosystem Services – CICES (Haines-Young & Potschin 2013).

The CICES classification, strongly recommended by the European Environmental Agency for use in the European Union (Haines-Young & Potschin 2013), is a strictly hierarchical system for practical application. The highest level is made up of three sections, divided into divisions, groups and classes: provisioning – all products of living organisms used by humans (including food, materials and energy), regulation and maintenance – all services in which living organisms are mediators or moderators of the surrounding environment for human benefit (including regulation of air composition, soil processes and pollution, counteraction of land degradation, disease control and others) and cultural – all non-material and non-consumer ecosystems products which influence the physical and mental condition of a human being (e.g. recreational, spiritual, aesthetic, educational, religious).

The practical and scientific use of the ES concept is related to three connected issues: (a) a clear definition of benefits, including the identification of their suppliers, (b) a description of measurement methods and measure indicators and (c) cartographic presentation of the spatial variation of supply and demand of ES.

Mapping ecosystem services is a complex problem that involves several closely related issues, the most important of which is the selection of a suitable spatial unit for the identification and assessment of ecosystem services. The nature of this unit determines the credibility of the spatial image and its potential use for scientific and practical purposes. The selection of a reference unit is influenced by several factors, including the size of the study area and the associated scale of analysis, the purpose of the analysis and the recipient of the results, and finally the availability of data representing an adequate level of detail. These prerequisites form a general basis for the considerations presented in this article, whose main objective is to present an original concept of a basic map for mapping the potential of ecosystems to provide services at a local and regional scale against the background of other solutions currently in use.

Mapping ecosystem services – different approaches

According to the UN Convention on Biological Diversity (CBD) (United Nations 1992) an ecosystem is defined as 'a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit'. This definition is very broad (much broader than in classic ecology textbooks) and can be applied at all spatial and temporal scales. Spatial explicitness is important to characterize ecosystems in terms of their natural conditions determined by climate, geology, soil properties, elevation etc. and, in terms of their physical and chemical conditions and how they are influenced by anthropogenic pressures. Although not explicitly stated in the definition, it is generally accepted that ecosystems should be internally homogeneous, in contrast to landscape systems which, by definition, are internally heterogeneous.

According to Hein et al. (2006), the influence of ecosystem services can be seen on four general levels of ecological systems: (1) global (> 1,000,000 km^2), (2) biome (10,000-1,000,000 km^2), (3) ecosystem (1-10,000 km^2) and (4) plot-plant (< 1 km^2). For each of these levels, various basic reference (mapping) units can be proposed that are conveniently grouped into two series, i.e., a series of homogenous units ('ecosystems') and of heterogeneous ones ('landscapes').

It is important that the type of unit used is related to the technique adopted for assessing the selected ecosystem services. There are several approaches (see review in Maes et al. 2012), from direct conversion of ecosystem maps (most often based on land use/land cover) (e.g. Burkhard et al. 2009) to the compilation of primary data and/or statistics (e.g. Kandziora et al. 2013) to the application of dynamic process-based ecosystem models (e.g. Schröter et al. 2005).

Based on a broad literature review, Syrbe and Walz (2012) compiled a list of the most commonly used reference fields. According to them, the different units used in practice can be referred to several categories.

A. Units assumed to be homogeneous (at least with regard to selected natural attributes):
- single patches, spatial elements of the landscape, geodesic units – they are the smallest homogeneous units due to the assumed choice of characteristics and degree of spatial and thematic generalization;
- 'smallest common geometry unit' generated automatically in GIS by overlapping maps of different components. This approach requires very extensive environmental databases and, as a result, can give less logical spatial representation as a result of the presence of a large number of irregularly shaped areas. In many cases, such areas can be generalized to heterogeneous units, in particular when for analyses of land cover or biodiversity issues;
- the so-called natural units, reflecting the diversity of natural environment components (soil, geology, vegetation, etc.).

B. Units assumed to be heterogeneous:
- administrative units, especially when existing data on social phenomena or spatial planning are used. However, it should be admitted that these units, although important for the management of resources, are not suitable for a detailed analysis of ecosystem service distribution;
- sub-catchments (or higher tiers) are useful reference areas for all services involved in water-related landscape processes (flood prevention, water treatment, etc.). They are also useful in determining the aesthetic value of the landscape and habitat valuation;
- landscape units which are distinguished not only on the basis of natural conditions but also land cover (land use), which are useful for assessing most benefits, particularly for large areas;
- regular artificial geometry units (e.g. raster grid), often used for data rescaling of very different resolutions (compare: Nemec & Raudsepp-Hearne 2013).

ES mapping is carried out on all scales; however, global-scale analyses of spatial distribution of services are rare. Naidoo et al. (2008) used selected WWF Global 200 ecoregions[1]. Luck et al. (2009) used the same, together with other databases (218 Endemic Bird Areas, 34 biodiversity Hotspots[2]), to rank the world's watersheds in order of priority for investing in the ecosystem services of water provision, flood mitigation and carbon storage. Petz et al. (2014), using a whole set of spatial data with resolutions 30', 3' and 30'' (e.g. GLC 2000, WWF biome, Soil Database FAO, GTOPO30 DEM), determined trade-offs and synergies between ecosystem services (carbon sequestration, erosion prevention, biodiversity) and livestock grazing intensity on rangelands. It should be emphasized that most of the above-mentioned analyses do not specify ES for the entire planet but only for some areas, which were chosen tendentiously on the basis of criteria related to the biological diversity of certain groups of organisms.

On the continent level (mainly EU Members), the most common reference spatial units are the types of ecosystems specified on the basis of land cover or land use data (Metzger et al. 2006; Maes et al. 2015). Okruszko et al. (2011) present an overview of the ecosystem services of European wetlands (using a representative sample of 102 protected wetlands larger than 5,000 ha) and the implications of hydrological alterations caused by future climate and socioeconomic

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[1] This network covers 233 terrestrial, freshwater and marine ecoregions important for biodiversity conservation (Olson & Dinerstein 1998). These units are different from those of Bailey's ecoregions (Bailey 2014), which are more biogeographically and ecologically oriented.

[2] The term 'hotspots' refers to areas of high species richness, endemism and/or threat and has been widely used to prioritise areas for biodiversity conservation (Egoh et al. 2008).

changes (scenarios for 2025 and 2050). Guerra et al. (2016) present a spatial and temporal (2001-2013) assessment of the provision of soil erosion prevention by vegetation in all European Mediterranean countries. The focus of Busetto et al. (2016) was forest biomass increment, while Thurner et al. (2016) mapped total forest carbon density.

Many continental-scale studies also employ other spatial units, not based directly on land cover. Stürck et al. (2014) analyzed flood regulation services in European river catchments. Their assessment was based on catchments classified into five categories depending on their size, maximum slopes and mean elevation. Liquete et al. (2015) assessed the supply of eight regulation and maintenance services, as well as core habitats and wildlife corridors for biota polygons, on the basis on gridded thematic primary data and indicator modeling. A similar solution was also used in South Africa (Egoh et al. 2008), where the coarsest resolution in the data sets was the scale of catchments and thus all other data (soil accumulation, soil retention and carbon storage – derived from vegetation maps and auxiliary data and models) were converted to this resolution.

At the European level, the most common source of spatial information necessary for defining ES for terrestrial ecosystems is the CORINE Land Cover (CLC 1990, 2000, 2006, 2012) (Metzger et al. 2006). The quality of its data varies between countries and should be supplemented by local data at local or regional level (Vihervaara et al. 2010). In addition, obtaining information on services from land cover/land use maps or habitat maps (Burkhard et al. 2009; Kienast et al. 2009) is appropriate only if the dominant service directly relates to land use (e.g. agricultural products) and the aim of the study is to determine the occurrence of a given service (Okruszko et al. 2011) and not a quantitative analysis. In addition, the rough spatial resolution (the minimum mapping unit is 25 ha) and thematic generalizations of the most common CLC data strongly limit the possibilities of working on a local or regional level (Burkhard et al. 2009, 2012; Vihervaara et al. 2010).

Continental scale analyses of ecosystem services are also based on artificial regular units (usually 1 km × 1 km – Haines-Young et al. 2012, or 10 km × 10 km – Anderson et al. 2009), and their results are often generalized and presented within NUTS-X boundaries at different regional subdivisions (NUTS-2 or NUTS-3), and then used to define clusters with similar change trajectories (Haines-Young et al. 2012; Zulian et al. 2014). As Kienast et al. (2009: 1117) notice, NUTS-X regions are "small enough to preserve specific environmental properties in the input data, large enough to account for spatial heterogeneity". Another approach was presented by Paracchini et al. (2014), who used Recreation Opportunity Spectrum as a method for mapping and assessing outdoor recreation as a cultural ecosystem service at continental level. Natural and artificial units are also combined. For this purpose, statistical data on service use are available (mainly for provisioning services) (Crossman et al. 2013). Such analyses may be exemplified by a study conducted by Morri et al. (2014), which combined analyses in a river basin with the division into communes to demonstrate a relationship between supply and demand for selected services related to water retention and supply, soil protection and carbon sequestration. Vihervaara et al. (2010) combined data on land cover and use with the division into reindeer rearing districts for a study in Lapland.

In regional or regional-local level studies, benefits are most often identified at the level of ecosystems located and distinguished by the use of different maps and spatial databases. For example, mountain grasslands services were tested by Lamarque et al. (2011) in the French Alps, while forest services were identified by Sodhi et al. (2010) in Southeast Asia, Grilli et al. (2016) in Beskid Żywiecki, Poland, and Decocq et al. (2016) in the European temperate forest biome along a latitudinal gradient from southern France to central Sweden (only small 1-50 ha forest patches). A special case is ES mapping on a detailed local scale where it is possible to use botanical and forest inventories, permanent plots or any other forms of direct observation of the terrain. Research areas are often mountain areas (Lavorel et al. 2011; Grêt-Regamey et al. 2013), protected areas (Palomo et al. 2013), small catchments (Sousa et al. 2016) and watersheds (Paudyal et al. 2015), as well as islands (Picanço et al. 2017).

At the end of this review, the ESMERALDA programme (Enhancing Ecosystem Services Mapping for Policy and Decision Making) should be mentioned. It is an EU project that aims to develop innovative, flexible mapping and assessment methods for ecosystem service evaluation across Europe, in individual countries and regions. In a recent report, ES mapping issues and omissions were detailed (Kopperoinen et al. 2016). Project outcomes have included the monograph *Mapping Ecosystem Services* (Burkhard & Maes 2017). In 2011 the program was supplemented with the MAES initiative (Mapping and Assessment of Ecosystems and their Services). One of the aims of the project is to identify ecosystem types using the EUNIS (European Nature Information System) and land cover analysis based on CORINE Land Cover, and delimitation of BAUs (Basic Assessment Units) representing ecosystem types determined on the basis of EUNIS. The result was a unit scheme (so-called MAES ecosystems). The results of the practical application of these solutions in particular European countries have been published, among others, by Jacobs et al. (2016) from Belgium, Albert et al. (2016) from Germany, as well as Ivanova et al. (2016) and Koulov et al. (2017) from Bulgaria. These last two works mainly concern TEV (Total Economic Value) monetary appraisal.

It is generally accepted that the MAES classification proposal may be useful for mapping ES on a national or continental scale, but is of limited significance for analysis at regional and local scales. This problem is commonly perceived. It is suggested (Burkhard & Maes 2017) that the basic map should be gradually refined. The basic geometry and main classes at an appropriate spatial resolution can be derived directly from satellite images or from existing land cover/land use maps. For policy-relevant information, the map should be re-classified using an ecosystem typology which represents the most important types of human ecosystem management to make best use of their services, e.g. by agriculture, forestry, fisheries, water management, nature protection or territorial planning. Such a basic map can be further refined thematically by providing more detailed information about the natural characteristics of the ecosystems and their biodiversity. GIS-based, so-called envelope- or niche-modeling as developed for habitat or climate change impact studies, allows the combination of non-spatially referenced species or habitat information with a set of environmental parameters such as elevation, soil, geology, climate, phenology, potential natural vegetation etc. to delineate the most likely areas of ecosystem presence. Further enhancement can be performed by attributing statistical information, e.g. crop yields or forest inventory data to the respective ecosystem classes (Burkhard & Maes 2017).

At this point, it is worth noting that the quality of source data and verification of maps and cartographic models are still marginal issues. The potential consequences of this, especially in the case of ES mapping at continental and global levels, are rightly emphasized by Schulp et al. (2014: 2), who states that "there is little knowledge about the influence of the mapping method and input data on the representation of spatial patterns of ecosystem service supply" (see also: Liquete et al. 2015; Parker et al. 2016; Burkhard & Maes 2017).

Map of ecosystem types – assumptions and results

The map of ecosystems is the basis for determining an area's potential to provide most ecosystem services. Particular ecosystem types differ in their ability to provide services to potential recipients. For this reason, it is becoming a priority to create the most accurate map legend that includes the categories of ecosystem types that will best determine the potential of study areas to provide services.

The formulation of a common methodology for identifying the potential of ecosystems to deliver various ecosystem services and mapping them at a regional scale required several assumptions and procedures to be adopted. These can be defined as follows:

- maximum use of data collected in a standard manner (statistics and spatial data included in geobases);
- the adoption of a limited number of reference area types (internally homogenous) and the determination of potential value indicators for them; an optimal spatial unit to express each potential separately is not sought;
- use only of data relating to surfaces (patches), and not taking into account linear nor point features;
- determining the potential for ecosystem types rather than for each individual ecosystem separately.

The MAES level 2 typology of ecosystems used for mapping and assessing ecosystems on an European scale distinguishes only seven types of terrestrial ecosystems (urban ecosystems, cropland, grassland, woodland and forest, heathland and shrub, sparsely or unvegetated land, inland wetlands) and one type of freshwater ecosystems (rivers and lakes) (Maes et al. 2013). The map of ecosystems of the study area constructed on the basis of this typology is too homogeneous and does not take into account the ecosystem diversity of the selected communes (Fig. 1).

The use of this legend is justified when large areas are being mapped, while in local or regional studies this type of legend is too general and insufficient to fully evaluate the study areas. Accordingly, our purpose is to provide a synthetic presentation of the spatial diversity of the cover, in such a way that each ecosystem type has an assigned size or range of environmental resources that provide specific ecosystem functions (especially the provisioning function, with less attention to the regulating and maintenance or cultural functions). The first step in the development of the ecosystem map (see: inset) was to create a new detailed

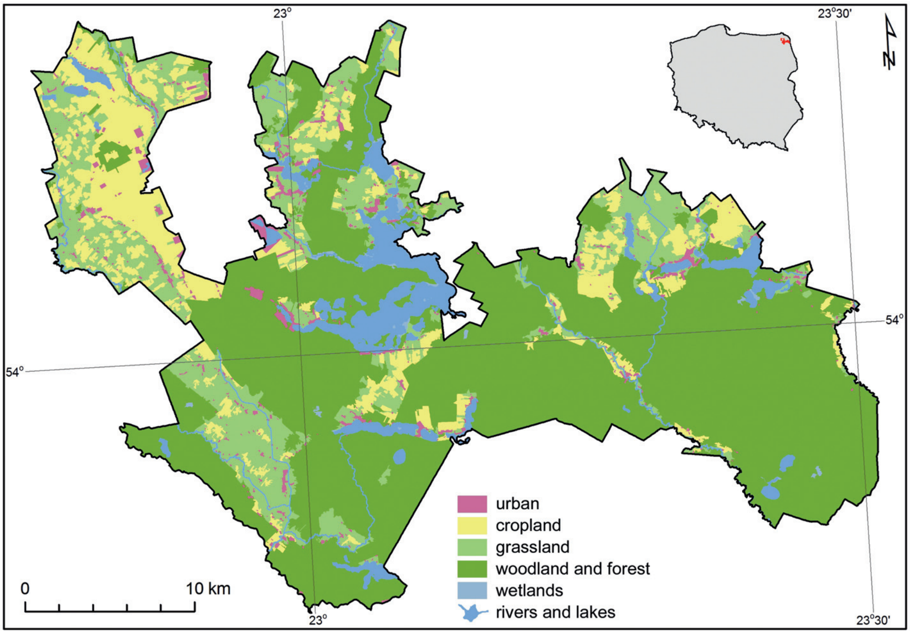

Figure 1. Map of ecosystems on the basis of the legend proposed by MAES (according to Solon et al. 2017)

legend that would allow for greater accuracy, reliability and completeness of the map content. In distinguishing ecosystem types, we included not only land cover, but also habitat condition and tree stand ages. Ultimately, 42 ecosystem types comprising 3,146 individual units were identified. The smallest map unit was an area of 5 hectares. The only exception was over-120-year-old riparian alder-ash forests (occupying an area less than 5 hectares), which were left on the resulting map to better illustrate study area diversity.

The classification of 25 types of forest ecosystems was based on typology, comprising alder boggy forests, alder-ash riparian forests, oak-hornbeam forests, pine (-spruce) and mixed pine forests, boggy pine and similar forests on peat, and the following tree stand age categories: 0-40, 40-60, 60-80, 80-120 and > 120 years. In order to specify the characteristics of grasslands (3 types) and arable lands (3 types), the following habitat categories were distinguished: (1) dry mineral, (2) moist mineral, (3) moist peat and mud, (4) poor sandy, (5) semi dry and fertile, (6) moist and fertile. Wetlands were divided into 4 categories: reeds and rushes on a peat substratum, low peatbogs, high and intermediate moors, and reeds and rushes on water. The classification of lakes (6 types) was based on the following criteria: area (ha), max and mean depth (m), conductivity, Ca content, fishing type, fertility type, stratification, and fishing ($kg \cdot ha^{-1}$) (details see: Solon et al. 2017). The legend of the map also includes built-up areas (1 category).

The development of the map was preceded by a detailed analysis of available cartographic materials. The data was derived from the following sources:

- orthophotomaps 1:5,000 (Head Office of Geodesy and Cartography),
- Database of Topographic Objects 1:10,000 (Head Office of Geodesy and Cartography),
- Map of Hydrological Division of Poland 1:10,000 (National Water Management Authority),
- Agricultural Map of Soils 1:25,000 (Institute of Soil Science and Plant Cultivation – State Research Institute),
- VMap Level2 1:50,000 (Head Office of Geodesy and Cartography),
- Detailed Geological Map of Poland 1:50,000 (Polish Geological Institute – National Research Institute),
- Wetlands Database 1:100,000 (Institute of Technology and Life Sciences),
- Digital Forest Map (Forest Data Bank),
- DTED Level2,
- field studies.

Particular map layers were vectorised using ArcGIS 10.2.2 software. The principal issue was to eliminate ecosystem polygons smaller than 5 ha in area and assign them attributes which described adjacent polygons with the longest boundary connected to the area of eliminated polygon using the Polygon-Neighbors and Join Field tools from the Data Management Tools toolbox. The main problem in determining the actual course of ecosystem boundaries in the study area was the use of different scales of source data (1:10,000 – 1:100,000). Another problematic issue was uncertainty and ambiguity in choosing suitable data due to the incompatibility of individual ecosystem boundaries presented on maps from different sources and the incompatibility of reference data.

The quality of cartographic source data was verified during field studies. In many cases, their content did not match the actual conditions, thus necessitating updates to the final map of ecosystem content. Errors in ecosystem typology definition were often extreme and concerned radically different habitat categories, e.g. an ecosystem mapped during cartographic works as a grassland on dry and fresh mineral habitats was in fact classified during terrain research as a bog with rushes, reeds and sedges.

The map of ecosystems (see: inset) is the basis for presentation of spatial correlations between ecosystem types and the indicators used. The criteria used for distinguishing individual types of ecosystems allowed for producing detailed maps of selected ecosystem services. Compared with the MAES map legend, the image of three selected communities is much more detailed, allowing for more

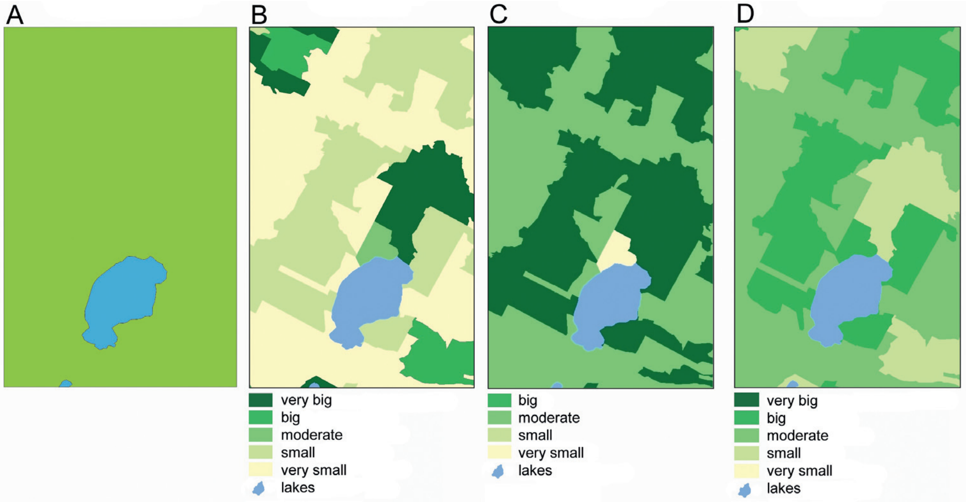

Figure 2. Comparison of the results of selected analyses based on the MAES map and our map of ecosystems: A – MAES map, B – content of Total Organic Carbon in soils, C – invasive species, D – oxygen production (according to Solon et al. 2017)

accurate spatial analysis and more precise definition of the area's potential to provide ecosystem services (Fig. 2). Furthermore, the map reflects well the structure of young glacial landscape.

Examples of application

The above map of ecosystems (see: inset) was used as a basic map for the cartographic presentation of spatial diversification of the potential of particular types of ecosystems for ES supply. The examples given are a modified version of the analysis presented more extensively in the monograph "Ecosystem services in a postglacial landscape – assessment of potential and utilisation" (Solon et al. 2017). The examples include one benefit from the *Provisioning* section (Fig. 3A) and five from the *Regulation and Maintenance* section (Fig. 3B-3F). One indicator from the *Regulation and Maintenance* section represents the division *Mediation of flows* (Fig. 3B), and the other represents different groups in the division *Maintenance of physical, chemical and biological conditions of the environment*. The detailed characteristics of the indicators are shown in Table 1 and the spatial variation is described in the text below.

A. Service – Forest fruits (indicator: abundance of wild species that produce edible berries)

Forest fruits are one of the most widely accepted ecosystem services. The main fruit plants in Poland include the European blueberry, red raspberry, blackberries, wild strawberry and cowberry and, locally, also small cranberry and other species. In intensively managed forests, where woodland clearcutting and preparation of soils is practised before artificial regeneration, the abundance of berries is reduced. On the other hand, their abundance and growth are also poorer in old stands (Nestby et al. 2011). Berry populations are stable in forests subject to gradual felling as well as in unmanaged natural forests (Mäkipää 1999).

The ecosystem potential for edible fruits supply in the study area is the highest in the youngest oak-hornbeam forests, mature (over 80 years old) pine (-spruce) and mixed pine forests as well as boggy pine and similar forests on peat of all age categories. Slightly lower potential is seen in pine (-spruce) and mixed pine forests of intermediate age (60-80 years old) as well as on high and

Table 1. List of indicators used for describing potential supply of ecosystems for individual ESs

Ecosystem service		Forest fruits (Fig. 3A)	Regulating of air quality (Fig. 3B)	Regulating the composition of the atmosphere (Fig. 3C)	Regulating incursions of alien species (Fig. 3D)	Regulating the composition of the atmosphere (Fig. 3E)	Maintaining biogeochemical properties of soil (Fig. 3F)
CICES	Section	Provisioning	Regulation & Maintenance	Regulation & Maintenance	Regulation & Maintenance	Regulation & Maintenance	Regulation & Maintenance
	Division	Nutrition	Mediation of flows	Maintenance of physical, chemical, biological conditions	Maintenance of physical, chemical, biological conditions	Maintenance of physical, chemical, biological conditions	Maintenance of physical, chemical, biological conditions
	Group	Biomass	Gaseous / air flows	Atmospheric composition and climate regulation	Pest and disease control	Atmospheric composition and climate regulation	Soil formation and composition
	Class	Wild growing plants and fungi and their products	Ventilation and transpiration	Global climate regulation by reduction of greenhouse gas concentrations	Global climate regulation by reduction of greenhouse gas concentrations	Micro and regional climate regulation	Weathering processes
Indicandum		Potential purchase of edible berries	Potential of ecosystems for the aerosol emissions of plant origin	The ability of ecosystems to carbon sequestration	Potential of ecosystems for the prevention of invasions by alien plant species	Potential of ecosystems for the oxygen emission	Soil fertility potential
Indicator		Abundance of wild species that produce edible berries	Efficiency of aerosol emissions of plant origin	Carbon stock in ecosystems	Resistance to invasions by alien plant species	Emission yield of oxygen	Degree of saturation of the soil sorption complex with base cations
Direct producer		Plants (without trees)	Plants	Plants and soil	Plants	Plants (mainly trees)	Soil

Ecosystem service	Forest fruits (Fig. 3A)	Regulating of air quality (Fig. 3B)	Regulating the composition of the atmosphere (Fig. 3C)	Regulating incursions of alien species (Fig. 3D)	Regulating the composition of the atmosphere (Fig. 3E)	Maintaining biogeochemical properties of soil (Fig. 3F)
Composition of the indicator	Total area coverage of species that produce edible berries	Expert evaluation based on literature data	Total stock of organic carbon in soil, undergrowth and stand of trees	Resistance calculated as a sum of normalized (to a 0-1 scale) values of B, N, S, and C, where: B – biomass calculated as an organic carbon content in the herb layer, N – number of plant species, S – share of species of C-type life strategy, C – tree stand crown density	Expert evaluation based on literature data	Saturation = S/T, where S = Ca^{2+} + Mg^{2+} + K^{+} + Na^{+}; T = S + Hh; Hh means hydrolytic acidity
Indirect/Direct	Direct	Indirect	Direct	Indirect	Direct	Direct
Simple/Complex	Simple	Simple	Complex	Complex	Simple	Simple
Calculated/Estimated	Estimated	Estimated	Calculated	Calculated	Estimated	Calculated
Original scale	Quotient	Rank order	Quotient	Quotient	Quotient	Quotient
Range of values	0-100	(0) 1-5	519-5,543	0.806-2.339	0-40	16-96
Unit of measure	Percentage of area	-	$t \cdot ha^{-1}$	-	$t \cdot ha^{-1} \cdot rok^{-1}$	%
Source data	434 relevés and literature data: Grau et al. (1996); Witkowska-Żuk (2008)	Krzymowska-Kostrowicka (1997) and other literature data	Fieldwork and laboratory studies in selected points representing different types of terrestrial ecosystems; literature data (Jagodziński 2011; Jelonek & Tomczak 2011; Skorupski et al. 2011)	Corg content in the undergrowth (fieldwork); species richness (relevés and fieldwork); life strategies according to Grime (literature data – Roo-Zielińska 2014); density of tree crowns (tax data of forest districts)	Krzymowska-Kostrowicka (1997) and other literature data	Field and laboratory studies in selected points representing different types of terrestrial ecosystems

intermediate moors (meso- and oligotrophic mires). Most ecosystem types are characterized by moderate potential of edible fruits supply. These include the remaining forest ecosystems (except alder boggy forests older than 60 years), and grasslands on dry mineral habitats. Rather low potential characterises alder boggy forests older than 60 years, and it depends only on the presence of black currant, whose cover seldom exceeds 5%. The relatively lowest potential for the supply of edible fruits is seen in grasslands on moist mineral habitats. All other ecosystem types do not generally support wild plants with edible fruits.

B. Service – Regulating air quality (indicator: efficiency of aerosol emissions of plant origin)

Various types of chemical compounds suspended in the air and plant and animal particles, called organic aerosols, are an element of the natural environment (in habitats used for recreational purposes) which shapes the quality of broadly understood bioclimate. Their concentration in the air depends not only on external factors, mainly weather, but also on internal ones directly related to plants as their producers. A small amount of volatile substances emitted into the air is sufficient to induce therapeutic effects in the human body (Krzymowska-Kostrowicka 1997).

Direct measurements of aerosol production are very difficult to conduct and, as a consequence, they are rarely performed. Therefore, the data compiled by Krzymowska-Kostrowicka (1997) were used for estimating the value of the indicator *efficiency of aerosol emissions of plant origin*, with data expressed using different scales converted to a rank scale.

The intensity of aerosol emissions of plant origin is the highest in all pine (-spruce) and mixed pine forests. Slightly lower (although still high) phytoaerosol production is found in oak-hornbeam forests and boggy pine and similar forests on peat as well as in all types of peat bogs, mires and moors. By the same level of potential are also characterized grasslands on dry mineral habitats. All riparian alder-ash and boggy alder forests together with grasslands on moist and wet habitats (mineral and peat/mud) produce just a little smaller quantities of phytoaerosols. All reeds and rushes are characterized by low levels of aerosol emissions, while in arable lands of different humidity-fertility habitats the production is negligible.

C. Service – Regulating air quality (indicator: carbon stock in ecosystems)

Carbon storage by ecosystems is one of the most important functions influencing all elements of the natural environment (Lal 2004, 2005; Wall et al. 2012). The social value of the ecosystem service, which is carbon sequestration, is significant because it is not limited to direct ecosystem-recipient relationships, but it also influences interactions between ecosystems that generate subsequent benefits. Soils and plant biomass are important reservoirs of carbon. The functioning of soils, and, primarily, the formation of their physical and chemical properties, is closely related to organic carbon content (TOC). Organic carbon losses lead to deterioration of soil conditions, which affects the biomass directly and negatively. As a result, this produces disturbances in the functioning of ecosystems and, consequently, loss or limitation of the capacity to provide ecosystem services by individual components of the natural environment.

The locally highest values of the organic carbon stock are observed in different types of peat bogs, mires and moors as well as in reeds and rushes on a peat substratum (up to 5,543 $t \cdot ha^{-1}$). The poorest are dry ecosystems (e.g. grasslands), where total carbon content is below 520 $t \cdot ha^{-1}$. Taking into account the area occupied by ecosystems of different types, the most important role is played by different forests, containing ca. 74% of carbon accumulated in the entire study area. In this group of ecosystems the richest are boggy pine and similar forests on peat (ca.

5,000 t · ha^{-1}), the poorest are pine (-spruce) and mixed pine forests (less than 1,800 t · ha^{-1}).

Young forest ecosystems of various types are characterized by reduced TOC content compared to over 60 years old ecosystems. The decrease of this indicator value is also observed in the oldest ecosystems (> 120 years).

D. Service – Regulating incursions of alien species (indicator: resistance to invasions by alien plant species)

Invasion of alien plant species is a type of territorial expansion of species beyond their natural habitat and/or biogeographic range, occurring rapidly and massively as a result of indirect and/or direct human involvement (Falińska 2004). Invasive species are a threat to local biodiversity and also cause economic losses.

So far no synthetic index accounting for most possible determinants has been developed to assess resistance to invasions by alien plant for particular ecosystems. The results presented here are based on a simplified method that takes into account only a few determinable ecosystem characteristics which attest to their resistance.

In the study area, habitats with relatively low resistance to invasions by alien species are broadleaved forests (alder boggy forests, alder-ash riparian forests and oak-hornbeam forests). Greater resistance is demonstrated by grasslands on moist habitats, reeds and rushes, as well as young (up to 60 years old) pine (-spruce) and mixed pine forests and boggy pine and similar forests on peat representing the intermediate (60-80 years) age class. The highest resistance is found in all types of peat bogs, mires and moors, grasslands on dry mineral habitats and – among forests – all the remaining types of coniferous forests.

Areas of low resistance to invasion are concentrated in the central part of the study area, where they form extended patches, whereas in the southern part they are represented by small patches related to creek valleys. In terms of area, there is clear predominance of ecosystems of moderate and high resistance, which cover 191.82 km^2 and 319 km^2, respectively. These ecosystems form a coarse grain mosaic that predominates in the remaining part of the study area.

E. Service – Regulating air quality (indicator: oxygen emission yield)

Oxygen production is one of the most important services provided by land ecosystems, especially forest ones. It plays a decisive role for the presence of life on Earth. A number of studies on the intensity of the photosynthetic process show that between 0.5 and over 1 kg of pure oxygen (O_2) enters atmospheric air from a 1 m^2 area of trees and shrubs during one growing season. The trees that supply the largest quantities of oxygen are beech, maple and black locust (1.1 kg), willow and oak (0.8 kg), and lime and ash (0.7 kg). Similar amounts of oxygen are produced by coniferous trees. One hectare of deciduous forest produces about 700 kg of pure oxygen within 24 hours. This amount of gas meets the daily oxygen demand of 2,500 people (cf. Krzymowska-Kostrowicka 1997).

Due to methodological difficulties and laboriousness of intensive direct measurements of oxygen production in ecosystems, the value of the indicator *emission yield of oxygen* was estimated on the basis of data compiled by Krzymowska-Kostrowicka (1997). Only terrestrial ecosystems were considered, because aquatic ecosystems have been poorly researched in this respect, and existing data are not comparable to terrestrial ecosystem data.

Oxygen production is very high (> 20 t · ha^{-1} · year^{-1}) in mature alder boggy forests (from 60 to over 120 years old) and in oak-hornbeam forests up to 60 years old. In the other age categories of alder boggy forests and oak-hornbeam forests and in mature pine (-spruce) and mixed pine forests (from 80 to over 120 years old), it is slightly lower (although still high), ranging between 15-20 t · ha^{-1} · year^{-1}. Most forest ecosystems are characterized by moderate levels of oxygen emissions (10-15 $t \cdot ha^{-1} \cdot year^{-1}$). These are alder-ash riparian forests (all age categories), the youngest alder boggy forests, pine (-spruce) and mixed pine forests up to 80 years old and grasslands on dry mineral, moist mineral, moist peat and mud habitats. All boggy pine and similar forests on peat and wetlands (reeds and rushes on a peat substratum), and arable lands on habitats varying in terms of humidity and fertility are characterized by low oxygen production (5-10 $t \cdot ha^{-1} \cdot year^{-1}$). The lowest emission is seen in boggy ecosystems, e.g. grasslands ($< 5\ t \cdot ha^{-1} \cdot year^{-1}$).

F. Service – Maintaining biogeochemical properties of soils (indicator: degree of saturation of the soil sorption complex with base cations)

The degree of saturation of the soil sorption complex with base cations (V) is considered an important biochemical indicator of the efficiency of ecosystems (Degórski 2002). The content of calcium, potassium, magnesium and sodium (Ca^{2+}, K^{+}, Mg^{2+}, Na^{+}) in total sorption capacity is also an important feature of soil fertility. In addition, the degree of saturation is an important indicator of the agronomic quality of cultivated soils. Saturation of the soil sorption complex with base cations depends on many factors, including lithological-mineralogical conditions, soil acidity, humus type, etc. The higher the value of this indicator, the better ecosystem resistance to external factors, e.g. anthropogenic pollutants (Ulrich et al. 1984).

Considering the entire study area, ecosystems with humid soils with moder and mull humus types and high trophism are characterized by best biochemical properties. The highest values of saturation are characteristic for soils of ecosystems with the oldest stands of alder boggy forests, alder-ash riparian forests on Fibric Histosols, high bog ecosystems with Fibric Histosols and in eutrophic mires with Fibric/Sapric Histosols (IUSS Working Group 2015), which is consistent with the natural content of these chemical components in these soil types, resulting from their trophism. Five groups of ecosystems demonstrating different levels of saturation of the soil sorption complex with base cations can be distinguished in the study area. The highest degree of saturation of the soil sorption complex with base cations is seen in the northwestern part (cultivated ecosystems) and northeastern part of the study area, characterized by a mosaic of ecosystems on fertile habitats.

Final Remarks

1. The map of ecosystems presented in the article shows only land use, not taking into account the category of use and the economic or protection status of the study area. At the same time, it accounts for habitat diversity and, indirectly, via the age classes of tree stands, the degree of maturity of forest ecosystems.
2. The map legend development principles and the resolution of the spatial map are so universal that similar maps can be constructed for any site (at least in the European Union), because most countries have a similar set of forest and soil-agricultural data.
3. The map was designed to occupy an intermediate position (in terms of thematic detail and spatial resolution) between maps showing the diversity of ecosystems in terms of plant communities (which requires detailed field data) and maps developed very locally based directly on level 3 or 4 CLC units.
4. The map legend design allows it (as well as derivative maps of the potential to provide benefits) to be generalized with regard to subject matter-related and cartographic parameters to match the CLC categories and MAES ecosystems. The results obtained through detailed research on a limited number of test areas can be extrapolated to larger areas, provided that they represent the same type of biotic, abiotic and economic conditions.
5. The approach to description of ecosystem types enables the use of a wide array

of methodological approaches to determining the potential for delivering benefits: from direct field measurements to the use of averaged statistical values to indicator value modeling. In the latter case, additional detailed data (capturing larger areas or 'points') are usually necessary.

6. It also seems that this type of maps can also be used in monitoring programmes covering a wide range of issues, from ecosystem services to biodiversity change to sustainable development.

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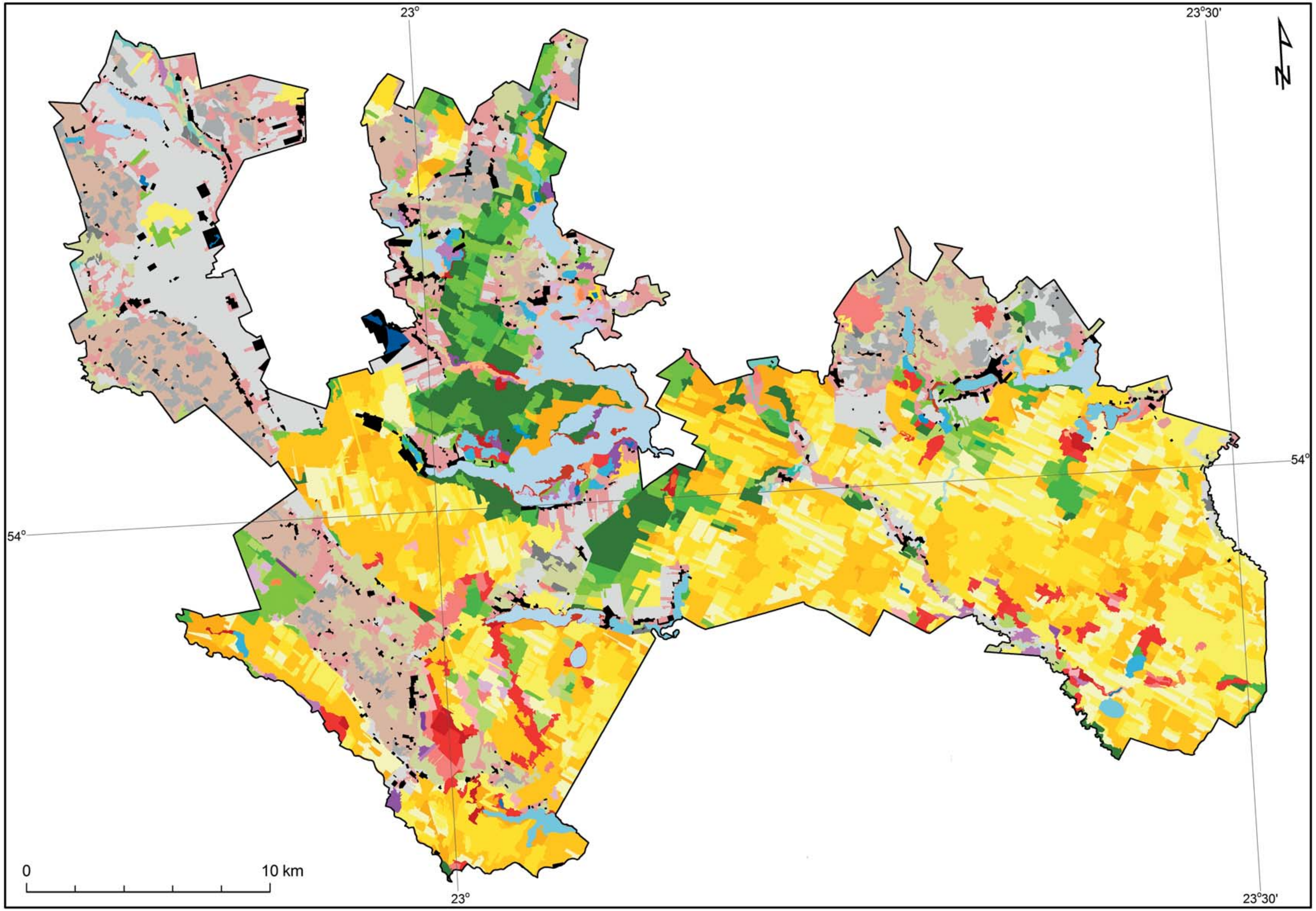
MAPPING ECOSYSTEM SERVICES – A NEW APPROACH IN REGIONAL SCALE

by Bogusława Kruczkowska, Jerzy Solon & Jacek Wolski



Type of ecosystems

- 🟪 1a. Alder boggy forests, tree stands 0-40 years old
- 🟪 1b. Alder boggy forests, tree stands 40-60 years old
- 🟪 1c. Alder boggy forests, tree stands 60-80 years old
- 🟪 1d. Alder boggy forests, tree stands 80-120 years old
- 🟪 1e. Alder boggy forests, tree stands more than 120 years old
- 🟩 2a. Alder-ash riparian forests, tree stands 0-40 years old
- 🟩 2b. Alder-ash riparian forests, tree stands 40-60 years old
- 🟩 2c. Alder-ash riparian forests, tree stands 60-80 years old
- 🟩 2d. Alder-ash riparian forests, tree stands 80-120 years old
- 🟩 2e. Alder-ash riparian forests, tree stands more than 120 years old
- 🟩 3a. Oak-hornbeam forests, tree stands 0-40 years old
- 🟩 3b. Oak-hornbeam forests, tree stands 40-60 years old
- 🟩 3c. Oak-hornbeam forests, tree stands 60-80 years old
- 🟩 3d. Oak-hornbeam forests, tree stands 80-120 years old
- 🟩 3e. Oak-hornbeam forests, tree stands more than 120 years old
- 🟨 4a. Pine (-spruce) and mixed pine forests, tree stands 0-40 years old
- 🟨 4b. Pine (-spruce) and mixed pine forests, tree stands 40-60 years old
- 🟨 4c. Pine (-spruce) and mixed pine forests, tree stands 60-80 years old
- 🟧 4d. Pine (-spruce) and mixed pine forests, tree stands 80-120 years old
- 🟧 4e. Pine (-spruce) and mixed pine forests, tree stands more than 120 years old
- 🟥 5a. Boggy pine and similar forests on peat, tree stands 0-40 years old
- 🟥 5b. Boggy pine and similar forests on peat, tree stands 40-60 years old
- 🟥 5c. Boggy pine and similar forests on peat, tree stands 60-80 years old
- 🟥 5d. Boggy pine and similar forests on peat, tree stands 80-120 years old
- 🟥 5e. Boggy pine and similar forests on peat, tree stands more than 120 years old
- 🟥 6a. Grasslands on dry mineral habitats
- 🟫 6b. Grasslands on moist mineral habitats
- 🟩 6c. Grasslands on moist peat and mud habitats
- ⬜ 7a. Arable fields on poor sandy habitats
- ⬜ 7b. Arable fields on semi dry and fertile habitats
- ⬛ 7c. Arable fields on moist and fertile habitats
- 🟧 8a. Reeds and rushes on peat substratum
- 🟧 8b. Low peatbogs
- 🟧 8c. High and intermediate moors
- 🟥 8d. Reeds and rushes on water
- 🟦 9a. Big mesotrophic lakes
- 🟦 9b. Big eutrophic lakes
- 🟦 9c. Medium sized eutrophic lakes
- 🟦 9d. Dystrophic lakes
- 🟦 9e. Small eutrophic lakes
- 🟦 9f. Man-made water reservoirs
- ⬛ 10. Built-up areas

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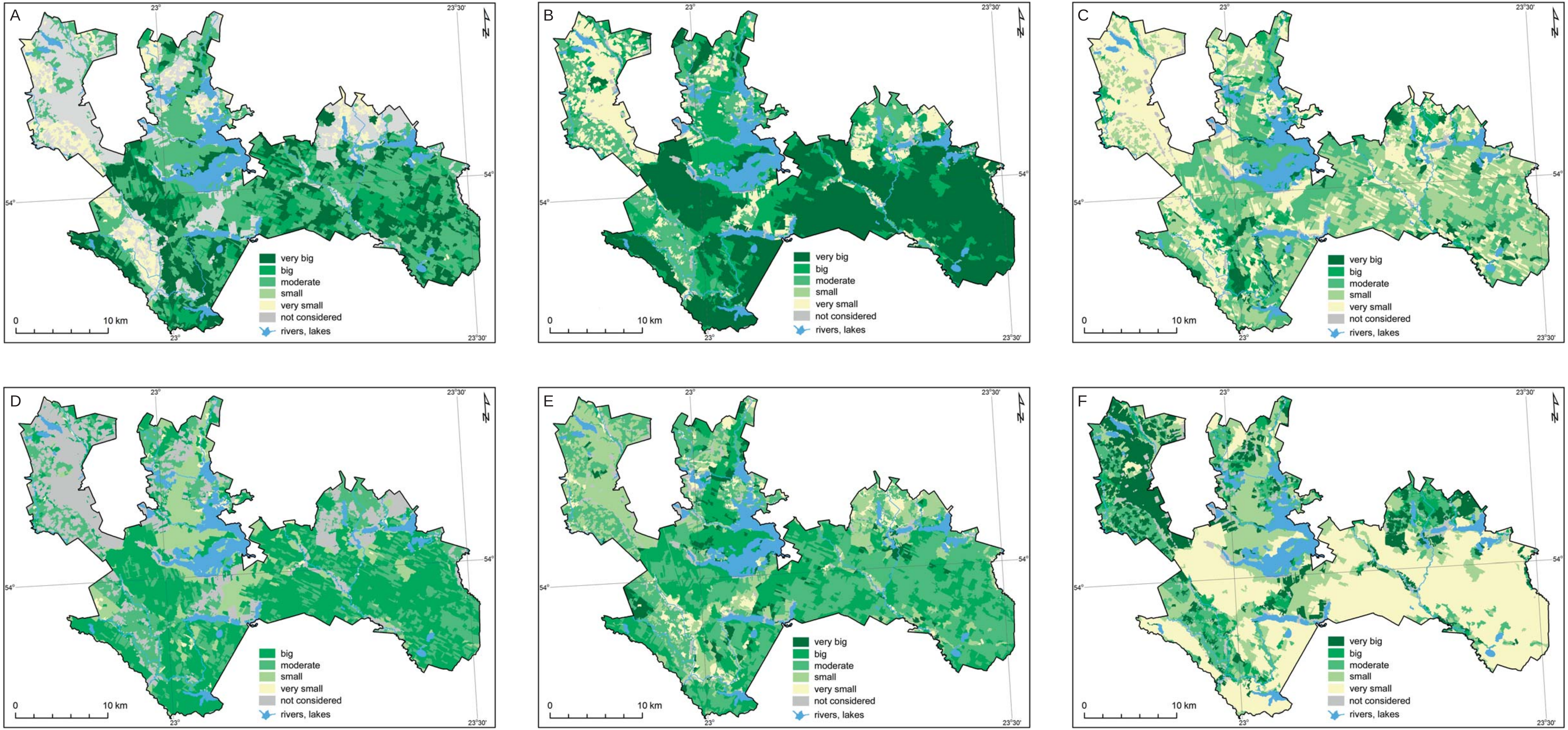

Figure 3. The potential of ecosystems to provide: A. "Forest fruits" service based on the "Abundance of wild species that produce edible berries" indicator; B. "Regulating of air quality" service based on the "Efficiency of aerosol emissions of plant origin" indicator; C. "Regulating the composition of the atmosphere" service based on the "Carbon stock in ecosystems" indicator; D. "Regulating incursions of alien species" service based on the "Resistance to invasions by alien plant species" indicator; E. "Regulating the composition of the atmosphere" service based on the "Emission yield of oxygen" indicator; E. "Maintaining biogeochemical properties of soil" service based on the "Degree of saturation of the soil sorption complex with base cations" indicator (according to Solon et al. 2017)

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