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# POTENTIAL OF PROVISIONING AND REGULATING ECOSYSTEM SERVICES IN POSTGLACIAL LANDSCAPE

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## POTENCJAŁ EKOSYSTEMÓW DO ŚWIADCZENIA USŁUG ZAOPATRZENIOWYCH I REGULACYJNYCH W KRAJOBRAZIE MŁODOGLACJALNYM

STRESZCZENIE: W niniejszym artykule zaprezentowano wyniki badań nad przestrzennym zróżnicowaniem potencjału ekosystemów do dostarczania wybranych usług zaopatrzeniowych i regulacyjnych. Każde z wybranych do prezentacji świadczeń (cztery usługi zaopatrzeniowe – plony zbóż, miód, biomasa zwierząt kopytnych, zapas drewna na pniu; jedna usługa regulacyjna –sekwestracja węgla w glebie) jest przykładem innego podejścia do definiowania i obliczania wskaźników określających potencjał do świadczenia usług. Wyniki zróżnicowania przestrzennego potencjałów przedstawiono na mapach, obejmujących trzy gminy z Polski północno-wschodniej.

SŁOWA KLUCZOWE: potencjał ekosystemów, plony zbóż, miód, zwierzęta łowne, zapas drewna na pniu, sekwestracja węgla, usługi ekosystemowe

**Introduction**

The general objective of the study was to present different methods for identification and assessment of ecosystem services provided by various ecosystems in postglacial landscape. Our study focused on ecosystem-oriented approach in which the potential of ecosystems to deliver goods and services was analyzed. Other approaches, e.g. society-oriented (dealing with goods and services demands) or process-oriented (focused on uptake of goods and services) were applied only additionally.

Five ecosystem services were selected for the analysis: four provisioning services (harvested crops, honey, ungulate biomass, timber standing crop) and one regulating service – carbon sequestration in soils. Each of them represents different approach for defining and calculating measures and indicators of ecosystem potential. The place of chosen services in the scheme of Common International Classification of Ecosystem Services (CICES)[1] is presented in table 1. Results of estimation of spatial differentiation of ecosystem potential are presented on maps covering three communes in north-eastern Poland.

**Table 1.** Place of chosen ecosystem services in Common International Classification of Ecosystem Services (CICES)

| Section | Division | Group | Class | Ecosystem service |
|---|---|---|---|---|
| Provisioning | Nutrition | Biomass | Cultivated crops | Cereals (eg. wheat, rye, barely) |
| | | | Reared animals and their outputs | Honey |
| | | | Wild animals and their outputs | Game |
| | Materials | Biomass | Fibres and other materials from plants, algae and animals for direct use or processing | Timber |
| Regulation & Maintenance | Mediation of waste, toxics and other nuisances | Mediation by ecosystems | Filtration/ sequestration/ storage/ accumulation by ecosystems | Carbon sequestration |

Ecosystem potential is understood as an ecosystem capacity to deliver (supply) goods and services[2]. The individual ecosystem capacities to supply services are strongly linked to:

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1 R. Haines-Young, M. Potschin, *Common International Classification of Ecosystem Services (CICES): Consultation on version 4, August-December 2012*, EEA Framework Contract No EEA/IEA/09/003, 2013.

2 B. Burkhard et al., *Mapping ecosystem service supply, demand and budgets*, "Ecological Indicators" 2012 no. 21, p. 17–29.

- natural conditions; e.g. natural land cover (vegetation foremost), hydrology, soil conditions, fauna, elevation, slope and climate;
- human impacts; mainly land use but also emissions, pollution, etc.

Flow of ecosystem services is influenced not only by the capacity of a certain ecosystem, but also by human needs and the desired level of provision for this service by society, which connects inseparably supply and demand of ecosystem services[3]. Ecosystems provide the necessary structures and processes, which in turn define the capacity or potential to deliver services. Ecosystem supply is the full of potential ecological functions or biophysical elements in an ecosystem to provide a potential service, irrespective of whether humans currently use or value that function or element[4].

## Study area

The survey was carried out in three rural communes – Giby, Nowinka and Suwałki in north-east Poland (Podlaskie voivodeship) (figure 1). Study area encompasses 796 km$^2$. Relief and morphology were shaped by glacial and peri-glacial geomorphologic processes. Forests cover over 54% of the area, while arable lands about 13% and grasslands over 17%. Lakes cover about 5%. Lands of great natural value comprise a significant part of the study (e.g. Wigry National Park, Natura 2000 sites). The average population density of the studied communes accounts for 12 inhabitants/km$^2$ [5].

Three communes differ in the structure of land use and in the intensity of anthropogenic changes. The Giby commune, dominated by forests (approx. 75 %), is characterized by a large number of lakes, and almost lack of industry. The large coverage of Natura 2000 sites (over 80%) confirms the high nature value in the commune.

The Nowinka commune is characterized by the predominance of forests (approx. 60%) that are part of the Wigry National Park and the Augustów Forest. Farmland comprise approx. 27% of the commune. A significant area is occupied by waters here. The commune is dominated by protected natural ecosystems, which occupy 84% of the area. Natura 2000 sites cover 78%. The biggest advantage of the commune is the beautiful landscape, tourism and rich peat deposits.

3 O. Bastian et al., *The five pillar EPPS framework for quantifying, mapping and managing ecosystem services*, "Ecosystem Services" 2013 no. 4, p. 15–24.

4 H. Tallis et al., *A Global System for Monitoring. Ecosystem Service Change*, "BioScience", 2012 no. 62 (11), p. 977–986; J. Maes et al., *Mapping ecosystem services for policy support and decision making in the European Union*, "Ecosystem Services" 2012 no.1(1), p. 1–122.

5 Bank Danych Lokalnych (Local Data Bank*)*, 2016, www.bdl.stat.gov.pl [20–10–2016].

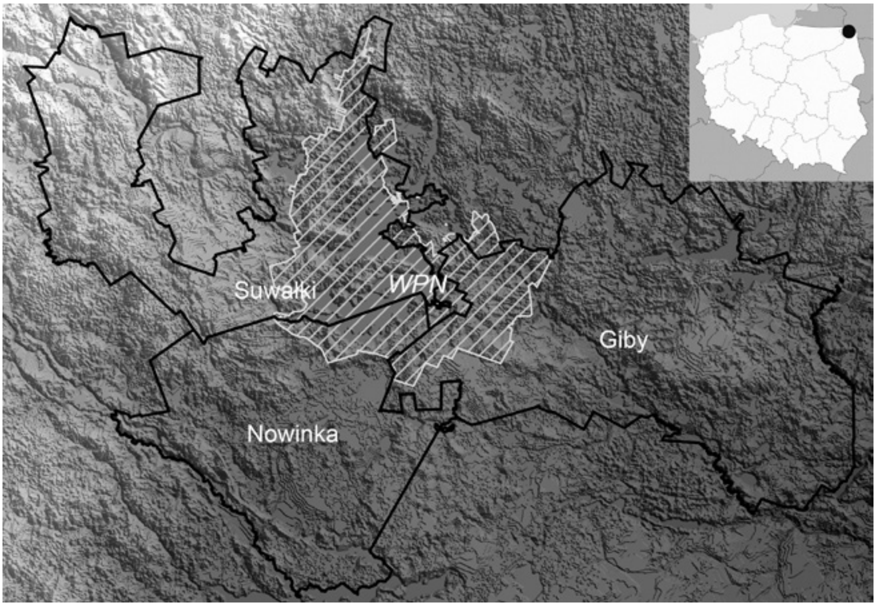


**Figure 1.** Study area

Source: elaborated by B. Kruczkowska.

The Suwałki commune has an agro-forest character. Farmlands constitute approx. 55%, while forests – 29%. Agriculture, successfully developed on the plains, play a dominant role in the economy of the commune. Farmlands are managed mostly (approx 84%) by individual farmers. The characteristic feature of agriculture in the Suwałki commune is the diversity of production, and the dominance of dairy cattle and pigs.

## Data and Methods

### Basic spatial units

Two types of basic spatial units were used for presentation of results:

- the hunting units (official spatial division specified for breeding, protecting and obtainment of wild animals) – for analysis for the potential provision of ungulates biomass;
- ecosystems and ecosystem types – for the rest of analysed services[6].

[6] The final map includes 3146 separate patches (ecosystems) belonging to 44 ecosystem types of which 25 are different categories (age and habitat) of forests, three categories of grassland, three types of arable fields, four categories of wetlands, six classes of lakes, one category represents rivers and the last one – built-up areas (B. Kruczkowska et al., *Map of ecosystems – concept and realization,* "Geographia Polonica" (in preparation).

## Potential harvested crops from agro-ecosystems

Cultivation of edible plants used for human nutrition is a basic provisioning service from agro-ecosystems that is usually quantified using harvested crops[7]. In this research potential supply of agro-ecosystem services was estimated employing the indicator of agricultural production spatial valorisation IAPSV[8], which is based on the assessment of soil quality, climate, relief and water conditions. These factors are considered to have the greatest influence on yields on the local scale (a commune level). Each natural factor was defined using adequate parameter and was weighted reflecting its influence on agro-ecosystem productivity[9]. To calculate the indicator data from soil maps, slope maps based on DEM, maps of soil water retention and statistical data on cereal crops from the Local Data Bank of Central Statistical Office were used. In theory, the indicator can range from 19.5 to 119 points (below 30 means very poor arable lands, 30–59 – poor, 60–79 – good, above 80 – very good). The final cereal crops' potential from each agro-ecosystem was quantified using the indicator value substituted into one of the regression equations ($y = -0{,}339 + 0{,}541x$) developed for different regions in Poland[10].

## Potential honey production

To construct an indicator and then to map the potential honey production a more detailed definition of potential was proposed. It this understanding, ecosystem potential refers to a maximum theoretical honey supply from a given type of ecosystem and in the particular regional context, calculated for environmental setting (e.g. plant species composition, soil qualities, water balance etc.) best suited for honey production. This means that, for instance, to calculate honey potential of cropland located on fertile soil one needs to pick a crop (cultivated in the region on such a soil) that has the highest honey potential (bees can produce the largest amount of honey out of a hectare of a given crop).

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7 R. Haines-Young, M. Potschin, *Common International Classification of Ecosystem Services (CICES): Consultation on version 4, August-December 2012*, EEA Framework Contract No EEA/IEA/09/003, 2013; M. Kandziora et al., *Mapping provisioning ecosystem services at the local scale using data of varying spatial and temporal resolution*, "Ecosystem Services" 2013 no. 4, p. 47–59.

8 T. Witek (ed.), *Waloryzacja rolniczej przestrzeni produkcyjnej Polski wg gmin*, Puławy 1981; T. Witek (ed.), *Waloryzacja rolniczej przestrzeni produkcyjnej Polski wg gmin. Suplement*, Puławy 1994.

9 T. Witek, T. Górski, *Przyrodnicza bonitacja rolniczej przestrzeni produkcyjnej w Polsce*, Warszawa 1977.

10 K. Filipiak, *Ocena wykorzystania rolniczej przestrzeni produkcyjnej w Polsce w ujęciu regionalnym,* "Pamiętnik Puławski" 2003 no. 132, p. 73–79.

To estimate ecosystem potential for honey production, we took into account the quality of a bee pastures, namely, the abundance and accessibility of honey sources (nectar and honeydew) and pollen (a necessary nutrition for a bee family to function properly)[11].

The amount of nectar and pollen potentially produced by an ecosystem is directly linked to the actual floral resources of a plant community and its melliferous potential. This, in turn, is determined by plant species composition and honey potential of single species. The honey potential of individual plants was taken from The Great Atlas of Melliferous Plants [in Polish][12], which includes information on nectar secretion and pollen production for over 250 melliferous plants in temperate climate. Recognition of key honey species within types of ecosystems was based on the available phytosociological relevés (frequency of species established according to Braun-Blanquet[13]) taken in the study area and the general typologies of plant communities presenting species composition and dominance structure for Central Europe[14]. Crane and Walker[15], based on Haragsim work[16], listed trees that are important sources of honeydew, along with the information on the honey potential available in terms of yield per hectare.

For the indicator of potential honey production an ordinal scale from 0 to 5 was applied, where 0 means no relevant capacity to deliver a service, and 5 means very high relevant capacity. The scale corresponds to the maximum possible annual honey yields per hectare of a given ecosystem [kg/ha].

## Potential ungulate biomass

Hunting data (number of animals) from the annual hunting reports (2011–2014), covering 14 hunting units and the Wigry National Park served as basic material research to assess ungulate biomass. The detailed data we obtained from four forest districts (Suwałki, Szczebra, Pomorze, Głęboki Bród) and the Wigry National Park. Four species of big game animals were taken into account: moose (*Alces alces*), red deer (*Cervus elaphus*), roe deer (*Capreolus capreolus*), and wild boar (*Sus scrofa*).

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11 E. Crane, *Bees and beekeeping: science, practice and world resources*, Oxford 1990; P. Westrich, *Habitat requirements of central European bees and the problems of partial habitats*, in: A. Matheson et al. (eds), *The Conservation of Bees*, London 1996, p. 1–16.

12 Z. Kołtowski, *Wielki Atlas Roślin Miododajnych,* Warszawa 2006.

13 J. Braun-Blanquet, *Pflanzensoziologie*. "Grundzüge der Vegetationskunde, Pflanzensoziologie Grundzüge der Vegetationskunde" Wien 1964.

14 W. Matuszkiewicz, *Przewodnik do oznaczania zbiorowisk roślinnych Polski*, Warszawa 1981.

15 E. Crane, P. Walker, *Important honeydew sources and their honeys,* "Bee World" 1985 no. 66, p. 105–112.

16 O. Haragsim, *Medovice a včely*. "Státní zemědělské nakl", Praha 1966.

Ungulate biomass was calculated as the total biomass (kg / 100 ha) of the moose, red deer, roe deer and boar, according to the formula: ∑ (species density * unit weight). The following assumptions were adopted: (a) each population is evenly divided into males and females; (b) the unit weight (kg) of an animal is: for moose – male 400, female 300; for red deer – male 120, female 80; for roe deer 25; for boar – male 120, female 90.

## Timber standing crop

We define timber standing crop as thickness (volume in cubic meters) of wood in the stands (merchantable timber) in a given area. The basic material research to assess volume of timber standing crop was derived from administrative units of four forest districts (Suwałki, Szczebra, Pomorze, Głęboki Bród) and the Wigry National Park. It covered approx. 16 000 records originally addressed to local forest sites showing volume of timber standing crops. Data of age of tree species allowed to calculate the volume of timber in five age stand categories (0–40; 40–60; 60–80; 80–120; >120) in each site in forest communities corresponding to the legend presented on the map of ecosystems. Spatial differentiation of the volume of timber crop is presented on the map of ecosystems in five types of forest communities: alder forest, riparian forest, oak-hornbeam forest, pine and mixed pine forest and swamp/bog forest.

## Carbon sequestration in the soils

Forty nine undisturbed soil samples were collected from 18 points in different ecosystem types. Total organic carbon content (TOC) in mineral and organic-mineral samples was analysed using the Tiurin method, while that in organic samples was assessed using the Alten method. TOC capital in the soils to the depth of 50 cm was calculated by the formula:

$$TOC_{(capital)} = \frac{h \cdot D \cdot TOC}{10} \cdot (1 - q)$$

where:

$TOC_{(capital)}$ – capital of TOC in soils,
h – thickness of soil horizon,
D – bulk density,
TOC – content of TOC in soil horizon,
q – soil skeleton [%]/ 100

Map of soils was adapted to the scale of the map of ecosystems. To determine the content of TOC in soils of each of studied ecosystems, calculation results were counted into areas occupied by each ecosystem type.

# Results

## Spatial differentiation of indicator values for the provisioning ES

### Potential harvested crop from agro-ecosystems

In the research, the indicator of agricultural production spatial valorisation takes the values from 25 to 93. Over 55% of cropland belongs to very poor arable lands category, associated with soils formed from sands, poor in nutrients and usually permanently too dry. Only 26% of cropland constitutes good and very good arable lands with soils rich in nutrients and organic matter, with regulated water conditions. Potential harvested cereal crops from the studied agro-ecosystems amount to 13.2–50 dt $ha^{-1}$ $year^{-1}$ (figure 2), with the average crop 26.5 dt $ha^{-1}$ $year^{-1}$.

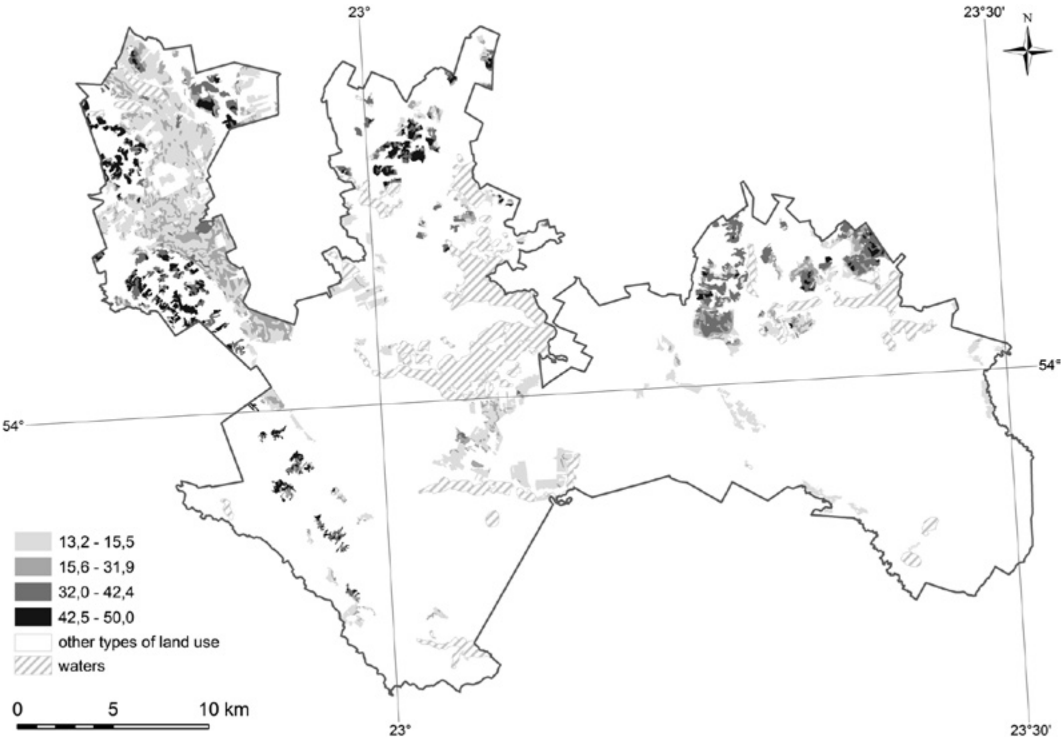


**Figure 2.** Potential harvested cereal crops [dt/ha/year]

Source: elaborated by A. Kowalska.

### Potential honey production

The highest potential to produce honey was achieved by cropland located on fertile soils, assuming that the selected crop would be most suited for honey production (e.g. phacelia – *Phacelia tanacetifolia* or buckwheat – *Fagopyrum esculentum*). Those plant species can give up to 300 kg of honey per hectare when forming continuous monocultures. According to our estimations, grassland on dry and fresh mineral substrate along with young swamp pine forests have also one of the highest capacity to provide honey. The lowest capacity was assigned to alder forest, riparian forest and wetlands, as they constitute, apart from water bodies and other non-vegetated areas, the poorest bee pasture. Honey potential of forest ecosystems was differentiated in relation to forest age in such a way that the youngest and the oldest tree stands were assigned higher values than middle age and mature forests (see Taki et al.[17]).

Higher honey potential could be found in the north-western part of the area, were grassland and cropland are dominant ecosystem types (figure 3).

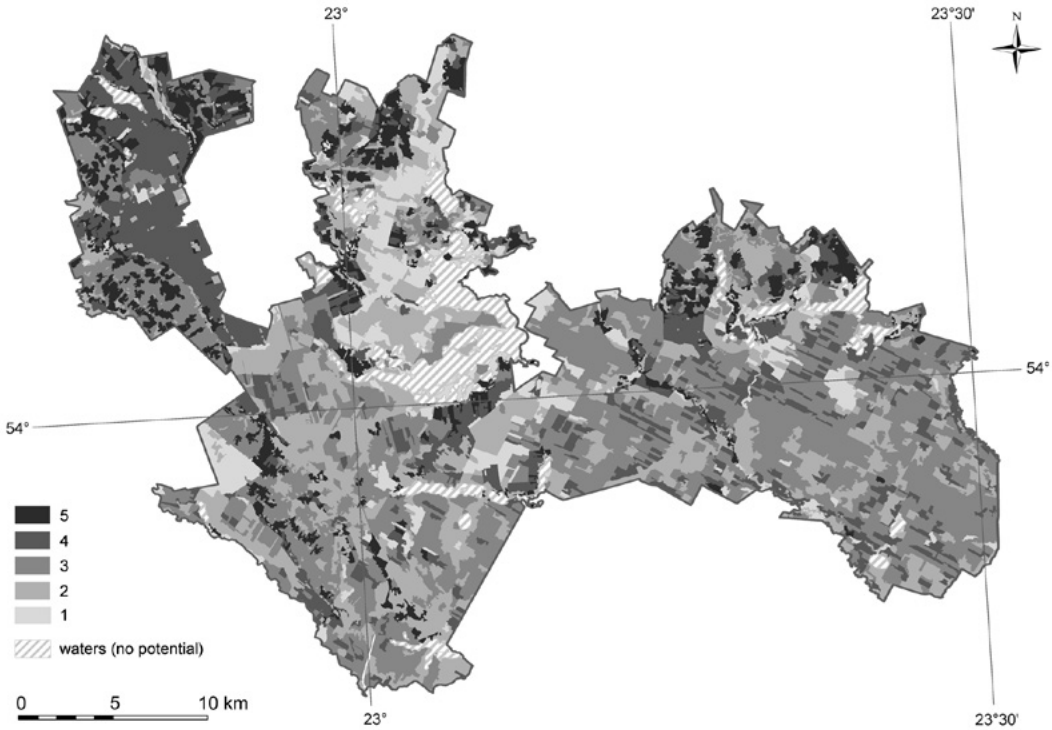


**Figure 3.** Potential honey production [kg/ha]

The value of 5 means high relevant capacity [approx. 300 kg/ha], whereas 1 – low relevant capacity. Waterbodies and other non-vegetated areas were assigned 0 Source: elaborated by A. Affek.

[17] H. Taki et al., *Succession influences wild bees in a temperate forest landscape: the value of early successional stages in naturally regenerated and planted forests*, "PLoS ONE" 2013 no. 8.

Apart from fertile grassland in the eastern part of Wigry NP, the rest of the Park, being covered by mature forest, has relatively low potential for honey production. In contrast, patches of young forest stands and clearings within vast areas of managed pine forests (outside WNP) may provide considerable amount of nectar and pollen.

## Potential ungulate biomass

Ungulate biomass varies from approx. 40 kg to about 600 kg/100 ha among hunting units. The greatest resource of wild ungulates is in the units with the proportion of forests between 60% and 80%, mainly in the forest hunting units of Giby and at some of the hunting units of Nowinka. The lowest value of biomass was reported in hunting units in the Suwałki commune and in northern part of Giby with a small proportion of forests (approx. 6 to 15%), (figure 4).


**Figure 4.** Potential ungulate biomass [kg/100 ha]

Source: elaborated by B. Grabińska and J. Solon.

From the point of view of land cover structure, the last one have mainly open-space character with dominance of fields, meadows and pastures.

The majority of game animal species are associated with various forest habitats. The percentage shares of habitat types in forests and the density of the animals constitute two closely interrelated elements. The greatest potential to deliver wild ungulate biomass is in the area with the highest proportion of forests. In contrast, the lowest resource of ungulates was reported on farmland and grassland. That spatial diversity of ungulate biomass in most cases is linked with the diversity of habitats and types of ecosystems.

### 3.1.4. Timber standing crop

The results of calculation of timber standing crop in each age category show that the smallest supply of wood is in youngest forests (0–40 years) and gradually increases with age stand. Maximum potential to deliver timber was achieved for the d-age category of stands (80–120 years). The Wigry National Park appeared to have significantly larger average volume of timber compared to four forest districts. That trend is observed in four types of forest communities: alder forest, riparian forest, oak-hornbeam forest and in pine and mixed pine forest. The last one is selected to illustrate the trend described above (figure 5).

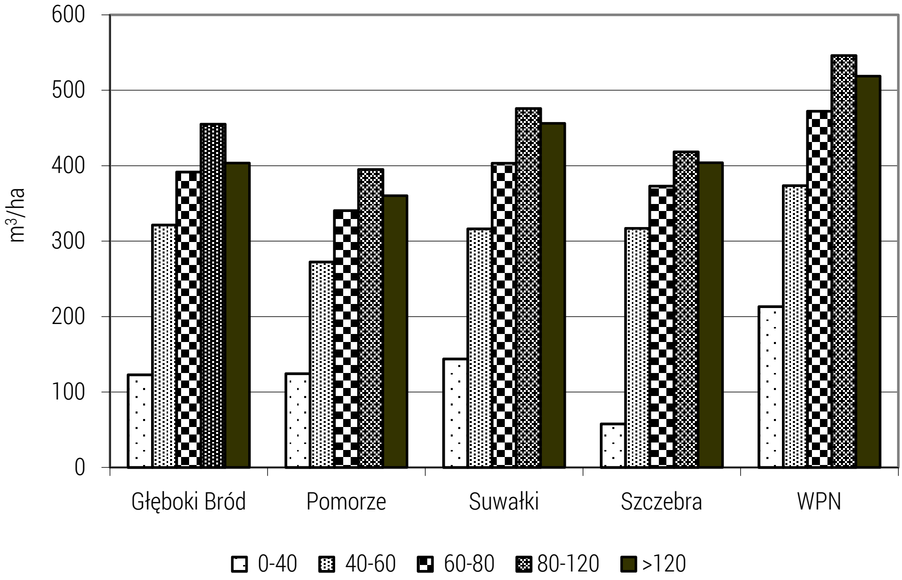


**Figure 5.** Volume of timber in different age categories of pine and mixed pine forests in four forest districts and in the Wigry National Park

Source: elaborated by E. Roo-Zielińska.

Spatial differentiation of the volume of timber standing crop presented on the map shows very clearly almost lack of potential to deliver timber in Suwałki (especially in the north part), which is mostly farmland. In turn, much higher values of timber volume was reported in the majority of the Wigry National Park and in the highly forested Giby commune, where we can find forests with more than 500 $m^3$/ha of timber volume. Some parts of Nowinka commune, especially adjacent to the Wigry National Park, are characterized by a rather big volume of timber standing crop (400–500 $m^3$/ha), (figure 6).

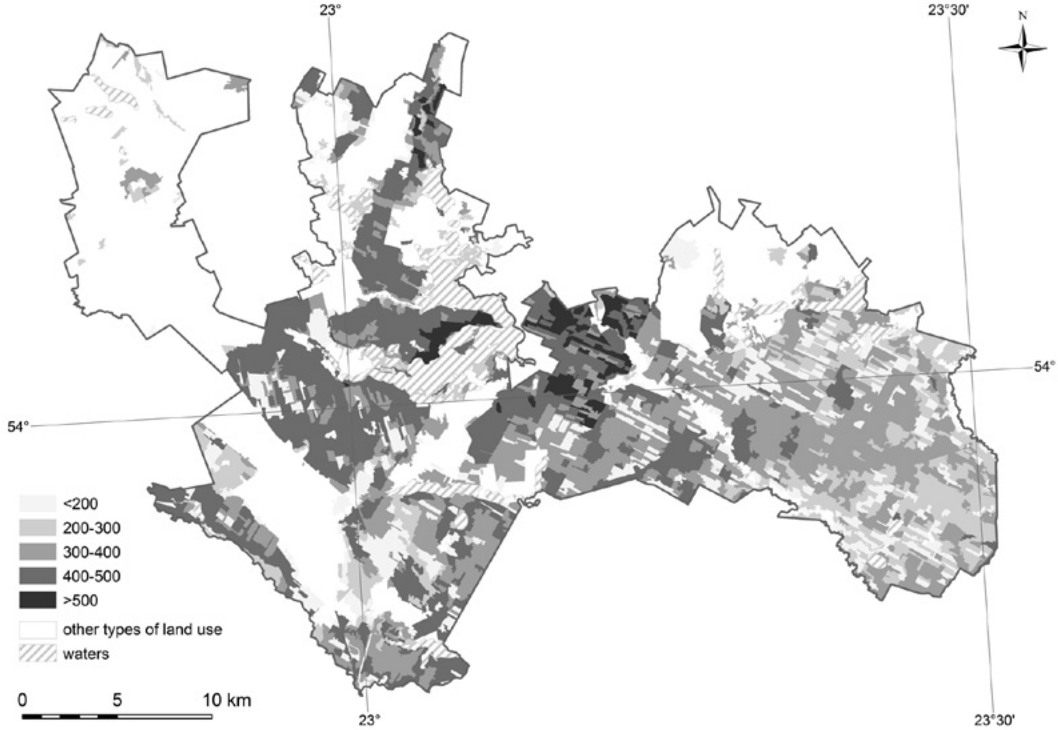


**Figure 6.** Volume of timber standing crop [$m^3$/ha]

Source: elaborated by E. Roo-Zielińska and J. Wolski.

## Spatial differentiation of indicator values for regulating ES

The study area is located in post-glacial landscape, which is characterized by the occurrence of many land forms developed as a result of glacier waters and ice-sheet impact. The soils of the study area developed from post-glacial sediments – glacial and fluvioglacial sands and tills, which influenced soil texture diversity – one of the main factors essential for the development of the particular soil type. Each type of ecosystem is characterized by different content of TOC.

The highest values are observed mainly in Histosols and Haplic Luvisols (WRB 2014) of wet habitats, both forest, grassland and arable, what is also correlated with at least sandy loam soil texture (mineral soils) and organic substrate. High content of TOC is characterized especially for swamps-swards, reedbeds, sedges (5478 t/ha), eutrophic mire (5250 t/ha), all categories of alder carr, riparian alder-ash forests and swamp coniferous forests and mixed swamp coniferous forests (2184–4683 t/ha). The low values (minimum 313 t/ha) are characteristic for all age categories of coniferous forests and mixed coniferous forests, grasslands and crop fields on mineral habitats (figure 7).

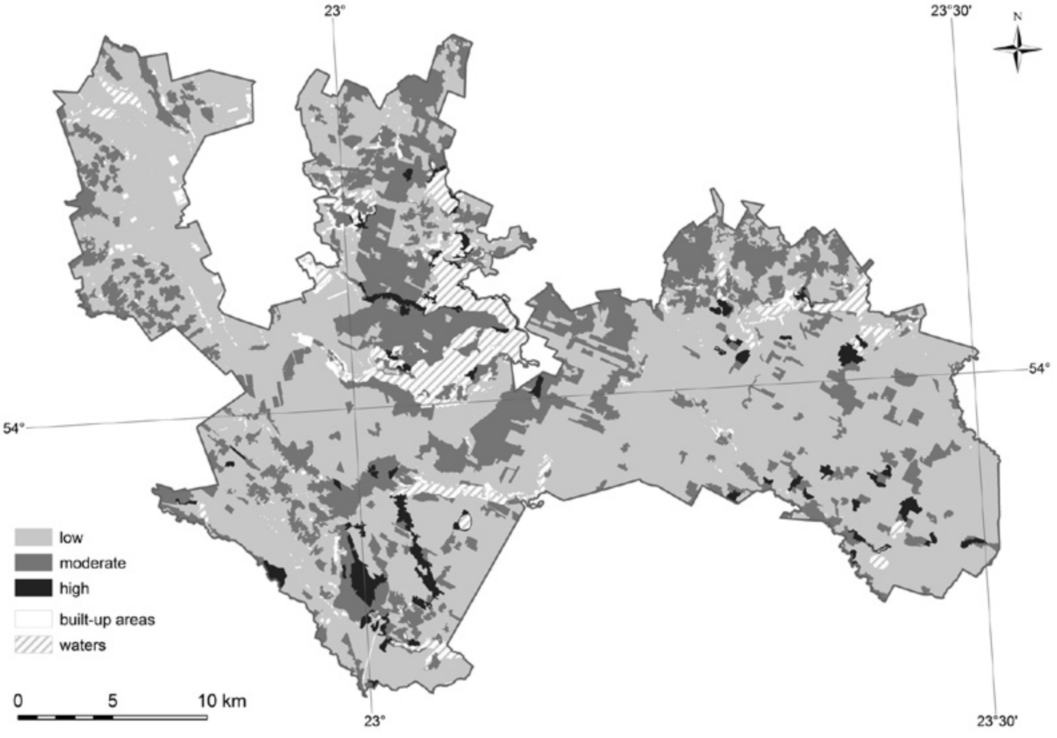


**Figure 7.** Content of Total Organic Carbon (TOC) in soils [t/ha]

Source: elaborated by B. Kruczkowska.

## Final Remarks

Methods applied for calculation of ecosystems' potential for delivering goods and services, described in this paper, represent wide spectrum of methodical approaches. The differences between them are shown in table 2 in s shortened form. It is worth to underline that we use simple direct method (as for timber standing crop), compound direct indicators (as for potential ungulate biomass), as well as compound indirect approaches resulting in surrogate indicators (as for potential honey production).

**Table 2.** Comparison of approaches to calculate indicators of chosen ecosystem services

| Ecosystem service | Input data | Calculation steps |
|---|---|---|
| Potential crop yield from agro-ecosystems | Abiotic data derived from detailed maps (soil quality, relief and water conditions) and general maps (climate), crop yield taken from regional statistical data | Abiotic valorisation of patches according to predefined formulas, calculation of potential yield from regression equation (formulas from literature), generalisation of results for ecosystem types |
| Potential honey production | Optimal plant species composition of ecosystem types (model based on field data and literature data), maximal supply of nectar, honeydew and pollen by plant species (literature data) | Recalculation of potential honey precursors supply to honey production (formulas and coefficients from literature), separately for ecosystem types |
| Potential ungulate biomass | Detailed field censuses of number of animals by species and hunting units (data completed by Forest Service and national park) | Recalculation from numbers of animals of different species into total biomass with the help of coefficients derived from literature |
| Timber standing crop | Treestand volume detailed data for each forest patch (field measurements completed by Forest Service) | Simple averaging by ecosystem types |
| Carbon sequestration in the soils | Own field data from chosen points, additional data from literature | Spatial extrapolation of point data values based on soil map, generalisation to ecosystem types |

Source: elaborated by J. Solon.

The analysis of the spatial differentiation of evaluated or measured services show that each of them represents a unique spatial pattern, which depends of distribution of several elements of the natural environment and/or types of human activities. Depending on the service, there are: abiotic conditions (e.g. harvested crop, carbon sequestration in the soils), land cover structure on the landscape level (e.g. ungulate biomass), type and age categories of forests as well as forest management direction (e.g. timber standing crop), species composition of plant communities, which – in turn – depends on abiotic conditions and land use (e.g. honey).

Simple reclassification of indicators' values (see table 3) and summing up of newly established values made it possible to evaluate the the joint potential of ecosystems for delivering the analysed five services (figure 8).

**Table 3.** Reclassification of variables' values

| New Classes | Original scales | | | | |
|---|---|---|---|---|---|
| | crop [dt/ha] | honey [points] | game [kg/100 ha] | timber [m³/ha] | TOC [t/ha] |
| 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 13–15 | 1 | 40–100 | 1–200 | 1–500 |
| 2 | 15–20 | 2 | 100–200 | 200–300 | 500–1000 |
| 3 | 20–30 | 3 | 200–300 | 300–400 | 1000–2000 |
| 4 | 30–40 | 4 | 300–400 | 400–500 | 2000–4000 |
| 5 | 40–50 | 5 | 400–500 | 500–600 | 4000–10000 |

Source: elaborated by J. Solon.

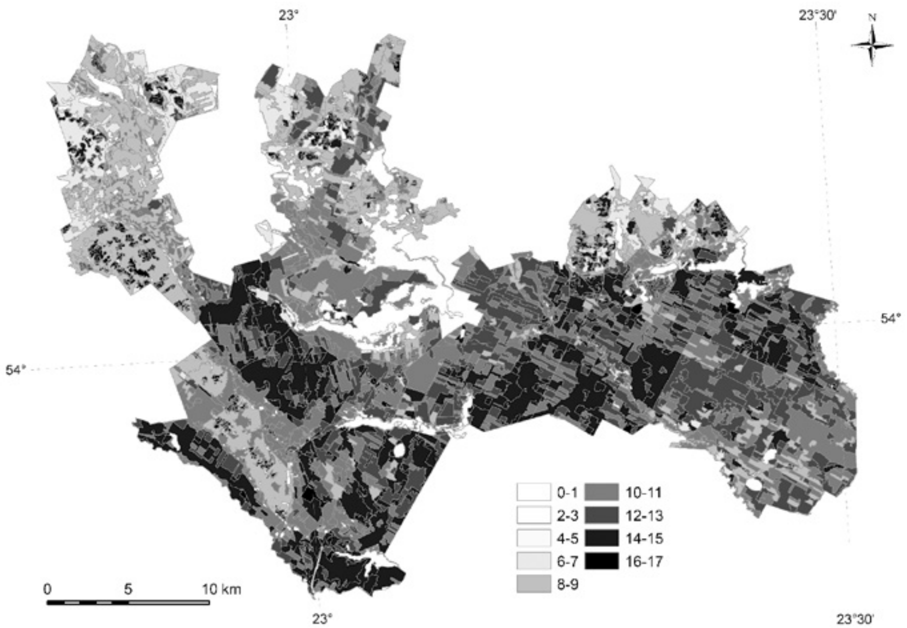


**Figure 8.** Joint valorization of the ecosystem potential for delivering five analyzed services (original values as on Figs. 2–4 and 6–7 recalculated according to the scheme presented in table 3 and summed up)

Source: elaborated by J. Solon.

The highest possible rank of total potential for a patch is 20 (not 25, as potential crop yield and timber standing crop were calculated for mutually excluding areas), but in fact the real highest rank equals to 17 and occurs on less than 0.2% of the total area. It is worth to notice than ca. 80 % of the analysed area represents ranks between 8 and 15, what means that almost all types of ecosystems have the meaningful potential for delivering more than one service. The highest potential is characteristic for mixed and pine forests, as well as for older age classes of boggy pine forests (13–15 points), while the lowest for meadows (7–9 points) and pit bogs and swamps (9–10). The other types of ecosystems (alder carrs, riparian forests, oak-hornbeam forests, arable fields) are of intermediate character (the sum of ranks is in the range from 8 to 12). This results show clearly that for all theoretical and practical purposes ecosystems (and their landscape complexes) should be treated as multifunctional entities.

At the end it is necessary to underline that our study was conducted in a local scale, what influenced all the methodical approaches. The choice of methods for identification, estimation and evaluation of the ecosystems' potential for selected services, their indicators and measures depends on the geographical scale (local, regional, general). First of all, the following elements should be taken into account to determine the proper spatial unit (ecosystem / hunting unit / landscape) for the evaluation of a particular service: (1) land cover structure, (2) biotic factors (vegetation and fauna), (3) abiotic factors (type of soils, climatic conditions) and (4) anthropogenic pressure (intensity of forest management, silviculture, forest practices and forest policy).

Methodical approaches adopted in our study as well as results obtained may serve as a roadmap for other studies conducted in similar spatial scales.

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## Literature


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