

Land cover and landscape diversity analysis in the West Polesie Biosphere Reserve

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A b s t r a c t. The aim of this research was to present the land cover structure and landscape diversity in the West Polesie Biosphere Reserve. The land cover classification was performed using Object Based Image Analysis in Trimble eCognition Developer 8 software. The retrospective land cover changes analysis in 3 lake catchments (Kleszczów, Moszne, Białe Włodawskie Lakes) was performed on the basis of archival aerial photos taken in 1952, 1971, 1984, 1992, 2007 and one satellite scene from 2003 (IKONOS). On the basis of land cover map structure, Shannon diversity index was estimated with the moving window approach enabled in Fragstats software. The conducted research has shown that the land cover structure of the West Polesie Biosphere Reserve is diverse and can be simply described by selected landscape metrics. The highest level of land cover diversity, as showed by Shannon Diversity Index, was identified in the western part of the West Polesie Biosphere Reserve, which is closely related to the agricultural character of land cover structure in those regions. The examples of three regional retrospective land cover analyses demonstrated that the character of land cover structure has changed dramatically over the last 40 years.

K e y w o r d s: land cover structure, landscape diversity, OBIA, landscape metrics, West Polesie Biosphere Reserve

INTRODUCTION

Land cover structure (LCS) changes in space and time have been the subject of many studies which can be conducted efficiently thanks to the development of techniques for the collection, processing, analysis and modelling of geographic information (Turner *et al.*, 2007). The fast development of desktop GIS software, wide availability of aerial and satellite images, as well as land cover or land use (LCLU) databases (*eg* CLC 2006) encourage research in the field of

LCS. GIS technology is also used in many other sciences which are not typically associated with geodesy or cartography. In the presented paper the authors describe the methods of satellite data processing for land cover and landscape diversity mapping.

Land cover data, especially agricultural land use, can be used for many purposes: to analyse the agricultural capacity of the area (Anaya-Romero *et al.*, 2011), to explore the energy potential of a short-rotation coppice (Kollas *et al.*, 2009) or to prepare a sediment yield map (Mahmoodabadi, 2011). Remotely sensed data is often the main data source for LULC maps and gives a great possibility of monitoring agricultural areas for rapid and continuous assessment of plant, soil and water resources (Kostrzewski *et al.*, 2002). A good example of such approach is given in a work by Bagheri *et al.* (2012) where ASTER was used for the prediction of nitrogen content in corn canopy.

Due to the ongoing international debate in literature concerning the distinction between the definitions of land use and land cover, it is also necessary to clarify our opinion in this matter. According to the authors of the present study, similarly to Jansen and Gregorio (2003), land cover refers to items that can be observed on the surface of the Earth, and this applies to both natural and anthropogenic elements, whereas the term 'land use' refers to the way in which these biophysical resources are used by humans, the result of which are certain goods and services to the society.

It also seems natural that the classification of the satellite scene/aerial image, prepared with the use of a set of training fields or by object classification (Object Based

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Image Analysis was used in this research), results in a land cover map on the basis of which, by further studies, land use map could be prepared. Various aspects of land cover and land use definitions are also discussed by Ciołkosz *et al.* (2011). Citing the work of several authors (Fisher *et al.*, 2005; Jankowski, 1977) and European research programs Corine Land Cover and Land Use/Land Cover Area Frame Statistical Survey (LUCAS), the authors discuss different ways of understanding the concepts discussed.

Classification of both aerial and satellite images is one of the most common ways to obtain information about land cover. There are several technical approaches which allow to relate satellite images with the nature of vegetation. Research carried out over the past few decades proves that the use of remote sensing data to characterise vegetation type is very efficient (Saadat *et al.*, 2011). Image classification performed with the manual approach by a skilled operator who is well acquainted with the field situation of the development area allows obtaining fully satisfactory results. However, in the case of large research areas (like the West Polesie Biosphere Reserve, WPBR), manual methods become inefficient, require generalizations and the introduction of a minimal mapping area. An alternative solution is to use automatic image classification algorithms. Among various methods and solutions developed in recent years in order to improve the accuracy of land cover classification results, object-oriented image classification methods seem to be an especially interesting approach (Chmiel *et al.*, 2007).

The modern approach to image classification without the need for training samples was presented and confirmed in many scientific projects (Blaschke 2010; Tompalski and Wężyk, 2012; Wężyk *et al.*, 2006). Contrary to the pixel based classification techniques, object based image analysis (OBIA) can replace the traditional methods of visual interpretation (Lewiński, 2007) or even the supervised classification method commonly used today (Mas *et al.*, 2010). Object oriented approach to classification is particularly well suited for high-resolution images (Drzewiecki *et al.*, 2013; Tansey *et al.*, 2009; Szostak *et al.*, 2013). OBIA technique extends the standard classification methods that are based only on single pixel values. Pixels are first grouped into objects in a process called segmentation. This is the initial step of the analysis and can be followed by various steps of resizing, merging, splitting and classifying the objects which are the primary subject of the processing. Assigning classes to objects can be based not only on their spectral values (*eg* mean value of NIR band), but also on shape, size and attributes of neighbouring objects. What is also of great importance is the fact that all the analysis steps (so called ruleset) can be used on multiple datasets without any interaction with the user (Hay and Castilla, 2006).

Implementation of environmental protection, space management and urban planning demands at least a basic set of spatial data about landscape. Previous experiences based on

remote sensing techniques confirm the high relevance of satellite and aerial images in these fields of research. Methods for these purposes are still being developed and improved, as well as an integrated approach to spatial analysis with the use of multisource data (Białousz *et al.*, 2010). The importance of land use is greater than that of other factors, because of the direct human involvement (Abrishamkesh *et al.*, 2011). The estimation of pace and direction in which land cover changes occur is crucial in natural resources management, especially in conservation planning.

Categorized land cover maps are the primary data source for landscape analysis concerning land cover diversity and structure. Studies of this type are the domain of landscape ecology which is largely founded on the notion that environmental patterns strongly influence ecological processes (Turner *et al.*, 1989). Landscape structure is crucial for the maintenance of biodiversity (Antrop, 2005).

Landscape ecology uses landscape metrics, a sort of environmental indicators, defined as measurable biotic and abiotic characteristics of the environment, which allow to obtain quantitative data concerning ecological resources and landscape functioning (McAlpine *et al.*, 2002).

Nowadays, landscape metrics are often used for the quantification of landscape patterns (Gustafson, 1998) and are often used as indicators for landscape functions (Uuemaa *et al.*, 2009). Uuemaa (2013) reviewed landscape metrics and, according to three main groups of landscape functions classification: habitat, regulation and information (De Groot, 2006), pointed that landscape metrics have been mostly used in evaluating these three landscape functions and changes in land use and land cover landscape structure.

Computer software is an important element associated with landscape metrics. There are many desktop software packages that have been designed to provide calculations and analysis of landscape structure patterns in categorical maps. Many of them have common features, *eg* Fragstats 3.3, r.li, GRASS, V-Late 1.1, PA4 beta, Pattern/Texture, APACK, IAN, and some of them are available as open source software packages (Zaragozi *et al.*, 2012).

In the present study, land cover map of whole WPBR area was obtained with OBIA approach and next, on the basis of this map, landscape diversity metrics was calculated. Additionally, for three selected catchment areas, the land cover and landscape diversity changes analysis was conducted with the use of large scale land cover map carried out by manual feature extraction from ortophotomaps.

MATERIALS AND METHODS

The West Polesie Biosphere Reserve was established in 2002. It includes almost the whole physiographic meso-region of the Łęczna-Włodawa Lakeland and stretches from the River Bug below Wola Uhruska in the south-east to Stawy Siemień (Siemień Ponds) in the Tyśmienica River valley in the north-west.

The Łęczna-Włodawa Lakeland is the largest area in Poland that groups lakes occurring outside the areas formed by glacial morphogenesis of the last glaciations. The flatness of the terrain and shallow-lying first level of ground waters cause that considerable parts of the lakeland are permanently or temporarily water-logged. Broad peatbogs and marshes have developed on the wetlands. Lakes (61) are the characteristic element of landscape. It is estimated that they are 11.300 years old. The centre of the Biosphere Reserve is the Polesie National Park. It is surrounded by 3 landscape parks, connected by a protected landscape area (Chmielewski *et al.*, 2005, Fig. 1).

As a source for data set, 8 satellite images were used. These images were collected on 20th September 2009, by a German satellite constellation called RapidEye. The RapidEye sensor has a multispectral push broom imager with a spatial resolution of 6.25 m and captures data in the spectral bands: blue (440-550 nm), green (520-590 nm), red (630-685 nm), red edge (690-730 nm), and near infrared (760-850 nm) (RapidEye, 2010). The RapidEye Ortho product Level 3A (after radiometric and geometric correction) was used.

Land cover classification was performed with OBIA approach. The analyses were performed on each of the RapidEye satellite images separately using one rule designed to process all the data. The processing consisted of several steps – first, additional layers were created (NDVI, NDWI, standard deviation of NIR band in 3x3 window), followed by segmentation, classification and additional refinement steps. All the processing was done within Trimble eCognition Developer 8 software.

Multiresolution segmentation algorithm (Baatz and Schape, 2000) was used to create meaningful objects, representing features registered in the satellite image. The scale parameter was set to 150, which resulted in segmentation that generalized not-needed small features (single trees, individual houses), but preserved the detailed borders between crucial land use classes. All RapidEye bands were used in this process, together with standard deviation layer of NIR band, which helped extracting the urban areas.

The classification was based on samples which were collected manually on each satellite image and then used to define the membership functions for each class. Although each of the images was collected in slightly different conditions, the chosen features of the objects allowed to distinguish the classes in all of them. These features were: mean value of each band, mean value of NDVI and NDWI indices, mean value of standard deviation of NIR band (3x3 window), object area and shape index. Seven land cover classes were distinguished: water, moors and rush communities, low vegetation, deciduous forest, coniferous forest, arable and built-up areas.

The research area was very large and thus the elaborated land cover map included omnifarious land cover forms (the western part of the WPBR is agricultural, central and eastern regions are largely covered with forests and wetlands). The authors were particularly interested to get the best possible classification results, especially in relation to wetlands (bogs, sedge-moss communities, rushes and other wetland areas), therefore, in the final stage of land cover map preparation, some manual adjustments in OBIA classification results

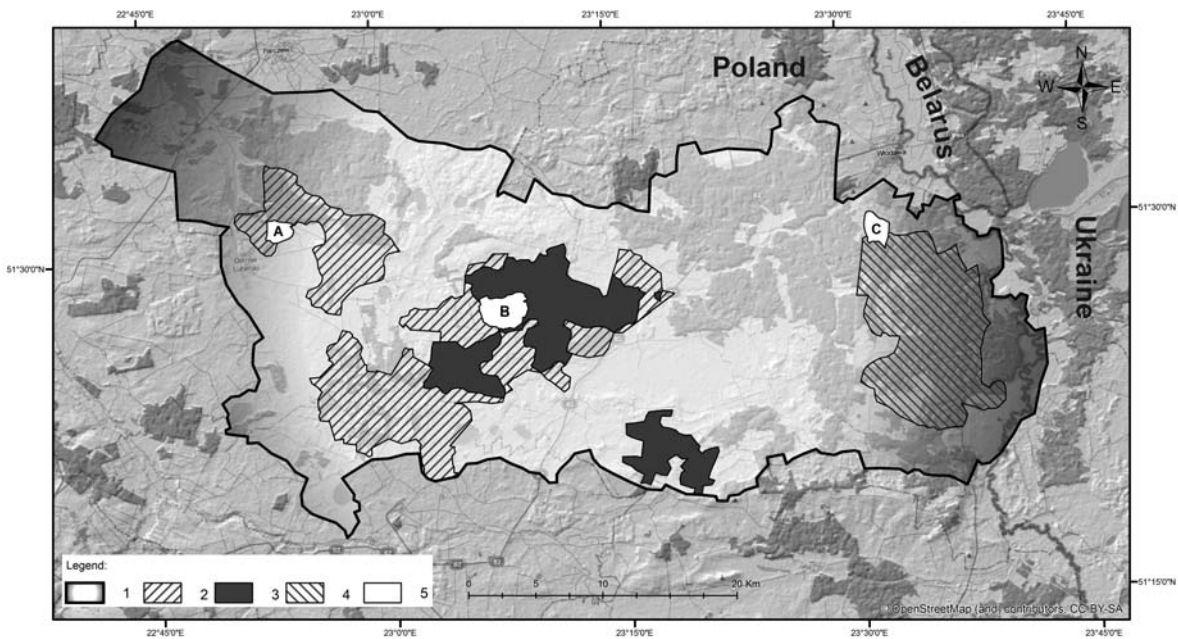


Fig. 1. West Polesie Biosphere Reserve (research area) against the background of other protected areas in the East of Poland. 1 – WPBR border, 2 – ‘Łęczyńskie Lakeland’ Landscape Park, 3 – Polesie National Park, 4 – Sobibór Landscape Park, 5 – catchments selected for detailed land cover changes, lakes: A – Kleszczów, B – Moszne, C – Białe Włodawskie.

were made. In this way, 2.57% of the total area of the reserve was reclassified, the adjustments being related mostly to moor areas wrongly classified as coniferous forests and built-up areas which did not always coincide with the real range of built-up areas. In the next stage, the vector map of land cover was converted to raster format (ESRI GRID) with 15 m ground sample distance (GSD) and then Shannon Diversity Index (SHDI) landscape metrics was estimated. The SHDI formula is:

$$\text{SHDI} = - \sum_{i=1}^m P_i \ln P_i,$$

where: m – number of stretch classes in the landscape, P_i – proportion of participation of a particular stretch class (i) in the landscape.

SHDI landscape metrics was calculated in FRAGSTATS software (McGarigal *et al.*, 2002) in the *moving window* approach. Several attempts were made to estimate SHDI based on raster resolution finer than 15 m GSD, but such a set of data was too large for FRAGSTATS and the software did not even start to calculate the indices. Raster resolution of 15 m GSD used for such a large area proved to be the limit of the SHDI calculation process.

The moving window approach requires the operator to experimentally determine the value of a search radius (r), relevant to the minimum mapping area (Eden *et al.*, 2000). Using too high a rounding radius value results in excessive generalization, too small radius value does not preserve the data continuity. Having performed some tests, the authors used the 1 000 m rounding radius. The natural situation is that depending on the size of the adopted parameter of rounding radius the edge of research area is not estimated. To estimate those edges, the source land cover map should be prepared beyond the boundaries of the research area.

Beside the OBIA processing for the whole study area, a detailed land cover and landscape metrics changes analyses were performed for three additionally selected areas (lake catchments), where SHDI achieved very high values. For these three studied catchments several archival aerial photographs and satellite images were collected. The photos were acquired: Kleszczów and Moszne Lakes in 1952, 1992, 2007; for Białe Włodawskie Lake in 1971, 1984, 2003^{IKONOS} and 2007. Archival aerial photographs were delivered by the Central Department of Geodesy and Cartography in Poland (CODGiK), unfortunately they were not available for the whole WPBR area for the same periods of time. Orthorectification of aerial photographs was carried out in ER-Mapper software with the use of the ground control point method (GPC) and terrain elevation model. The total RMS error of orthorectification process was lower than 1.7 m. Satellite images from 2003 were acquired by the IKONOS satellite, while the aerial photos from 2007 were acquired and converted into an ortophotomap by MGGP Aero from Tarnow. The detailed land cover structure of the three selected catchments was prepared by the manual feature extraction method carried out with the use of ESRI

ArcGIS software. In the next stage, on the basis of the land cover maps prepared for the three selected catchments, SHDI landscape metrics (in the moving window approach with the rounding radius of 100 m) was calculated. The last step was to prepare a map of SHDI changes by establishing the catchments areas where the value of landscape metrics increased, decreased or remained unchanged (with use the of map algebra in ArcGIS Spatial Analyst).

RESULTS AND DISCUSSION

The result of the OBIA processing consisted of 111 878 objects covering the whole study area. The mean object size was equal to 4 4691 m², and the standard deviation was equal to 876 353 m².

The accuracy assessment of the classification result was based on 300 randomly distributed points, with manually labelled class names. The confusion matrix (Table 1) contains the results of the assessment and points out which classes were the most difficult to classify. The overall classification accuracy equalled 0.81 (kappa = 0.77), the average producer and user accuracy equalled 0.79 and 0.83, respectively. The period of satellite imagery acquisition (20th September) favoured the high classification accuracy of arable areas as it was at the time when the majority of arable crops had already been harvested so these areas were not confused with low vegetation areas.

Based on the results of OBIA classification, land cover map of the WPBR was prepared (Fig. 2). Surface area and the percentage of each class of land cover are presented in Table 2.

The prepared distribution map of SHDI landscape metrics (Fig. 3) shows that the index values for landscape diversity of the investigated area fluctuate from 0.04 to 1.92. The highest values were recorded at Lake Piaseczno (south-western part of this area is shown in Fig. 2), in particular in the area where rapid development of summer resort building was identified (the maximum value of SHDI). On the area of 14 662.58 ha (10.08% of the WPBR) the SHDI value exceeds 1.5. The lowest SHDI values are associated with large areas of pine stands that occur mainly in the eastern part of the reserve (Sobibór superintendency) and arable areas are dominant in the central and partly in the western part of the WPBR.

The diversity of land cover patches may indicate multifunctionality of the area, it can also be an indicator of the high sensitivity of the area to changes in its structure and function. Low diversity of coverage suggests stability and durability of the land use structure.

The three investigated lake catchments are situated in the areas of very high SHDI values. The retrospective land cover analysis demonstrated that in the 3 investigated lake catchments the character of land cover structure has changed dramatically over the last four decades. The primary directions of land cover changes are as follows:

Table 1. Error matrix for processed satellite imagery (OBIA)

Classification result	Reference data							Total	UA	CE
	a	w	b	lv	df	cf	m			
a	94		4	9			2	109	0.86	0.14
w		14						14	1.00	0.00
b	1		35	1				37	0.95	0.05
lv	4		15	42	1	1	2	65	0.65	0.35
df		1			18	2		21	0.86	0.14
cf		1			2	25	5	33	0.76	0.24
m	1	3	1				16	21	0.76	0.24
Total	100	19	55	52	21	28	25	300		
PA	0.94	0.74	0.64	0.81	0.86	0.89	0.64			
OE	0.06	0.26	0.36	0.19	0.14	0.11	0.36			

Classes: a – arable areas, w – water, b – built-up areas, lv – low vegetation, df – deciduous forest, cf – coniferous forest, m – moors and rush communities, UA – users accuracy, CE – commission error, PA – producers accuracy, OE – omission error.

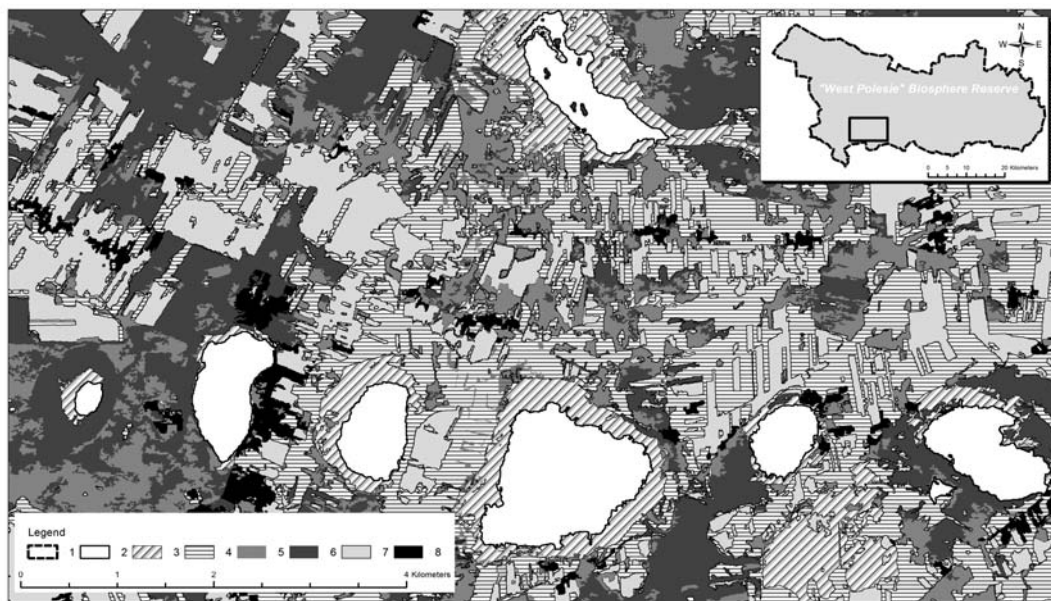


Fig. 2. Land cover map of the WPBR (selected scrap). 1 – WPBR border, 2 – water, 3 – moors and rush communities, 4 – low vegetation, 5 – deciduous forest, 6 – coniferous forest, 7 – arable areas, 8 – built-up areas.

- rapid shrinking of open water area and overgrowing of the lakes with macrophyte communities,
- complete disappearance of the labyrinth system of mid-moor pools and stagnant water bodies (lakes Kleszczów and Moszne catchments), very characteristic of the former Polesie landscape,
- large-scale shrinkage of the area of moors (moss-grown sites, cyperaceous meadows, moor-shrub communities and low moors),
- very high increase in afforestation, especially in Lake Moszne catchment,

- intensive development of recreational use of mesotrophic as well as some eutrophic lakes. It is also indicated that the majority of these changes has an unfavourable influence on the natural values of this region.

Detailed data about land cover changes in selected catchments are given in Table 3.

As for the whole WPBR area, also for the three catchments SHDI was calculated with the moving window approach (rounding radius = 100 m). Knowledge of the landscape metric values from the two different periods of time allowed to identify areas in which the metrics value has increased, decreased or remained unchanged (Fig. 4).

Table 2. Land cover structure of the WPBR

Land cover class	Area (ha)	% of the whole WPBR
Water	4 264.24	2.90
Moors and rush communities	3 530.56	2.41
Low vegetation	41 284.41	28.12
Deciduous forest	18 534.10	12.62
Coniferous forest	52 336.87	35.65
Arable areas	24 471.52	16.67
Built-up areas	2 398.97	1.63
Total	146 820.67	100.00

In the case of Lake Kleszczów catchment basin the SHDI appreciation is associated with the gradual disappearance of peat-bog patches which have overgrown with shrubs and forest patches as a result of the ongoing primary succession. Arable areas should be considered as the most stable in terms of landscape because in the case of the said catchments their SHDI value has not changed.

In Lake Moszne catchment basin, an increase of SHDI has a similar etiology to Lake Kleszczów catchment basin – the loss of peatland patches and the development of mosaic patches of rush and forest communities. Due to the rapid development of rush communities, the increase of SHDI value was also reported on lake surface. In this catchment basin the most significant decrease of flood waters and the increase of forest area occurred. Since the uniform extensive

patches of wetlands and peat bogs have been replaced by equally extensive patches of forest, the SHDI changes map does not show these areas as ones with strongly changing landscape diversity (Table 3 and Fig. 4B).

Land cover changes in Lake Białe Włodawskie catchment are related to the rapid development of built-up areas. The increase in the diversity of landscape mosaic concerns areas of the lake shore and the northern part of the catchment basin. In contrast to the previous two catchments, changes in landscape diversity are mainly anthropogenic.

The land cover map of the WPBR elaborated with OBIA and the use of SHDI landscape metrics allowed to specify the actual LCS of WPBR and identify areas of greatest landscape mosaic diversity which are subject to intense land cover transformations over time.

Many researchers have investigated the influence of spatial resolution and OBIA classification results on landscape metrics (Baldwin *et al.*, 2004; Turner *et al.*, 1989), considering that the analysis of landscape metrics must be made with explicit knowledge of their sensitivity, because variations in the value of landscape metrics can be the result of the approach used to analyse the images (Mas *et al.*, 2010).

Most studies concerning landscape metrics are based on remotely sensed data, and focus on the changes during the past 30 years. Nevertheless it is not rare that the number of land use/cover classes and resolution is not mentioned in the study. This makes the comparison of the results very hard, if not impossible. Moreover, the interpretation of the results may also be difficult because the pixel size and the number of land use/cover classes used in the study must be mentioned (Uemaa *et al.*, 2013).

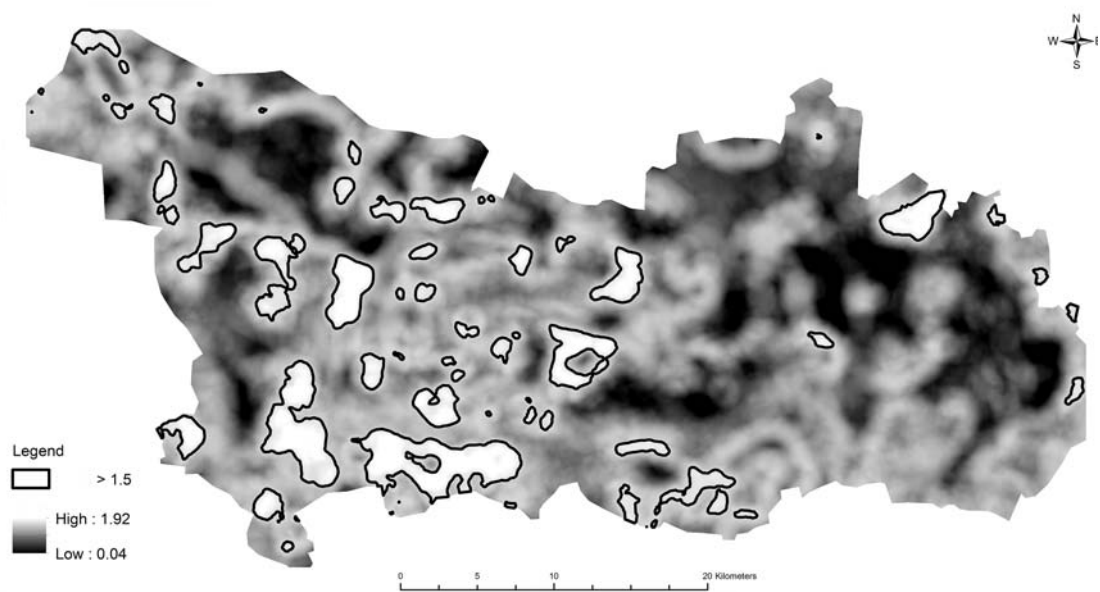
**Fig. 3.** SHDI landscape metric of the WPBR.

Table 3. Land cover changes in the 3 selected catchments (ha)

No.	Land cover class	Lake												
		Kleszczów				Moszne				Białe Włodawskie				
		1952	1992	2007	Changes 2007-1952	1952	1992	2007	Changes 2007-1952	1971	1984	2003	2007	Changes 2007-1971
1.	Lake water table	48.41	46.62	43.21	-5.2	17.7	12.2	11.6	-6.1	102.3	103.2	102.3	102.1	-0.2
2.	Peat pits	0	0	0	0	123.6	0	0	-123.6	0	0	0	0	0
3.	Sandy shore	0	0	0	0	0	0	0	0	2.8	1.9	5.0	3.8	1
4.	Stagnant water bodies	0.30	0	0	-0.3	3.4	1.7	0.8	-2.6	0.0	0.0	0.2	0.2	0.2
5.	Macrophyte communities	5.50	8.37	9.93	4.43	0	5.5	5.4	5.4	3.2	2.9	3.6	3.0	-0.2
6.	Transitional moors	46.28	28.41	7.99	-38.29	318.3	82.1	87.7	-230.6	1.2	0.0	0.0	0.0	-1.2
7.	Rush communities	2.08	3.01	17.16	15.08	19.9	50.1	19.8	-0.1	1.1	1.8	0.0	6.6	5.5
8.	Forest	37.93	59.31	86.89	48.96	69.4	434.4	473.7	404.3	59.9	86.5	84.5	89.2	29.3
9.	Felling sites	0	0	0	0	0	0	0	0	14.6	3.9	2.3	1.6	-13
10.	Meadows	24.83	21.90	3.23	-21.6	30.2	67.4	65.2	35	38.1	11.3	33.9	21.4	-16.7
11.	Arable areas	105.21	101.34	94.11	-10.95	164.2	93.1	80.8	-83.4	84.4	75.8	38.8	41.0	-43.4
12.	Built-up areas	1.85	3.33	9.53	7.87	0.9	0.7	2.1	1.2	33.2	53.6	70.2	71.8	38.6
13.	Main roads	0.15	0.25	0.49		2.3	2.7	2.8	0.5	4.3	4.2	4.3	4.4	0.1
	Total	272.54	272.54	272.54		749.9	749.9	749.9		345.1	345.1	345.1	345.1	

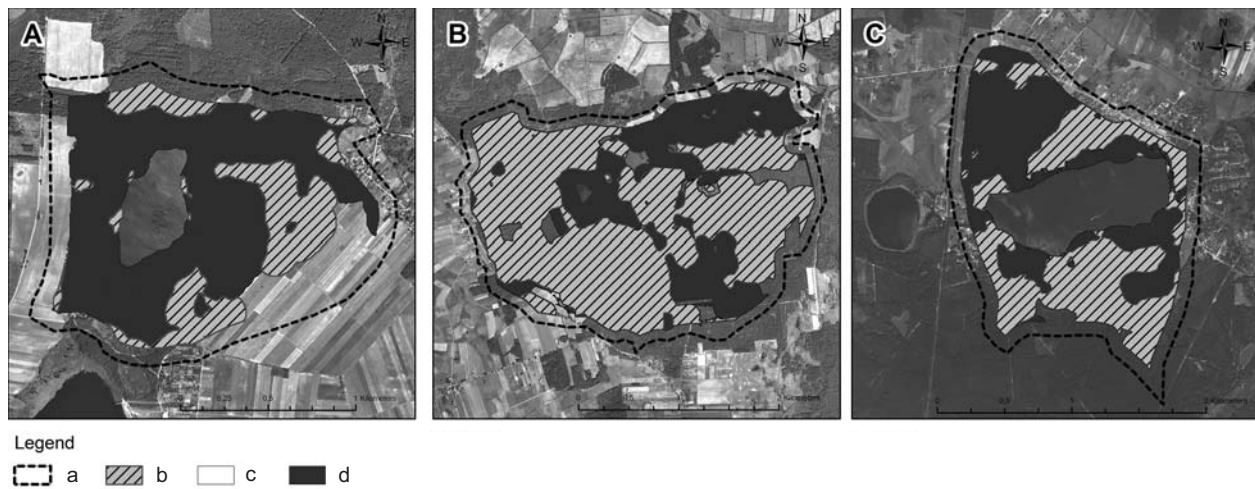


Fig. 4. Changes of landscape metric (SHDI) in the 3 selected catchments, Lake: A – Kleszczów, B – Moszne, C – Białe Włodawskie: a – catchment boundary, b – depreciation of SHDI (-1.4-0.01, -1.8-0.01, -1.6-0.01, respectively for A, B, C), c – almost unchanged (-0.009-0.01, respectively for A, B, C), d – increase of SHDI (0.011-1.6, 0.011-1.3, 0.011-1.7, respectively for A, B, C).

Keeping that in mind, the authors conducted a few tests and the landscape metrics estimation was performed with different raster resolution and rounding radius parameters on categorical maps obtained through both OBIA and manual feature extraction.

The main advantage of landscape metrics is its simplicity and the speed of calculation, as rapid environmental changes demand easily obtainable indicators. Landscape metrics as a part of geospatial data analysis provides background information as well as scenario testing of environmental policies and monitoring goals set by international conventions and agreements (Uuemaa *et al.*, 2013). During interpretation of landscape metrics value estimation results, special care should be taken. The authors suggest that landscape metrics can be interpreted only against the background of a current land cover map. High values of landscape metrics prove the increase of diversity of landscape patches, but only together with the analysis of the actual land cover structure one can tell whether these changes are natural (eg development of patches of scrub communities resulting from natural succession) or perhaps the result of human activity (development of built-up areas and roads, to change the way of agricultural use).

In the WPBR moderately low SHDI values were connected with vast areas of farmland with visible traces of ploughing (western and central part of the reserve), and large pine monocultures in the superintendency of Sobibór.

CONCLUSIONS

1. Shannon diversity index landscape metric analysis has shown that the areas of greatest landscape diversity are naturally valuable, constituting a mosaic of hydrogenic, peat, forest and meadow ecosystems. The areas with the lowest

Shannon diversity index values in the West Polesie Biosphere Reserve are large forests and vast areas of agricultural land (meadows and arable areas).

2. All three studied catchments are characterized by very intensive dynamics of land cover structure changes and the general increase in Shannon diversity index. Shannon diversity index value does not identify the direction of the landscape changes, but only the magnitude of the changes in the diversity of its structure and function.

3. Landscape metrics are easy obtained environmental indicators and their interpretation related to the land cover map allows to identify ecologically unstable areas.

4. Object-oriented image classification, subject to the use of multispectral remotely sensed data (especially collected in early autumn), makes it possible to identify arable areas (0.94 producers accuracy in the 146.820 ha) and forests (0.86 producers accuracy in the 146.820 ha) in the study area with very high accuracy.

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