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LANDSCAPE ECOLOGICAL STRUCTURE OF THE ROZTOCZE AND SOLSKA FOREST REGIONS: A COMPARATIVE STUDY OF MODELS FROM 1988 AND 2011

Tadeusz J. Chmielewski, Barbara Sowińska

Department of Landscape Ecology and Nature Conservation, University of Life Sciences in Lublin
Dobrzańskiego str. 37, 20-262, Lublin, tadeusz.chmielewski@up.lublin.pl, barbara.sowinska@wp.pl

Summary. Performing a synthesis of various methods of description of the structure and functioning of landscape systems, and in particular of the results of studies by MacArthur and Wilson [1968], Levis [1968], Maynier [1970], Baudry [1984], Forman and Gordon [1984, 1986], Löw 1985] and many others, in the years 1986–1988 Tadeusz J. Chmielewski developed a concept of landscape as a polyecosystemic zone-sequence-knot system [Chmielewski 1986, 1988]. In accordance with that concept, ecosystems functioning in a mosaic of ecotopes, with numerous gradients of moisture and fertility of habitats, but also whole landscape units linked by means of functional-spatial relations, create a complex system whose primary functional-spatial features can be represented in the form of a zone-sequence-knot model.

The development of the zone-sequence-knot model of the ecological structure of the landscape of Roztocze and the Solska Forest permitted the demonstration of the key role of the Roztocze National Park in the organisation of the spatial arrangement of ecological zones and sequences. That arrangement resembles the shape of a hand or a fan, oriented in the south-western direction.

Comparison of models of the ecological structure of the landscape of Roztocze and the Solska Forest from 1988 and 2011 indicates a great importance of the application of natural-landscape units as the basic structural units of which the zone-sequence-knot model is constructed. The comparison of the two models indicates also a great usefulness of the GIS techniques in the process of analysis of the ecological structure of landscapes and in addressing protective and conservation measures to a specific area.

Key words: landscape structure, ecological corridors, ecological knots, landscape modelling, biosphere reserve

INTRODUCTION

The theory of island biogeography [MacArthur and Wilson 1967] brought to the attention of researchers the problems of migration routes of plant and ani-

mal organisms across areas that are hostile to them. Those observations became an inspiration for undertaking a number of research and concept works on the appearance and functioning of environmental islands [Moore 1962, Arvill 1969] and ecological corridors [Levis 1968] within the landscape, and also on their role in the creation of biodiversity.

Increasingly numerous studies revealed that the proper functioning of nature at the scale of landscapes, regions and continents requires the preservation of functional-spatial continuity of ecosystems, and especially the possibility of free migration of species and mutual enrichment and supply of populations and ecosystems with matter, energy and biological information [Levis 1968, Arwill 1969]. A search began for suitable models of landscape, reproducing the functioning of nature in sequential or linear structures.

The best known model of this type is the patch-matrix-corridor model developed by Forman and Gordon [Forman 1983, Forman and Gordon 1981, 1984, 1986]. The model describes landscape structure as a system of ecological patches (aquatic, wetland, forest, grassland etc.) and ecological corridors linking them (water – wetland, water – grassland, forest, xerothermic etc.), distributed on a „landscape background" transformed by man, referred to as the *matrix*.

Another model landscape ecological structure derives from studies on the ecological role of hedgerow networks in the landscape (ecological Hedgerow Network) [Meynier 1970, Baudry 1984]. The network is formed by natural or planted belts of vegetation in a linear (espalier) or sequential form. The functioning of the network depends, among other things, on the type of the „hedgerow", the kind of the surrounding ecosystems, the size of the „mesh" and the number of „knots" in the network, and also on the shape of the links between its elements [Spellenberg and Gaywood 1993].

Performing a synthesis of various methods of description of the structure and functioning of landscape systems, and in particular of the results of studies by MacArthur and Wilson [1968], Levis [1968], Maynier [1970], Baudry [1984], Forman and Gordon [1984, 1986], Löw [1985] and many others, in the years 1986–1988 Tadeusz J. Chmielewski developed a concept of landscape as a polyecosystemic zone-sequence-knot system [Chmielewski 1986, 1988]. In accordance with that concept, ecosystems functioning in a mosaic of ecotopes, with numerous gradients of moisture and fertility of habitats, but also whole landscape units linked by means of functional-spatial relations, create a complex system whose primary functional-spatial features can be represented in the form of a zone-sequence-knot model.

The model has been applied e.g. for the description of the ecological structure of the following areas with outstanding nature values: The Nida Basin Landscape Parks Group [Chmielewski 1986], the regions of Roztocze, the Solska Forest and the Janowskie Forests (Fig. 1) [Chmielewski 1988], the Kampinoski National Park [Chmielewski 1997], the functional area of the Poleski National Park [Chmielewski 1999], the functional area of the Sobiborski Landscape Park [Chmielewski (ed.) 2002], the West Polesie Biosphere Reserve

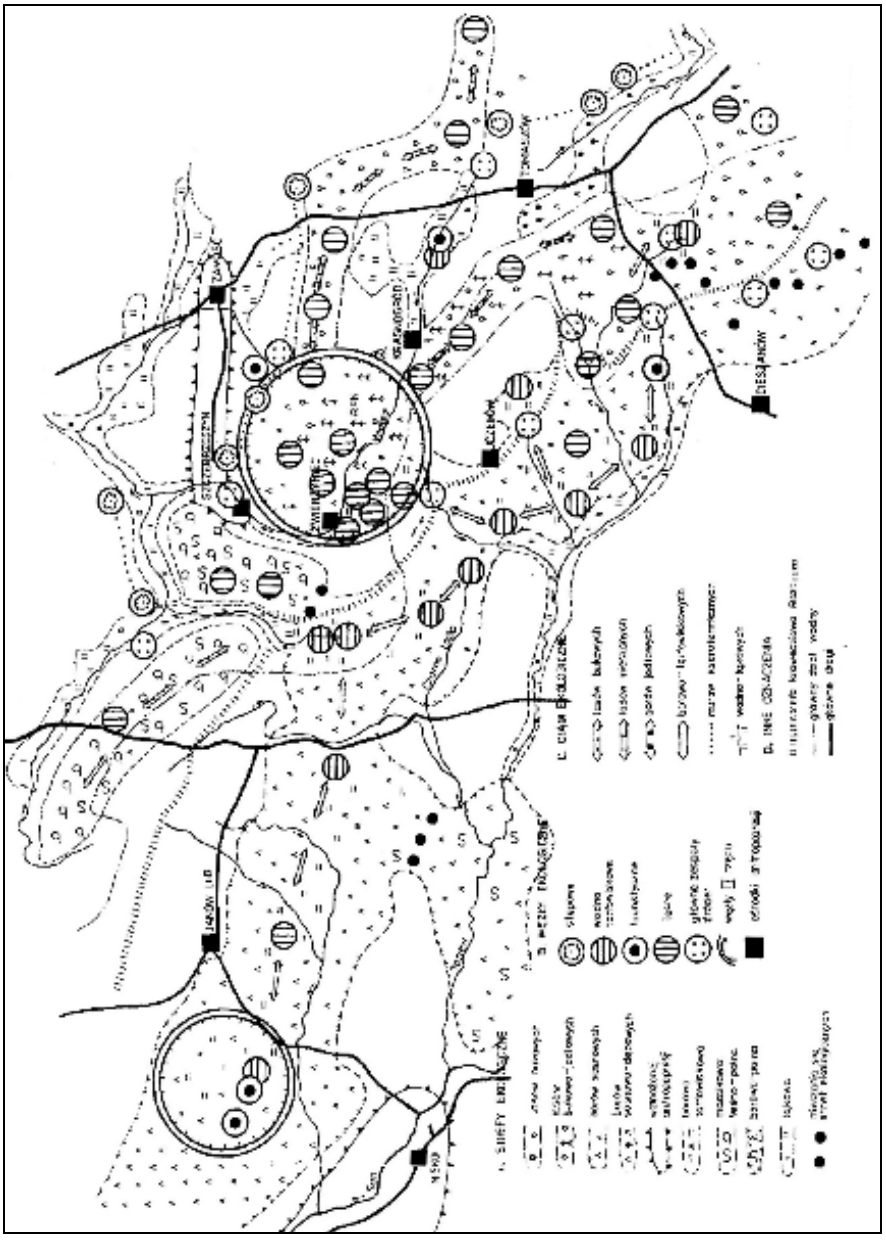

Fig. 1. Archival drawing of the preliminary concept of ecological structure of the landscape of Roztocze, the Solska Forest and the Janowskie Forests [Chmielewski 1988]

[Chmielewski (ed.) 2005]. The method and the techniques of its implementation have been continually improved.

This paper presents the results of analyses concerning the ecological structure of landscape of Roztocze and the Solska Forest, nominated for the status of a UNESCO biosphere reserve, with an area of ca. 240 000 ha [Chmielewski (ed.) 2004]. Comparison of the current analyses with a model from 23 years ago (Fig. 1) permits the estimation of both the degree of development of the method and of the progress in the ecological-landscape studies of the region.

MATERIAL AND METHOD

Analyses of the ecological structure of the projected Roztocze – Puszcza Solska Biosphere Reserve were conducted in the system of nature-landscape units – fragments of space isolated on the basis of analysis of convergence of the reach of boundaries of various components of the natural environment, of the land use structure and of the landscape physiognomy. The delimitation of the nature-landscape units was performed with the use of the following:

- a map of tectonic blocks and faults of Roztocze, 1 : 50 000;
- geomorphological maps of the edge zone of Roztocze, 1 : 50 000;
- a map of the main morphotectonic elements of Roztocze, 1 : 50 000;
- The Atlas of Hydrographic Division of Poland, 1 : 200 000;
- a digital soil-agricultural map, 1 : 25 000 ;
- habitat and tree-stand maps, 1 : 25 000;
- topographical maps in the geotiff format, 1 : 25 000;
- an orthophotomap created on the basis of aerial photos from the period of 2002–2003, with a pixel field resolution of 0.25 m;
- a Numeric Model of Terrain (NMT) with vertical resolution of 0.6 m and horizontal resolution of 15 by 15 or 30 by 30 m;
- a map of nature values of the Roztocze – Puszcza Solska Biosphere Reserve, 1: 50 000.

All of those materials have been reduced to a uniform scale of representation (1 : 50 000). The work was conducted in the ArcGis 9.3 environment [Sowińska and Chmielewski 2008].

In accordance with the method developed and described in detail by Chmielewski [2001, 2011], in the structure of the Reserve three types of systems were identified:

1. **Zone systems**, in the form of groups of similar nature-landscape units, linked with strong functional-spatial relations. Depending on the dominant form of land cover, water-grassland, forest, farming-settlement and mosaic character zones were identified.

2. **Sequence systems**, in the form of **ecological sequences** – i.e. routes of privileged migration of matter, energy and information within the landscape of

a specific zone, and **ecological corridors** – i.e. routes of migration between related zones, running across areas with a different character. The identified ecological sequences and corridors were water – grassland, forest (beech, mixed, fir forests), forest – wetland, and xerothermic grasses. They are created within the landscape by sequentially arranged groups of nature-landscape units.

3. **Ecological knots**, i.e. areas with particular species richness, and often also with notable habitat diversity, low degree of anthropogenic transformation and a mature structure of ecosystems. Depending on the types of the component ecosystems, the identified knots were of water, water – wetland, faunistic, forest and steppe character, and there were also anthropogenic knots – settlement centres and adjacent areas. The areas of the knots were usually assumed to cover complete nature-landscape units or local groups of such units, less frequently fragments of units (subunits or natural patches of land under uniform land use forms).

Also identified were the main **ecological barriers** in the form of heavy-traffic roads and railway lines.

RESULTS

Within the area of the study a total of 541 nature-landscape units were identified, with areas from 10 to 3617 ha [Sowińska and Chmielewski 2011]. The ecological structure of the landscape of Roztocze and the Solska Forest somewhat resembles the shape of the hand (Fig. 1 and 2). The central element is the Roztoczański National Park, from which the various ecological zones and sequences stretch in various directions. In the West Roztocze and in the Biłgorajska Plain the particular nature-landscape units form local complexes with a characteristic sequential layout. Whereas, in the remaining areas that layout is mosaic. The northern edge of West Roztocze and the northern fragment of the Tarnogród Plateau are typical agricultural zones. The landscape of the northern and central parts of Central Roztocze have a clearly mosaic character. In turn, the Biłgorajska Plain and the southern sector of the South Roztocze are an extensive zone of pine forests with mid-forest peatlands as valuable ecological knots.

Water – grassland ecological sequences are created by the valleys of rivers Wieprz, Gorajec, Por, Tanew, Biała Łada, Szum and Sopot. The richest internal structure is characteristic of sequence corridors accompanying water courses not transformed by man, as in their transects they represent a whole range of ecotopes, distributed in accordance with the gradients of habitat wetness and fertility. Such corridors usually serve the broadest range of species. Often they also possess high physiognomic values. Notable among those are the central stretch of the river Wieprz, river Tanew at its lower course, and the valleys of rivers Szum and Sopot. The forest ecological sequences are strongly varied in their character. The sequence of mixed forests comprises small forest patches in the northern part of West Roztocze, the sequence of fir forests runs through the forest complexes of the Krasnobród Landscape Park, the sequence of beech forests

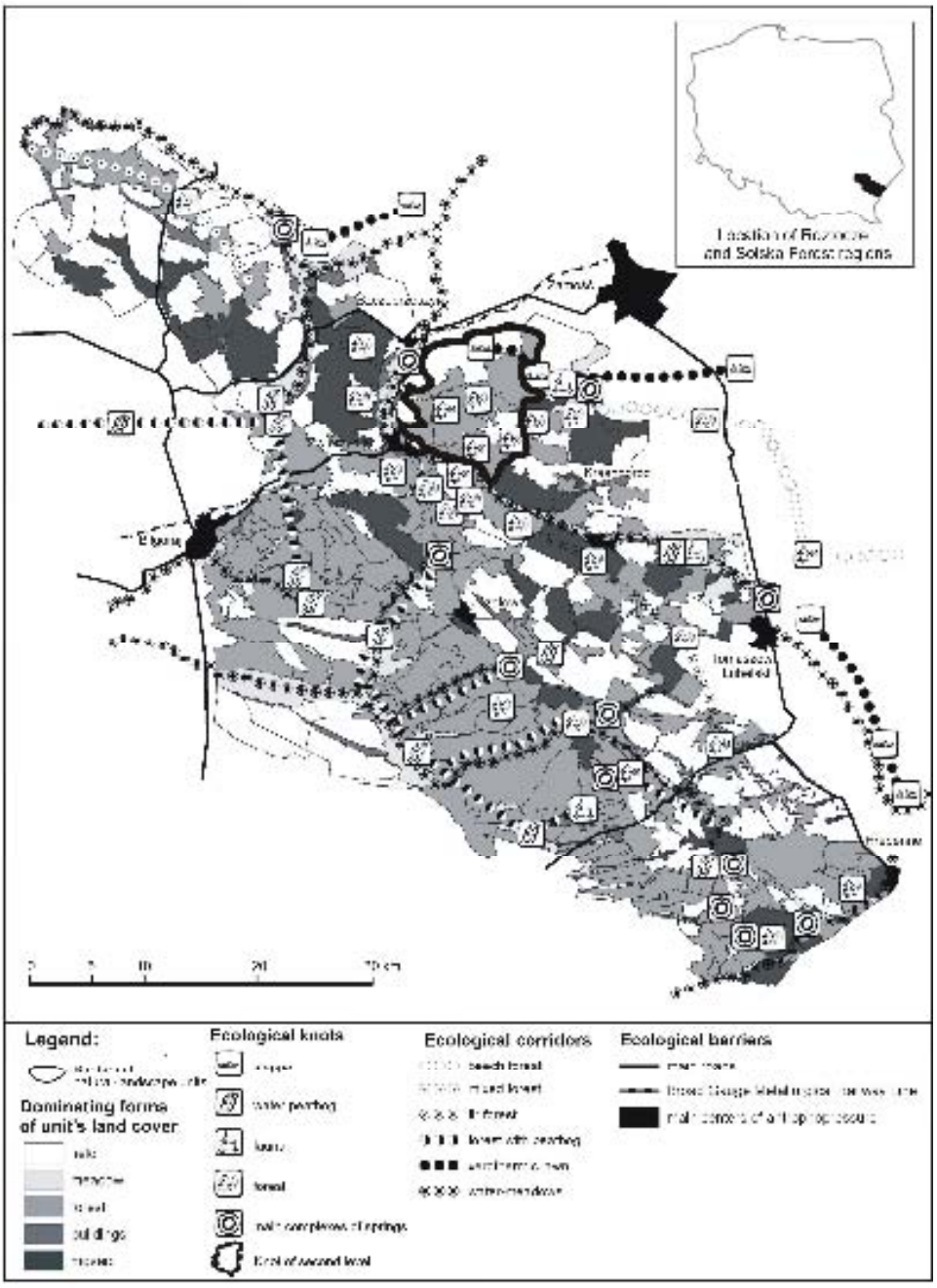

Fig. 2. Zone-sequence-knot model of the projected Roztocze – Puszcza Solska Biosphere Reserve (elaborated by T.J. Chmielewski and B. Sowińska in 2011, figure simplified for the purposes of this publication)

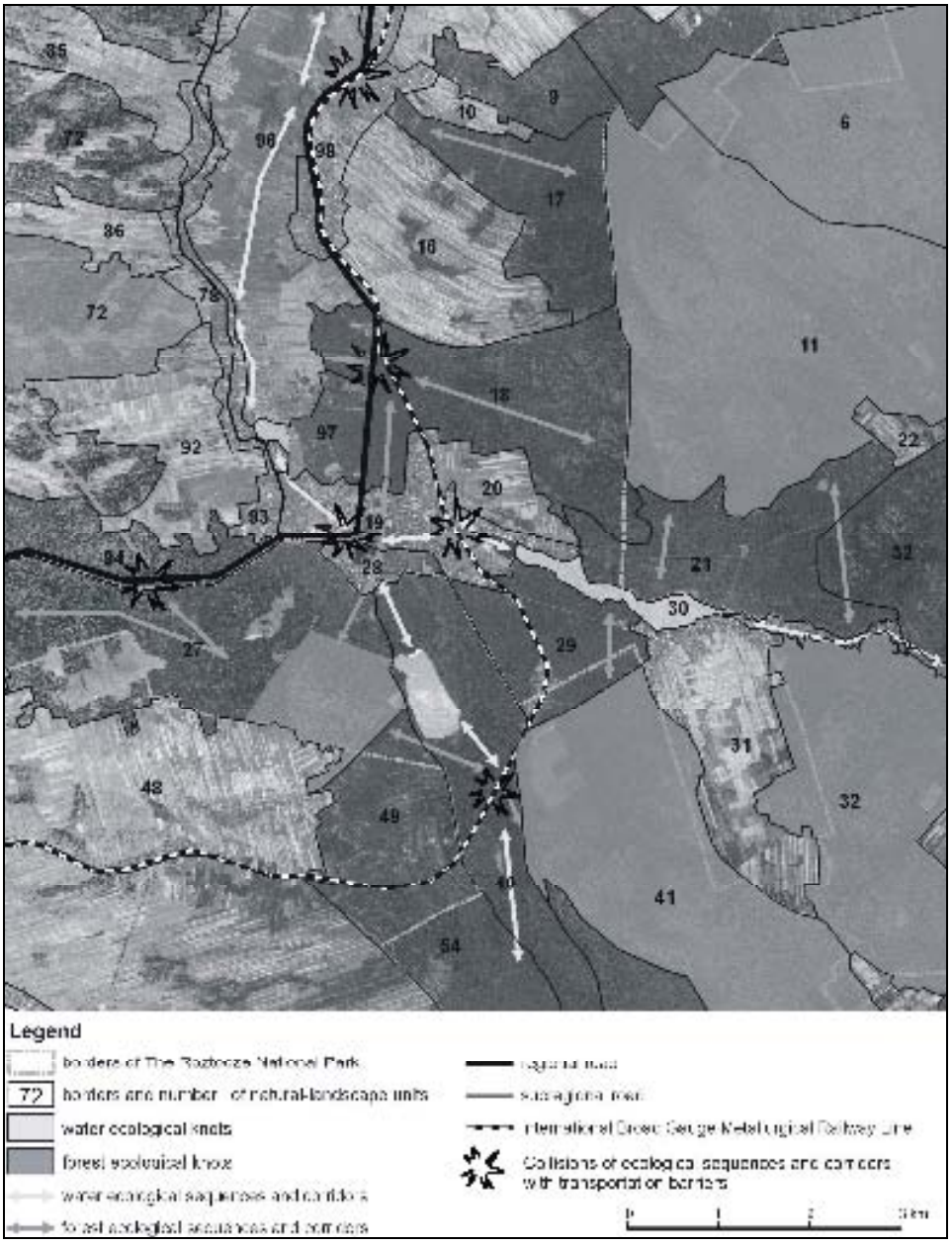

Fig. 3. Collisions of the transport system with the network of ecological sequences and corridors in the western part of the Roztoczański National Park (elaborated by T.J. Chmielewski and B. Sowińska in 2011)

starts within the Roztoczański National Park and extends beyond the boundaries of the Reserve, and sequences of forests with peatlands link the extensive forests complexes of the Biłgorajska Plain with the edge zone of Roztocze.

The model is complemented with 59 ecological knots whose reach includes a fragment of or from 1 to 3 nature-landscape units. Dominant are knots with forest character (25), and those with water and water-wetland character (a total of 23). Particular attention is attracted here by the ecological forest macro-knot of the Roztoczański National Park, characterised by exceptional species richness and low degree of anthropogenic transformation. It is the focal point for ecological sequences extending in various directions along the axes of several types of ecological zones rich in knot areas (Fig. 2).

The ecological system of Roztocze and the Solska Forest is dissected by several ecological barriers, the two most important of which are the international road route Warsaw – Lublin – Zamość – Hrebenne – Lviv, and the national road Zamość – Biłgoraj with the parallel wide-gauge metallurgical rail line (linia hutnicza szerokotorowa). The negative effect of those two barriers pertains in particular to the western part of the Roztoczański National Park, where they intersect the ecological sequence of river Wieprz and the forest sequences and ecological corridors linking the forest complexes of Central and West Roztocze (Fig. 3).

COMPARATIVE ANALYSIS OF MODELS FROM 1988 AND 2011

The fundamental difference between the models of ecological structure of the landscape of Roztocze and the Solska Forest from 1988 and 2011 is the division of the whole area into 541 nature-landscape units, applied in the new model. Those are the basic structural units of which the model of landscape systems is built.

Another methodological difference is the much more detailed illustration of the spatial structure of landscape zones and the possibility of detailed analysis of the structure of ecological sequences and corridors.

The third difference is the specific determination of boundaries of ecological knots, in the form of boundaries of nature-landscape units, or ecological patches, instead of symbolic circles on the map.

The fundamental technical difference between the models from 1988 and 2011 is that the new model was developed within the GIS environment, with the resultant possibility of creating a system of spatial information on the biosphere reserve and precise addressing of data and conservation tasks to specific areas.

Comparison of the models in terms of their subject-matter indicates, among other things, that:

1. The number of the main ecological sequences and knots did not change, but in the model from 2011 their delimitation is much more accurate. Also, a greater number of local ecological sequences and corridors were identified.

2. In the course of work on the model from 2011 the authors observed a notable pressure of construction on river valleys, in many areas causing spatial isolation of valley sequences and ecological corridors from the other structures of landscape systems.

3. Analysis of the model from 2011 revealed the existence of a considerable number of points of collision between the ecological and the anthropogenic systems.

CONCLUSIONS

The development of the zone-sequence-knot model of the ecological structure of the landscape of Roztocze and the Solska Forest permitted the demonstration of the key role of the Roztocze National Park in the organisation of the spatial arrangement of ecological zones and sequences. That arrangement resembles the shape of a hand or a fan, oriented in the south-western direction.

Comparison of models of the ecological structure of the landscape of Roztocze and the Solska Forest from 1988 and 2011 indicates a great importance of the application of nature-landscape units as the basic structural units of which the zone-sequence-knot model is constructed. Comparison of the two models indicates also a great usefulness of the GIS techniques in the process of analysis of the ecological structure of landscapes and in addressing conservation measures to a specific area.

The model from 2011 permits the identification of a considerable number of threats to the landscape ecological system of the region. The data should scrupulously used in work on conservation plans for the national park, landscape parks and Natura 2000 areas, and on the spatial development plans of the communes.

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STRUKTURA EKOLOGICZNA KRAJOBRAZU ROZTOCZA I PUSZCZY SOLSKIEJ – ANALIZA PORÓWNAWCZA MODELI Z ROKU 1988 ORAZ 2011

Streszczenie. Dokonując syntezy różnorodnych sposobów opisu struktury i funkcjonowania systemów krajobrazowych, a w szczególności wyników prac MacArthura i Wilsona [1968], Levisa [1968], Mayniera [1970], Baudry [1984], Formana and Gordona [1984, 1986], Löwa [1985] i wielu innych, Tadeusz J. Chmielewski w latach 1986–1988 opracował koncepcję krajobrazu jako poliekosystemowego układu strefowo-pasmowo-węzłowego [Chmielewski 1986, 1988]. Według tej koncepcji ekosystemy funkcjonujące w mozaice ekotopów, z licznymi gradientami wilgotności i żyzności siedlisk, ale także całe jednostki krajobrazowe, powiązane relacjami funkcjonalno-przestrzennymi, tworzą złożony system, którego główne cechy funkcjonalno-przestrzenne można odwzorować w postaci modelu strefowo-pasmowo-węzłowego.

Opracowanie strefowo-pasmowo-węzłowego modelu struktury ekologicznej krajobrazu Roztocza i Puszczy Solskiej pozwoliło wykazać kluczową rolę Roztoczańskiego Parku Narodowego w organizacji przestrzennego układu stref i pasm ekologicznych. Układ ten przypomina kształtem dłoń lub wachlarz, skierowany na południowy zachód.

Porównanie modeli struktury ekologicznej krajobrazu Roztocza i Puszczy Solskiej z 1988 i z 2011 r. wskazuje na wielkie znaczenie zastosowania jednostek przyrodniczo-krajobrazowych jako podstawowych jednostek strukturalnych, z których budowany jest model strefowo-pasmowo-węzłowy. Porównanie obu modeli wskazuje też na wielką przydatność technik GIS w procesie analizowania struktury ekologicznej krajobrazu oraz adresowania zadań ochronnych do konkretnego terenu.

Słowa kluczowe: struktura krajobrazu, korytarze ekologiczne, węzły ekologiczne, modele krajobrazowe, rezerwat biosfery