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PHOTOINTERPRETATION ANALYSIS OF LANDSCAPE STRUCTURE IN LAKE WATERSHEDS OF SUWAŁKI LANDSCAPE PARK (NORTH-EASTERN POLAND)

ABSTRACT: Direct watersheds of lakes Hańcza, Kojle, Perty and Kamenduł and fragment of the Szeszupa river watershed were considered as model areas to study the usefulness of photointerpretation method for evaluation of the state and changes in ecological structure of watershed. The usefulness of this method was tested for delimitation of areas of highly and moderately barrier systems and non-barrier ones as related to pollution. Best results were achieved using colour infrared photographs at scales of 1:10 000 analysed stereoscopically.

Ecological structure of watershed was characterised by synthetic parameters and statistical distributions of area and borders of landscape patches. Statistical distributions of patche size of fields, forests, meadows and bogs in watersheds of Hańcza lake and the Szeszupa river are extremely asymetric.

KEY WORDS: ecological landscape, photointerpretation, Suwałki Landscape Park.

1. INTRODUCTION

Recognition and optimisation of ecological structure of landscape towards its greater resistance to unfavourable effects due to anthropopressure require the preparation of proper methods for quantitative description of this structure. These methods should include both the spatial vastness as well as the patchiness of this structure. This can be attained by aerial photograph interpretation assisted by field investigations.

In order to become an effective tool for an ecologist studying the landscape, photointerpretation should provide numerical characteristics of the watershed natural structure, easy to be interpreted ecologically and a map showing the spatial distribution of elements of ecological structure.

Aerial photographs record the natural landscape as a set of solids, areas, lines and points. In the photointerpretation process the spatial system of these geometric elements may acquire a natural sense by assigning them to a particular ecological system identified in the landscape by the criterion of function (Mozgawa in press). One of such systems are biogeocenotic barriers modifying in the watershed area the qualitative-quantitative state of waters supplying aquatic systems and preventing the pollution runoff to surface waters.

The aim of this research has been the preparation and empirical testing of such method of processing the information from aerial photographs, which on the basis of easily distinguished geometric area, linear and point elements would allow to describe quantitatively the watershed from the point of the function of the barrier for the pollution of surface waters.

2. RESULTS

2.1. MATERIAL AND METHOD

Four watersheds in the Suwałki Landscape Park (SLP) were chosen as model objects (Fig. 1). For determining the potential possibilities of photointerpretation method colour infrared photographs (CIR) were used with an emulsion layer sensitive to the range of photographic infrared, commonly used in photointerpretation to recognize forms of surface cover and vegetation damages due to their great information capacity confirmed in empirical investigations already completed.

Suwałki Landscape Park has only fragments covered by colour infrared photographs. Thus the choice of watersheds was limited to areas having such a cover. As a result of comparing maps of hydrological division (Bajkiewicz-Grabowska 1993) and maps of ranges of area covered by colour infrared photographs, analysed were direct watersheds of lakes: Hańcza (area 1050 ha), Kamenduł (area 94 ha), and Kojle-Perty (area 236 ha) and fragments of the Szeszupa river watershed on the section from the Jaczniówka to the Szeszupa outflow from Postawelek lake (area 794 ha) (Fig. 1). In the study, colour infrared aerial photographs were taken on July 8, 1987 at noon in full sun at a scale of 1:10 000, using a Russian SN-6M spectrozonal film.

Topographical maps at a scale of 1:10 000, photo-draft made of panchromatic photographs taken in 1979 and the map of hydrographical division after Bajkiewicz-Grabowska (in press) were used during the interpretation as auxiliary material. The watershed borders were transfered from the map of hydrographical division to interpreted photographs, making slight corrections of the course of dividies according to the stereoscopic model of the area. A high class device "Interpretoskop C" was used for interpreting. Interpretation of aerial

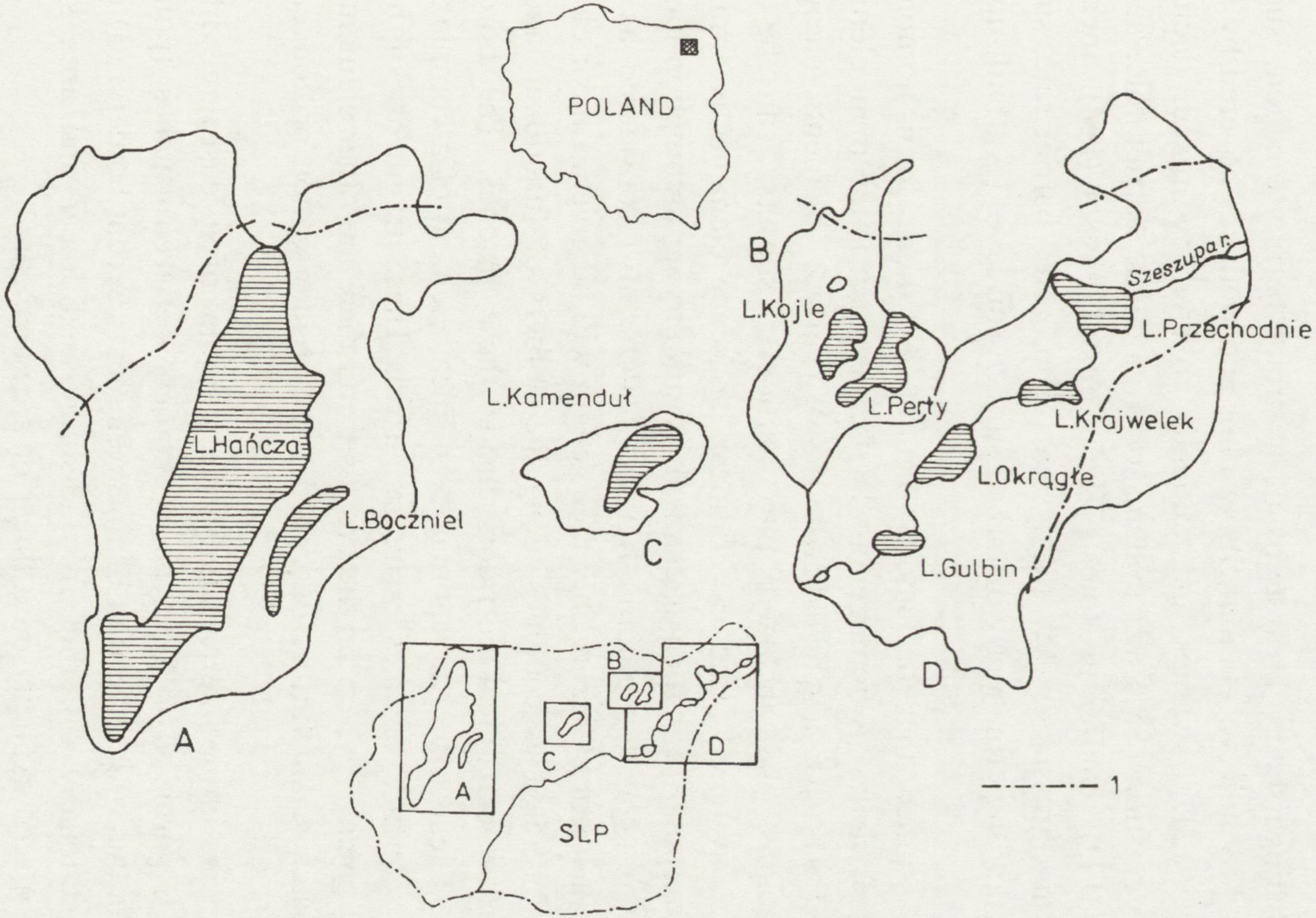

Fig. 1. Selected watersheds as model areas for photointerpretation studies
A – Hańcza lake, B – lakes Kojle and Perty, C – Kamenduł lake, D – the Szeszupa river, 1 – border of Suwałki Landscape Park

photographs was directed towards the recognition of elements of watershed biogeocenotic barrier system, conditioning the effect of terrestrial ecosystems on aquatic ones. Elements of this systems can be recognized on aerial photographs as areas, linear and point elements.

On the basis of current investigations (Di Castrii et al. 1988, Forman and Godron 1986) the distinguished areas were divided into subsets varying by the barrier function.

There were distinguished: (1) systems of a strong barrier function, such as: swamps not covered by high vegetation (S); swamps and wetlands covered by shrubs and deciduous trees (SD); swamps and wetlands covered by mixed, deciduous--coniferous high vegetation (SM), (2) systems of a moderate barrier role, such as: deciduous forests (FD); coniferous forests (FC); mixed forests (FM); meadows, pastures and perennial grasslands (M), (3) systems of a "zero" barrier role, such as: arable land and land with permanently disturbed surface soil layer (A); built-up areas (B).

It has been assumed that the above mentioned areas form homogenous functional landscape patches. A homogenous landscape patch is the main element of landscape mosaic (Forman and Godron 1986). Surface elements, recognized on aerial photographs and included into particular subsets, can be taken approximately as ecosystems. Structure of linear landscape elements is similar on sections made at any point of particular element. A simplifying assumption has been taken, namely that elongated geometric figures shall be also considered as linear elements and that for linear elements only their length will be given. Linear elements are ecologically interpreted as ecotones along the borders of functional landscape patches or as narrow ecological corridors inside these patches. The border of functionally different landscape patches may be a linear element of a complex cross – section, e.g., a sequence of trees, stream, road. These fragments of borders between functional patches, where on the cross-section there are other elements than on neighbouring patches, are further on called lines of intersection or convergence lines.

The point elements in the interpretation were: (1) joint of at least three different landscape patches regardless of the type of borders between patches (points of convergence); (2) points of intersection of linear elements except borders; (3) details of the surface functionally differing from distinguished linear and area surface elements, spatially placed explicity on a linear or area element.

Combinations of area, linear and point elements are used to describe the interior of a functional landscape patch, because a non-homogenous inside landscape patch may contain: (1) islands, i.e., area elements surrounded by the material of the functional patch or having maximum one contact point with patch border (small forests, small water bodies, building sites, etc.); (2) any combination of linear elements (roads, ditches, tree rows); (3) point elements (points of intersection of linear elements, single trees, shrubs, boulders etc.).

Each functional landscape patch should be characterized by its interior and borders. The interior must specify islands (described as each landscape patch), linear and point elements. The patch borders contain information on: (1) adjacent patch types and the length of uninterrupted contact with neighbouring patches; (2) which border fragments have a character of convergence line; (3) number and character of convergence points.

On the "start" of such photointerpretation a map of ecological structure of the watershed should be made. The measurements necessary for determining the numerical characteristics of areas of patches, length of linear elements or distribution of point elements would be carried out on the map. After transformation of the map of ecological structure of the watershed from a graphical into a digital form, general populations of random variables are obtained, giving a whole structure of these variables for the entire watershed. Giving for the general population the distributive series and (or) statistical measures the watershed is characterized numerically. This provides numerical data for landscape investigations mentioned in the introduction.

In recognizing area elements, general principles of photointerpretation were applied, using such interpretation characters as colour, structure of photograph and massiveness of objects. The date of air raid created difficulties mostly in distinguishing arable lands (A) from meadows (M), which was important for the difference in their functioning as biogeocenotic barriers. Photographed haymaking effect was used as an auxiliary element for separating these areas.

The species mixture of forests and mid-field shelterbelts was easy to distinguish. Coniferous species, reflecting little infrared radiation, differ significantly by the colour of photograph from deciduous species. The area was considered as coniferous forests (FC) when rough estimation of the percentage of the coniferous was 60–100%; as a mixed (FM), when the percentage of the conifers was 30–60%; and as a deciduous (FD) one when a percentage of the conifers was less than 30%.

Similar classification criteria of the contribution of coniferous species was also applied for swampy areas (SM and SD). When classifying the area into categories SM and SD there was frequently used the effect of shining of the water bodies through tree crowns and information from the topographical map on the wetland character of the analysed fragment of the terrain.

The border of built-up area (B) overlapped with the border determined by means of photointerpretation of the so-called site allotment on which the buildings were standing. On the basis of foliograms, maps of watershed ecological structure were made, presenting in graphical-digital symbols types of functional patches and the course of linear elements inside the patches. Maps of ecological structure were digitalised using among others a digitiser KAR – A2 linked with a microcomputer.

Because of the key significance of the structure of terrain belts adjacent to waters for aquatic ecosystems (P a w l i a k i a w i c z i u s 1981), an additional digitalisation of functional patches was made in the 0–50 and 50–150 m wide belt from the borderline between land and water. Digitalisation of terrain belts was made on drawings from maps of ecological structure of the watershed, covering above mentioned zones adjacent to waters.

A considerable percentage of SLP areas has aerial photographs taken on: (a) 1–2.06.1971, 1:190 000 scale panchromatic photographs, (b) 4–5.06.1970, 1:25 000 scale panchromatic photographs, (c) 8.07.1987, 1:10 000 scale infrared colour photographs.

Information contained in photographs taken at different dates allowed to study directions of long-term changes within the direct watersheds of lakes: Hańcza, Kamenduł and Kojle-Perty and of the Szeszupa river section watershed. These changes were investigated only on areas within SLP. As a large part of Hańcza lake watershed is beyond the SLP, the studies on changes in this watershed were limited to its eastern part between the lake and the divide line of the Hańcza lake and the Szeszupa river watersheds.

2.2. CHARACTERISTICS OF BASIC MATERIAL FOR DESCRIPTION AND COMPARISON OF LANDSCAPE COMPONENTS

Results of interpretation of photographs make the functional analysis of the landscape possible. Thus, they should be compiled for particular watersheds in a way which would allow for their further transformation. Hańcza lake watershed was chosen as an example of preliminary data processing. Data on the watershed provide an initial material for calculation of the synthetic parameters for the watershed.

Both for the whole set of landscape patches and their particular types, the number of areas in following 1 hectare classes of distributive series decreases (Table 1). Arithmetical means and standard deviations shown in Table 1 were estimated according to all areas of a given type, before being disclassified in the distributive series. Significant influence of large area patches on arithmetical mean and standard deviation makes the calculation of these measurements on the basis of distributive series different than given in the table. Only for a large watershed it is possible to compile the area size structure in the form of distributive series. For small watersheds, where the number of landscape patches of particular types is small, the area structure may be determined only by statistical measures or area percentage.

An example of comparison of data on area structure of system elements of a varying barrier role in the shore zone of open waters is given in Table 2. These data allow to study relations between areas in the zone especially significant for purity of rivers and lakes, and together with data in Table 1, allow to study relations among areas in the whole watershed and in the near water zone.

Each landscape patch (if not being an island) adjoins at least two other patches. The length of the border of patches belonging to systems of a different barrier role can be estimated according to data in Table 3. The length of borders sections between the same types of patches in the entire watershed is a random variable, the distribution of which is illustrated by the given distributive series. Interpretation of data included in Table 3 can be explained on the example of meadows: acc. to data

Table 1. The structure of kinds of areas (Hańcza lake watershed)

Kind of patch*	Classes of dividing series (ha)											Statistical measures of patch sets			
	0–1.00	1.01–2.00	2.01–3.00	3.01–4.00	4.01–5.00	5.01–6.00	6.01–7.00	7.01–8.00	8.01–9.00	9.01–10.00	>10	n	$\bar{x}$	δ	Σ
M	42	13	5	–	2	2	1	1	–	–	8	74	5.29	16.70	391.46
A	15	13	6	5	1	3	1	2	1	1	4	52	3.40	3.92	176.80
B	41	1	–	–	–	–	–	–	–	–	–	42	0.30	0.25	12.60
S	57	2	1	–	–	–	–	–	–	–	–	60	0.39	0.42	23.40
SF	51	6	5	1	3	–	1	–	–	–	–	67	0.87	1.33	58.29
FD	41	6	5	–	1	1	–	–	–	–	–	54	2.97	7.15	160.38
FM	12	3	1	1	2	–	–	1	1	–	–	21	7.05	10.55	155.10
FC	10	4	2	–	2	–	–	1	–	–	–	19	2.82	4.89	53.58
W	26	–	–	–	–	–	–	–	–	–	1	27	0.70	3.07	18.90
Total	295	48	25	7	11	6	3	5	2	1	13	416			1050.51

*Meadows, pastures and perennial grasslands, A – arable land and areas with constantly disturbed surface soil layer, B – built-up areas, S – swamps not covered by high vegetation, SF – swamps and wetlands covered by shrubs and deciduous trees, FD – deciduous forests, FM – mixed forests, FC – coniferous forests, **W – water; without Hańcza lake (with Boczniel lake); $\bar{x}$ – arithmetical mean; δ – standard deviation; Σ – total area of patch type.

Table 2. Contribution of different kinds of area in belts adjacent to lakes (Hańcza lake watershed)

Kind of area*	Areas in terrain belts (ha)		Contribution of area to terrain belt (%)	
	0–50 m	50–150 m	0–50 m	50–150 m
FC	23.41	42.96	41	26
FM	13.51	34.29	23	21
FD	1.11	6.68	2	4
B	0.97	4.87	2	3
M	15.11	52.77	26	32
A	2.97	16.13	5	10
SF	0.63	5.92	1	4
S	–	0.31	0.0	0.1
Total	57.71	163.93	100.0	100.0

* Explanations see Table 1.

in the first line, the border between meadows and arable land in the whole watershed is 32 150 m long. Altogether there are 133 borders between meadows and fields, this including 48 border sections within 0–100 m length, 33 sections in the interval 101–200 m etc.

Arithmetical means and standard deviations given in Table 3 were calculated according to the length of all ecotones before arranging them in the distributive series. Data in Table 3 show that in the majority of analysed ecotones the class number decreases with the increasing value of middle class of distributive series. This indicates that for the random variable "ecotone length", as well as for the random variable "area of landscape patch", there is in Hańcza lake watershed a type of extremely asymmetric distributions of a positive skewness, which can be approximated by the hyperbole equation. Lines in the table: M–M, A–A, indicate the number of places, where the watershed border crosses the landscape patch, meadow (M) and arable (A), respetively.

Table 4 complements Table 3 in all cases of ecotones and convergence lines described by multisegment symbols (e.g., M–R–A), for which the length structure in the form of distributive series cannot be given because of the small number of border sections (n<20). Characteristics of ecotone and convergence line length of small watersheds can be composed as presented in Table 4.

The length of linear elements inside particular types of landscape patches is given in Table 5. With consideration to area of patches given in Table 1 the length of roads can be interpreted as a measure of technical infrastructure of landscape

Table 3. Structure of ecotone lengths (Hańcza lake watershed)

Ecotone type*	Classes of dividing series (m)											Statistical characteristics of ecotone lengths (m)			
	0–100	101–200	201–300	301–400	401–500	501–600	601–700	701–800	801–900	901–1000	>1000	n	$\bar{x}$	δ	Σ
M–A	48	33	11	14	13	3	2	4	2	1	2	133	242	247	32150
M–B	24	19	1	–	–	–	–	–	–	–	–	44	98	54	4300
M–M	18	7	2	5	2	1	–	–	–	–	–	35	161	145	5650
M–FD	30	27	18	8	5	1	1	2	1	–	1	94	211	194	19800
M–W	16	4	3	–	1	–	–	–	–	–	–	24	108	100	2600
M–FC	8	20	1	2	1	–	–	–	–	–	–	33	162	112	5350
M–FM	12	17	11	10	2	–	–	–	–	–	1	53	218	183	11550
M–SF	34	23	9	6	1	1	4	1	–	–	–	79	175	168	13850
M–S	24	13	5	4	1	1	1	–	–	–	1	50	168	177	8400
A–A	5	4	4	5	1	–	–	1	–	–	–	20	240	170	4800
A–FD	14	8	3	1	1	–	–	–	–	–	–	27	135	124	3650
A–S	20	6	1	–	–	–	–	–	–	–	–	27	80	53	2150
A–B	17	4	–	–	–	–	–	–	–	–	–	21	69	39	1450

$\bar{x}$ – arithmetical mean; δ – standard deviation; Σ – total ecotone length (rounded to 50 m), * – explanations see Table 1.

patches disturbing functioning of the nature. The length of streams is a drainage parameter of particular types of landscape patches.

Table 4. Statistical characteristics of ecotones and convergence lines lengths in meters (Hańcza lake watershed) for n ≤ 20

Ecotone type*	Statistical characteristics			
	n	$\bar{x}$	δ	Σ
A–FM	15	157	144	2350
A–FC	4	100	87	400
A–W	11	50	–	550
FD–FD	14	214	139	3000
FD–FM	17	203	324	3450
FD–SF	14	107	112	1500
FD–S	14	93	62	1300
FD–W	14	436	544	6100
FD–FC	20	200	153	4000
FM–FM	6	233	107	1400
FM–SF	17	326	395	5550
FM–SM	1	150	–	150
FM–S	10	100	81	1000
FM–B	2	100	50	200
FM–W	9	383	440	3450
FC–FC	2	50	–	100
FC–SF	5	190	102	950
FC–S	1	50	–	50
FC–W	1	150	–	150
SF–S	9	117	189	1050
SF–B	1	50	–	50
SF–W	9	94	96	850
SF–SF	2	50	–	100
S–B	1	50	–	50
S–W	4	75	43	300

Table 4, continued

M–R**–A	17	132	92	2250
M–R–FM	8	112	70	900
M–R–B	17	62	32	1050
M–R–W	2	50	–	100
M–R–SF	3	50	–	150
M–R–S	1	50	–	50
M–RT***–W	4	450	524	1800
M–R–FC	4	125	43	500
A–RT–W	3	150	82	450
A–R–B	4	50	–	200
A–R–SF	2	50	–	100
A–RT–W	1	50	–	50
A–R–FC	3	83	47	250
FM–R–SF	2	100	50	200
S–R–B	1	50	–	50
S–RT–M	1	450	–	450

* Explanations see Table 1, ** R – road, *** RT – row of trees, n – number of ecotone or convergence line sections, $\overline{x}$ – arithmetical mean of the set, d – standard deviation, Σ – total length of ecotones or convergence lines.

2.3. LANDSCAPE STRUCTURE PARAMETERS AND THEIR COMPARATIVE DESCRIPTION FOR EXAMINED WATERSHEDS

Analysing the not published here initial material for all 4 model watersheds, these watersheds can be compared using different measures of patchiness and ecotonal character. Model watersheds differ in the percentage of area covered by particular types of landscape patches. Elimination of the lake areas from calculations shows that the Szeszupa river watershed has about 31% of arable land (A), the Kamenduł lake watershed – 29%, Kojle-Perty lakes watershed – 24%, Hańcza lake watershed – 17%. Similar percentage of meadows have watersheds of lakes: Hańcza (37%), Kamenduł (38%), whereas it is much smaller (ca 14%) in Kojle-Perty lakes watershed. The greatest forestage (FC + FM + FD cover 43% of land area) is in the Kojle-Perty lakes watershed. In Hańcza lake watershed forest cover 35% of the area, in Kamenduł lake watershed – 27% and in the Szeszupa river watershed – 21%.

The built – up land area (B) is similar in all four model watersheds and is about 1% of each watershed area. The biggest average size of meadow patches (M) is in the Szeszupa river watershed – some 9 ha. In Hańcza lake watershed average meadow has 5 ha, whereas in watersheds of lakes Kojle-Perty and Kamenduł – 2 ha.

The biggest average patch of arable land (A) attaining 76 ha, is also characteristic for the Szeszupa river watershed. In waterheds of lakes Hańcza and Kojle-Perty average arable land patch is 3 ha, whereas in Kamenduł lake watershed – 2 ha. Among swampy grounds, the smallest average swamp patch is typical for swamps not overgrown by high vegetation (S). Average size of such patches does not exceed 0.5 ha in watersheds of lakes Hańcza and Kamenduł and of the Szeszupa river and 1 ha in watershed of lakes Kojle-Perty.

Average area of deciduous forest stands and forestations (FD) fluctuates between 0.4 ha in watershed of lakes Kojle-Perty and 3 ha in the Szeszupa river watershed. Mixed forest stands (FM) reach the size of 1 ha on average in Kamenduł lake watershed and 7 ha in Hańcza lake watershed. Average size of forest stands and mid-field shelterbelts of conifers (FC) fluctuates between 3 ha in Hańcza lake watershed and 6 ha in watershed of lakes Kojle-Perty. These results have been surely affected by inclusion into the subsets FD, FM, FC of small midfield forests and also forest stands belonging to large forest complexes. An analysis of structure of areas overgrown by high plants have shown that in watersheds of Hańcza lake and the Szeszupa river over 50% of these areas are smaller than 1 ha. Mean size of built-up area is 0.2 ha in Kojle-Perty lakes watershed, 0.3 ha in Hańcza lake watershed and the Szeszupa river watershed, and 0.4 ha in Kamenduł lake watershed.

33 types of ecotones and 16 types of convergence lines have been recorded in Hańcza lake watershed. The longest sections on the average (320 m) in that watershed are in the FM–SF ecotone. There are also 33 types of ecotones, but up to 29 convergence lines in the Szeszupa river watershed. The ecotone SF–W in that watershed has the longest average sections (420 m). In lakes Kojle-Perty watershed, 37 ecotone types and 18 types of convergence lines have been recorded, whereas in the smallest watershed of Kamenduł lake – 15 ecotone types and 4 convergence line types.

Meadow-arable land ecotones (M–A) prevail in all watersheds. 4600 m of them fall on 1 km^2 of Kamenduł lake watershed, and 4482 m, 3121 m and 2350 m on 1 km of Szeszupa river watershed, Hańcza lake watershed and Kojle-Perty lakes watershed respectively.

Detailed data on watersheds (Tables 1–5) have been transformed into a set of synthetic parameters of landscape structure (Table 6) in the following way: (1) percentage of system areas (a) has been calculated by summing up the area of system components; (2) average patch in ha (b) has been determined as an arithmetical mean on the basis of average areas of patch types and their number within particular types of systems; (3) the patchiness (c) is characterized by the number of all patches in a specific systems per 1 km^2 of watershed; (4) ecotonal

Table 5. Total length of linear elements within particular kinds of area (Hańcza lake watershed)

Type of area*	Kind of linear elements	
	roads (m)	streams (m)
A	2110	–
M	7250	820
FD	640	–
FM	1020	–

* Explanations see Table 1.

character (d) in meters per 1 km^2 of watershed was determined on the basis of the length of ecotones and convergence lines of all types of patches in a specific systems.

Accepted method of ecotonal character calculation causes that border fragments between patches with different barrier role, e.g. meadows and arable land were introduced first to describe the ecotonal character in moderate barrier systems as meadow borders and then in non-barrier system as field borders. Analysis of data in Table 2 shows that the percentage of high barrier areas is quite even for watersheds of: Hańcza lake – 8%, the Szeszupa river – 8% and Kamenduł lake – 7%. The percentage is higher only in Kojle-Perty lakes watersheds – 12%. The percentage of moderately barrier systems is the highest (72% of the area) in the Szeszupa river watershed. In other watersheds the area of these systems approximates 50% of the watershed. Distinctly the highest area of non-barrier systems is in the Szeszupa river watershed (30%). Area of such systems in other model watersheds is 20% approximately. Barrier structure of land belt adjacent to water (0 to 50 m) indicate that the worst protection conditions are for Kojle-Perty lakes, 25% of which are in non-barrier systems. The structure of this 50–150 m belt adjacent to these lakes indicates also the unfavourable conditions for water protection. Among the model watersheds examined also Kamenduł lake has unfavourable conditions for water protection, in which non-barrier systems cover in the 0–50 m zone some 20% of the area, in the 50–150 m zone – about 19% (Table 7).

Watershed of the Hańcza lake has the smallest average patch in highly barrier systems (0.64 ha) and the biggest average area of patch of non-barrier systems (3.89 ha) is in the Szeszupa river watershed. The patchiness for highly barrier systems is the highest in Hańcza lake watershed and is 12 patches of these systems per 1 km^2 of watershed. The highest patchiness (23 patches per 1 km^2) of all system types for 4 model watershed has been observed in Kamenduł lake watershed for moderately barrier systems. The highest ecotone character is displayed by moderately

Table 6. Features of landscape structure in chosen SLP watersheds

Kinds of systems (and areas)*	Features	Watersheds (area)			
		l. Hańcza (1050 ha)	l. Kojle-Perty (230 ha)	Szeszupa r. (794 ha)	l. Kameduł (94 ha)
Highly barrier (S, SF, SM)	a	8	12	8	7
	b	0.64	1.61	1.89	1.33
	c	12	8	4	5
	d	3567	3933	2457	2539
	e	–	–	–	–
	f	–	–	1660	–
Moderately barrier (FD, FM, FC, M)	a	72	51	56	46
	b	4.50	2.79	4.43	1.95
	c	16	18	8	23
	d	14730	9975	10416	12231
	e	8910	530	4370	590
	f	820	300	1800	–
Non-barrier (A, B)	a	18	21	30	22
	b	2.01	2.11	3.89	1.87
	c	9	10	8	13
	d	4829	5369	7486	7065
	e	2110	630	4310	570
	f	–	–	–	–

a – percentage of system area in the watershed, b – average patch size in ha, c – degree of patchiness of the watershed (number of patches per 1 km^2), d – length of ecotone in $m \cdot km^{-2}$, e – roads in m, f – streams in m; * Explanations see Table 1.

barrier systems. This parameter of landscape structure fluctuates between 9975 $m \cdot km^{-2}$ of Kojle-Perty lakes watershed and 14730 $m \cdot km^{-2}$ of watershed. The lowest ecotone character (2457 $m \cdot km^{-2}$ of Hańcza lake watershed) has been recorded for highly barrier systems of the Szeszupa river watershed) (Table 6).

Table 7. Percentage of barrier system areas* in land belts of 0–50 and 50–150 m in adjoining open waters

Kind of system (and area)	Watershed			
	Hańcza lake	Kojle-Perty lakes	Szeszupa river	Kameduł lake
Highly barrier (S, SF, SM)				
0–50 m	1	37	46	35
50–150 m	4	25	32	33
Moderately barrier (FD, FM, FC, M)				
0–50 m	92	38	45	45
50–150 m	83	51	53	39
Non-barrier (A, B)				
0–50 m	7	25	9	20
50–150 m	13	24	15	29

*Explanations see Table 1.

2.4. TRENDS IN LANDSCAPE STRUCTURE CHANGES OVER THE YEARS 1971–1987

Changes were analysed only for chosen fragments of model watersheds within the SLP (Fig. 2, Table 8). Generally the changes are not great as regards land use, not exceeding 4 ha of watershed, with a tendency towards changing meadows into areas covered by high vegetation. Anthropopressure significantly increased – new farm buildings were built and some mid-field shelterbelts were removed.

3. DISCUSSION

The exceptional efficiency of photointerpretation as regards natural resources research is well known and recognized. Empirical studies confirm also the thesis that photointerpretation may be also a good tool for learning the ecological structure of postglacial landscape which is characterized by high degree of natural systems complication.

Photointerpretation is based on an assumption that geometric area, linear and point elements on aerial photographs have an explicit ecological interpretation connected with the structure and functioning of ecological landscape (functional

Table 8. Trends of long term changes in studied SLP watersheds

Kind of changes	Watershed and periods of changes							
	l. Hańcza		Szeszupa r.		l. Kojle-Party		l. Kamenduł	
	1971–1979	1979–1987	1971–1979	1979–1987	1971–1979	1979–1987	1971–1979	1979–1987
Roads (in m)								
– gain				270				
– loss		300						
Tree rows (in m)								
– loss			195					
Tree groups (number of groups)								
– loss	2		4	6		1		2
Single trees (specimens)								
– loss	3		6	3		5	1	
Buildings								
– pulled down				1				
– reconstructed				3				
– built	5	8	2	7		1		

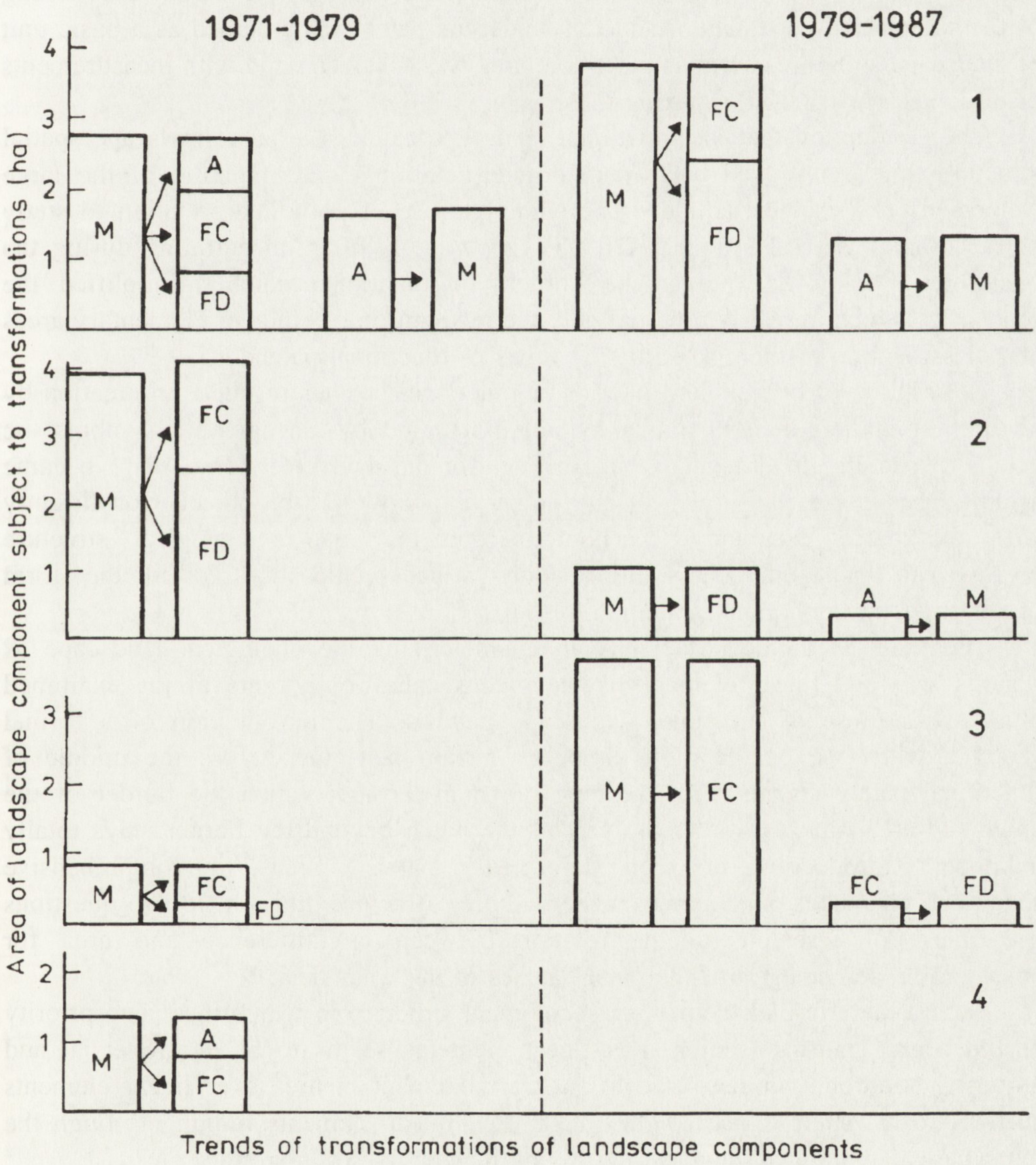

Fig. 2. Trends of long term changes of selected SLP watersheds
1 – eastern part of Hańcza lake watershed (within SLP), 2 – the Szeszupa river watershed (within SLP), 3 – Kojle-Perty lakes watershed (within SLP), 4 – Kamenduł lake watershed. Explanations see Table 1

patches, ecotones, convergence lines, convergence points). Thus, photointerpretation could be carried out at a simplifying assumption that the ecological landscape consists as if of an area, linear and point geometric forms filling the landscape space in different combinations. Due to such methodological approach, attention was placed on surface forms prevailing in lake district landscape which determine the functioning of the whole landscape. The functional landscape patch was assumed as a basic unit of landscape structure, whereas the whole area was characterized with measurements of all landscape patches occurring there.

The assumption that the functional landscape patch is a basic landscape spatial structure unit has proved usef in photointerpretational determination of the large watershed area structured. It does not limit the use of photointerpretation to study more complex natural systems (Chmielewski 1988). Concentrating during the photointerpretation on finding the borders of functional patches simplified the procedure, which in reality required only the recognition of kinds of elementary areas and classification of them to particular types of functional patches.

Description of borders and interior of functional patches resulted in creation by photointerpretation method a map, which illustrated by cartographic symbols the details of nature heterogeneity interesting for the interpreter. The map became a tool allowing for cartographical and numerical study on the object. Constistently with the goal of the study, the photointerpretation map of ecological structure was used to obtain only such information, which could be used in the form of variables for ecological modelling.

The main methodical difficulty in characterizing the ecological landscape as regards area and linear elements is the inconsistency of borders of the examined object with those of functional landscape patches. The introduction of a formal ecotone, when the border of a divide or terrain belt runs across the middle of functional patch, signals only the type of patch through which the border of the examined area runs. However the part of the patch beyond the border stays totally unknown. Introduction of such deformed patch areas to comprehensive specifications makes concluding on the real area structure difficult. It also questions usefullness of research on the relation between circumference and area for considerable percentage of functional patches in the watershed.

Such a hierarchy of elements of ecological structure in which there is a priority of functional landscape patch over linear elements seems to be controversial and requiring additional studies. Due to such arrangement of area over linear elements such as roads, streams, narrow tree belts etc., linear elements running through the inner part of functional patch do not divide it into smaller area units.

Empirical studies on SLP model watersheds proved that particular functional landscape patches adjoin usually many other types of functional patches. This is the reason of originating of numerous convergence points, distributed on the circumference of the patch. These elements are easily recognized on maps of ecological structure. Because of their abundant occurrence they should become an object of ecological studies as they may be a special place of matter, energy and biological information concentration. Assuming that the functional patch as the main element of landscape structure leaves little room for the exposure of another possible functional division into units of type: matrix, islands and ecological corridors (Forman and Godron 1986). A model division into matrix, islands and ecological corridors would require and exceptionally high professional level interpreters. Empirical studies proved that such functional division is practically impossible for the whole watershed, although photointerpretation allows for general division into fragments with different matrix features.

An own terminological convention was adopted in this study for environment islands. It makes easier the data arraggement during elaboration of the photointerpretation map of ecological structure. An area element inside the earlier determined borders of functional patch or adjacent to the patch border in one point was called an island. As understood by Forman and Godron (1986), each functional landscape patch would be a kind of environment island.

The changes resulted from research (Fig. 2) should be interpreted that each change of area type causes indirectly also changes of linear and point type in the contact zone of functional landscape patch with neighbouring patches. Few years difference in dates of taking photographs may not catch also the shorter cycle of changes from A to M or from M to A and the return to primary utilization. There is also the greatest probability of making mistakes in recognition of a specific area on photographs in the group of changes from A to M and (or) M to A.

The paper presents a proposal of photointerpretation procedure based on easily distinguishable area, linear and point elements. Empirical studies have probably covered all combinations of area, linear and point elements in lake district landscapes and confirmed the efficiency of suggested methods. Its practical use shall be determined by landscape ecologists, for whom photointerpretation method may become an effective tool.

4. SUMMARY

Aerial photographs may be an efficient tool for an ecologist if information contained in them would be processed into a set of numerical characteristics of natural structure of the landscape that can be interpreted ecologically and a map illustrating spatial distribution of elements of the ecological structure.

The method of quantitative landscape description from the point of view of barrier function for pollution of surface waters was shown on the example of four watersheds in the Suwałki Landscape Park (Fig. 1). Infrared colour aerial photographs of proved high information capacity taken in summer 1987 and panchromatic aerial photographs taken in 1971 and 1979 were used in the study.

Elements of biogeocenotic barrier system conditioning the influence of terrestrial ecosystems on aquatic ecosystems were recognized in photointerpretation process. Homogenous functional landscape patches having high and moderate barrier function and also without such significance, as well as linear and point elements of landscape structure were distinguished.

The photointerpretation resulted in a map of ecological structure of studied watersheds. Its transformation from graphic into numerical form provided a description of elements examined which can be statistically elaborated and made possible the description of watershed structure by means of synthetical coefficients and statistical distributions. Special attention was paid to the characteristic of land belt directly adjoining the water bodies.

Size structure of landscape patches of different barrier function for pollution of surface waters in the whole watershed (Table 1) and in the belt directly adjoining lakes (Table 2) were analysed. The structure (Table 3) and statistical distributions (Table 4) of contact zones (ecotones) among

homogenous landscape patches of a similar and different barrier function were determined as well as the contribution and kind of linear elements of landscape structure within homogenous landscape patches (Table 5). On the basis of results of above analysis the structure of studied watersheds (Table 6) and land belt directly adjoining surface waters (Table 7) were compared in the aspect of the barrier role for pollution running off to surface waters. Long term changes of ecological structure of examined watersheds were described on the basis of analysis of aerial photographs taken in different years (Table 8, Fig. 2).

Analysis of the watersheds structure and their tendencies to changes presented in this paper may be useful for ecologists when planning water protection measures in the SLP.

5. POLISH SUMMARY

Zdjęcia lotnicze mogą stać się efektywnym narzędziem pracy ekologa, jeżeli zawarta w nich informacja zostanie przetworzona na zbiór liczbowych charakterystyk struktury przyrodniczej terenu, poddających się interpretacji ekologicznej, i mapą ilustrującą przestrzenne rozmieszczenie elementów struktury ekologicznej.

Metodą opisu ilościowego krajobrazu z punktu widzenia funkcji barierowej dla zanieczyszczenia wód powierzchniowych przedstawiono na przykładzie czterech zlewni położonych na obszarze Suwalskiego Parku Krajobrazowego (rys. 1). W pracy wykorzystano spektrostrefowe zdjęcia lotnicze o sprawdzonej wysokiej pojemności informacyjnej, wykonane latem 1987 r. oraz zdjęcia lotnicze panchromatyczne z lat 1971 i 1979.

W procesie fotointerpretacji rozpoznawano elementy systemu barier biogeocenotycznych warunkującego oddziaływanie ekosystemów lądowych na wodne. Wyróżniano jednolite funkcjonalnie płaty krajobrazu o silnej i umiarkowanej funkcji barierowej oraz nie odgrywającej takiej roli, jak również elementy liniowe i punktowe struktury krajobrazu.

Efektem fotointerpretacji stała się mapa struktury ekologicznej badanych zlewni, po jej przekształceniu z formy graficznej na postać cyfrową uzyskano opis badanych elementów poddający się obróbce statystycznej i umożliwiający opis struktury zlewni przy pomocy syntetycznych wskaźników i rozkładów statystycznych. Szczególną uwagę zwrócono na charakterystykę pasa terenu bezpośrednio przyległego do zbiorników wodnych.

Analizowano strukturę wielkościową płatów krajobrazowych o różnej funkcji barierowej dla zanieczyszczenia wód powierzchniowych w całej zlewni (tab. 1) i w pasie bezpośrednio przylegającym do jezior (tab. 2). Określono strukturę (tab. 3) i rozkłady statystyczne (tab. 4) stref kontaktowych (ekotonów) między jednolitymi płatami krajobrazu o podobnej i różnej funkcji barierowej, jak też udział i rodzaj liniowych elementów struktury krajobrazu, przebiegających wewnątrz jednolitych płatów krajobrazu (tab. 5). Na podstawie wyników powyższych analiz porównano strukturę badanych zlewni (tab. 6) i pasów terenu bezpośrednio przylegających do wód otwartych (tab. 7), z punktu widzenia roli barierowej dla zanieczyszczeń spływających do wód powierzchniowych. Na podstawie analiz zdjęć lotniczych wykonywanych w różnych latach określono tendencje zmian wieloletnich struktury ekologicznej badanych zlewni (tab. 8, rys. 2).

Przedstawione analizy struktury zlewni i tendencji ich zmian mogą być użyteczne dla ekologów przy projektowaniu przedsięwzięć ochrony wód na terenie SPK.

6. REFERENCES

1. Bajkiewicz-Grabowska E. 1993 – Physiogeographical and hydrographical characteristics of Suwałki Landscape Park (north-eastern Poland) – Ekol. pol. 41: 7–26.
2. Chmielewski T. 1988 – O strefowo-pasmowo-węzłowej strukturze układów ponadekosystemalnych [On the sonal-band-nodal structure of superecosystem structure] – Wiad. ekol. 34: 165–185.

3. Di Castrii F., Hansen A. J., Holland M. M. 1988 – A new look at ecotones – Biol. int. spec. issue 17: 163 pp.
4. Forman R. T. T., Godron M. 1986 – Landscape ecology – John Wiley and Sons, New York, 619 pp.
5. Mozgawa J. (in press) – Zastosowanie zdjęć lotniczych do charakterystyki ekotonalności i plamistości krajobrazu na przykładzie pojeziernych krajobrazów Polski północno-wschodniej [The use of aerial photographs to characterize ecotones and mosaics in landscape as exemplified by lakeland landscapes of north-eastern Poland] (In: Problemy ekologii krajobrazu pojeziernego Polski północno-wschodniej [Ecological problems of the lakeland landscape in north-eastern Poland] Eds. E. Dąbrowska-Prot, J. Łuczak) – Zesz. nauk. Komit. Człow. Środ. PAN.
6. Pawliakiawiczius A. 1981 – Ecological role of the forest stand of the lake slopes – Acad. Sci. Lithuanian SSR, Vilnius.