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AN ECOSYSTEM VALUATION METHOD FOR SMALL WATER BODIES

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Abstract: The paper discusses the development of a valuation method for small water bodies in a landscape park of agricultural character, since for such an area small water bodies are of considerable importance, primarily hydrological and natural. Analyses were conducted in the Dezydery Chłapowski Landscape Park. The object of the study comprised 13 water bodies differing in terms of landscape, morphological parameters (depth, shape, surface area, shoreline development) as well as aquatic and marsh vegetation. Some of these water bodies are typical in-field hollows, some are located in built-up areas, while two are located in a forest complex. The aim of the presented investigations was to develop a valuation method for small water bodies based on inventoried aquatic and marsh vegetation and including modifications of nature analysis methods such as the phytosociological method by Braun-Blanquet and ecological indexes according to Zarzycki. Using environmental variables statistical models were developed, describing dependencies between individual species and analysed variables. Investigations were conducted in the years 2008-2009, in which phytosociological relevés were prepared during the vegetation season. Analyses concerned vegetation of the littoral zone and the limnetic (open water) zone. The ecological status of water bodies was calculated on the basis of data concerning aquatic and marsh vegetation and the measured surface area of a given water body. Results indicate the advisability of having small water bodies covered with legal protection measures. In turn, the water bodies which underwent severe degradation should be remediated using available measures (dredging, creation of biogeochemical barriers).

Keywords: water ecosystems, water bodies, valuation method, statistical methods

Introduction

Small water bodies and drainage ditches are essential elements of agricultural landscape. As ecosystems they serve many important biocenotic, hydrological and economic functions [1-6].

According to a definition proposed by Drwal and Lange [7] small water bodies may be defined as water bodies of any genesis, found permanently, periodically or even occasionally in early post-glacial areas, with an arbitrarily assumed surface area of max 1 hectare, characterised by a predominance of vertical over horizontal matter and energy

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exchange, an evident relationship with surface and subsoil waters within the boundaries of their topographic catchments, as well as the internal homogeneity of the aquatic environment, and their physical and chemical characteristics being strongly influenced by local conditions.

Small water bodies differ in terms of their genesis. Some of them were formed naturally in originally dry depressions, as a result of accumulation of water from local surface runoff. Their genesis is similar to that of morainal lakes.

Artificial small water bodies of anthropogenic origin are mainly former peat borrow pits filled with water, most typically of regular shapes. Their functioning in landscape is most frequently determined by the presence of shallow ground water [8].

Small water bodies are most typically shallow bodies of water, thus devoid of thermal stratification. However, at considerable diurnal temperature differences water mixing may be observed in the water body. Then the water body will behave like a monomictic lake, with the difference that it does so in a diurnal cycle. The difference consists in the fact that such water bodies do not have a profundal pelagic zone, a thermocline, or a deeply situated bottom [9]. In small water bodies also physical and chemical factors are highly variable as a consequence of the limited size of these water bodies, slight water exchange and high susceptibility to the effect of land and the atmosphere [10].

Threats to small ecosystems of inland waters most frequently result from inappropriately conducted agricultural activity, connected most typically with intensification of production, and directly with the increasing area of arable fields and the destruction of in-field small water bodies [11].

Factors degrading small in-field water bodies include also soil drainage measures, sewage discharge and unauthorized dumping sites located in their vicinity [12], which having a periodical impact lead to a deterioration of the ecological status of the water body and as a consequence to its disappearance. The area in which an aquatic ecosystem was previously functioning becomes a wasteland, devoid of any function or productivity, and it is soon absorbed by the nearby fields.

A threat to the appropriate functioning of water ecosystems in agricultural areas is also connected with the anthropogenic degradation of the littoral zone, which serves the role of a biogeochemical barrier [13-16]. Clearing of trees around water bodies and removal of reed vegetation without providing any protective or reclamation measures lead to an accelerated accumulation of pollutants in bottom sediments and in water, and as a result - to a more rapid eutrophication of the ecosystem [17-19].

Qualitative degradation results also from unconscious human activity, connected with the construction of piers and incompetent shore reinforcement. Quality parameters in aquatic ecosystems are also altered by grazing and fish farming, which in turn causes an increase in the amount of organic matter in the body of water due to excessive baiting of bred fish.

The primary objective of the presented study was to develop a valuation method for small water bodies located in the General Dezydery Chłapowski Landscape Park. The valuation method for water bodies was developed on the basis of a survey of aquatic and marsh vegetation as well as modified nature valuation methods (the Braun-Blanquet method and ecological indexes according to Zarzycki). The paper presents also 3 *canonical variate analysis* (CVA) models, illustrating dependencies between macrophyte species found in the

water bodies and environmental variables (E, pH, H, temperature, location and the size of the water body).

This newly developed method of valuation of small water bodies should provide an incentive for further scientific investigations concerning water bodies, taking into consideration their hydrological and ecological functions, particularly the determination of biotic and abiotic parameters of the aquatic environment in order to optimise protection measures for these small water bodies.

Object of the study

Investigations were conducted in the Gen. Dezydery Chlapowski Landscape Park. Analyses were carried out on 13 bodies of water differing in terms of their location in landscape, area, shape, development of the shore line, aquatic vegetation, and type of geological subsoil on which they are found. Some water bodies are typical in-field hollows, some are located in developed areas, while two are situated in a forest complex.

Water bodies located in forests

Two water bodies denoted as Nos. 1 and 2 are located in the Rabinsko-Blociszewski Forest Complex. The first is small, covering an area of approx. 92 m² and it is located in the south-eastern part of the forest complex, in a small hollow among oaks with an admixture of hornbeams and birches. Slightly loamy sands predominate in the surface subsoil layers. The small water body is characterised by a small maximum depth (0.5 m) and considerable thickness of bottom deposits (in relation to the surface of the water body) originating mainly from falling leaves, which are accumulated within the water body.

The second water body (No. 2) is an artificial drainless depression of approx. 885 m². Its surroundings are composed mainly of spruces, oaks and larches. Characteristic features of this water body are related with its milky colour and sandy loams predominating in the upper layers of the subsoil. The subsoil of this hollow is composed mainly of mineral deposits, with a thickness reaching up to 1 m in places.

Water bodies located in agricultural areas

Analysed water bodies located in agricultural areas were denoted as Nos. 3-7 and 8. Water body No. 3, covering an area of 2538 m², is situated north of a village of Golebin Stary. The water body is surrounded primarily by arable fields and agriculturally utilised meadows, with the predominance of willows, lilacs and hawthorns within the shore line. The maximum depth in this water body is 1.5 m, while bottom deposits primarily of organic origin are 30 cm thick.

Water body No. 4 is located in the most diverse surroundings. From the east the water body borders on a thicket mainly composed of false acacia, birch and oaks, behind which there is a hard-surfaced road. The other sections of the shore line are mainly composed of arable fields and solitary trees (birches, pines and oaks). On the east around a dried-up ditch the area is covered with a large patch of nettle, which suggests nitrate run-off from fields. The water body occupies an area of 1668 m², while the surface subsoil layer at the water body is composed of loose sands.

Water body No. 5 was reconstructed in 1995. In the course of the water body reconstruction works shores were formed from the north, west and south as steep

embankments, while the eastern shore remained flat. The water body is surrounded by arable fields on its three sides, which influences the process of eutrophication in the water body. This water body is characterised by a limited deposition of bottom sediments (10 cm), while its surface area amounts to 1929 m². The topsoil in the areas adjacent to the water body is composed mainly of loamy sands.

Water body No. 6 is located close to water body No. 5. This water body is located east of the village of Rogaczewo Małe in a natural depression with a max depth of 1 m. From the north-east the water body is surrounded with a thicket composed mainly of false acacia, while it is separated from arable fields with a narrow belt of meadows. The water body covers an area of 919 m², with its bottom being filled with organic sediments of considerable thickness. Adjacent areas in terms of their grain size distribution are composed mainly of loose sands.

Water body No. 7 is located within the boundaries of Turew. This body of water is one of the larger water bodies analysed here. It is 3026 m² in area and the pond basin is mostly overgrown with reed rushes. Willows as well as smaller numbers of hawthorns and false acacias are growing within a short distance of the water body shores. Adjacent areas comprise arable fields divided by a meadow from the south. A hard-surfaced road runs from the west.

Water body No. 8 is located farthest to south-west of all the analysed water bodies. It is located approx. 1 km south of the village of Graniecznik. In the 1960's this water body retained greater amounts of water and it was used by the inhabitants of nearby villages for recreational purposes. At present it has become shallow and is gradually disappearing. In 2009 in the summer-autumn period a lack of water was observed in the water body. It is a typical in-field water body surrounded by fields on all sides, with abundantly developing rush vegetation, which overgrows almost the entire water sheet of the water body.

Water bodies located in built-up areas

Water bodies denoted as Nos. 9-12 and 13 are located in built-up areas. Water body No. 9 is a pond located in the palace park in Turew. It is a flow-through water body of 1344 m² in area. The water body is surrounded mainly by park tree plantings, predominantly oaks, alders, maples as well as tree-of-heaven ailanthus. Soil at this water body is composed mainly of sandy loam.

Water body No. 10 was analysed in the village of Rabin. It is surrounded by roads on two sides, from the north-west it is an asphalt road, while from the south it is a hard-surfaced road. Adjacent areas are mainly meadows. In the narrow belt at the water body there are trees typical of rural areas, lindens and apple trees, as well as willows characteristic of fluvial areas. This water body occupies an area of 1992 m² and deposits of organic substance are found on the bottom.

Water bodies Nos. 11 and 12 are located in the village of Luskowo. They are small drainless hollows covering an area of 358 and 432 m², respectively. The primary tree species around the water bodies are poplars, willows and false acacias. In 2010 trees at water body No. 11 were cleared. Both hollows are typical rural water bodies in character.

Water body No. 13 located in Wyskoc is surrounded by an asphalt road from the north, buildings from the south and a brick wall from the west. This water body is surrounded mainly by lindens, maples and birches and covers an area of 1173 m². The surface soil layer at the water body is composed predominantly from loamy sands.

Methods

Floristic studies aiming at the determination of a valuation method for small water bodies

Within two successive vegetation seasons (2008-2009) analyses were conducted on the vegetation cover on thirteen small water bodies located in the Gen. Dezydery Chlapowski Landscape Park. An inventory of macrophyte species was made for the analysed water bodies and their abundance and cover indexes were determined for individual species according to the method developed by Braun-Blanquet [20, 21]. Polish and Latin nomenclature of hydromacrophytes was adopted on the basis of a study by Mirek et al [22].

In the first and second year the surface area of patches occupied by the dominant species was recorded. The area was measured using an M-10 precision odometer by Temex and a DISTO D5 laser by Leica. For the dominant species in the patch (Fig. 1) ecological indicator scores were identified according to Zarzycki et al [23]. For the needs of this study these parameters were considered, which pertain directly to the species closely related with water.

The analysis included also cover of the water body by aquatic and marsh vegetation.

Fig. 1. Patches of vegetation on the water body

Applying ecological indicator scores for dominant plants and using the formula presented below $[Z_c]$ individual indicators were determined for the water body:

- Light - L ,
- Thermal - T ,
- Soil moisture content at water body - W ,
- Trophism - Tr ,
- Water acidity - R ,
- Grain size distribution of soil at water body - D ,
- Organic matter content - H ,
- Resistance to NaCl content in water - S ,
- Resistance to heavy metal contents in water - M .

The ecological indicator score for the water body (1):

$$Z_z = \sum_{n=i} [Z_n \cdot P_n] \quad (1)$$

where: Z_z - ecological indicator score (eg trophism indicator) for water body z , Z_n - ecological indicator score for plant n , P_n - surface area [%] covered by plant n in relation to total vegetation cover of the water body, i - number of patches with dominant species.

Using collected data and the adopted reference model (a reference water body) a valuation method was developed for water bodies based on aquatic vegetation. An oligotrophic water body was used as the reference water body. By conducting a comparative analysis of the investigated water body and the reference water body a value was obtained, which illustrated the ecological status of the analysed water body (2) (the higher the E value, the worse the ecological status of the water body).

Ecological status of water body:

$$E = \left(|k_4 \Delta L| + |k_2 \Delta T| + |k_{1,2} W| + |k_4 \Delta Tr| + |k_8 \Delta R| + |k_3 \Delta D| + |k_8 \Delta H| + |k_8 \Delta S| + |k_8 \Delta M| \right) + |10 \Delta P| - 0,5I \quad (2)$$

where: E - ecological status of water body, $k_{1,2}$, k_2 - correction factors for group II indexes (T , K , W , D having a lesser effect on the condition of a water body), k_4 , k_8 - correction factors for group I indexes (L , Tr , R , H , S , M having a greater effect on the condition of a water body), ΔL , ΔT , ΔK , ΔW , ΔTr , ΔR , ΔD , ΔH , ΔS , ΔM - increments in analysed indexes in relation of the reference water body, ΔP - increment in vegetation cover of the water body in relation to the reference water body, I - number of species if aquatic and marsh plants.

Results

Ecological status of water bodies

Ecological status of all analysed water bodies located in the Gen. Dezydery Chłapowski Landscape Park was calculated for the years 2008-2009. The beginning of July of each of the two years was assumed as the date considered to be representative, since most aquatic and marsh plants exhibit intensive growth in this period.

A lobelia lake was adopted as the reference water body, with a 15% (0.15) lake basin cover by *Lobelia dortmanna* (L.). The following values of ecological indexes were assumed for this water body: $L = 5$, $T = 3.5$, $W = 3$, $Tr = 4$, $R = 4$, $D = 4$, $H = 2$, $S = 0$ and $M = 0$ [19].

Ecological status of water body No. 1

In the first year the water body was covered solely by *Lemna minor* (L.), with this species covering 100% basin of this water body. In July 2009 two additional dominant species appeared (Table 1), ie *Polygonum hydropiper* (L.) and *Juncus effusus* (L.).

Applying the formula for the ecological indicator score for the water body, values were calculated, presented in Table 2 for the water body in the years 2008 and 2009.

Based on Tables 1 and 2 the ecological status of the water body was calculated using the previously presented formula. The E value for the water body in the first year was 46.9, while in the second year it amounted to 45.02, which indicates a slight improvement of the ecological status in terms of aquatic and marsh vegetation.

Table 1

Patches of vegetation and aquatic and marsh species in water body No. 1

		year 2008	year 2009
Basin cover with aquatic and marsh vegetation		1	1
Number of aquatic and marsh species		1	3
Patches of plants and area covered in water body:			
year 2008		year 2009	
<i>Lemna minor</i> (L.)	1	<i>Lemna minor</i> (L.)	0.9
		<i>Polygonum hydropiper</i> (L.)	0.05
		<i>Juncus effusus</i> (L.)	0.05

Table 2

Ecological indicator scores for water body No. 1

	<i>L</i>	<i>T</i>	<i>W</i>	<i>Tr</i>	<i>R</i>	<i>D</i>	<i>H</i>	<i>S</i>	<i>M</i>
2008	4	3.5	6	3.5	4.5	0	3	1	0
2009	4.05	3.5	5.85	3.5	4.4	0.4	2.95	0.9	0

Ecological status of water body no. 2

Only one patch of *Glyceria fluitans* (L.) R. Br. plants was recorded in water body No. 2 both in 2008 and 2009. The patch covered the water body to a limited extent (Table 3).

Table 3

Patches of vegetation and aquatic and marsh species in water body No. 2

		year 2008	year 2009
Basin cover with aquatic and marsh vegetation		0.15	0.18
Number of aquatic and marsh species		3	3
Patches of plants and area covered in water body:			
year 2008		year 2009	
<i>Glyceria fluitans</i> (L.) R. Br.	1	<i>Glyceria fluitans</i> (L.) R. Br.	1

Based on the proposed formula the values given below were calculated (Table 4). Using data from Tables 3 and 4 the ecological status (*E*) was calculated, which were found to be similar. The slight difference was influenced only by the water body cover with aquatic and marsh vegetation and in 2008 the *E* value was 23, while for 2009 it was 23.3.

Table 4

Ecological indicator scores for water body No. 2

	<i>L</i>	<i>T</i>	<i>W</i>	<i>Tr</i>	<i>R</i>	<i>D</i>	<i>H</i>	<i>S</i>	<i>M</i>
2008	4	3.5	5.5	4	4	4.5	3	1	0
2009	4	3.5	5.5	4	4	4.5	3	1	0

Ecological status of water body No. 3

Both in the first and the second year of analyses 5 distinct patches of plants were observed in the water body. *Phragmites australis* (Cav.) Trin. ex Steud. significantly predominated on this water body, covering a greater part of the water body. Complete vegetation cover in both years exceeded 70%; however, in 2009 the water body was characterised by a greater vegetation cover (Table 5).

Using the proposed formulas as well as collected or calculated data from Tables 5 and 6, the ecological status of the water body was determined, amounting in 2008 to 18.98, while for 2009 it was 21.33.

Table 5

Patches of vegetation and aquatic and marsh species in water body No. 3

		year 2008	year 2009
Basin cover with aquatic and marsh vegetation		0.72	0.83
Number of aquatic and marsh species		11	10
Patches of plants and area covered in water body:			
year 2008		year 2009	
<i>Phragmites australis</i> (Cav.)Trin. ex Steud.	0.7	<i>Phragmites australis</i> (Cav.)Trin. ex Steud.	0.75
<i>Ceratophyllum demersum</i> (L.)	0.1	<i>Ceratophyllum demersum</i> (L.)	0.15
<i>Phalaris arundinacea</i> (L.)	0.07	<i>Carex acutiformis</i> Ehrh.	0.05
<i>Carex acutiformis</i> Ehrh.	0.07	<i>Lemna trisulca</i> (L.)	0.03
<i>Oenanthe aquatica</i> (L.) Poir.	0.06	<i>Lemna minor</i> (L.)	0.02

Table 6

Ecological indicator scores for water body No. 3

	<i>L</i>	<i>T</i>	<i>W</i>	<i>Tr</i>	<i>R</i>	<i>D</i>	<i>H</i>	<i>S</i>	<i>M</i>
2008	4.31	3.53	5.13	3.55	4.13	4.15	2.42	0.84	0
2009	4.35	3.52	5.05	3.45	4.17	3.92	2.47	0.85	0

Ecological status of water body No. 4

A greater diversity in terms of the occurrence of aquatic and marsh vegetation was found in water body no. 4 during the second testing date. Plants found in greatest numbers formed 5 patches in 2008 and 2009 (Table 7). Considerable changes were observed in the water body, concerning one species (*Typha angustifolia* (L.)), which increased its area in relation to the previous year. Ecological indicator scores for the water body are given below (Table 8). Calculated values of ecological status were high and in the first year of the study amounted to 19.96, while in the second it was 17.12.

Table 7

Patches of vegetation and aquatic and marsh species in water body No. 4

		year 2008	year 2009
Basin cover with aquatic and marsh vegetation		0.9	0.7
Number of aquatic and marsh species		10	11
Patches of plants and area covered in water body:			
year 2008		year 2009	
<i>Typha latifolia</i> (L.)	0.42	<i>Typha latifolia</i> (L.)	0.4
<i>Phragmites australis</i> (Cav.)Trin. ex Steud.	0.23	<i>Typha angustifolia</i> (L.)	0.4
<i>Typha angustifolia</i> (L.)	0.2	<i>Phragmites australis</i> (Cav.)Trin. ex Steud.	0.15
<i>Ceratophyllum submersum</i> (L.)	0.1	<i>Eleocharis palustris</i> (L.) Roem. et Schult.	0.03
<i>Lemna minor</i> (L.)	0.05	<i>Oenanthe aquatica</i> (L.) Poir.	0.02

Table 8

Ecological indicator numbers for water body No. 4

	<i>L</i>	<i>T</i>	<i>W</i>	<i>Tr</i>	<i>R</i>	<i>D</i>	<i>H</i>	<i>S</i>	<i>M</i>
2008	4.11	3.5	5.57	3.76	4.43	4.01	2.06	0.48	0
2009	4.04	3.5	5.48	3.71	4.43	4.02	1.87	0.58	0

Ecological status of water body No. 5

When comparing small water body No. 5 with the other water bodies it was found that the former is characterised by a relatively high number of aquatic and marsh species. In the first year there were 10 species, while in the second it was 13. They covered a 60% basin area of the water body in 2008, a year later they increased their area to 70% (Table 9).

Table 9

Patches of vegetation and aquatic and marsh species in water body No. 5

		year 2008	year 2009
Basin cover with aquatic and marsh vegetation		0.6	0.7
Number of aquatic and marsh species		10	13
Patches of plants and area covered in water body:			
year 2008		year 2009	
<i>Typha angustifolia</i> (L.)	0.4	<i>Typha angustifolia</i> (L.)	0.37
<i>Potamogeton natans</i> (L.)	0.28	<i>Phragmites australis</i> (Cav.) Trin. ex Steud.	0.31
<i>Phragmites australis</i> (Cav.) Trin. ex Steud.	0.21	<i>Potamogeton natans</i> (L.)	0.2
<i>Typha latifolia</i> (L.)	0.06	<i>Typha latifolia</i> (L.)	0.07
<i>Sparganium erectum</i> L. em. Rchb. s.s.	0.05	<i>Sparganium erectum</i> L. em. Rchb. s.s.	0.05

Calculated ecological indicator scores for the water body did not differ much in terms of both dates of analyses (Table 10), while the values of ecological status amounted to 17.65 for 2008 and 16.7 for 2009.

Table 10

Ecological indicator scores for water body No. 5

	<i>L</i>	<i>T</i>	<i>W</i>	<i>Tr</i>	<i>R</i>	<i>D</i>	<i>H</i>	<i>S</i>	<i>M</i>
2008	4.10	3.5	5.66	3.55	4.51	3.91	1.95	0.61	0
2009	4.15	3.5	5.62	3.56	4.42	3.85	2.02	0.68	0

Ecological status of water body No. 6

In 2008 the greatest proportion of water body no. 6 was overgrown by *Carex acutiformis* Ehrh., while in 2009 it was *Lemna minor* (L.) occupying 40% surface area (Table 11). Common duckweed increased the cover four-fold area in relation to 2008, which influenced the ecological status of the water body, in the first date of analysis amounting to 19.09. In the second date of analysis a considerable deterioration was observed for the ecological status ($E = 28.68$) (Table 12).

Table 11

Patches of vegetation and aquatic and marsh species in water body No. 6

		year 2008	year 2009
Basin cover with aquatic and marsh vegetation		0.5	1
Number of aquatic and marsh species		9	10
Patches of plants and area covered in water body:			
year 2008		year 2009	
<i>Carex acutiformis</i> Ehrh.	0.35	<i>Lemna minor</i> (L.)	0.4
<i>Typha latifolia</i> (L.)	0.3	<i>Carex acutiformis</i> Ehrh.	0.2
<i>Ceratophyllum submersum</i> (L.)	0.2	<i>Ceratophyllum submersum</i> (L.)	0.2
<i>Lemna minor</i> (L.)	0.1	<i>Typha latifolia</i> (L.)	0.15
<i>Phalaris arundinacea</i> (L.)	0.05	<i>Oenanthe aquatica</i> (L.) Poir.	0.05

Table 12

Ecological indicator scores for water body No. 6

	<i>L</i>	<i>T</i>	<i>W</i>	<i>Tr</i>	<i>R</i>	<i>D</i>	<i>H</i>	<i>S</i>	<i>M</i>
2008	3.825	3.675	5.45	3.95	4.425	4.3	2.45	0.5	0
2009	3.86	3.565	5.645	3.76	4.435	2.855	2.58	0.6	0

Ecological status of water body No. 7

In water body no. 7 *Phragmites australis* (Cav.)Trin. ex Steud. was observed to predominate, covering 95% total surface covered by plants in that water body. A marked predominance was found for one plant species (Table 13). Taking into consideration ecological indicator scores for the water body (Table 14) the ecological status was determined for two dates, the *E* value for the first date amounting to 25.27, while for the second *E* = 21.08.

Table 13

Patches of vegetation and aquatic and marsh species in water body No. 7

		year 2008	year 2009
Basin cover with aquatic and marsh vegetation		0.72	0.8
Number of aquatic and marsh species		7	8
Patches of plants and area covered in water body:			
year 2008		year 2009	
<i>Phragmites australis</i> (Cav.)Trin. ex Steud.	0.82	<i>Phragmites australis</i> (Cav.)Trin. ex Steud.	0.95
<i>Lemna minor</i> (L.)	0.18	<i>Lysimachia nummularia</i> (L.)	0.05

Table 14

Ecological indicator scores for water body No. 7

	<i>L</i>	<i>T</i>	<i>W</i>	<i>Tr</i>	<i>R</i>	<i>D</i>	<i>H</i>	<i>S</i>	<i>M</i>
2008	4.41	3.5	5.59	3.5	4.09	3.28	2.59	1	0
2009	4.42	3.5	5.42	3.52	4	4.02	2.47	0.95	0

Ecological status of water body No. 8

The analysed water body was more diverse in terms of its species than the previously discussed small water body no. 7. The occurrence of 10 aquatic and marsh species was recorded in 2008 and 12 in 2009. At the second date a considerable increase was observed in the area covered by *Phragmites australis* (Cav.) Trin. ex Steud. along with the

appearance of *Batrachium circinatum* (Sibth.) Fr. (Table 15). Despite the relatively good ecological status of this water body ($E = 22.33$ in 2008 and $E = 20.66$ in 2009), the functioning of the water body is disturbed by the cyclical lowering of the water stages, which may lead to its complete degradation (Table 16).

Table 15

Patches of vegetation and aquatic and marsh species in water body No. 8

		year 2008	year 2009
Basin cover with aquatic and marsh vegetation		1	1
Number of aquatic and marsh species		10	12
Patches of plants and area covered in water body:			
year 2008		year 2009	
<i>Phragmites australis</i> (Cav.) Trin. ex Steud.	0.45	<i>Phragmites australis</i> (Cav.) Trin. ex Steud.	0.63
<i>Schoenoplectus lacustris</i> (L.) Palla	0.2	<i>Schoenoplectus lacustris</i> (L.) Palla	0.13
<i>Typha latifolia</i> (L.)	0.13	<i>Typha latifolia</i> (L.)	0.1
<i>Polygonum amphibium</i> (L.)	0.13	<i>Oenanthe aquatica</i> (L.) Poir.	0.07
<i>Typha angustifolia</i> (L.)	0.09	<i>Batrachium circinatum</i> (Sibth.) Fr.	0.07

Table 16

Ecological indicator scores for water body No. 8

	<i>L</i>	<i>T</i>	<i>W</i>	<i>Tr</i>	<i>R</i>	<i>D</i>	<i>H</i>	<i>S</i>	<i>M</i>
2008	4.22	3.5	5.56	3.56	3.44	3.85	2.08	0.67	0
2009	4.31	3.5	5.53	3.62	3.6	4.02	2.25	0.7	0

Ecological status of water body No. 9

Water body no. 9 was characterised by poor aquatic and marsh vegetation, which covered the water body to a limited degree. In 2008 only 5 species of marsh and aquatic plants were recorded, of which only *Carex rostrata* Stokes formed a patch, while in 2009 the second patch of plants appeared and it was *Oenanthe aquatica* (L.) Poir. (Table 17).

Table 17

Patches of vegetation and aquatic and marsh species in water body No. 9

		year 2008	year 2009
Basin cover with aquatic and marsh vegetation		0.2	0.3
Number of aquatic and marsh species		5	7
Patches of plants and area covered in water body:			
year 2008		year 2009	
<i>Carex rostrata</i> Stokes	1	<i>Carex rostrata</i> Stokes	0.6
		<i>Oenanthe aquatica</i> (L.) Poir.	0.4

On the basis of formulas ecological indicators scores were calculated for the water body (Table 18), which constituted the basis for the calculation of ecological status, amounting to 25.4 for the first date of analyses, whereas in the second date it was 17.84.

Table 18

Ecological indicator scores for water body No. 9

	<i>L</i>	<i>T</i>	<i>W</i>	<i>Tr</i>	<i>R</i>	<i>D</i>	<i>H</i>	<i>S</i>	<i>M</i>
2008	4	3.5	5	3.5	3	5	3	0	0
2009	4	3.5	5.2	3.7	3.4	4.8	2.6	0	0

Ecological status of water body No. 10

Water body no. 10 is an example of dynamic changes, potentially occurring in the plant covers of small in-field water bodies. In 2009 in the water body a greater number of species was observed, but being considerably scattered, with only 3 patches being found, ie by 2 less than in 2008 (Table 19). An analysis of ecological status showed a slight deterioration of water body quality, with the calculated status being 23.9 for 2008 and 25.32 for 2009 (Table 20).

Table 19

Patches of vegetation and aquatic and marsh species in water body No. 10

		year 2008	year 2009
Basin cover with aquatic and marsh vegetation		0.7	0.85
Number of aquatic and marsh species		7	10
Patches of plants and area covered in water body:			
year 2008		year 2009	
<i>Phragmites australis</i> (Cav.)Trin. ex Steud.	0.3	<i>Phragmites australis</i> (Cav.)Trin. ex Steud.	0.4
<i>Ceratophyllum submersum</i> (L.)	0.28	<i>Typha angustifolia</i> (L.)	0.4
<i>Typha angustifolia</i> (L.)	0.2	<i>Lemna minor</i> (L.)	0.2
<i>Lemna minor</i> (L.)	0.18		
<i>Glyceria maxima</i> (Hartm.) Holmb.	0.04		

Table 20

Ecological indicator scores for water body No. 10

	<i>L</i>	<i>T</i>	<i>W</i>	<i>Tr</i>	<i>R</i>	<i>D</i>	<i>H</i>	<i>S</i>	<i>M</i>
2008	4.15	3.5	4.77	3.4	4.51	3.34	2.27	0.72	0
2009	4.2	3.5	5.6	3.5	4.3	3	2.2	1	0

Ecological status of water body No. 11

In comparison with water body no. 10, the small water body no. 11 is characterised by a lower diversity of marsh and aquatic species. Only 3 patches were reported in both dates of analyses. The water body both in the first and second year was covered mainly by *Lemna minor* (L.) (Table 21).

Table 21

Patches of vegetation and aquatic and marsh species in water body No.11

		year 2008	year 2009
Basin cover with aquatic and marsh vegetation		0.8	1
Number of aquatic and marsh species		6	6
Patches of plants and area covered in water body:			
year 2008		year 2009	
<i>Lemna minor</i> (L.)	0.6	<i>Lemna minor</i> (L.)	0.6
<i>Typha latifolia</i> (L.)	0.3	<i>Typha latifolia</i> (L.)	0.2
<i>Alisma plantago-aquatica</i> (L.)	0.1	<i>Oenanthe aquatica</i> (L.) Poir.	0.2

The dominance of common duckwheat resulted in a poor ecological status of that water body, which amounted to 33.61 in 2008 and 33.46 in 2009 (Table 22).

Table 22

Ecological indicator scores for water body No. 11

	<i>L</i>	<i>T</i>	<i>W</i>	<i>Tr</i>	<i>R</i>	<i>D</i>	<i>H</i>	<i>S</i>	<i>M</i>
2008	4	3.2	5.8	3.65	4.45	1.75	2.6	0.7	0
2009	4	3.5	5.8	3.7	4.4	1.8	2.6	0.6	0

Ecological status of water body No. 12

Water body No. 12, similarly as the above mentioned water body no. 11, is located in a village of Luskowo. In the first and second years of the study 5 plant patches were observed. *Lemna minor* (L.) predominated in this water body, which in 2009 occupied 80% surface area. Also in the same year a reduction was found for the patch of *Oenanthe aquatica* (L.) Poir. from 25 to 4% (Table 23). Changes in vegetation influenced the ecological indicator scores for that water body (Table 24), which in turn was reflected in the ecological status of the water body, in the first year of analyses amounting to 27.75, while in the second year it was 40.78. This indicates a considerable deterioration of the ecological status of this water body.

Table 23

Patches of vegetation and aquatic and marsh species in water body No. 12

		year 2008	year 2009
Basin cover with aquatic and marsh vegetation		0.7	1
Number of aquatic and marsh species		8	8
Patches of plants and area covered in water body:			
year 2008		year 2009	
<i>Lemna minor</i> (L.)	0.5	<i>Lemna minor</i> (L.)	0.8
<i>Oenanthe aquatica</i> (L.) Poir.	0.25	<i>Phragmites australis</i> (Cav.) Trin. ex Steud.	0.13
<i>Phragmites australis</i> (Cav.) Trin. ex Steud.	0.15	<i>Oenanthe aquatica</i> (L.) Poir.	0.04
<i>Phalaris arundinacea</i> (L.)	0.05	<i>Rumex palustris</i> Sm.	0.02
<i>Rumex palustris</i> Sm.	0.05	<i>Phalaris arundinacea</i> (L.)	0.01

Table 24

Ecological indicator scores for water body No. 12

	<i>L</i>	<i>T</i>	<i>W</i>	<i>Tr</i>	<i>R</i>	<i>D</i>	<i>H</i>	<i>S</i>	<i>M</i>
2008	4.12	3.52	5.65	3.67	4.27	2.12	2.6	0.7	0
2009	4.08	3.51	5.86	3.53	4.40	0.82	2.87	0.94	0

Ecological status of water body no. 13

The most abundant species in water body no. 13 included *Lemna minor* (L.), *Glyceria notata* Chevall. and *Sparganium erectum* L. em. Rchb. s.s. (Table 25). In 2009 a reduction was found for the area covered by *Lemna minor* (L.) and an increase in the area of *Glyceria notata* Chevall. (Table 25). Taking into consideration the ecological indicator indexes were calculated for that water body (Table 26), in 2008 amounting to 32.82 and in 2009 to 23.33.

The *E* value indicates an improvement of the ecological status concerning mainly the flora of that water body.

Table 25

Patches of vegetation and aquatic and marsh species in water body No.13

		year 2008	year 2009
Basin cover with aquatic and marsh vegetation		0.75	0.4
Number of aquatic and marsh species		10	12
Patches of plants and area covered in water body:			
year 2008		year 2009	
<i>Lemna minor</i> (L.)	0.6	<i>Lemna minor</i> (L.)	0.4
<i>Glyceria notata</i> Chevall.	0.17	<i>Glyceria notata</i> Chevall.	0.3
<i>Sparganium erectum</i> L. em. Rchb. s.s.	0.09	<i>Typha latifolia</i> (L.)	0.1
<i>Carex acutiformis</i> Ehrh.	0.07	<i>Schoenoplectus lacustris</i> (L.) Palla	0.07
<i>Schoenoplectus lacustris</i> (L.) Palla	0.04	<i>Sparganium erectum</i> L. em. Rchb. s.s.	0.07
<i>Typha latifolia</i> (L.)	0.03	<i>Carex acutiformis</i> Ehrh.	0.06

Table 26

Ecological indicator scores for water body No.13

	<i>L</i>	<i>T</i>	<i>W</i>	<i>Tr</i>	<i>R</i>	<i>D</i>	<i>H</i>	<i>S</i>	<i>M</i>
2008	3.96	3.53	5.75	3.68	4.15	1.39	2.91	0.84	0
2009	3.97	3.53	5.55	3.76	3.97	2.34	2.79	0.76	0

A comparison of ecological status of analysed water bodies

Ecological status scores for water bodies located in the Gen. Dezydery Chlapowski Landscape Park ranged from 16.7 for water body no. 5 to 49.6 for water body No. 1. The best ecological status was recorded for water bodies nos. 4 and 5, classified both in 2008 and 2009 to class I.

Table 27

Values of ecological status (*E*) depending on classes for water bodies in 2008 and 2009

Water body	year 2008		year 2009		change
	<i>E</i> value	class	<i>E</i> value	class	
No. 1	49.6	IV	45.02	IV	·
No. 2	23	II	23.3	II	·
No. 3	18.98	I	21.33	II	↓
No. 4	17.96	I	17.12	I	·
No. 5	17.65	I	16.7	I	·
No. 6	19.09	I	28.68	II	↓
No. 7	25.27	II	21.08	II	·
No. 8	22.33	II	20.66	II	·
No. 9	25.4	II	17.84	I	↑
No. 10	23.9	II	25.32	II	·
No. 11	33.61	III	33.46	III	·
No. 12	27.75	II	40.78	IV	↓
No. 13	32.83	III	23.33	II	↑

Ecological status classes for water bodies: < 20 - class I; 20.01-30 - class II; 30.01-40 class III; > 40 - class IV

The worst ecological status was reported for water body no. 1, in which *E* values exceeded 40 both in the first and second year of analyses. Eight water bodies remained in

the same class, in two the ecological status was observed to improve, resulting in their classification to a higher class, while three were classified to a lower class, with body no. 12 dropping by two classes in 2009 (Table 27).

In the second year of the study the number of water bodies belonging to class IV increased, while the number of water bodies belonging to class I decreased (Fig. 2). This situation shows a deterioration of quality of the analysed water bodies in terms of the occurrence of macrophytes in the Park. For the water bodies of the lowest classes (III and IV) it is necessary to undertake protection measures connected with the removal of bottom deposits, deepening of water bodies and an inhibited development of aquatic and marsh plant species, which dominated in the water body (in order to eliminate monocultures and enhance biodiversity in the water body).

Fig. 2. Classes of ecological status of water bodies: A - 2008, B - 2009

Statistical analysis

The models presented below were created based on the discriminatory analysis. The aim of the investigations was to verify which variables determine colonisation of small water bodies by macrophytes, as well as indicate which species of the littoral zone are characteristic of forest, in-field and park water bodies as well as those located in built-up areas. The model was constructed with the use of canonical variate analysis (CDA) and a canonical variety of Fisher's linear discriminatory analysis (LDA) [24, 25].

The discriminatory analysis was used to compare the effect of different variables (E, pH, H, temperature, location and size of water body) on the distribution of macrophytes in morphometrically varied water bodies.

The following step-wise analysis was applied in order to verify which variables to the greatest degree determine the distribution of macrophytes in water bodies. All variables were assessed and next these models were included in the model, which most contributed to the discrimination of groups based on the p and F values for the analysed variable. This process was repeated until the p value dropped below 0.05 for the investigated variable.

In order to determine the boundary significant level the Monte Carlo permutation test was performed (separately for each variable and next for the whole model). All lists, calculations and graphic elements were performed in the Canoco for Windows package and

in the Microsoft Excel spreadsheet. The following tools from the Canoco for Windows package were used: Canoco for Windows 4.5, CanoDraw for Windows and WCanoIMP.

The model given below presents dependencies between analysed variables and the distribution of macrophytes in water bodies (Fig. 3).

Fig. 3. The CVA model ($n = 52$) illustrating dependencies between variables (E , pH , $temp.$, H) and distribution of macrophytes in water bodies at $p < 0.05$

The E value (ecological value) was positively correlated with two species, *Alisma plantago-aquatica* (L.) and *Lemna minor* (L.), and the appearance of these species in a water body indicates a deterioration of the ecological status in an ecosystem. Improvement of the ecological status of water bodies was influenced first of all by *Potamogeton natans* L. and *Typha angustifolia*, L., as indicated by the distance between variable E and species (the character of a destimulant).

Strong dependencies were found between water pH values and colonisation of water bodies by different species of macrophytes. Basic reaction was preferred by *Glyceria notata* Chevall., *Schoenoplectus lacustris* (L.) Palla and *Sparganium erectum* (L.) em. Rchb., while acid reaction was favourable for *Glyceria fluitans* (L.) R. Br. The littoral zone of the deepest water bodies was most abundantly colonised by the following species: *Phragmites australis* (Cav.) Trin. ex Steud., *Carex acutiformis* Ehrh., *Carex rostrata* Stokes,

Potamogeton natans (L.), *Phalaris arundinacea* (L.), *Ceratophyllum submersum* (L.) and *Typha angustifolia* (L.). Analogous correlations were observed between the temperature measured in water and identified macrophyte species.

Fig. 4. The CVA model ($n = 52$) illustrating dependencies between location and distribution of macrophytes in analysed water bodies at $p < 0.05$

The two models shown below present dependencies between the distribution of species in analysed water bodies and location and size of these water bodies (Figs. 4 and 5). The greatest biodiversity was found for water bodies located in arable fields. Typical plants appearing in park water bodies included *Oenanthe aquatica* (L.) Poir. and *Carex rostrata* Stokes (eliminated from the model due to the considerable distance from point 0.0). *Alisma plantago-aquatica* (L.), *Lemna minor* (L.), *Glyceria notata* Chevall., *Sparganium erectum* (L.) and *Glyceria fluitans* (L.) (eliminated from the model due to the considerable distance from point 0.0) were species most abundantly colonising water bodies located in built-up areas and in forests.

The size of water bodies turned out to be a variable determining the distribution of macrophytes in the littoral zone of water bodies (Fig. 5). In the smallest water bodies in terms of their surface area first of all *Lemna minor* L. and *Oenanthe aquatica* (L.) Poir.

were found most typically, while such species as *Phragmites australis* (Cav.) Trin. ex Steud., *Schoenoplectus lacustris* (L.) Palla, *Ceratophyllum demersum* (L.) and *Polygonum amphibium* (L.) colonised water bodies of the greatest surface area, as it was indicated by the positive correlation between these species and the largest water bodies.

Fig. 5. The CVA model ($n = 52$) illustrating dependencies between the size of water bodies location and distribution of macrophytes in analysed water bodies at $p < 0.05$

Discussion

Small water bodies situated in agricultural areas are these elements of landscape, in which the effect of human activity is evident. Aquatic and marsh plants are some of the most sensitive elements of these ecosystems. As it was shown by studies conducted by Arczynska-Chudy [26] in the Gen. Dezydery Chlapowski Landscape Park in the 50 analysed ecosystems a total of 181 species of vascular plants were identified.

Aquatic and marsh vegetation is characterised by a specific distribution within the colonised water body. Arczynska-Chudy [26] distinguished three groups of water bodies depending on the vegetation developing in these bodies of water:

1. water bodies with the dominance of one or two communities,
2. small water bodies, in which vegetation forms a mosaic of overlapping phytocenoses,
3. water bodies, in which a zonal distribution of vegetation is found, forming concentric circles around the water sheet.

By interpolating the proposed classification onto thirteen analysed water bodies of the Gen. Dezydery Chlapowski Landscape Park it may be stated that the first group comprises water bodies nos. 1, 2, 3, 7 and 9, the second nos. 4, 5, 8 and 13, while the third contains water bodies nos. 10, 6, 11 and 12. Among the discussed water bodies the greatest species diversity was found for water bodies nos. 5 and 13, while the smallest in nos. 1, 2 and 9. Variable habitat conditions resulted in the formation of small and frequently only single-species patches of aquatic vegetation.

In the years 2003-2004 in the Gen. Dezydery Chlapowski Landscape Park studies on vegetation dynamics were conducted by Arczynska-Chudy [26]. By comparing literature data with the collected results it may be stated that in water body no. 3 an increase was observed for the share of *Phragmites australis* (Cav.) Trin. ex Steud. from 66.2% in 2004 to 75% in 2009 with a simultaneous reduction of the proportion of *Ceratophyllum demersum* (L.) from 33.8% in 2004 to 15% in 2009 (Table 5). Even greater changes were observed in the vegetation cover in water body no. 5 (Table 9). In 2009 an increase was found in the proportion of rush vegetation represented by *Phragmites australis* (Cav.) Trin. ex Steud. by 16.2% and *Typha angustifolia* (L.) by 7.1% in relation to the data from 2004, as well as a decrease in the share of submerged vegetation *Potamogeton natans* (L.) by 29.9%. The share of *Sparganium erectum* L. em. Rchb. s.s. remained practically identical. In turn, the greatest changes were observed in water body no. 6 in relation to 2004; the proportion of submerged vegetation represented by *Ceratophyllum submersum* (L.) dropped by 30.1% at a simultaneous increase in the area covered by *Carex acutiformis* Ehrh. by 1.1%. The appearance of a patch of *Lemna minor* (L.) and *Oenanthe aquatica* (L.) Poir. was also observed (Table 11).

A reduction of the area covered by submerged vegetation *Ceratophyllum* sp. may indicate that the water bodies are becoming shallow, since species of submerged plants are highly sensitive to changes in the water table. The process of shallowing and overgrowing is evident in water body no. 8. In the period with low precipitation totals a complete lack of water was recorded. A lack of precipitation and a lowering of the water table within a short time lead to overgrowing of small water bodies, disappearance of the water table and the appearance of rush associations replacing the previous aquatic vegetation communities.

Small water bodies are elements of the agricultural landscape, which are threatened with degradation. As it results from studies conducted by Bosiacka and Radziszewicz [27], among 56 small water bodies and in-field swamps located in 1965 within the town and commune of Kolobrzeg only 26 survived to the year 2001. They others were covered by waste or become complete dry, and next were managed by agriculture. Also studies conducted by Markuszewska [28] showed a considerable decrease in the number of small water bodies in agricultural areas in the vicinity of Krotoszyn. In 1986 in that area there were 1130 water bodies and in 2000 only 775 remained. If the rate of changes remains comparable, within the next 10-20 years also these small water bodies may disappear from landscape. Among the thirteen analysed water bodies in the Gen. Dezydery Chlapowski Landscape Park water bodies nos. 4, 8 and 11 are most threatened with drying out.

Taking into consideration functions of small water bodies as well as the fact that they are highly sensitive elements of agricultural ecosystems exposed to anthropogenic factors, they would have to be covered by legal protection (establishment of areas of ecological value), while water bodies of low ecological value should be subjected to remediation processes (eg dredging, deepening) in order to restore their previous functions.

Conclusions

1. Based on the proposed valuation method the best ecological status in terms of aquatic and marsh vegetation was found for water bodies Nos. 4 and 5.
2. In three water bodies the ecological status was observed to deteriorate (Nos. 3, 6 and 12), while in case of two water bodies it improved (Nos. 9 and 13).
3. Water bodies Nos. 1 and 12 were characterised by plant cover of limited diversity, which to a considerable degree influenced their ecological status - the water bodies in the second year of analyses was classified to class IV.
4. The improvement of ecological status (E) of the water bodies was influenced by such macrophyte species as *Potamogeton natans* (L.) and *Typha angustifolia* (L.), while its deterioration was influenced by *Lemna minor* (L.) and *Alisma plantago-aquatica* (L.).
5. Species characteristic of the water bodies with an elevated water pH include *Glyceria notata* Chevall., *Polygonum amphibium* (L.), *Schoenoplectus lacustris* (L.) Palla and *Sparganium erectum* L. em. Rchb. s.s., while acid reaction was preferred by *Glyceria fluitans* (L.) R. Br.
6. Most plant species colonised in-field water bodies, which were characterised by a greater floristic diversity in relation to the other types of water bodies.
7. The largest water bodies were colonised by *Phragmites australis* (Cav.) Trin. ex Steud., *Schoenoplectus lacustris* (L.) Palla, *Ceratophyllum demersum* (L.) and *Polygonum amphibium* (L.), while in the smallest water bodies in terms of their surface area first of all *Lemna minor* L. and *Oenanthe aquatica* (L.) Poir. were found most frequently.
8. Due to their multifaceted functions served in landscape and sensitivity to anthropogenic factors small water bodies should be covered by legal protection *eg* by being granted the status of an area of ecological value.
9. Destroyed water bodies should be subjected to remediation measures (*eg* removal of sediments, elimination of pollution sources, maintenance of vegetation buffer zones around water bodies).

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PRZYRODNICZA METODA WALORYZACJI MAŁYCH ZBIORNIKÓW WODNYCH

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Abstrakt: Praca dotyczy opracowania metody waloryzacji małych zbiorników wodnych na terenie parku krajobrazowego o charakterze rolniczym, gdyż dla tego typu obszaru małe zbiorniki wodne mają duże znaczenie, głównie hydrologiczne i przyrodnicze. Badania były prowadzone na terenie Parku Krajobrazowego im. gen. D. Chłapowskiego. Obiektem badań było 13 zbiorników różniących się położeniem w krajobrazie, parametrami morfologicznymi (głębokością, kształtem, powierzchnią, rozwinięciem linii brzegowej) oraz występowaniem roślinności wodnej i bagiennej. Część oczek wodnych to typowe zagłębienia śródpolne, część jest zlokalizowanych na terenach zabudowanych, natomiast dwa położone są w kompleksie leśnym. Celem prezentowanych badań było opracowanie metody waloryzacji małych zbiorników wodnych na podstawie zinwentaryzowanej roślinności wodnej i bagiennej oraz uwzględniając modyfikacje metod przyrodniczych, takich jak metoda Braun-Blanqueta i wskaźniki ekologiczne wg Zarzyckiego. Wykorzystując zmienne środowiskowe, stworzono także modele statystyczne opisujące zależności pomiędzy poszczególnymi gatunkami a badanymi zmiennymi. Badania prowadzono w latach 2008-2009, w których podczas sezonu wegetacyjnego wykonane zostały zdjęcia fitosocjologiczne. Badania dotyczyły roślinności strefy litoralnej oraz otwartej toni wodnej. Dla oznaczonych gatunków makrofitów określono ilościowość i towarzyskość według metody Braun-Blanqueta. Na podstawie danych dotyczących roślinności wodnej i bagiennej oraz zmierzonej powierzchni zbiornika obliczono ich stan ekologiczny. Wyniki wskazują na celowość objęcia małych ekosystemów wodnych ochroną prawną. Natomiast zbiorniki, które uległy głębokiej degradacji, powinny zostać zrehabilitowane poprzez dostępne zabiegi (bagrowanie, tworzenie barier biogeochemicznych).

Słowa kluczowe: ekosystemy wodne, zbiorniki wodne, metoda waloryzacji, metody statystyczne