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Relationship between plant life forms and ecological indices in a lacustrine ecosystem

Research Article

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Abstract: This study is the first to analyze the relationship between ecological indices (substrate moisture, nutrient content, substrate dispersion/aeration, substrate pH and humus content) and life forms of the vascular flora in and around Lake Provala; these relationships may serve as reliable indicators of the ecological conditions prevailing in this ecosystem. Since the development of certain life forms, in addition to climatic conditions, depends on plant requirements for several major environmental factors expressed as ecological indices, we established the relationship between the ecological index and life form of vascular plants collected over an eight year period in this system using correspondence analysis. We found a significant correlation between the development of certain life forms and levels of substrate moisture, nutrient content and substrate dispersion/aeration. These relationships help explain the predominance of hemicryptophytes and hydro-helophytes in the riparian zone of the lake, as these forms are perfectly adapted to water-saturated or aquatic environments rich in nutrients and relatively well aerated. There was no significant relationship between life forms and substrate pH or the content of organo-mineral compounds (humus) in the soil.

Keywords: *Life forms • Ecological indices • Flora • Lacustrine ecosystem*

1. Introduction

Lacustrine ecosystems and their contiguous riparian zones form suitable habitat for the development and proliferation of many plant species adapted to life in the water, and near the shores on highly moistened or somewhat drier substrates. Floristic studies are important because they provide preliminary data for plant ecologists who intend to study the ecology and biodiversity in a given area.

It is well known that plants are good bioindicators of the prevailing environmental conditions in which they grow [1]. Ellenberg was among the first to provide a theoretical and methodological basis for the evaluation and use of ecological indices of plants [2-4]. Besides Ellenberg, a number of other researchers have studied these bioindicator values of plants in great detail [5-10].

In addition to these ecological indices, environmental research also relies on the analysis of life forms (after Raunkiaer), which reflect the degree of adaptation of plant species to specific climatic conditions. The range of life forms found in the flora of a certain area indicates not only how adapted these plants are to climatic conditions, but also provides an indication of the possible stressors and their impacts on the studied ecosystem [11].

In this study, we assessed ecological indices according to life form of plant species known to occur around Lake Provala, Serbia. Our results provide insight into the relationships between individual life forms and their most important bioindicator values.

Multi-year floristic studies (1996-2004) were carried out around Lake Provala, Vojvodina Province, Serbia (5°29'N, 18 °86'E, 79 m). The Danube River flows 5.5 km west of the lake. At mean water level, the average lake surface area is 42,000 m^2 and its volume, is approximately 282,580 m^3 (maximum depth 19 m). The lake was created during the great flood of 1924, when the Danube River breached a levee causing the rushing water to produce a basin which has since

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persisted [12,13]. At its deepest, the transparency of the lake water is 150 cm. The physico-chemical parameters of Lake Provala water show high dissolved oxygen values as a result of high levels of organic production in the period April-August. There was also an evident decrease in dissolved oxygen during the autumn months, pH values exceeding 8.3 during vegetation period (April-August), and variable contents of biogenic salts (mesotrophic, average mineral N content; meso-mesoeutrophic, P content) [14].

Despite a number of earlier studies of the biota surrounding the Lake Provala ecosystem [14-18], our study is the first to examine the relationships among important ecological indicators and life form of the vascular flora of the lake. These indicators provide simple insight into the ecological conditions of this lake, which is dominated by vascular macrophytes.

2. Experimental Procedures

All species of vascular plant encountered around the lake and its riparian zone were collected from April to August between 1996 and 2004 and identified based on a number of taxonomic references of common flora in the region [19-22].

Life forms of identified plant species were assigned according to Soó [23]. Ecological indices (bioindicator values) of plant requirements for moisture (F), chemical reaction of the environment (R), contents of nitrogen and nitrogen compounds (N), content of humus, *i.e.*, organo-mineral compounds (H) and dispersion/aeration of the environment (D) were assigned according to Landolt [6]; these five indices were found to be sufficiently descriptive to accurately define the ecological status of this system.

Values of the ecological indices are expressed on the scale 1-5, where 1 stands for minimum requirements and 5 for maximum requirements (Table 1). The mean value of each ecological index was calculated as the sum of numerical values of the ecological index for all plant species divided by the total number of species in the studied area.

Since in our work we compare ecological indices, which are expressed in relative values, against life forms, which are expressed descriptively, we applied correspondence analysis in order to obtain exact values of relations between them. This statistical procedure is often used in the analysis of ecological data sets (http://ordination.okstate.edu/CA.htm). It is a descriptive technique that serves to establish a measure of correspondence between rows and columns in complex tables; two- or multi-dimensional frequency tables are standardized by defining their relative frequencies. The fundamental hypothesis is based on the homogeneity of rows and columns [24]. For this reason, row and column totals of the matrix of relative frequencies are used [24]. Correspondence analysis also allows for the possibility of testing hypotheses using χ^2 values by partitioning the total χ^2 value based on the sum of squares of deviations of actual frequencies from expected ones in a contingency table [24].

Correspondence analysis was used in this study to explain the relationship among categorical variables. Categorical variables used were plant species, life form and ecological index. We used the biplot technique, which is a representation of categorical variables graphed simultaneously. This procedure allows for the presentation of relationships among the categories of row and column variables in the same space (http://www.gseis.ucla.edu/courses/data/hsb2,clear). The biplot allows us to interpret the distances between two row points and between two column points, but not the distances between row and column points. Statistical analysis was performed using STATISTICA 8.0 software (StatSoft).

3. Results

During the course of the study, we collected 65 plant species [17] (Table 1). All of the species collected belonged to the phylum *Magnoliophyta;* 41 were in the class *Magnoliopsida* and 24 in the class *Liliopsida*. These 65 species of identified flora were grouped into 7 life forms (Table 2).

Correspondence analysis was used to assess the relationships between the registered life forms and the five ecological indices under study (Figure 1a-e). In the case of the ecological indices F, N and D, the χ^2 values were statistically significant indicating that there exists a high association between the frequencies of the life forms and humidity (F), nitrogen/nutrient content (N) and aeration/dispersion (D) (Table 3). In the case of the ecological indices R and H, chi square value was not statistically significant (Table 3).

The correspondence analysis explained about 94% of the relationship between life forms and the ecological indices F (moisture) and N (contents of nitrogen and nitrogen compounds) and about 90% of the relationship with the ecological index D (aeration/dispersion) (Figure 1a, c, e).

4. Discussion

Interactions among various environmental factors, including light, temperature, sediment composition, amount of nutrients, availability of carbon, water

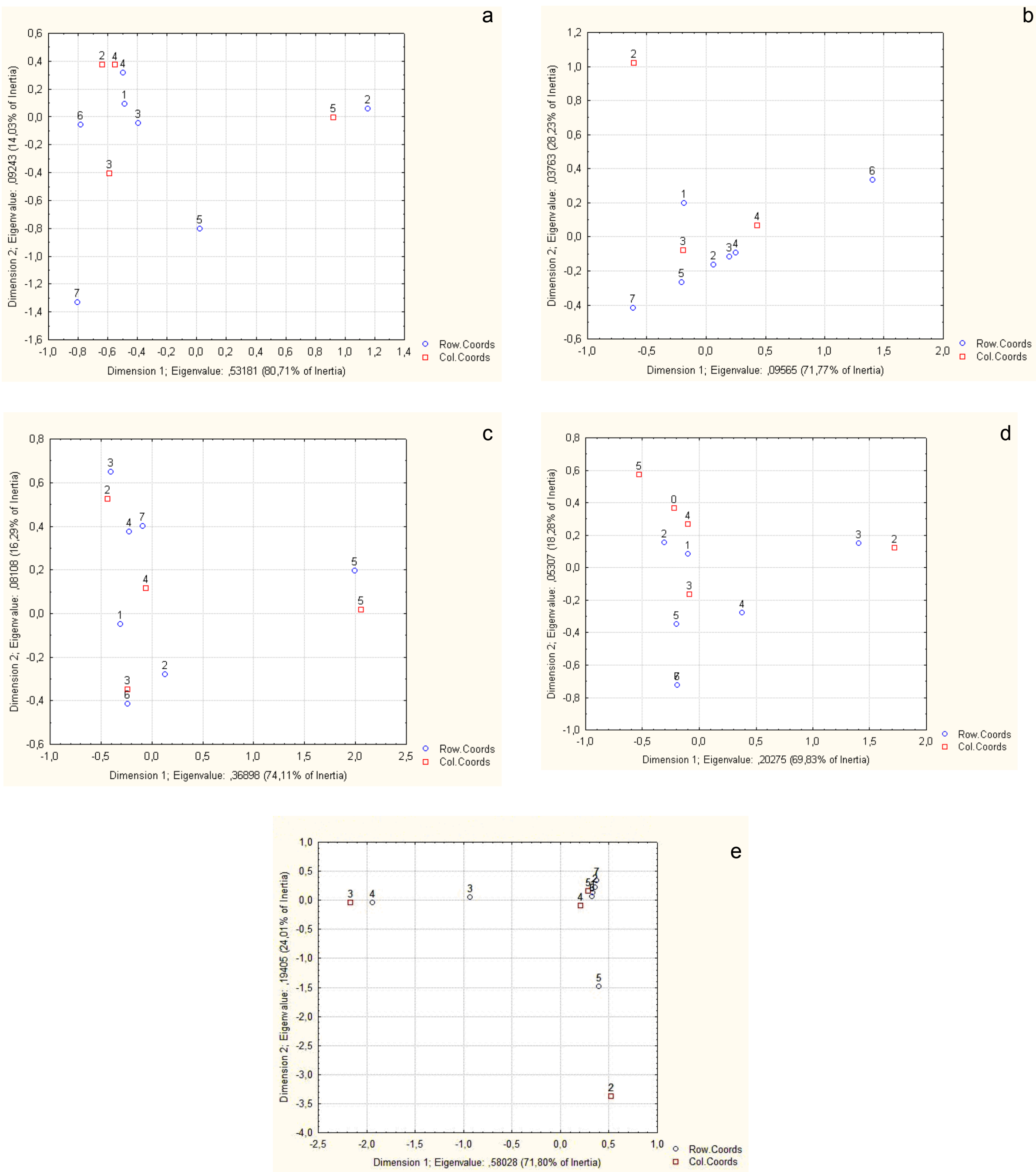

Figure 1. Biplots of life forms and ecological indices F, R, N, H and D (a, b, c, d and e, respectively). (a,c,d,e) Numbers 1-7 stand for the life forms as labeled in Table 2, numbers 2-5 stand for the ecological index as labeled in Table 1. (b) Numbers 1-7 stand for the life forms as labeled in Table 2, numbers 2-4 stand for the ecological index as labeled in Table 1.

flow and shading are of crucial importance for the development and productivity of macrophytes [25-32]. The dominant hydro-ecological conditions in the studied area resulted in considerable floral biodiversity, as is demonstrated by the presence of 65 *Magnoliophyta* plant species, which characterizes this aquatic ecosystem as macrophytic.

In Lake Provala, only three hydrophytes (*Myriophyllum spicatum* L., *Nymphoides peltata* (Gmel.) O. Kunt., and *Ceratophyllum demersum* L.) are found in abundance. Because of their competitiveness and adaptability, these species did not enable the development of other hydrophytes [33,34]. The above hydrophytes formed pure stands in our study site. In the shallowest parts of

Group of life forms	No.	Plant species	Life form	Ecological index				
				F	R	N	H	D
Hemicryptophytes	1.	*Agrimonia eupatoria* L.	H	2	4	3	3	4
	2.	*Althaea officinalis* L.	H	3	3	4	3	4
	3.	*Agrostis capillaris* Sibth.	H	3	2	2	3	4
	4.	*Arrhenatherum elatius* (L.)Mert. et C. Koch	H	3	3	4	3	4
	5.	*Calystegia sepium* (L.) Br.	H	4	4	4	3	5
	6.	*Carex hirta* L.	H	4	3	3	3	5
	7.	*Juncus inflexus* L.	H	4	3	3	3	5
	8.	*Lotus tenuis* Kit.	H	3	4	2	3	5
	9.	*Eupatorium cannabinum* L.	H	4	4	4	3	4
	10.	*Galium mollugo* L.	H	3	3	4	3	4
	11.	*Carex vulpina* L.	H-HH	5	4	2	4	4
	12.	*Epilobium hirsutum* L.	H-HH	4	3	4	4	5
	13.	*Juncus atratus* Krock.	H	4	2	3	4	5
	14.	*Lythrum salicaria* L.	H-HH	4	3	3	4	5
	15.	*Mentha aquatica* L.	H-HH	5	3	3	4	5
	16.	*Mentha pulegium* L.	H	4	3	4	4	5
	17.	*Ononis spinosa* L.	H-Ch	2	3	2	3	5
	18.	*Plantago major* L.	H	3	3	4	3	5
	19.	*Poa palustris* L.	H	5	4	3	4	5
	20.	*Potentilla anserina* L.	H	3	3	4	3	5
	21.	*Prunella vulgaris* L.	H	3	3	3	3	4
	22.	*Ranunculus repens* L.	H	4	3	4	3	5
	23.	*Rumex crispus* L.	H	3	3	4	2	4
	24.	*Sambucus ebulus* L.	H	3	4	4	3	4
	25.	*Scutellaria galericulata* L.	H	5	3	3	5	5
	26.	*Solidago serotina* Ait.	H	4	3	3	x	x
	27.	*Stachys palustris* L.	H	4	3	3	4	5
Hydro-helophytes	28.	*Bolboschoenus maritimus* (L.)Palla.	HH–G	5	4	3	3	5
	29.	*Butomus umbellatus* L.	HH	5	3	4	4	5
	30.	*Alisma plantago-aquatica* L.	HH	5	3	3	3	5
	31.	*Ceratophyllum demersum* L.	HH	5	4	5	3	5
	32.	*Hydrocharis morsus-ranae* L	HH	5	3	4	3	5
	33.	*Glyceria maxima* (Hartm)Holm.	HH	5	4	5	3	5
	34.	*Myriophyllum spicatum* L.	HH	5	4	2	4	5
	35.	*Nymphoides peltata* (Gmel.)Kuntze	HH	5	3	4	5	5
	36.	*Phragmites communis* Trin.	HH	5	3	3	3	4
	37.	*Potamogeton pectinatus* L.	HH	5	4	4	3	4
	38.	*Ranunculus paucistamineus* Tsch.	HH	5	3	4	3	5
	39.	*Lemna minor* L.	HH	5	3	3	4	5
	40.	*Lycopus europaeus* L.	HH	5	3	3	5	5
	41.	*Lysimachia vulgaris* L.	HH	4	3	3	4	5
	42.	*Schoenoplectus lacustris* (L.) Palla	HH-G	5	3	3	4	4
	43.	*Typha angustifolia* L.	HH	5	4	3	3	5
	44.	*Typha latifolia* L.	HH	5	3	4	3	5
	45.	*Typhoides arundinacea* (L.) Mnch.	HH-H	5	3	4	3	4

Table 1. Plant species sampled in and around Lake Provala, their life forms and ecological indices.

H–hemicryptophytes; HH-hydro-helophytes; Ch–chamaephytes; G–geophytes; M–micro-phanerophytes, MM–mega-mesophanerophytes, Th - therophytes TH - hemitherophytes; F – humidity value, R – reaction value, N - nutrient value, H – humus value, D – dispersion/aeration deficiency value.
Note: Landolt did not provide values of ecological indices H and D for the species S. serotina.

Group of life forms	No.	Plant species	Life form	Ecological index				
				F	R	N	H	D
Geophytes	46.	*Cirsium arvense* (L.) Scop.	G	3	3	4	3	4
	47.	*Agropyrum repens* (L.) Beauv.	G	3	3	4	2	3
	48.	*Juncus compressus* Jacq.	G	4	3	3	3	5
	49.	*Heleocharis palustris* (L.) R. Br.	G-HH	5	4	2	4	5
	50.	*Carex praecox* Schreb.	G-H	2	4	2	2	3
Phanerophytes	51.	*Amorpha fruticosa* L.	M	4	3	3	3	3
	52.	*Populus alba* L.	MM.-M	3	4	4	3	3
	53.	*Populus nigra* L.	MM-M	4	4	4	3	3
	54.	*Robinia pseudo-acacia L*	MM	2	3	4	3	3
	55.	*Salix alba* L.	MM-M	4	4	4	2	3
	56.	*Salix cinerea* L.	M	5	3	2	4	5
	57.	*Sambucus nigra* L.	MM-M	3	3	4	3	4
Thero phytes	58.	*Bidens tripartitus* L	Th	5	3	5	4	4
	59.	*Bromus mollis L.*	Th	3	3	4	3	4
	60.	*Centaurium umbellatum* Gilib.	Th	5	4	5	3	5
	61.	*Odontites rubra* Gilib.	Th	3	3	4	3	5
	62.	*Xanthium italicum* Moretti	Th	3	3	5	3	2
Hemit-hero-phytes	63.	*Inula britannica* L.	TH.-H	4	4	3	3	4
	64.	*Dipsacus laciniatus* L.	TH	3	4	4	3	5
Chame-phytes	65.	*Solanum dulcamara* L.	Ch (N)	3	3	4	3	5
		Mean values of ecological indices		**3.94**	**3.29**	**3.49**	**3.28**	**4.44**

continued **Table 1.** Plant species sampled in and around Lake Provala, their life forms and ecological indices.

H – hemicryptophytes; HH - hydro-helophytes; Ch – chamaephytes; G – geophytes; M – micro-phanerophytes, MM – mega-meso phanerophytes, Th - therophytes TH - hemitherophytes; F – humidity value, R – reaction value, N - nutrient value, H – humus value, D – dispersion/aeration deficiency value.
Note: Landolt did not provide values of ecological indices H and D for the species S. serotina.

Life form	Plant species
Hemicryptophytes (1) (H, H-HH, H-Ch)	27
Hydro-helophytes (2) (HH, HH–G, HH-H)	18
Geophytes (3) (G, G-HH, G–H)	5
Phanerophytes (4) (M, MM.-M, MM)	7
Therophytes (5) (Th)	5
Hemitherophytes (6) (TH.-H, TH)	2
Chamaephytes (7) Ch (N)	1
Total	65

Table 2. Frequencies of plant species sampled according to life form.

the lake (up to 1 m), *N. peltata,* a floating, rooted, and decorative hydrophyte with a long flowering period, dominated. In Lake Provala, it reached a vegetation peak during the summer period and it vegetated until late fall when it could still be found in bloom. In the middle of the lake (1-2 m depth), stands of *C. demersum,* a submersed, unrooted hydrophyte, was prevalent, but covered only small areas. The deeper parts of the lake (>2 m) were dominated by pure stands of *M. spicatum*, a highly adaptable and competitive species which tolerates low-light conditions and low water temperatures and which exhibits negative allelopathic effects by inhibiting the development of other hydrophytes [33]. Besides the above three species, the following hydrophytes could be found growing as individual plants: *H. morsus-ranae*, *P. pectinatus*, *R. paucistamineus* and *L. minor*.

Ecological index	χ^2 value	P (df)
Index F	42.80*	P=0.0009 (18)
Index R	8.66	P=0,7314 (12)
Index N	32.36*	P=0.0200 (18)
Index H	17.20	P=0.5054 (18)
Index D	51.73*	P=0.0000 (18)

Table 3. χ^2 values for the relationship between life form and ecological index. P-values (α 0.05) and degrees of freedom (df) for each test are presented.

As a consequence of the large-scale dominance of the three species of hydrophytes discussed, the biodiversity of flowering plants in the lake itself is quite poor. This pattern results in increased floral diversity along the marginal zone, where plant species adapted to tolerating variations in substrate moisture can find favorable conditions for development. Although it is an aquatic ecosystem, hemicryptophytes were more numerous than hydro-helophytes in Lake Provala.

Analyses of the relationship between ecological indices (F, R, N, S and D) and life forms of the study plants showed a clear association between certain ecological factors and the development of particular life forms in vascular plants. There was a significant correlation between the development of the studied life forms and the level of substrate humidity (F), nutrient content (N) and dispersion/aeration of the substrate (D). No significant association could be found between the ecological indices for the chemical reaction of the substrate (R) and humus content (H), and the development of certain life forms.

The hydro-ecological characteristics of Lake Provala and its riparian zone resulted in the predominance of hemicryptophytes and hydro-helophytes. These species are fully adapted to the conditions of a moisture-saturated or aquatic environment, as indicated by a mean ecological index F, of 3.94. The development of hemicryptophytes and hydro-helophytes was stimulated by the eutrophic substrate/environment rich in nutrients, as indicated by a mean ecological index N of 3.49 and a poorly aerated substrate/environment with a mean ecological index D, of 4.44. In addition, the physico-chemical properties of the water classified the trophic status of the lake as mesoeutrophic (regarding N content) to eutrophic (regarding P content), with a considerable dissolved oxygen deficiency during the vegetation period [14].

Such hydro-ecological conditions encourage the development of numerous vascular plants, which indicates the presence of eutrophic conditions. A number of authors [14,27,35] maintain that an intensive growth and development of macrophytes in the long run can accelerate the process of eutrophication, which in turn results in a still more abundant plant growth in subsequent seasons, starting from the shallow parts of this specific lake ecosystem. This growth cycle has the potential to disturb the overall ecological balance of this lake system. In view of the current uses of the lake (sports and recreation), it is important to monitor the development of the macrophytic vegetation and undertake adequate control measures to ensure that the abundance of macrophytes and phytoplankton remains manageable, as increases in their abundance would upset the ecological balance of the lake.

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