Oceanological and Hydrobiological Studies

International Journal of Oceanography and Hydrobiology

Volume 43, Issue 2

ISSN 1730-413X (138–146)
eISSN 1897-3191 2014

VERSITA

DOI: 10.2478/s13545-014-0126-y
Original research paper

Received: *November 15, 2013*
Accepted: *March 05, 2014*

The impact of land use and water quality on the flora of ecotones along a small lowland river (Central Poland)

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Key words: riparian zone, river valley, alder forest, restoration, macrophytes, IndVal

Abstract

The presented study describes the plant species diversity within the terrestrial-water ecotone in relation to the land-use form in a river valley. The study was performed in a lowland river valley where the main forms of riparian zones are partially urbanized, forested and agricultural; the latter being most commonly observed in the investigated region. The present study examines the vascular flora of ecotones where more than 100 plant species were identified. Ecological indices were calculated at all sampling sites based on Zarzycki's ecological values and biodiversity indices. In addition, the aim of the study was to identify the relationships between the physico-chemical parameters of the water and the floristic indicators in the neighbouring ecotones.

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Abbreviations: EZ – built-up ecotones, EL – alder forest ecotones, ER – agricultural ecotones, IV - Indicator values.

INTRODUCTION

The freshwater ecosystems are among those most modified and threatened by human impact (Malmqvist & Rundle 2002, Gaudi 2005), mainly due to landscape manipulation (Allan & Flecker 1993). Intentional and/or unintentional changes in rivers and river catchments are caused by increased agricultural impact and urbanization (Gaudi 2005, MEA 2005). Urbanization directly affects the hydrographic properties of river systems by reducing the permeability of land surface and groundwater recharge, and by delivery of pollutants (e.g. Patten 1998, Savini & Kammerer 1961 in Gaudi 2005, Chin 2006). Agriculture is one of the most important sources of water pollution, either by production of sediments or chemical waste (Meybeck 2001, Davies et al. 2008). Pesticides, synthetic fertilizers, sewage and animal wastes from feedlots enter rivers along different routes with groundwater and storm-water runoff (Berka et al. 2001). The high level of nitrates and phosphates delivered from point and area sources of contamination may be significantly reduced by plants growing in the riparian zone, particularly riparian forests (Naiman & Dacamps 1997, Anbumozhi et al. 2005). Riparian plant communities moderate water temperature, regulate river flow and control bank erosion (Palink et al. 2000). However, agricultural expansion and urbanization frequently involves the whole catchment area up to the river channel. The ecological consequences of converting the floodplain areas to cropland and the development of flooding and erosion control infrastructure are closely connected with the removal of natural vegetation, which results in the degradation of wildlife ecosystems (Gaudi 2005, Sudduth & Meyer 2006, Florsheim et al. 2008). Anthropogenic changes are particularly conspicuous along river corridors, the most significant of which is the modification of vegetation in riparian zones (Naiman & Dacamps 1997, Davies et al. 2008). These transitional areas occurring between terrestrial and water ecosystems, characterized by distinctive hydrological, soil and biotic conditions and influenced by river water, are responsible for many functions considered to be crucial for the preservation of ecological and aesthetic conditions of a river (Verry et al. 2004, Naiman et al. 2005, Richardson 2008).

In the light of this widespread land-use transformation, an assessment of the ecological condition of rivers is needed, both for designing an effective management policy and as a basis for biodiversity conservation (Freeman & Ray 2001, Water Framework Directive 2000/60/EC, MEA 2005). Knowledge of riparian vegetation is of major importance for characterizing the function of the terrestrial-water ecotone (Clerici et al. 2013). The present study describes the results of the research on plant species diversity and water quality within the land-water zone of a small lowland river in relation to the land-use form employed in adjacent habitats.

MATERIALS AND METHODS

Study area

The Mrożyca is a small 33.4 km-long river which has its source near the town of Brzeziny, Central Poland. It is a left, 4th order tributary of the Mroga River, which is itself a right tributary of the Bzura River (Fig. 1). As the headwater area of the Mrożyca is located at an altitude of 192.0 m a.s.l. in the eastern part of the Łódź Heights and its mouth is at a level of 120.6 m a.s.l., the river has quite a steep gradient of 2.14‰. The Mrożyca River basin is distinctly asymmetrical and prolate, with an area of 117.3 km^2, and its left part is much more developed than the right one. There are a few short left tributaries, of which the most important are the 4.6 km Grzmiąca and an unnamed stream with a source near the village of Bratoszewice. The Mrożyca basin runs across a considerable reduction in the ground level as its area covers four erosion escarpments within the Łódź Heights, descending stepwise into the Warsaw-Berlin proglacial stream valley. This basin morphology accounts for a rather steeply sloping longitudinal profile of the river bed, its swift current and considerable erosive potential. The highest culmination of the basin is located in the SW part of the watershed at an altitude of 259.9 m a.s.l.

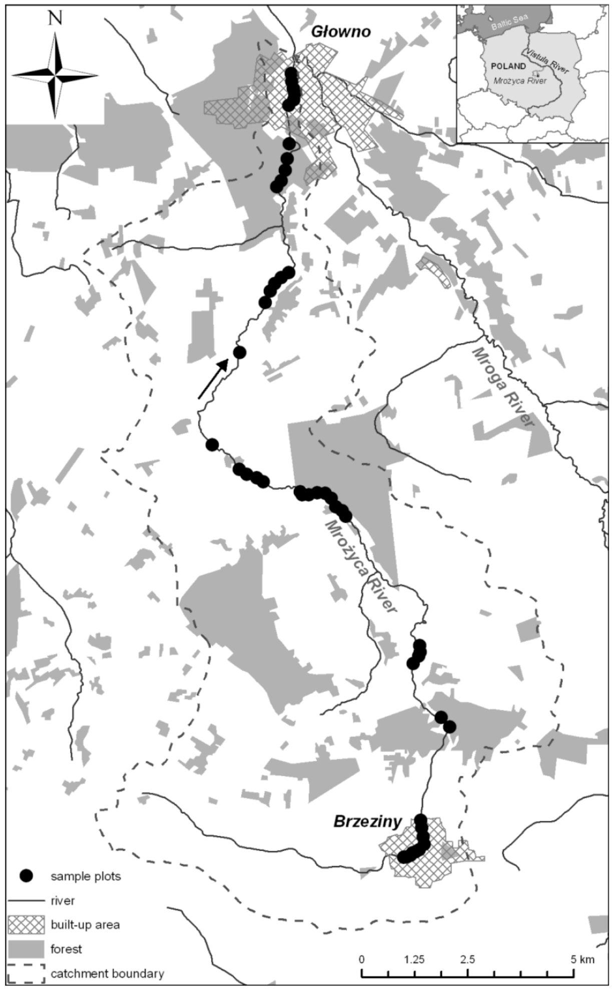

Fig. 1. Location of sampling plots along the Mrożyca River

The management structure of the Mrożyca catchment (based on Corine Land Cover 2006) is mainly dominated by agricultural lands – over 84% of the total land area; forests cover approximately 8% of the total area. The catchment sections representing the middle and lower river course have been exposed to the most intensive agricultural development, while the source and mouth sections are characterized by the highest degree of urbanization. Different types of land use in the Mrożyca River valley have required different treatments to be performed in the river bed, which have been carried out to a greater or lesser extent. Parts of the Mrożyca river banks running through the urbanized areas of the river valley are covered with fascine, and the river channel was straightened in the towns of Brzeziny and Głowno, a typical modification for some urbanized areas. However, no morphological modifications can be observed as the river runs through most agricultural areas or the most natural river sections which cut through the forested parts of the river valley. Generally, the extent of human interference is not significant along the largest part of the river channel, apart from the area of bridges and water-mills, and the places where the latter existed in the past. The studied ecotone is mostly shaded by trees and shrubs. The least amount of shading occurs in built-up areas where, if the trees have been preserved, their branches are pruned and their crown closure is relatively small. In contrast, the shade in agriculture ecotones is similar to that of forest ecotones, where so many short crowns of trees and shrubs grow on the embankment that it is difficult for the sunlight to reach the riverbed.

Methods

Vegetation sampling

The research encompassed 47 sample plots in the Mrożyca River valley, which were subjected to floristic ecotone investigation, 10 of which were also evaluated with respect to their water parameters (Fig. 1). Floristic investigations were carried out in the growing season of 2010. The object of the study was the vascular ecotone flora. The sample plots were rectangular, with dimensions 5 × 50 m, and were positioned in such a way that a fragment of the river bed was included inside each plot, and the longer sides were parallel to the bank. These areas were located in relation to the land use in the homogeneous parts of the valley: fifteen plots were located in the vicinity of cultivated fields (ER), 16 plots − near built-up areas (EZ) and the other 16 − in the vicinity of alder forests (EL).The cover of all vascular plant species, i.e. herbs, shrubs and trees, was estimated in each plot using a ten-degree cover-abundance scale (Londo 1976) with "1" indicating a few individuals covering less than 1% and "10" indicating vegetation cover of more than 90% of the total plot area, which allowed both the number of species and the proportion of the area covered to be estimated. Plant species were categorized as macrophytes according to Szoszkiewicz et al. 2010.

The following parameters were calculated at each sampling site:

- ecological indices based on the ecological values of Zarzycki et al. (2002). These indices were calculated as a weighted average: the weights were treated as a cover-abundance scale expressed by the Londo scale.
- biodiversity indices: the number of species, Shannon's and evenness indices. These values were calculated using the MVSP (ver. 3.13) software.

Water quality analysis

The quality of the Mrożyca river water was assessed for 10 of the sample plots by evaluating the following parameters: temperature, pH, conductivity, BOD5 and the amount of dissolved oxygen, as well as the concentrations of ammonium, nitrate, nitrite and phosphate ions. The water used in physicochemical analyses was sampled once a month from spring 2010 (May) to spring 2011 (April). All procedures were carried out according to Polish Standards. Spectrophotometric measurements of iron, ammonium nitrate, nitrite and phosphate ion concentrations were performed with the use of a VIS Metertech SP830 spectrometer. Potentiometric measurements were carried out with a Hydromet ERH-111 combination electrode coupled with an Elmetron CP-411 pH meter. Conductivity was analyzed using a HYDROMET CD-2 sensor, dissolved oxygen was analyzed using an Elsent CTN 9202S sensor. Sensors were coupled with Elmetron CCO-401 equipment.

Statistical analysis

As the data were not normally distributed even after transformations, only non-parametric tests were used. The relationships between floristic indices and water parameters were tested by Spearman's rank correlation coefficient. The Kruskal-Wallis test, a non-parametric analysis of variance for more than 2 independent groups of data, and the Dunn *post-hoc* test were used to determine the relationship between indicator values and the type of land use in the valley. All statistical analyses were performed using STATISTICA 9.0 software (StatSoft Inc. 2010).

Plant species significantly associated with each type of ecotone were identified based on indicator values (IndVals) (Dufrêne & Legendre 1997). IndVals were calculated using PC-ORD statistical software (McCune & Mefford 2011). Also in PC-ORD, the significant maximum IndVals for each subcluster were identified using the Monte Carlo randomization test. The average physico-chemical values were used for all statistical analyses.

RESULTS

The total species inventory for the studied sampling sites consisted of 128 plant species: *Urtica doica, Aegopodium podagrarie* and *Phalaris arundinacea* being the most abundant ones, occurring on more than 80% of the investigated areas, independent of the land-use form in the valley. Of the 128 species identified, 30 were identified as closely related to the specific type of ecotone.

The largest number of species occurred in ecotones on the border between the river and in the alder forest (Table 1). Twelve taxa were associated with forest areas, including *Scirpus sylvaticus* and *Veronica beccabunga* with the highest affinity, while 11 vascular species, including archaeophytes such as *Ballota nigra* and invasive alien species such as *Echinocystis lobota*, were associated with agricultural sections of the river valley. In addition, *Anthriscus sylvestris* and *Ulmus laevis* were distinguished by high stability and significant cover. The third significant group of species comprised those associated with ecotones in built-up areas (Table 1). Only 7 species were included in this group, including dominant *Geranium pratense*, *Dactylis glomerata* and *Convolvulus arvensis*.

Only 3 of the 8 analyzed floristic indicators (trophic status IV, Shannon's and evenness indices) were not found to differ significantly between the EZ, ER and EL groups. The EL flora was found to differ significantly from the EZ flora with regard to the remaining five indicators, however, the ER flora was observed to differ with regard to only two indicators: trophic status and moisture IV (Fig. 2). It is worth noting that the differences observed between the EZ and ER flora were significantly lower.

Physical and chemical parameters of the Mrożyca river water were very diverse (Table 2). Significant seasonal differences were observed in nutrient concentrations: high concentrations were observed in early spring and winter, while lower concentrations − in summer. Differences in the concentrations of nutrients were also determined by the type of land use − the highest concentrations of ammonium nitrogen and nitrate were observed in the vicinity of cultivated fields (ER) and built-up areas (EZ) (Table 3).

In addition, water quality was not found to exert a significant influence on the floral composition of the ecotones. Of the 8 calculated ecological indicators, only light and Evenness were correlated with changes in phosphate concentration (Table 4). No statistically significant correlation was found between the other water parameters and ecological indices of the ecotone flora.

Table 1

Indicator value scores (IndVal) and associated significance (P) obtained by Monte Carlo permutations for plant species in the three studied types of ecotones. Species are listed in descending order of IndVal in each group. Significant characteristic taxa of each stream have IndVal>15 and P<0.1

Species name	IndVal (%)	p-value	Light IV	Moisture IV	Trophic status IV
Built-up ecotones – EZ					
Geranium pratense L.	66.3	***	4.0	3.0	4.0
Arctium lappa L.	37.5	**	5.0	3.0	5.0
Glechoma hederacea L.	34.6	*	3.0	3.5	4.0
Convolvulus arvensis L.	33.7	**	5.0	2.5	3.0
Crepis paludosa (L.) Moench	27.3	*	3.0	4.5	4.0
Dactylis glomerata L.	27.1	*	3.0	4.5	4.5
Mentha longifolia (L.) L.	17.9	*	4.0	4.5	4.0
Agricultural ecotones – ER					
Ulmus laevis Pall.	60.7	***	3.0	4.0	4.0
Sambucus nigra L.	51.4	**	4.0	3.5	4.5
Anthriscus sylvestris L.	49.3	**	4.0	3.0	4.5
Echinocystis lobata (F. Michx.) Torr. & A. Gray	46.8	***	4.5	3.5	4.5
Aegopodium podagr aria L.	46.1	**	3.5	3.5	4.0
Symphytum officinale L.	33.9	*	4.0	4.5	4.0
Athyrium filix-femina (L.) Roth	31.8	*	2.0	3.5	3.0
Chelidonium majus L.	31.3	*	3.5	3.0	4.5
Dryopteris carthusiana (Vill.) H. P. Fuchs	26.7	**	2.0	3.5	3.5
Taraxacum officinale L.	22.7	*	4.0	3.0	4.0
Ballota nigra L.	16.8	*	4.0	3.0	4.5
Forest ecotones – EL					
Veronica beccabunga L.	55.7	***	4.5	5.5	3.5
Scirpus sylvaticus L.	54.2	***	4.0	4.5	4.0
Elodea canadensis Michx.	53.0	***	4.0	6.0	3.0
Cirsium oleraceum (L.) Scop.	50.5	**	3.5	4.5	4.0
Alnus glutinosa (L.) Gaertn.	49.8	***	3.0	5.0	3.5
Solanum dulcamara L.	48.8	**	4.0	4.5	3.5
Caltha palustris L.	46.0	***	4.0	5.0	4.0
Myosotis palustris (L.) L. emend. Rchb.	39.4	**	4.0	4.5	4.0
Filipendula ulmaria (L.) Maxim.	31.5	*	3.0	4.5	4.0
Poa palustris L.	31.2	**	4.0	4.0	4.0
Phragmites australis (Cav.) Trin. ex Steud.	28.4	*	4.5	5.5	3.5
Galium palustre L.	25.0	*	4.0	4.5	3.0

* - p < 0.1; **- p<0.01; *** - p<0.001

Table 2

Average values, maximum, minimum and mean standard deviations of water physico-chemical parameters

Values	Water temperature (°C)	Dissolved oxygen ($mg\ dm^{-3}$)	Conductivity ($\mu S\ cm^{-1}$)	pH	BOD_5 ($mg\ dm^{-3}$)	Phosphates PO_4^{3-} ($mg\ dm^{-3}$)	Nitrates NO_3^- ($mg\ dm^{-3}$)	Nitrites NO_2^- ($mg\ dm^{-3}$)	Ammonia NH_4^+ ($mg\ dm^{-3}$)
Mean	9.60	7.93	180.88	7.72	6.92	1.22	3.34	0.06	1.50
max	20.00	13.70	265.50	8.21	13.70	2.97	5.65	0.23	9.08
min	1.40	4.90	130.80	6.79	3.00	0.16	0.44	0.01	0.09
mean standard deviation	1.00	0.82	20.81	0.15	1.11	0.37	0.71	0.03	1.30

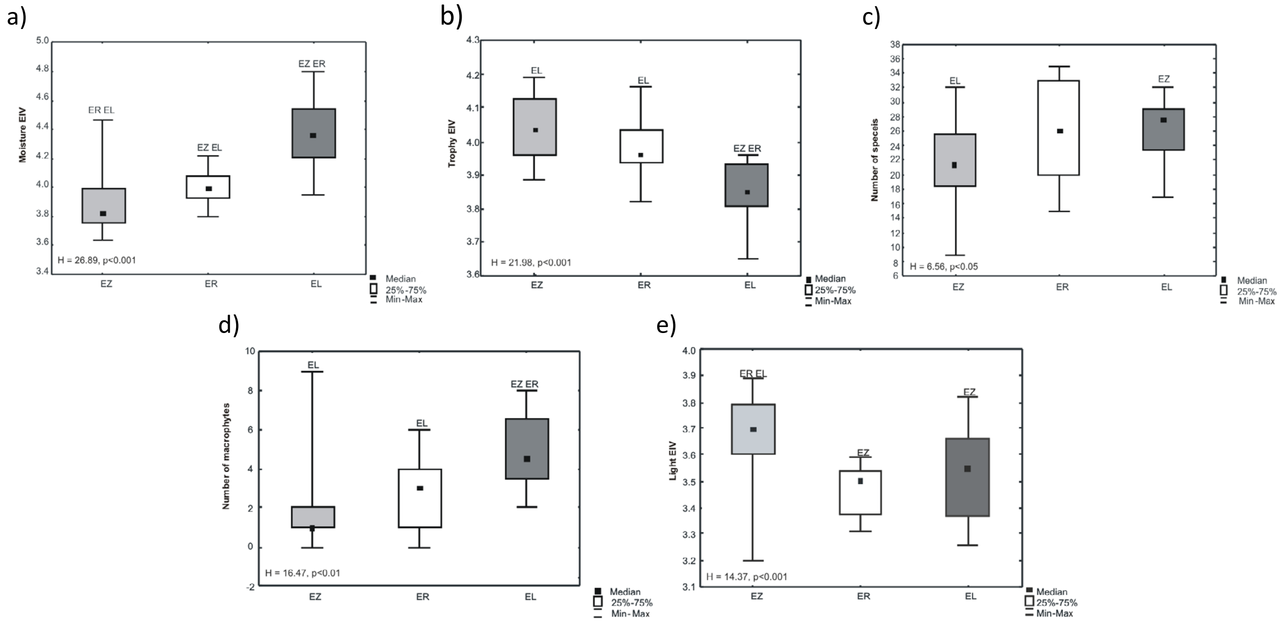

Fig. 2. Diversity of moisture IV (a), trophic status IV (b), the number of plant species (c), the number of macrophytes (d) and light IV (e) in built-up ecotones (EZ), agricultural ecotones (ER) and forest ecotones (EL). Over the bars information about statistically significant differences between ecotones (Kruskal-Wallis's and Dunn's test)

Table 3

The content of ammonium and nitrate in water samples in three types of ecotones

Ecotone type	Nitrates NO_3^- ($mg\ dm^{-3}$)			Ammonia NH_4^+ ($mg\ dm^{-3}$)		
	average	max	min	average	max	min
EZ	3.30	5.65	0.44	0.74	3.41	0.09
ER	3.43	4.72	1.99	2.02	9.08	0.18
EL	3.23	4.36	1.11	0.91	3.51	0.16

Table 4

Correlation between ecological indices and water parameters (Spearman's rank correlation). The correlation coefficient marked with an asterisk are statistically significant ($p<0.05$)

Ecological index	Conductivity ($\mu S\ cm^{-1}$)	pH	BOD_5 ($mg\ dm^{-3}$)	Phosphates PO_4^{3-} ($mg\ dm^{-3}$)	Nitrates NO_3^- ($mg\ dm^{-3}$)	Nitrites NO_2^- ($mg\ dm^{-3}$)	Ammonia NH_4^+ ($mg\ dm^{-3}$)
Light IV	0.48	-0.08	0.45	**0.67***	0.05	0.22	0.03
Moisture IV	-0.04	-0.22	-0.19	-0.02	-0.21	0.26	0.36
Trophic status IV	0.22	0.13	0.10	-0.26	0.26	-0.24	-0.25
Acidity IV	0.55	-0.31	0.39	0.27	-0.15	0.13	-0.05
Number of macrophytes	0.01	-0.07	-0.13	0.21	-0.10	0.24	0.35
Number of plant species	0.02	0.12	-0.14	0.28	0.32	0.42	0.56
Shannon index	0.12	0.16	0.13	0.48	0.30	0.47	0.55
Evenness	0.36	-0.12	0.48	**0.88***	0.33	0.60	0.36

DISCUSSION

As ash-alder forest is the dominant climax forest community in the studied area of the Mrożyca valley (Matuszkiewicz 2008), as well as in many other areas around the Central European Lowlands (Bodeux 1955, Prieditis 1997, Douda 2008), the ecotones developed on the border between the forest and the river channel (EL) can be considered as reference habitats. The two other investigated types of ecotones, EZ and ER, developed as a result of different types of human impact.

The different types of land use in the riparian zone and in the vicinity of the river create different conditions for plants (Rodewald & Bakermans 2006). The largest number of species occurred in the plots located in the ER ecotones. EL plots were more homogenous in terms of the number of plant species, while the EZ plots were more heterogeneous: the number of species per plots varied from 9 to 35. The occurrence of *Glechoma hederacea* in EZ, and *Symphytum officinale, Aegopodium podagraria* or *Anthriscus sylvestris* in ER indicates that communities of *Glechometalia hederaceae* R.Tx. in R.Tx. et Brun-Hool 1975 (Matuszkiewicz 2002) are present in natural riparian forests. Their presence confirms the potential of riparian vegetation to regenerate. However, the occurrence of ruderal species (*Convolvulus arvensis*, *Ballota nigra* or *Chelidonium majus*) is an indicator of disturbances in the riparian ecosystems caused by land-use changes. This co-occurrence of varied site conditions caused by different types of land use results in the high biodiversity observed in EZ and ER, as reported in numerous studies, including Zalewski et al. (1998), Bornette et al. (1998) and Pedroli et al. (2002). However, a high density of macrophytes may competitively exclude other plant species, which results in reduced biodiversity (Weiher & Keddy 1995, Ferreira et al. 2002, Zedler & Kercher 2004, Minchinton et al. 2006). The high plant diversity observed within the EL zone (Fig. 2) is also dependent on the availability of different habitats. The presence of tree roots, woody debris and hanging branches within the forested riparian zone plays a significant role in the river system by controlling the water energy dissipation and sediment transport (Keller & MacDonald 1995, Bilby & Bisson 1998, Milner & Gloyne-Phillips 2005).

The storage of organic and inorganic material is balanced, which provides a diverse range of microhabitats for plants (Darveau et al. 2001). Boggy areas with accumulated organic material, which were occupied by helophytes such as *Veronica beccabunga, Caltha palustris, Scirpus sylvaticus* or *Myosotis palustris*, were observed exclusively in the EL plots (Table 1). Plant diversity within the ecotones is further enhanced by some patches being located in the shade of the tree canopy, whilst others − in sunny areas. The maintenance of scattered forest patches along a river channel is very important to biodiversity preservation (Aguiar & Ferreira 2005, Rodewald & Bakermans 2006, Fernandes et al. 2011, Clerici et al. 2013).

The logging of riparian forests affects the recharge, infiltration and runoff rates, and increases the bank erosion (Patten 1998, Sweenay et al. 2004). It also drastically changes the light conditions. Although a high light availability level would be expected in riparian zones located in urbanized and agricultural areas (EZ and ER) (Baart et al. 2010), the number of plant species identified in EZ were found to prefer diverse light and moisture conditions (Fig. 2), possibly due to the presence of residential and industrial buildings and/or recreational green areas along the river, significantly increasing the range of insolation in the river channel and riverbanks within urbanized areas.

In contrast, it is not surprising that the EIV light index is less diversified within the ER zone, as the zone is usually overgrown by herbaceous vegetation. However, the light conditions may be diversified by the co-occurrence of self-sown woody species *Ulmus laevis* and *Sambucus nigra*. Although the presence of single trees, narrow strips of trees or forests along river channels is a characteristic feature of a highly-fragmented agricultural landscape (Rodewald 2003), too dense canopy of riparian woodlands or herbaceous vegetation may prevent the penetration of sunlight into the lower vegetation layers and thus may reduce the plant diversity (Manolaki & Papastergiadou 2013).

The limited light access in the water precludes photosynthesis in the water column and promotes anaerobic conditions suitable for denitrification (Weisner et al. 1994, Toet et al. 2003, Weisner & Thiere 2010, Harrison et al. 2011). Moreover, forest and macrophyte vegetation may supply bacterial communities with large amounts of organic matter needed for the denitrification process, as well as accumulation of litter that provides a large surface area for the attachment of such biofilms as denitrifying bacteria (Bastviken et al. 2003, Sirivedhin & Gray 2006). High productivity of emergent macrophytes may then result in a high nitrogen uptake by the vegetation itself and contribute to nitrogen retention (Greenway & Woolley 1999, Greenway & Woolley 2001, Meuleman et al. 2002, Braskerud 2002).

Forest vegetation significantly reduces the influence of agricultural nutrients and chemicals on surface river waters (Meybeck 2001, Anbumozhi et al. 2005) as the eutrophication rate of the river is slowed by the retention of organic substances in long-living woody species (Zalewski et al. 1998). Presumably this is why the riparian vegetation of the studied EL plots is characterized by a significantly lower trophic index than the EZ and ER plots (Fig. 2) where most of the identified plants are associated with eutrophic and productive biotopes.

The different forms of land use within urbanized, agricultural and forested areas create a wide range of habitats for the riparian vegetation. High habitat heterogeneity favors the occurrence of a wide range of species, which in turn provides ecological and aesthetic benefits. Natural water purification by diverse plant assemblages brings also economic benefits (MEA 2005). Riparian vegetation should be preserved as an important potential source of propagules and as a dispersal corridor for numerous plant species. Data from the UK (Mooney & Marshall 2001) and from Denmark (Hald 2002) indicate that the maintenance of a 2-m-wide uncultivated zone along streams or river channels may significantly enhance the biodiversity of riparian ecotones.

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