Jakubínský, J., Cudlín, P. (2018), Impact of hydromorphological features of small watercourses on the quality of ecosystem services pp. 26-33. In Gastescu, P., Bretcan, P. (edit, 2018), *Water resources and wetlands*, 4th International Conference Water resources and wetlands, 5-9 September 2018, Tulcea (Romania), p.312

Available online at http://www.limnology.ro/wrw2018/proceedings.html

4th International Conference Water resources and wetlands, 5-9 September 2018, Tulcea (Romania)

IMPACT OF HYDROMORPHOLOGICAL FEATURES OF SMALL WATERCOURSES ON THE QUALITY OF ECOSYSTEM SERVICES

Jiří JAKUBÍNSKÝ, Pavel CUDLÍN

Global Change Research Institute CAS, Belidla 986/4a, 603 00 Brno, Czech Republic, tel. +420601383196, *e-mail: jakubinsky.j@czechglobe.cz, cudlin.p@czechglobe.cz*

Abstract

Morphological characteristics of watercourses can significantly affect their ecosystem functioning and consequently the quality of services provided by riparian ecosystems to human society. This paper aims to identify the main hydromorphological parameters, which can affect the spectrum of ecosystem services, especially in the case of small streams. Several basic functions provided by the river landscape were analysed - namely the flood mitigation, control of water erosion rates, habitat provision, function of migratory corridors, the fresh water supply and recreational and aesthetic functions. These functions were quantified using data obtained by field research within the areas of interest as well as from other available datasets. Since the relationship between the state of watercourses and the ecosystem services provided is heavily influenced by local natural conditions, these characteristics have been studied within several different areas located in the Czech Republic. Specifically, small stream watersheds in different types of Central European landscape, subjected to a variable extent of anthropogenic pressure, have been investigated. The results of the study show that the morphological state of watercourses directly affects especially the riparian zone, adjacent to the watercourses. Be specific, the degree of riverbed incision, bank slope and type of channel-forming material can be considered as a key parameter affecting the quality of ecosystem services.

Keywords: hydromorphological status, small stream, riparian area, ecosystem services, Czech Republic

1 INTRODUCTION

River ecosystems play one of the key roles in the process of shaping the nature of the current life environment and provide many ecosystem functions and services to human society (de Groot et al. 2002). Man uses these services virtually from the beginning of its existence, but gradually these ecosystems are also affected by the humans (e.g. Meybeck, 2003), and thus the possibility of maintaining or restoring their natural state is significantly reduced. The process of anthropogenic influence occurs both directly – most often through intervention into the morphometric parameters of riverbeds and riparian zones, and indirectly, usually by a change in the land use throughout the watershed involved. Daily (1997) stated, that ecosystem services are the conditions and processes which ensure the sustainable and full-fledged human life through natural ecosystems and their sub-components. Generally, the ecosystem services can be considered as benefits that nature provides to individuals, societies and the national economies. The importance of evaluating or assessing functions and services of floodplain ecosystems is seen by Boyd and Wainger (2003) in the wide potential to use the information, including, but not limited to, the planning of river restorations and other management practices in the given specific environment.

Anthropogenic impacts on the quality of river ecosystems (i.e. their biodiversity) are also reflected in the impact on ecosystem services that are very important for the society (Postel and Carpenter, 1997) due to reduction in their original environmental, socio-cultural and economic values (Costanza et al. 1997, de Groot et al., 2002). According to Demek et al. (2011), the most important functions of fluvial ecosystems include for example the limitation of the number and intensity of floods, the contribution in formation of groundwater resources, the reduction of surface water pollution, filtering of rainwaters, easy access to drinking and service water, the creation of suitable habitats for fauna and flora, and last but not least, ensuring fertile agricultural land.

However, the importance of studying fluvial ecosystems in a long-term aspect, lies in the process of understanding the functions and services discussed (see e.g. Hynes, 1975) and the research of the nature of interactions between the riverbed and its floodplain (e.g. Amoros et al., 1987 or Décamps et al. 1988). The quantification of the environmental status of watercourses and their riparian zones using appropriate indicators can be considered as one of the key topics, especially in addressing the flood risk issues within the riverine landscapes.

The highest values of the ecosystem services of river landscapes in terms of their quality and quantity are very often achieved at the sites close to the riverbeds – within the area of the riparian zone. The lower rate of anthropogenic pressure caused by unfavourable conditions for economic utilization (usually the narrow stripes of vegetation on the river banks which are more difficult to reach), is probably the main cause. The ecological significance of the riparian zones for the performance of functions and services has been relatively frequently studied in the past by many authors such as Welcomme (1979), Naiman and Decamps (1997) or Naiman et al. (2005). A very extensive overview of the potential ecosystem values in the riparian areas was provided by Malanson (1993).

This article presents research results aimed at identifying the main hydromorphological parameters, which can affect the spectrum of ecosystem services, especially in the case of small streams. Therefore the main research questions were:

- to find out which specific ecosystem services are provided by small watercourses in Central European conditions,
- what is the quality of these services in terms of their benefits for human society, and
- which particular hydromorphological characteristics most influence the provision of ecosystem services (both in the positive and negative sense).

Regarding the results of this study, the analyses carried out show that the morphological state of watercourses directly affects especially the riparian zone, adjacent to the watercourses. Be specific, the degree of riverbed incision, bank slope and type of channel-forming material can be considered as a key parameter affecting the quality of ecosystem services within the areas of interest.

2 DATA AND METHODS

In order to analyse the relationship between the hydromorphological status of the watercourses and the quality of the functions and services provided by these streams and their riparian landscape, several watersheds of small watercourses in the Czech Republic were selected. When choosing the watersheds, the consideration was taken into account primarily to capture the widest possible range of natural conditions and anthropogenic pressure degree to which these ecosystems are facing. An overview of the geographical localization of selected area of interest is given in Fig. 1 and their basic characteristics are listed in Table 1.

Table 1. Selected descriptive characteristics of the areas of interest

Area of interest (watershed)	**BR**	**DN**	**KC**	**KS**	**LS**	**RZ**	**SR**
Watershed area [km^2]	72.7	26.9	5.9	218.3	21.2	6.6	98.5
River landscape area [ha]	368.81	434.04	26.62	2266.09	149.91	12.13	127.17
Length of the streams studied [km]	66.04	16.42	5.53	32.28	10.05	6.59	18.28
River density [$km.km^{-2}$]	1.42	0.70	1.69	0.23	0.65	1.16	2.34
Average specific discharge [$l.s^{-1}.km^{-2}$]	5-10	< 2	10-15	2-5	< 2	25-35	10-15
Population density [$inhab./km^2$]	43.8	106.8	12.9	62.5	2058.8	5.0	36.0
Prevailing type of watercourses*	HG	LW	HL	LW/HL	LW	MT	HL/HG
Dominant land-use type(s)**	F/A	A	F/M	A	U/A	F	F/A

Note: BR – Borovsky p., DN – Dunajovicky p., KC – Kochavecky p., KS – Kosatecky p., LS – Leskava, RZ – Ryzi p., SR – Stropnice; *Types of watercourses according to classification of Langhammer et al. (2009): LW – Lowland, HL – Hilly, HG – Highland, MT – mountain. ** Land-use types: F – forest, A – agricultural, U – urban, M – meadows.

The hydromorphological properties of the selected watercourses were evaluated in all these locations. The evaluation was based on the national methodology for the assessment of hydromorphological status – HEM (Langhammer 2014), which is a part of the assessment process to determine the overall ecological status of the watercourses resulting from the requirements of the EU Water Framework Directive (2000/60/EC). The value of the ecosystem functions provided by the given watercourses was expressed on the basis of a wide range of data that allowed the value of each function to be quantified – an overview of specific data sources is given in Table 2.

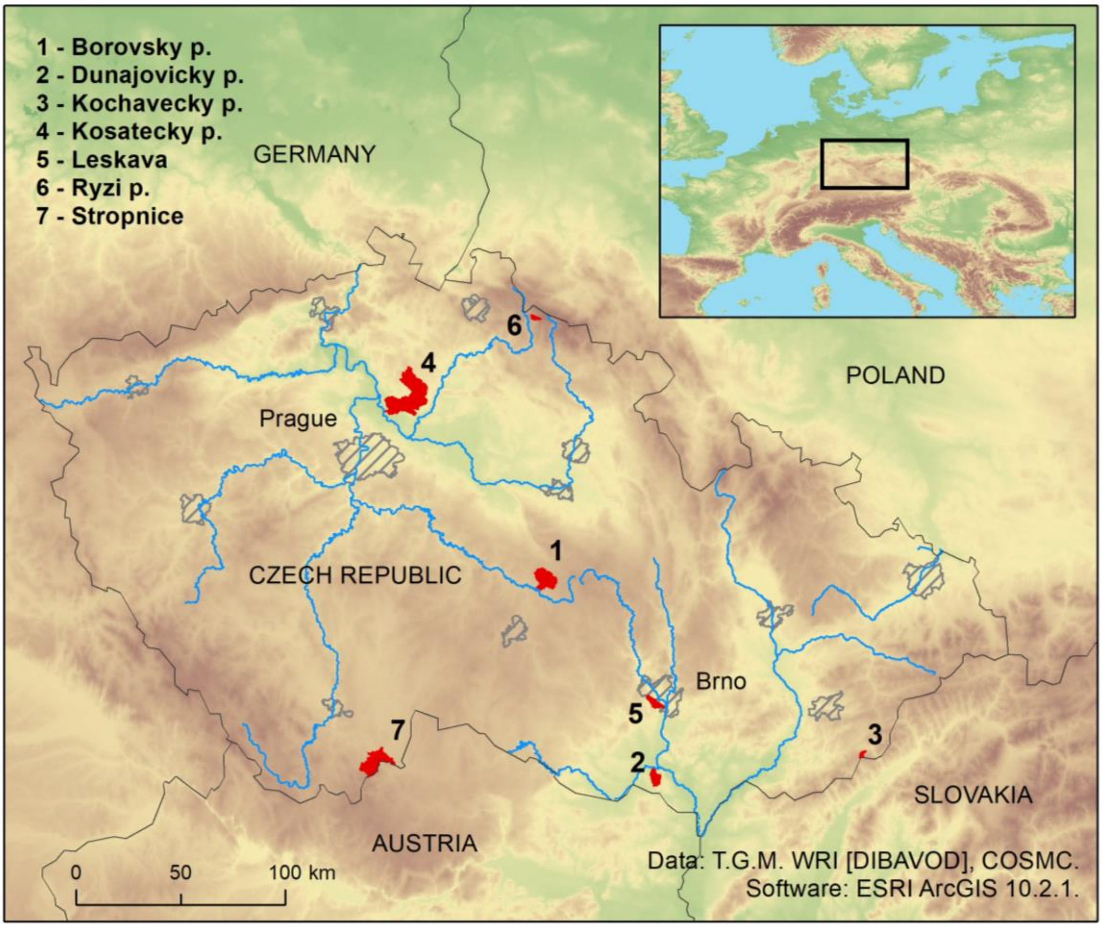

Figure 1. Location of areas of interest (selected watersheds) in the Czech Republic

Specific datasets was used to determine the rate of ecosystem services provided and the scale was always dependent on the extent of the data source. Then the scale was divided into three quartiles (for example in case of the service water provision the highest recorded water consumption meant the better rate of ecosystem services). From the highest recorded values the thresholds for distinguishing the various categories, suggesting the rates of services provided, were derived. Detailed information about the nature of the data and the methodology used for the analysis of riparian ecosystem services are described in Jakubínský (2016).

Table 2. Indicators used to quantify the value of ecosystem services provided by the river landscapes

Ecosystem services category	Ecosystem service	Indicator of the ecosystem service rate
Provisioning	Provision of service water	Amount of water withdrawals from the riverbed used for economic purposes (irrigation, industry, etc.)
	Drinking water provision	Water quality (chemical and biological indicators) Amount of water withdrawals used for drinking purposes (ground water and surface water)
	Energy	Amount of energy provided by the hydropower plants.
Regulating	Flood protection	Soil water retention capacity of the river landscape Extent of the natural inundation areas along the streams
	Climate regulation	Character of vegetation cover within the river landscape (esp. size of shade areas) Terrain properties (i.e. depth of a valley)

		Presence of the wetlands in the floodplain areas
	Habitat service	Number of migration barriers in the riverbed (weirs, dams, etc.)
Cultural	Aesthetics & Recreation	Number of recreational facilities close to the river landscape (in max. distance of 1 km from the river) Length of hiking trails in the river landscape

3 RESULTS

Based on the overall evaluation of all resulting data (see Fig. 2), the optimal hydromorphological quality was assumed to be the mountain watercourses in the Ryzi Brook watershed located in the Krkonose Mts., whose average values were very close to the "close to nature" state (i.e. 1st class according to the classification of Czech National Standard ČSN EN 15843). On the contrary, in the urban Leskava Brook, flowing through several city districts of Brno, the most degraded morphological conditions (i.e. medium modified status of the 3rd class) were found. The watercourses in the intensively exploited agricultural landscape of the Labe River lowland and South Moravia (i.e. the Kosatecky and the Dunajovicky Brook watersheds) achieved approximately comparable hydromorphological status.

In terms of quality of the ecosystem function performance the Borovsky Brook watershed achieved average best values, followed by the watersheds of the Ryzi Brook and the Stropnice River (see Table 3). Since the assessment of some of the analysed functions (e.g. climatic function) is partly based on an expert estimate which brings a degree of subjectivity to the process, it is unlikely that the minor differences between some of the resulting values are considered to be significant, but rather as an indicative distinction of studied watersheds and the rate of their ecosystem service provision. In general, the studied watersheds can be divided into three categories – watersheds whose ecosystems performed the analysed functions very well (i.e. the Borovsky Brook, Ryzi Brook and Stropnice River watersheds), basins with an average rate of the ecosystem function performance (i.e. the Kosatecky and Kochavecky Brook watersheds) and basins with more limited performance of these functions (the Dunajsky and Leskava Brook).

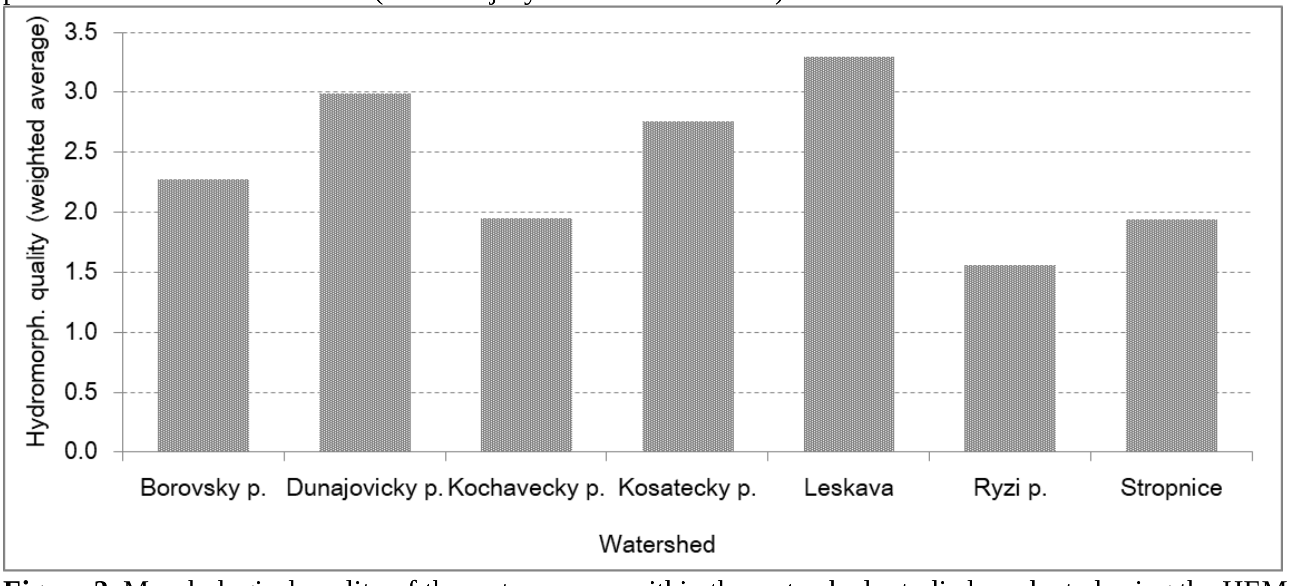

Figure 2. Morphological quality of the watercourses within the watersheds studied, evaluated using the HEM method

Between the hydromorphological status and the quality of services, provided by the ecosystems of these river beds, there is a dependence (correlation coefficient -0.77); with decreasing hydromorphological quality (i.e. increasing value of the indicator), the overall quality and quantity of services, provided by the riparian ecosystems, decrease (Fig. 3). In general, we can say that the morphological status of the watercourse affects the character and rate of ecosystem service provision by the river landscape.

Table 3. Scores of the rate of performance of selected ecosystem services provided by the river landscapes within the areas of interest (3 p. = highest quality, 2 p. = medium quality, 1 p. = low quality, 0 p. = does not provide the given service)

Watershed		BR			DN		KC		KS		LS		RZ		SR		
Part of watershed		E	EA	A	EA	A	E	EA	EA	A	EA	A	E	EA	E	EA	A
Ecosystem services	Flood protection	2	1	1	2	3	1	1	2	2	1	2	2	2	2	2	1
	Drinking water provision	3	2	1	0	1	1	1	3	3	0	1	0	3	0	2	2
	Climate regulation	1	1	2	0	1	0	2	1	1	0	1	1	2	1	2	1
	Provision of service water	1	1	2	0	0	1	1	1	2	1	0	1	1	1	2	2
	Habitat service	2	2	3	1	1	1	3	1	2	0	1	1	2	2	2	2
	Energy	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
	Aesthetics & Recreation	0	1	3	0	0	0	2	1	0	0	0	3	2	2	2	1
In sum		10	10	15	4	8	6	12	10	12	4	6	9	14	9	15	10
Average for the watershed		1,46			0,75		1,13		1,38		0,63		1,44		1,42		

Note: BR – Borovsky p., DN – Dunajovicky p., KC – Kochavecky p., KS – Kosatecky p., LS – Leskava, RZ – Ryzi p., SR – Stropnice | E – erosion part, EA – erosion-accumulation part, A – accumulation part of the watershed. The shade of grey colour in the table refers to the significance of the result – the darker the better rate of ecosystem services.

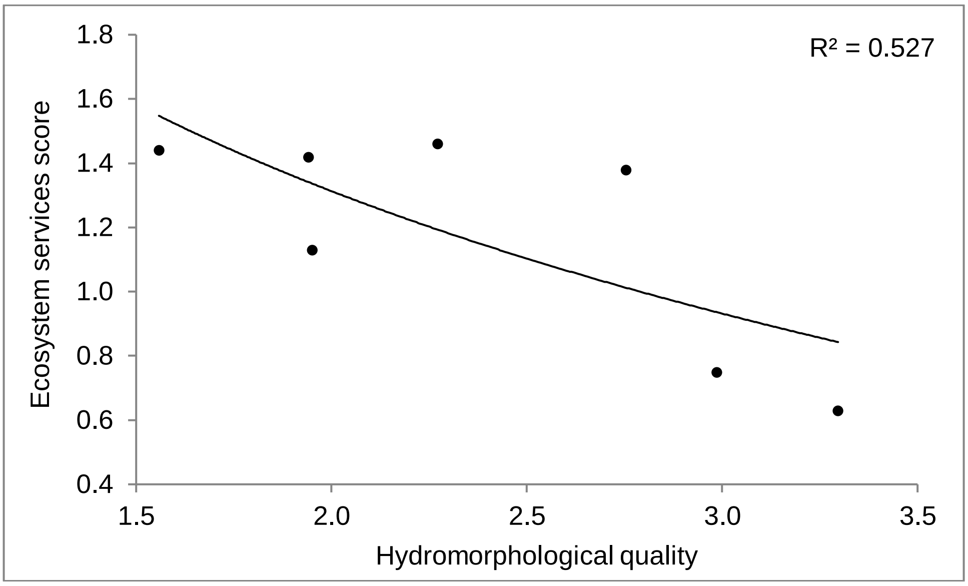

Figure 3. Dependence between the hydromorphological quality of selected streams (the lower the value, the better the morphological status) and ecosystem services provided by the riparian landscape (the higher the score, the higher the quality of the services provided)

As the above-mentioned findings, regarding the quality of the ecosystem service provision in the riverine landscape, testify the importance of man's impact on the landscape, it is necessary to identify the sites with increased "societal demand" for the improvement of the current environmental state. These are the stream segments and surrounding riparian areas, characterized by significantly degraded environmental values and the associated limited ability to provide natural ecosystem functions and services. At identification of the sites with potential to increase the quality of ecosystem functions and services it is also necessary to take into account the real development opportunities arising from the specific land use management; e.g. in the urban areas it cannot be expected a change leading to increasing their rate of flood protection function or the segments with very low average discharges are not suitable to restore their climatic, energy or production functions. Based on the information about the morphological status of the watercourses (see Figure 2) and the quality of the ecosystem functions (see Table 3), the potential for improvement of the current state was determined, as shown in the graph in Fig 4.

The Ryzi Brook riparian area was evaluated as a territory with the average lowest potential for improvement of the current environmental status. This area in view of its size, diversity of the relief, existing character of the land cover and the level of nature protection (the territory is a part of the Krkonose Mts. National Park), does not have room for changes that could significantly improve the quality of analysed functions. A very low potential to improve the qualitative parameters of the ecosystem can be also expected in the Leskava Brook riparian zones, where the presence of urban development highly reduce the potential of functions and services that this area would provide to human society.

In contrast, there are the landscapes in the Kosatecky Brook and the Borovsky Brook catchments, where the possible enhancement of the quality of a relatively wider spectrum of ecosystem functions was identified. These catchments are characterized by the conditions in which it is theoretically possible to make changes that would improve the quality of life of the locals by increasing the integrity of watercourses with their immediate surroundings. Such changes include, among other things, the restorations of river ecosystems or the economically less demanding spontaneous renaturations, based according to Just et al. (2005) especially on the clogging of treated riverbeds by suspended load, overgrown by trees and herbs and the gradual disintegration of artificial riverbed structures. These measures are taken into account especially in segments within the agricultural landscape, while during the assessment of potential has not taken into account the issue of land ownership and property settlement.

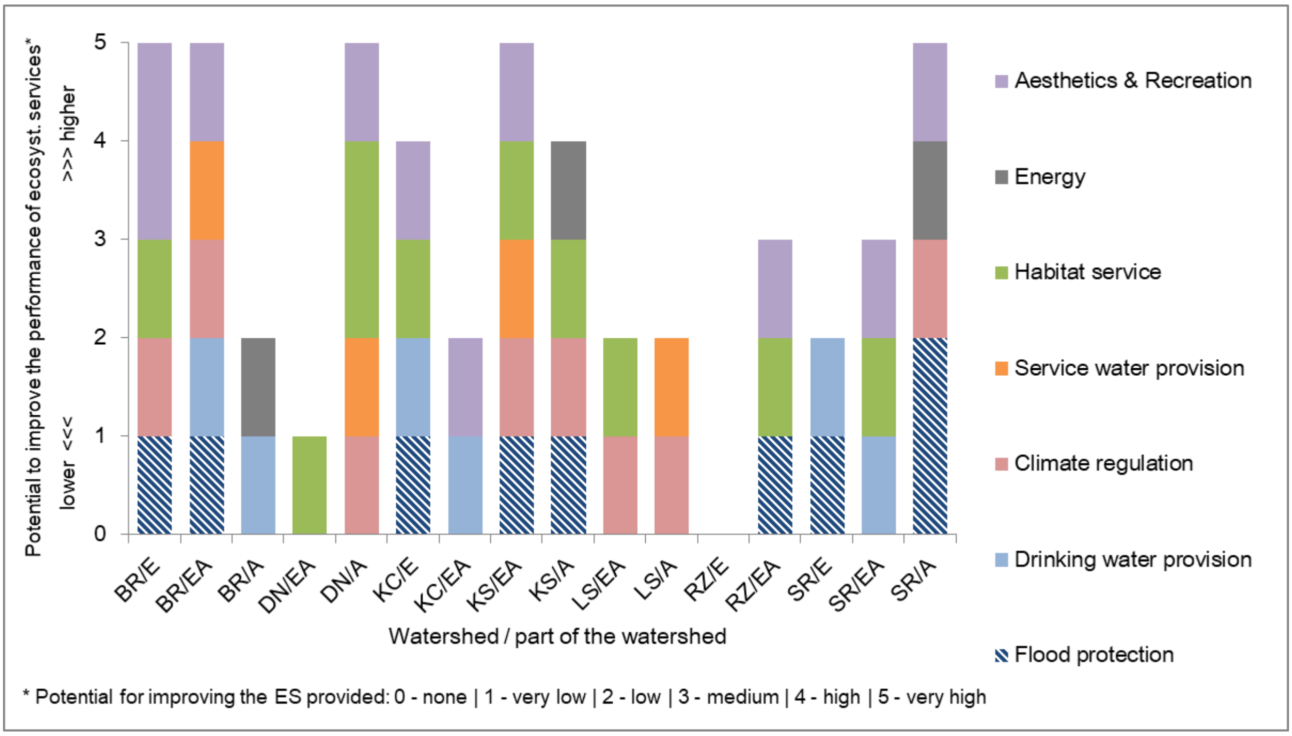

Figure 4. Potential for increasing the rate of ecosystem service provision by river landscapes within the areas of interest (Note: For explanations of the abbreviations see Table 3.)

4 DISCUSSIONS

The results mentioned confirm the validity of the hypothesis concerning the relationship between the degree of watercourses degradation and the quality of the functions and services provided by the riparian ecosystems. The catchment area with the most degraded watercourses is characterized by a limited range of ecosystem functions and services, with a lower overall quality, compared to the areas where the watercourses occur in the close to nature state. Since these findings are based on a relatively large set of input data, which includes variable natural conditions and anthropogenic pressures on the landscape, it is possible to assume the validity of these conclusions generally within the small watercourse catchments in the intensively used agricultural landscape of Central European countries. However, these conclusions cannot be generalize for the potential to improve the quality of ecosystem functions and services, since it is a type of the property, influencing the possibilities of landscape restoration, that depends primarily on a wide range of locally specific, mostly socio-economic conditions.

The dependence between the hydromorphological state and the services provided by the riparian ecosystems is particularly noticeable in the case of watercourses flowing through the urban areas – in case of this study, that is the Leskava Brook, flowing through the built-up areas in Brno. In part of the segments, this watercourse is characterized by the features typical for the so-called “urban stream syndrome”, defined by Meyer et al. (2005) and further developed by Walsh et al. (2005). In the remaining part of the studied watershed, the Leskava Brook can be characterized by the parameters typical for rural streams, or, according to Pinto and Maheshwari (2014), rather for peri-urban streams. This is a significant incision of the V-shaped riverbed, with a minimum range of its own river bottom and artificial banks. There is a possible analogy in the form of a “syndrome of rural streams”, whose symptoms could be met by a relatively large part of the hydrographic network in the Central European conditions. Within the studied watersheds, mainly the Dunajovicky and Kosatecky Brook catchments meet these conditions of rural streams. Significant artificial incision of riverbeds in the urban areas, which is also reflected in other biotic properties, is called “stream channel incision syndrome” (Shields Jr. et al. 2010).

5 CONCLUSION

The study of small watercourses and their landscapes is becoming more and more important in the context of ongoing environmental change whose impacts are often reflected in the riparian environment. Small streams in both urban and rural landscapes, in addition to direct impacts of current human activity, in the form of frequent adjustments and changes in the management of riparian zone, also face to indirect impacts in the form of more frequent occurrences of extreme hydrometeorological situations. All of these factors subsequently affect the ability of the ecosystems concerned to provide their ecosystem functions and services, which in many cases is also reflected, among others, in the quality of life of the locals.

The main findings of this paper point to the existence and quality of outlined interactions and their functioning in common Central European natural conditions, which can provide a framework for sustainable planning in the relevant field of the water and riparian areas management. The possibilities of practical use of the studied issue consist especially in connection with the analysis of natural hazards, which are increasingly relevant even in the small watercourse floodplains, especially in the vicinity of built-up areas. Information about the morphological, respectively overall ecological status of watercourses must be seen rather as a partial indicator of the ecosystem health, still shaped by a number of other variables on which this article seeks to capture. Knowledge of a wider range of these variables then allows identifying the main factors that affect the current complex status of the ecosystems, the quality of their services, as well as the potential for further development. At the same time, it is clear that a potential restoration of a degraded small stream ecosystem is only possible with the measures, taking into account the majority of causal factors and, in most cases, cannot be the result of changes in a single component of the whole system.

ACKNOWLEDGEMENTS

This work was supported by the Ministry of Education, Youth and Sports of CR within the National Sustainability Program I (NPU I), grant number LO1415 and also by the project “Small watercourses and riparian ecosystem management to mitigate the impacts of environmental change (SMART2Envi)”, Reg. No. LTC18069.

REFERENCES

Amoros, C., Rostan, J. C., Pautou, G., Bravard, J. P. (1987). The reversible process concept applied to the environmental management of large river systems. *Environmental Management*, 11. pp. 607–617.

Boyd, J., Wainger, L. (2003). Measuring Ecosystem Service Benefits: The Use of Landscape Analysis to Evaluate Environmental Trades and Compensation. Resources for the Future, Washington D. C. 156 p.

Costanza, R., D’Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O’Neill, R. V., Paruelo, J., Raskin, R. G., Sutton, P., Van Den Belt, M. (1997). The Value of the World’s Ecosystem Services and Natural Capital. *Nature*, 387. pp. 253–260.

Daily, G. C. (1997). Introduction: What are ecosystem services? In: DAILY, G. C. [ed.] Nature’s Services: Societal Dependence on Natural Ecosystems. *Island Press*, Washington, D. C. pp. 1–10.

De Groot, R. S., Wilson, M. A., Boumans, R. M. J. (2002). A Typology for the Classification, Description and Valuation of Ecosystem Functions, Goods and Services. *Ecological Economics*, 41 (3). pp. 393–408.

Décamps, H. A., Fortune, M., Gazelle, F., Pautou, G. (1988). Historical influence of man on the riparian dynamics of a fluvial landscape. *Landscape Ecology*, 1. pp. 163–173.

Demek, J., Havlíček, M., Mackovčin, P., Slavík, P. (2011). Změny ekosystémových služeb poříčních a údolních niv v České republice jako výsledek vývoje využívání země v posledních 250 letech. *Acta Pruhoniciana*, 98. s. 47–53. (in Czech)

Hynes, H. B. N. (1975). The stream and its valley. *Verh. Int. Ver. Theor. Ang. Limnol*., 19. pp. 1–15.

Jakubínský, J. (2016). Stream Landscapes – Regeneration and Evaluation. PhD. Thessis. Masaryk University, Faculty of Science, Dept. of Geography. 201 p. (in Czech)

Just, T., Matoušek, V., Dušek, M., Fischer, D., Karlík, P. (2005). Vodohospodářské revitalizace a jejich uplatnění v ochraně před povodněmi. *3. ZO ČSOP Hořovicko, Ekologické služby s.r.o., Agentura ochrany přírody a krajiny ČR a Ministerstvo životního prostředí ČR*, Praha. 359 s. (in Czech)

Langhammer J., Hartvich, F., Mattas, D., Zbořil, A. (2009). Vymezení typů vodních toků. Univerzita *Karlova v Praze, Přírodovědecká Fakulta*, Praha. 29 p. (in Czech)

Langhammer, J. (2014). HEM 2014 – Metodika monitoringu hydromorfologických ukazatelů ekologické kvality vodních toků. Univerzita Karlova v Praze, Přírodovědecká fakulta, Praha. 72 p. (in Czech)

Malanson, G. P. (1993). Riparian Landscapes. Cambridge Studies in Ecology. *Cambridge University Press*, Cambridge. 308 p.

Meybeck, M. (2003). Global analysis of river systems: from Earth system controls to Anthropocene syndromes. *Philosophical Transactions of the Royal Society of London*, 358 (1440). pp. 1935–1955.

Meyer, J. L., Paul, M. J., Taulbee, W. K. (2005). Stream ecosystem function in urbanizing landscapes. *Journal of the North American Benthological Society*, 24. pp. 602–612.

Naiman, R. J., Decamps, H. (1997). The ecology of interfaces: riparian zones. *Annual Review Ecology and Systematics*, 28. pp. 621–658.

Naiman, R. J., Décamps, H., McClain, M. E. (2005). Riparia, Ecology, Conservation, and Management of Streamside Communities. *Elsevier Academic Press*, London. 430 p.

Pinto, U., Maheshwari, B. (2014). A Framework for assessing river health in peri-urban landscapes. *Ecohydrology & Hydrobiology*, 14. pp. 121–131.

Postel, S., Carpenter, S. (1997). Freshwater Ecosystem Services. In: DAILY, G. C. [ed.] Nature's Services: Societal Dependence on Natural Ecosystems. *Island Press*, Washington D. C. pp. 195–214.

Shields Jr., F. D., Lizotte, Jr., R. E., Knight, S. S., Cooper, Ch. M., Wilcox, D. (2010). The stream channel incision syndrome and water quality. *Ecological Engineering*, 36. pp. 78–90.

Walsh, Ch. J., Roy, A. H., Feminella, J. W., Cottingham, P. D., Groffman, P. M., Morgan Ii, R. P. (2005). The urban stream syndrome: current knowledge and the search for a cure. *J. N. Am. Benthol. Soc*., 24 (3). pp. 706–723.

Welcomme, R. L. (1979). Fisheries Ecology of Floodplain Rivers. *Longman Group, Ltd*., London, UK. 317 p.