METHODS OF DETERMINING LANDSCAPE FUNCTIONS AND THEIR EVALUATION: A CASE STUDY OF HUSTOPEČE, CZECH REPUBLIC

Dagmar STEJSKALOVÁ, Petr KARÁSEK, Jana PODHRÁZSKÁ, Lenka TLAPÁKOVÁ

Abstract

The determination and evaluation of landscape functions by means of the index of functions in space and time is discussed in this paper. The analysis and quantification of landscape functions on the basis of landscape structure changes (landscape categories) can be used as background data for proposals and implementation of long-term measures that are part of the proposal for complex land consolidation (CLC), and for proposals of changes in functional land use in land-use plans (LUP). The method of determination and evaluation of landscape functions is based on seeking a correlation between landscape structure and prevailing functions, and on an attempt to quantify temporal changes in landscape functions (similar to the quantification of changes in landscape structure). The Hustopeče study area was chosen for the analysis and evaluation of landscape functions.

Shrnutí

Metody stanovení krajinných funkcí a jejich hodnocení: případová studie Hustopeče, Česká republika

Předmětem příspěvku je stanovení a vyhodnocení funkcí krajiny formou indexu funkcí v prostoru a čase. Analýza a kvantifikace krajinných funkcí na podkladě změn krajinné struktury (krajinných kategorií) lze využít jako podkladu pro návrhy a realizace opatření dlouhodobého charakteru, která jsou součástí návrhu komplexních pozemkových úprav (KPÚ) a pro návrhy změn funkčního využití krajiny v územních plánech (ÚP). K analýze a hodnocení krajinných funkcí je vybráno modelové území Hustopeče. Metoda stanovení a vyhodnocení krajinných funkcí je postavena na hledání korelací mezi krajinnou strukturou a převládajícími funkcemi a pokusu o kvantifikaci proměn krajinných funkcí v čase (podobně jako kvantifikace proměn krajinné struktury).

Keywords: *Landscape structure, landscape function, index of functions, land use, Hustopeče, Czech Republic*

1. Introduction

Landscape structure has a crucial influence on landscape functional characteristics. Any change in the landscape structure – in space and in time – affects the flows of energy and material in the landscape, landscape crossing capacity and habitability, its ecological stability and other properties and characteristics. Landscape functions can be defined as a set of functional effects, needs and phenomena complementing or conditioning one another, which are required by the society or directly emanate from the landscape itself (Krečmer, 1994). Landscape has a number of irreplaceable functions for the human society (Hradecký, Buzek, 2001), while these functions have changed in their priorities with the development of the human society. The quantification of these functions is very difficult. Landscape functions complement and condition one another; they are closely connected with landscape structures (categories) and are provided energies that are necessary for their maintenance at places where they would be unsustainable according to the natural potential of the territory. In general, landscape functions are divided according to the actual sight of the landscape. In this project, the terminology of production, residential and recreational functions (Havrlant, Buzek, 1985) is used, while other authors speak about natural (climatic, geological, hydrological and biological) functions, socio-economic and cultural functions (secondary functions when humans suppress natural functions and prefer socio-economic functions, which has a negative impact both on the landscape and on the living environment). In connection with landscape functions, landscape structure can be defined as a set of landscape categories exerting a set of

functional effects (Krečmer, 1994). Consequently, the spectrum of these effects should be specified in detail. The concept of functional objectives of the landscape may be determined by locality, i.e. "by a land charge" in the transferred meaning of the word, plans of land owners, designs of land-use planning documentation and government bodies. In general terms, the concept declared in a number of publications (Hradecký, Buzek, 2001; Demek, 1999) distinguishes two basic groups of landscape functions: natural functions (including natural processes creating conditions for life) and social and cultural functions (activities of humans exploiting the natural environment to their own benefits). In this context we speak about an economic function (including the production complex), ecological, recreational, cultural functions, etc. Some landscape functions cannot be quantified, e.g. the psychological function (Cílek, 2005).

The LANDEP method (Růžička, Miklos, 1982) is one of modern approaches to landscape evaluation and determination of its ecologically optimum use: it determines an optimum functional categorization of landscape based on a proposed grid of stable elements.

For our analysis and for the proposal of the evaluation of landscape functions we chose the classification of production and non-production functions (Tab. 1). Because we wanted to express functional effects, the landscape in our evaluation is considered a cadastral territory or a model territory in the wider sense of the word.

2. Material and methods

2.1 Data

Background data for the analysis of landscape functions were taken from the database of the multi-temporal analysis of landscape structures (Balej, 2006). The analysis consists in the evaluation of statistical and metric analyses (Godron, Forman, 1993) of three temporal horizons. The landscape structures are represented by classes of land use/land cover (LU/LC) of three temporal horizons (1st half of the 19th century and aerial photographs from the 1960s) and at the present (orthophotos from 2006). The database of the multi-temporal analysis of LU/LC was elaborated in 2010–2011.

No.	Landscape function
1	production
2	ecological
3	hydrological
4	aesthetic
5	recreational
6	residential
7	others

Tab. 1: Selection of assessable landscape functions (the rank of selected functions corresponds to a certain extent with the assessment of functions according to available data)

Landscape functions must be interpretable from the local to the regional perspective not only for the purpose of appropriate planning and management but also to enable the assessment of sustainable landscape development (Bastian et al., 2006).

2.2 Study area

The Hustopeče study area includes seven cadastres. The area of this territory is 9,237.9 ha and it is an intensively farmed landscape in southern Moravia with dynamic natural conditions.

In the study area, the functional use is predetermined by natural conditions, land use intensity in the last century and particularly by current requirements. It is necessary to conserve the landscape character and to increase the fineness of the grid of landscape segments.

A suitable procedure allowing the descriptive demonstration of actual land use and assertion of priority interests is variant visualization (3D visualization of landscape segments) when the necessary priorities of functional land use are projected into a new spatial landscape arrangement (Griffon, Nespoulous, Cheylan et al., 2011).This procedure will be applied at the end of the project to formulate the principles of preferable functional land use according to requirements for land use priorities (infiltration territory, nature conservation, etc.).

2.3 Evaluation of landscape functions

Many users and institutions participate in using the landscape (and/or the agricultural landscape). Using the multi-criterial analysis, a design of the optimum land use should be developed before a decision on land use is made. There are relatively few projects solving land use optimization because most frequently the essential data are missing (Assfalg, Werner, 1992). In other countries, optimization models are mainly used to address ecological and economic objectives (Centre of Common Research on Environment and Friendly Use of Agricultural Landscape at the University of Hohenheim).

Landscape functions can be evaluated either in absolute values of land use when one main function (hydrological, ecological, production, recreational,

aesthetic) is assigned to each category or by means of an index of functions when a certain weight (level) of the function concerned is assigned to each category of LU/LC (see below).

In this project, production and non-production functions are defined as follows:

- Agricultural production (arable land, cultivated meadows, intensive orchards and vineyards),
- Forest stands of spruce monocultures,
- Extraction of raw materials (quarries).

Non-production functions:

- Ecological function – the selection of landscape categories corresponds with the methodology for the determination of ecological stability coefficient – ESC (Míchal, 1985), the ecological function is represented by stable landscape segments (stable landscape structures – forests with natural species composition, pastures, scattered green vegetation, bodies of water, riparian stands, etc.),
- Hydrological function (bodies of water, water-courses, soil-conservation measures – balks),
- Aesthetic function – corresponds with the frequency of the occurrence of landscape categories that improve landscape impressiveness; in general, the criteria of landscape evaluation are based on the assessment of terrain slope, heterogeneity of the vegetation cover, representation of landscape elements, anthropogenic activity and its influence on the landscape both in positive and negative sense (Stejskalová, 2007), (in this project, the selection and assessment of landscape elements were simplified to the representation of linear green vegetation, scattered green vegetation, natural forest stands, bodies of water, water-courses, solitaires, certain spatial arrangement of landscape structure), and
- Recreational function (in fact all stable landscape structures, bodies of water).

2.4 Determination of the level (weight) of particular landscape function

To a selected category of LU/LC, a function fulfilled by this category will be assigned. However, this model is not applicable in practice, in a specific landscape. Each category in the landscape (if it is not fully supported and maintained anthropogenically, e.g. arable land) always fulfils several functions. for example, the production function it may fulfill the ecological function (permanent grassland, extensive orchard), the hydrological function (body of water) and may overlap with the landscape-aesthetic function (natural water-course with riparian stands), and some functions cannot be quantified at all, e.g. the psychological function in the landscape concept as our home or the space of our existence.

Level	Weight of evaluated function	Description
Level A	1.00	Landscape category fulfils one function
Level B	0.75	Landscape category fulfils two functions
Level C	0.50	Landscape category fulfils another function besides two functions
Level D	0.25	Landscape category fulfils more than 3 functions

Tab. 2: Determination of the level (weight) of landscape functions

Due to time consumption and costly database construction, three temporal horizons were selected (stable cadastre – 1st half of the 19th century, aerial photographs from the 1960s and contemporary orthophotos). LU/LC classes were determined based on the analysis of these data. This selection corresponds to the landscape use under feudalism, in the socialist era and under present market economy conditions. The stable cadastre provides information on landscape that was not yet affected by significant changes. Processes and impacts that resulted from a radical change in land use were already significant in the 1960s. In the 1990s, tendencies to remedy the past radical interventions continued; however, they currently bring about many negative trends (unification of agricultural landscape, building up of open space, etc.).

The following is an example of the evaluation and determination of function levels for landscape classes of stable cadastre: *arable land* – fulfils production function (level A); *vineyards* – fulfill production function (level A), on other levels they fulfill hydrological (level B), ecological (level C) and aesthetic (level D) functions; *gardens* – production (level A), ecological (level B) functions; *fruit orchards* – production function (level A); *permanent grasslands* – production (level A), hydrological (level B), ecological (level C) functions; *wetlands* – ecological (level A), hydrological (level B) functions; *forests* – ecological (level A), hydrological (level B), production (level A) functions; *bodies of water* – hydrological (level A), ecological (level B), production (level C) functions; *built-up areas* – residential functions (level A); *other areas* – other functions (level A); *scattered vegetation* – production (level A), ecological (level B) functions; *balks* – hydrological (level A), ecological (level B) functions; *quarries* – economic function (level A).

3. Results

Based on the evaluated landscape categories, selected landscape functions and determined levels of respective functions, the quantification of functions was performed by means of the index of functions and the intensity of the functional land use in the study area was evaluated.

3.1 Determination of indices of landscape functions (LF index)

Identical landscape categories (e.g. forest) do not always fulfill the same functions in each landscape (and at each time). For this reason, it is necessary to determine what "functional weight" is represented by a specific LU/LC category in a specific territory at a specific time.

The LF index is a unique value. In the study area, each LU/LC element is assigned a "weight" (level) of the function (see Tab. 2) – hence each category may fulfill up to four functions at the same time. The LU/LC areas with the same function (always within one level) are summed up and their proportion in the total studied area is calculated.

The proportion of each function is multiplied by the coefficient of weight (see Tab. 3). The weights of the coefficient were determined to be 1.0 for level A (i.e. prevailing – dominant function), 0.75 (for level B), 0.50 (for the third most important function – level C) and 0.25 (for the fourth most important function level D).

To calculate the index of landscape functions, the representation of selected functions in absolute areas (in hectares) was used. The areas of LU/LC with the same function are added up (always within one level). The total area of a given function (within a particular level) is multiplied by the respective coefficient. The results are added up and divided by the total area of the territory.

Formula for the calculation of the index of landscape functions – LF Index – see bellow (Formula 1).

Trends of the functional use of the territory will be expressed using the indices of landscape functions determined in different time periods. Determination of the indices of chosen functions:

Index $LF_{production}$ = [(5925.6 × 1) + (2307.4 × 0.75) + (0 × 0.50) + (503.6 × 0.25)] / 9266.9 = **0.840**

Index $LF_{ecological}$ = [(569.2 × 1) + (568.7 × 0.75) + (813.2 × 0.50) + (1786.8 × 0.25)] / 9266.9 = **0.200**

Formula 1

$$LF\ index = \frac{(LF_{level}\ A \times 1) + (LF_{level}\ B \times 0.75) + (LF_{level}\ C \times 0.50) + (LF_{level}\ D \times 0.25)}{total\ area\ of\ territory}$$

LU/LC	mid-19th century				1960s				2006			
	level*				level				level			
	A	B	C	D	A	B	C	D	A	B	C	D
Arable land	1	-	-	-	1	-	-	-	1	-	-	-
Vineyards	1	3	2	4	1	3	2	4	1	-	-	-
Gardens	1	2	3	4	1	3	2	4	2	1	3	4
Fruit orchards	1	2	3	4	1	3	2	4	1	-	-	-
Permanent grassland	1	3	4	2	3	1	2	4	3	2	4	1
Wetlands	3	2	4	-	2	3	4	-	2	4	3	-
Forests	3	1	2	4	1	3	2	4	1	3	2	4
Bodies of water	3	1	4	2	3	2	1	4	3	1	5	2
Built-up areas	6	1	-	-	6	1	-	-	6	1	-	-
Other areas	7	-	-	-	7	-	-	-	7	-	-	-
Scattered vegetation	1	4	2	3	2	4	2	1	2	5	4	3
Balks	3	4	1	2	3	4	2	1	3	2	4	-
Quarries	1	-	-	-	1	-	-	-	1	-	-	-

Tab. 3: Determination of the level (weight) of some functions for individual LU/LC classes. The numbers designate the functions listed in Tab. 1

** The evaluation of the above-mentioned functions in the period of stable cadastre is a theoretical problem but it is of significance as a comparative base for the evaluation of other periods. The LU/LC classes listed in Tab. 3 represent the result of unified legends from the period of stable cadastre, the 1960s and the present time. Other areas represent segments that cannot be included among other ones, neither is it possible to determine their functional use. Scattered vegetation represents alleys of trees, solitary trees, groups of trees and shrubs.*

3.2 Index of production land use

The Index of production land use (PLU) is absolute (dimensionless) value that is determined as a quotient of landscape categories fulfilling the production function and lands fulfilling non-production functions. It expresses the summarized evaluation of functional land use based on the representation of different landscape segments bearing different functional use on different levels while the production, hydrological and ecological functions are investigated in particular (i.e. functions that are significantly indicative of stability and/or non-stability of a particular territory at the present time). It is expressed by the indices of functions (Tab. 5) and is applicable to the assessment and comparison of trends of production use in various territories. Index PLU is expressed in the following form:

$$\mathbf{PLU} = LF_{production} / (LF_{hydrological} + LF_{ecological} + LF_{aesthetic} + LF_{recreational} + LF_{residental} + LF_{others})$$

Landscape function	area (ha)			
	level A	level B	level C	level D
production	5,925.6	2,307.4	0.0	503.6
ecological	569.2	568.7	813.2	1,786.8
hydrological	2,355.5	813.2	132.0	437.2
aesthetic	0.0	0.0	1005.9	945.2
recreational	0.0	437.2	1,786.8	0.0
residential	388.6	0.0	0.0	0.0
others	28.1	0.0	0.0	0.0
Total area	**9,266.9**			

Tab. 4: Proportions of selected functions and their levels (Hustopeče microregion, 2006)
Note: Method of calculation: LU/LC classes representing production function (No. 1) on level A are determined from Tab. 3. Areas of these classes (in ha) are added up. The addition gives a total area of the production function on level A (LU/LC: arable land, vineyards, fruit orchards, forests, quarries, etc.). Values for all functions on all levels are calculated in this manner.

where
- PLU < 1 – non-production landscape functions prevail (landscape categories fulfilling other functions in the landscape than production ones are dominant)
- PLU = 1 – balanced level of production and non-production landscape functions (landscape categories fulfilling non-production and production functions are in equilibrium)
- PLU > 1 – production landscape function prevails (landscape categories fulfilling mostly production functions are dominant)

3.3 Analysis of landscape functions in the study area

The Hustopeče study area includes 7 cadastral areas in southern Moravia and its total area is 9.2 km^2. The LU/LC evaluation was followed by the assessment of functional land use based on the LF index.

Evaluation based on the indices of functions (Tab. 7)
- 94–84% of landscape categories fulfill production function,
- production function is a priority, but it shows a downward trend,
- 28–19% of landscape categories fulfill ecological function,
- ecological function shows a downward trend all the time (regardless of the construction of hydrological structures),
- 39–34% of landscape categories fulfill hydrological function (the decreasing trend from the first half of the 19th century was stopped by the construction of the Nové Mlýny Water Reservoir in the Hustopeče micro-region),

PLU	Prevailing land use
< 0.5	Exclusively non-production land use
0.5 – 1.0	Non-production or production land use
1 – 1.5	Production land use
1.5 >	Exclusively production land use

Tab. 6: Determination of production land use intervals based on the indices of landscape functions

1825		1968		2006	
Landscape function	LF index	Landscape function	LF index	Landscape function	LF index
production	0.937	production	0.872	production	0.840
ecological	0.190	ecological	0.282	ecological	0.200
hydrological	0.386	hydrological	0.338	hydrological	0.339
aesthetic	0.170	aesthetic	0.136	aesthetic	0.080
recreational	0.000	recreational	0.000	recreational	0.132
residential	0.021	residential	0.035	residential	0.042
other	0.003	other	0.001	other	0.003

Tab. 5: Indices of landscape functions in the Hustopeče microregion in selected temporal horizons

- aesthetic function shows a downward trend,
- recreational and residential functions show a continually upward trend,
- other functions are difficult to evaluate.

3.4 Comparison of the functional use of model territories according to PLU

From Table 8 the following inferences can be made:

- study area has been used for production purposes since the first half of the 19th century,
- obvious downward trend of production land use (by 0.16) related to the development of non-production functions (mainly hydrological, ecological, etc.),
- if the first half of the 19th century is taken as the initial period, a change by 13.1% in the correlation between production function and non-production functions occurred in the region.

4. Summary

Research on correlations between the landscape structure and the functional use of agricultural landscape was conducted in the study area for two years. It is a part of the five-year project of Research Plan MZE0002704902 Integrated Systems of Soil, Water and Land Conservation and Use in Agriculture and Rural Development. Only partial results are presented; nevertheless, they can be applied as

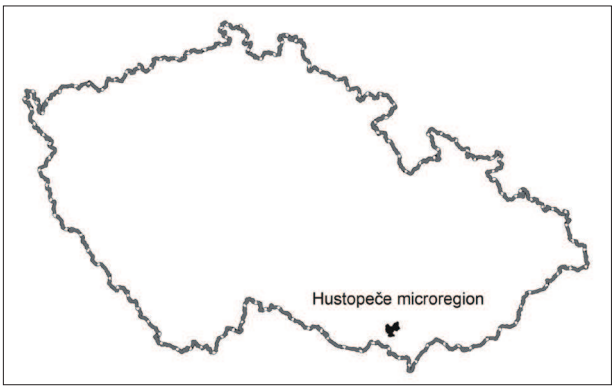

Fig. 1: The study area in the Czech Republic

Landscape function	1825	1968	2006
production	0.937	0.872	0.840
ecological	0.190	0.282	0.200
hydrological	0.386	0.338	0.339
aesthetic	0.170	0.136	0.080
recreational	0.000	0.000	0.132
residential	0.021	0.035	0.042
other	0.003	0.001	0.003

Tab. 7: Indices of landscape functions in the Hustopeče micro-region

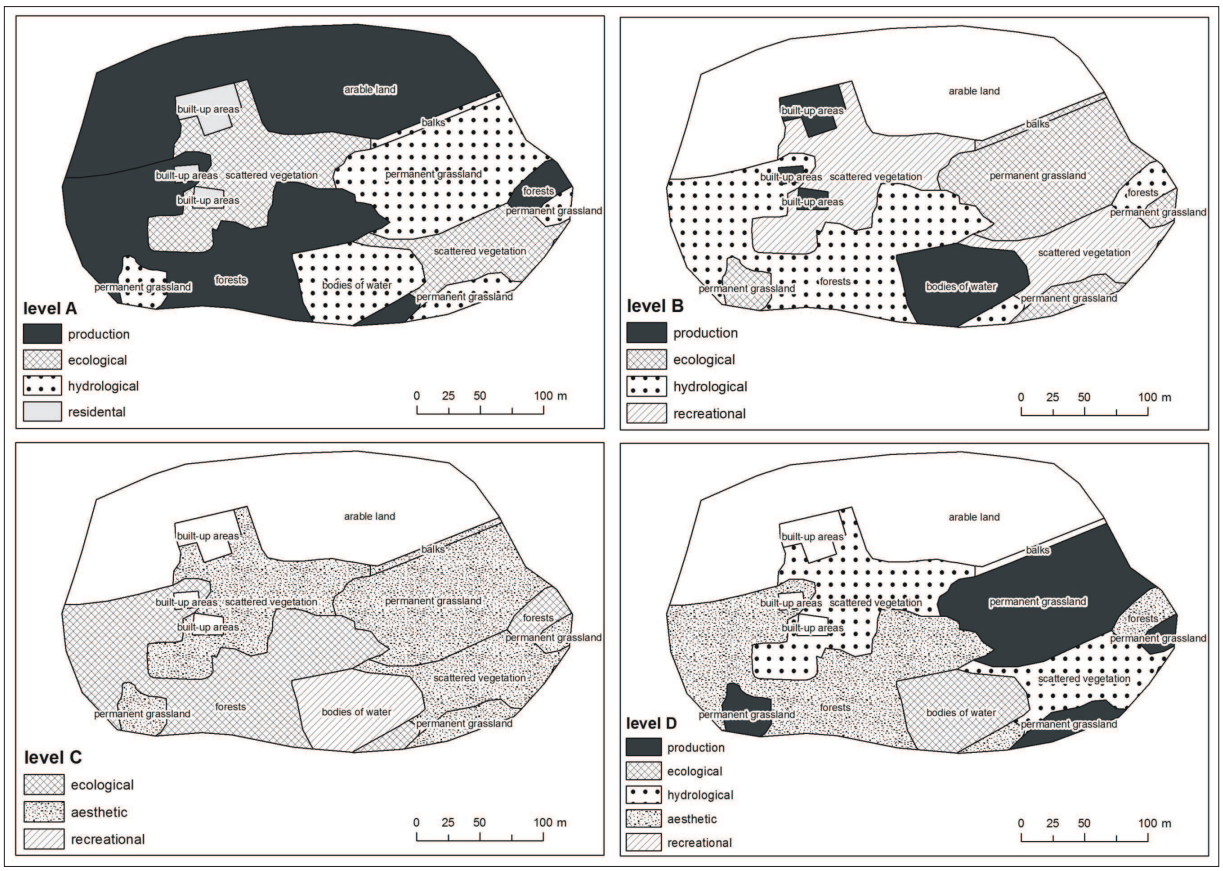

Fig. 2: Example of functional land use evaluation in a part of the study area (Hustopeče micro-region, 2006)

background data for proposing an optimization model of landscape structure and functional use of the study area. The functional use of the study area will be defined to propose optimization on the basis of preferable needs of land conservation. The analyses of landscape structure document that the landscape in the study area has undergone high unification, geometrization and reduction of grid fineness. Since the 1960s, the Hustopeče micro-region has moved into the category of coarse-grained landscape. In the distribution of the present landscape categories, it is very difficult to trace the original spatial arrangement.

Hustopeče micro-region	1825	1968	2006
PLU	1.22	1.10	1.06

Tab. 8: Production land use in the study area

The analyses of landscape functions illustrate the fact that the correlation between landscape category and function does not show direct proportionality. The Hustopeče micro-region has always been used for production purposes. Non-production landscape functions cannot be increased only by the large-scale extension of the proportion of landscape categories fulfilling the non-production functions (i.e. quantitatively), but their spatial arrangement and quality are very important (naturalness), too. A decrease in the production function by 5–10% and an increase in non-production functions by 10% would contribute to the balanced functional land use (to landscape stability). For the evaluation of the functional land

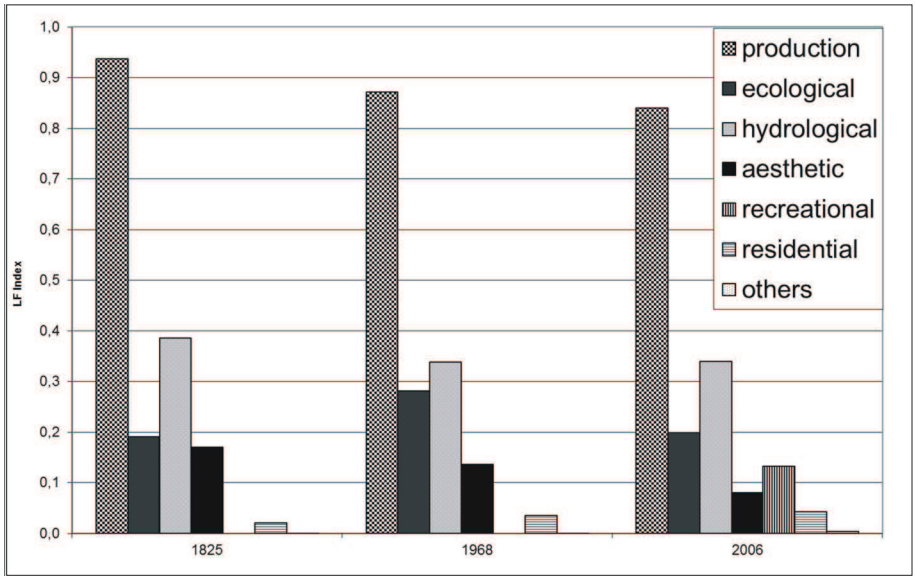

Fig. 3: Indices of functional land use in the Hustopeče micro-region at three temporal horizons (Tab. 7)

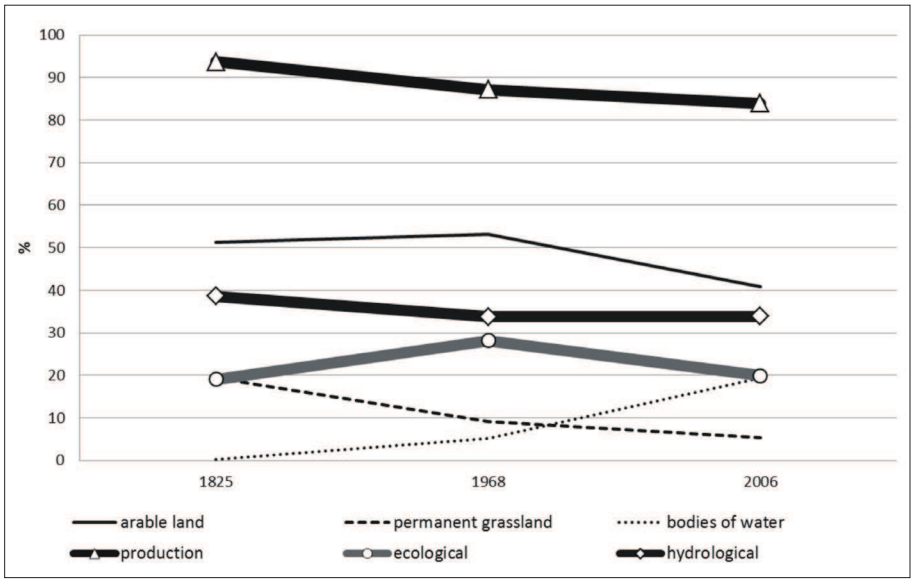

Fig. 4: Correlations between selected LU/LC classes and prevailing functions (Hustopeče micro-region)

use, it is more appropriate to use the index of functions rather than the evaluation according to one (dominant) function. In spite of all above-mentioned evaluations, it is to state that the economic pressure from the sixties has receded in favour of the non-production land use.

Changes in landscape categories representing non-production functions have the lowest influence on functions. Although there have been changes in the structures representing non-production functions in the study area, their influence on selected functions is not identical. The ecological function does not show an upward trend. To improve this function, more complex changes in landscape structure are necessary (mainly changes in the size and spatial arrangement of landscape categories

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Author´s addresses:

Ing. Dagmar STEJSKALOVÁ, e-mail: *stejskalova.dagmar@vumop.cz*
Mgr. Petr KARÁSEK, e-mail: *karasek.petr@vumop.cz*
Ing. Jana PODHRÁZSKÁ, Ph.D., e-mail: *podhrazska.jana@vumop.cz*
Research Institute for Soil and Water Conservation, v.v.i.
Division of Land Consolidation and Landscape Use in Brno
Lidická 25/27, Brno 602 00, Czech Republic

RNDr. Lenka TLAPÁKOVÁ, Ph.D., e-mail: *tlapakova.lenka@vumop.cz*
Research Institute for Soil and Water Conservation, v.v.i.
B. Němcové 2625, Pardubice, 530 02, Czech Republic

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