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POTENTIAL POSSIBILITIES OF SOIL MESOFAUNA USAGE FOR BIODIAGNOSTICS OF SOIL CONTAMINATION BY HEAVY METALS

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Abstract

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The study of potential possibilities of mesofauna as bioindicator of soil contamination by heavy metals is one of the most important areas of urban ecology and soil biology. The work presents the results of ecotoxicological and bioindicative assessment of the environment and the biota of the Melitopol urbosystem of Ukraine. The dynamics of chemical properties of soils in different functional zones of the city is analysed. The complex indices of pollution of environmental components are determined. A bioindicative assessment of the ecological condition of the territory of the urbosystem on the indicators of vitality of the soil mesofauna is carried out. For the first time, regional species-bioindicators for the territory of the city of Melitopol were determined. The ecomorphic structure of soil mesofauna of various functional zones of the city was revealed.

Key words: heavy metals, biodiagnostics, soil mesofauna, urbosystem, ecotoxicological assessment.

Introduction

In urban areas, there is a degradation of edaphotops under the influence of anthropogenic pressure. Biodiagnostics is a tool that allows the timely detection of technogenically transformed areas of the city. As indicators of the state of anthropogenically disturbed soils of urbosystems, it is advisable to use complexes of mesopedobionts that specifically react to changes in environmental factors (humidity, temperature, chemical composition of soils, etc.) (Bardgett, 2002; Berger et al., 1993; Coleman, Crossley, 2004; Livesley et al., 2016; Paoletti, Hassall, 1999; Rebele, 1994).

In soil biodiagnostics, researchers study the structure, biodiversity and the state of the populations of soil animals, as well as the peculiarities of the ecological mechanisms of mesopedobionts response to the effects of pollutants (Dai et al., 2004; Didden, Rombke, 2001; Holmstrup, 2000; Kohler, 2002; Kunah, 2016; Paoletti, 1999).

Increasing the level of pollution causes the inhibition of saprophagous or activation of their vitality. A number of researchers attribute this process to the composition of pollutants that cause acidification or degradation of soils (Whitacre, 2013; Yorkina, 2016). Chemical contamination is reflected in the activity, quantity, diversity and age structure of mesopedobionts populations (Didden, Rombke, 2001; Holmstrup, 2000; Livesley et al., 2016; Zhukov, Shatalin, 2016). As a result of the presence of heavy metals in the soil, the number and diversity of mesopedobionts decreases, and the number of some species that fully occupy an ecological niche increases. As the susceptibility to heavy metal pollution increases, mesopedobionts rank in a row: woodlouse - mollusks and earthworms - spiders - polygons (Badtyev, 2007).

Thus, pollutants affect the reduction of the number, the biomass of invertebrates, cause depression of the saprophagous, increase the press of predators, change the spatial distribution and impoverishment of the species composition (Bardgett, 2002; Coleman, Crossley, 2004; Edwards, 1992; Engelmann, 1978; Wood, 2012).

The objective of the research was to study the groups of mesopedobionts in the context of biotopic features of soil contamination by heavy metals.

Material and methods

According to the research program, an ecotoxicological assessment and bio-diagnostics of Melitopol urbosystem were performed, and the ecological state of the city was established, in accordance with the structural and functional organization of the urbosystem (Table 1).

In the city of Melitopol there are the following types of soil: turf, mainly gleying sand, clay and sandy loam soils in combination with mild humus sands, Southern black humus and slightly argillaceous, dark brown saline soils. By mechanical composition there are sandy, clay and clay-sandy soils.

For ecological characteristics of soil of Melitopol urbosystem, the following set of parameters has been selected: the reaction of medium (pH), the content of mobile forms of heavy metals with high biological activity – lead, cadmium, copper and zinc. Acidity was determined by a potentiometric method using a pH – meter of millivoltmeter pH-121 (ionomer EB 74). The content of moving forms of heavy metals was carried out by atomic absorption spec-

T a b l e 1. Location of functional areas of the city of Melitopol.

№	Functional zone	Name (functional purpose)
1	RZR	Area of the 'Refma' plant (industrial zone)
2	CP	City Park (recreational area)
3	MZTG	MZTG factory area (industrial zone)
4	MD	Microdistrict (residential area)
5	DPAM	District of plants 'Avtokoliorlyt' and MEMZ (industrial zone)
6	IIG	Institute of Irrigated Gardening (recreation area)
7	MHD	Melitopol hotel district (residential area)
8	DNM	District of cottages in New Melitopol (residential area)
9	KB	Kisiyarskaya beam (residential area)
10	TC	Telecentre (transport area)
11	SC	Southern crossing (transport, industrial zone)
12	BB	Berdyansk bridge (transport area)
13	PSH	Pishchane (residential area, highway area)
14	FP	Forest Park (recreation area)
15	AF	Airfield (residential area)

tral analysis using the VARIAN AA240FS spectrometer. Extraction of moving forms of heavy metals was carried out with ammonium acetate buffer solution at pH 4.8.

Sampling of soil was carried out by the method of an envelope measuring 5×5 m from a depth of 20–30 cm. To characterize the ecotoxicological state of soils, the indicators of total pollution were calculated according to the formula (Dmitrenko, 2012):

$$Z_c = \sum\left(\frac{C_i}{C_{\phi i}} + \ldots + \frac{C_i}{C_{\phi n}}\right) - (n-1),$$

where C_i is the concentration of heavy metals in the soil, μg/g; Cf_i is the background value of this concentration, μg/g; n - the number of total substances to be determined.

To estimate the level of soil contamination, an indicative scale of the risk of soil contamination is used (Table 2) (Dmitrenko, 2012).

T a b l e 2. Approximate scale of soil contamination risk.

Category of soil pollution	**Total pollution indicator Z_C**
Acceptable	< 16
Moderately dangerous	16….32
Dangerous	32…128
Extremely dangerous	> 128

T a b l e 3. Criteria for assessing the quality of soils in the state of mesopedobionts (according to Batdiyev, 2007).

Decrease of vitality with respect to norm	**Criteria of the ecological state of water objects**				
	favorable ES	**tense ES**	**critical ES**	**crisis ES**	**catastrophic ES**
G_i %	less than 11	11–25	26–50	51–80	more than 80

Note: ES - ecological situation.

The degree of soil contamination was determined by the index of vitality of invertebrates. To do this, depending on the sensitivity to soil contamination by moving forms of heavy metals, the representatives of the soil mesofauna were divided into groups, each of which was assigned the weighting coefficients (Badtyev, 2007):

- Isopoda live in relatively clean soil ($W_i = 1$),
- Mollusca (Gastropoda), *Lumbricina* live in a moderately contaminated soil ($W_{m,l} = 0.8$),
- the presence of *Aranei* indicates weakly contaminated soil ($W_a = 0.6$),
- while the representatives of the superclass Myriapoda adapt in soils with an average level of pollution ($W_m = 0.4$).

The method of soil quality bioindication is based on the comparison of the index of vitality of soil invertebrates in the studied and control sites. To do this, the sites of bioindication by size 5x5 m were made. On each of them, 5 soil trenches were made using an envelope method with the help of a sapper blade. The size of the trench was 25x25 cm, depth of 30 cm. The soil of the trench was placed on a transparent film and carefully split. The found animals were placed in transparent packages with the help of the tweezers. Then, the data of bioindication in the studied area G_{bi} were compared with the data of bioindication in the control section G_{bc} by the formula (Badtyev, 2007):

$$\Delta G_6 = (G_{6c} - G_{6i})/G6c \times 100\ \%.$$

The ecological status of the soil was evaluated according to the criteria in Table 3. The calculations and graphic design of the data obtained in the work were carried out using the Microsoft Excel program and the software package 'STATISTICA - 6.0'.

Results and discussion

As the degree of soil contamination bioindicators, we used mesopedobionts – the representatives of the Diplopoda and Chilopoda classes, Aranei and Isopoda series, Trachelipodidae, Armadillidiidae, Lumbricidae, Enidae, Limacidae, Hygromiidae, Helicidae and Bradybaenidae families (Stoev, 2002).

In Melitopol, the most alkaline soils are in the area of industrial facilities (plant 'Refma' (pH = 7.68 ± 0.40), MZTG factory (pH = 7.69 ± 0.34), Avtokoliorlyt and MeMZ plants (pH = 7.56 ± 0.40), transport highways (South crossing pH = 7.70 ± 0.37), Berdyansk bridge (pH = 7.97 ± 0.42), Telecentre (pH = 7.47 ± 0.41) and residential areas (Pishchane (pH = 7.43 ± 0.38), Kiziyarskaya beam (pH = 7.68 ± 0.33), the district of Melitopol hotel (pH = 7.59 ± 0.34).

The results of ecotoxicological assessment of the state of Melitopol urbosystem testify that the background content (FP) of lead amounted to 0.3 MAC, zinc - 0.2 MAC, copper - 0.35 MAC, while cadmium in reference sites is present in small amounts (0.02 MAC).

Ecotoxicological assessment of the spatial distribution of movable forms of heavy metals in the city shows that their distribution is uneven. Elements with spatially coordinated behaviour (Pb, Cu and Zn) form areas of pollution in the form of stable associations around their sources. These associations are most characteristic of emissions of certain industries (for example, in areas adjacent to major companies of the city, Pb concentration consistently exceeds MAC by 1.5–2 times, and zinc - 4 times. They are in the areas of highways. Moving forms of cadmium are found in the functional areas of industrial facilities (MZTG factory, 'Avtokoliorlyt', MeMZ and 'Refma' plants) exceeding MAC by 1.5 times. The excess of background values set by the content of Pb was found in all soil samples of Melitopol urbosystem. The general linear model allowed to establish that the factors of the season, the type of zone and pH determined 94% of the variability of the content of movable forms of lead (Table 4). A statistically significant predictor of lead is the year. Throughout the period of studies, the content of movable forms of lead naturally increased. Seasonal features were also found to be important in the dynamics of this heavy metal: in spring, its content is regularly lower than in autumn, which can be linked to the dynamics of precipitation in the steppe zone of Ukraine. Probably, in winter there is a flushing of lead from the soil profile. Also, this feature can be explained by the biotic factor, the effect of which is accumulated during the vegetation season. The general linear model indicates a lack of statistically significant influence of soil pH on the content of movable forms of lead (p = 0.22). But it should be noted that direct comparison of pH and content of movable forms of lead allows to obtain a strong correlation between these parameters (r = 0.60, p = 0.00).

Obviously, this connection is not functional, but due to the influence of general factors, both on the pH variation, and on the variation of the content of moving forms of lead in the soil. The variation of lead content due to the zone type is statistically significant (Table 8).

The highest indicators of lead were recorded along the transport highways (Southern crossing and Berdyansk bridge - 2.7 MAC), production facilities ('Avtokoliorlyt' and MeMZ plants - 2 MAC, 'Refma' plant - 2.1 MAC, MZTG factory - 1.8 MAC) and residential areas (Microdistrict - 2 MAC, Kisiyarskaya beam - 2.1 MAC). The lowest indicator is on the ter-

T a b l e 4. Total linear model of the influence of the year, season, zone type and pH content of moving lead in the soil (R2 = 0.94).

Parameter	**Sum of squares**	**Degrees of freedom**	**The average amount of squares**	***F*-reference**	***p*-level**
Constant	2522.55	1	2522.55	143.24	0.00
pH	26.55	1	26.55	1.51	0.22
Year	917.01	4	229.25	13.02	0.00
Season	105.81	1	105.81	6.01	0.01
Zone	75700.48	14	5407.18	307.03	0.00
Error	7555.20	429	17.61	–	–

T a b l e 5. The general linear model of influence of year, season, zone type and pH content of moving zinc in the soil (R2 = 0.97).

Parameter	**Sum of squares**	**Degrees of freedom**	**The average amount of squares**	***F*-reference**	***p*-level**
Constant	2094.57	1	2094.57	111.04	0.00
pH	27.99	1	27.99	1.48	0.22
Year	602.11	4	150.53	7.98	0.00
Season	151.01	1	151.01	8.01	0.00
Zone	185903.32	14	13278.81	703.97	0.00
Error	8092.11	429	18.86	–	–

T a b l e 6. The general linear model of influence of year, season, zone type and pH content of moving copper in the soil (R2 = 0.95).

Parameter	**Sum of squares**	**Degrees of freedom**	**The average amount of squares**	***F*-reference**	***p*-level**
Constant	583.47	1	583.47	152.17	0.00
pH	8.61	1	8.61	2.25	0.13
Year	7.20	4	1.80	0.47	0.76
Season	38.35	1	38.35	10.00	0.00
Zone	27563.25	14	1968.80	513.48	0.00
Error	1644.90	429	3.83	–	–

ritory of the City Park, which was at the level of the background value. The tendency to increase the content of lead in the surface layer of soil is also noted in the area of residential areas. Increasing in the concentration of lead in samples from the territory of a number of industrial enterprises is not significant.

The variability of the content of movable forms of zinc by 97% is determined by such factors as year, season, zone type and pH (Table 5).

T a b l e 7. The general linear model of influence of year, season, zone type and pH content of movable cadmium in the soil (R2 = 0.95).

Parameter	Sum of squares	Degrees of freedom	The average amount of squares	F-reference	p-level
Constant	1.21	1	1.21	72.65	0.00
pH	0.03	1	0.03	1.81	0.18
Year	0.24	4	0.06	3.67	0.01
Season	0.06	1	0.06	3.72	0.05
Zone	120.30	14	8.59	516.57	0.00
Error	7.14	429	0.02	–	–

T a b l e 8. The content of moving forms of heavy metals in the soils of the functional zones of the city of Melitopol (μg/g).

Functional zone	Pb^{2+}	Zn^{2+}	Cu^{2+}	Cd^{2+}	Total indicator of soil contamination level, Z_c	Category of soil contamination
RZR	39.58±1.83	71.56±4,37	35.62±1.43	1.55±0.067	122.90±3.28	Dangerous
KB	41.74±1.88	55.78±3.28	15.54±0.89	0.26±0.007	45.69±0.84	Dangerous
MZTG	36.86±2.2	60.78±2.25	13.5±0.78	1.52±0.048	101.95±3.32	Dangerous
MD	48.01±2.63	14.19±0.75	2.4±0.16	0.06±0.002	16.07±0.33	Acceptable
DPAM	42.79±2.28	26.94±1.65	21.84±0.43	1.78±0.08	107.81±2.65	Dangerous
IIG	8.38±0.47	6.29±0.38	12.05±0.59	0.06±0.003	12.75±0.22	Acceptable
CP	5.52±0.29	6.42±0.25	2.61±0.11	0.06±0.002	3.68±0.08	Acceptable
MHD	14.78±0.86	8.04±0.44	5.5±0.34	0.05±0.004	8.48±0.23	Acceptable
DNM	7.66±0.45	12.71±0.52	1.47±0.08	0.06±0.002	6.29±0.38	Acceptable
TC	22.25±1.44	13.95±0.64	3.01±0.15	0.12±0.008	15.92±0.30	Acceptable
SC	40.32±1.72	14.06±0.81	12.49±0.55	0.26±0.011	31.46±0.68	Moderately dangerous
BB	53.72±2.84	60.55±4.05	13.13±0.65	0.72±0.050	70.28±1.07	Dangerous
PSH	9.77±0.41	7.81±0.42	12.29±0.68	0.40±0.023	32.07±0.86	Moderately dangerous
AF	25.97±1.15	7.83±0.34	2.8±0.14	0.07±0.005	10.14±0.20	Acceptable
FP	5.17±0.15	4.56±0.23	1.03±0.04	0.01±0.001	1.97±0.56	Acceptable

In the seasonal aspect, there is a natural tendency to increase the content of movable forms of zinc in autumn compared with the spring period. The influence of pH on the content of moving forms is not statistically significant, but direct comparison gives a statistically significant correlation ($r = 0.49$, $p = 0.00$). For the annual dynamics, a statistically significant trend is established. Throughout the period, the content of moving forms of zinc increases. An analysis of the content of moving zinc forms in Melitopol soils showed their significant excess in edaphotops of the functional zones of industrial objects ('Refma' plant - 3.2 MAC, MZTG factory - 2.6 MAC), residential areas (Kisiyarskaya beam - 2.5 MAC) and highways (Berdyansk bridge - 2.7 MAC) (Table 8).

The smallest amount of zinc was noted in the recreational destinations (City Park and Institute of Irrigated Gardening), but the indicator slightly exceeded the background value by 1.2 and 1.3 times, respectively.

The general linear model explains 95% of the variability of the content of moving copper forms in the soil of the city (Table 6).

Statistically probable predictors are the season and the type of functional zone. During the years, the statistically probable trends of change in the content of moving copper forms have not been established. In spring, the content of mobile forms of copper is statistically less than in autumn. Acidity of soils also did not show statistically significant influence within the framework of the model, but a direct correlation is obtained with a high correlation coefficient of pH and moving forms of copper ($r = 0.41$, $p = 0.00$). Of course, the general factors may explain the correlation between these soil properties.

The content of copper exceeds the maximum MAC in the area of industrial facilities ('Refma' plant - 11.4 MAC, 'Avtokoliorlyt' and MeMZ plants - 7 MAC, MZTG factory - 4.6 MAC), residential areas (Kisiyarskaya beam, Peshchany - 4.8 MAC), highways (Southern crossing - 4.8 MAC, Berdyansk bridge - 4.5 MAC), recreational areas (Institute of Irrigated Gardening - 4.0 MAC). At the same time, in certain functional zones, the concentration of copper did not exceed MAC (CP, MD, DNM) (Table 8).

The general linear model explains 95% of the content variability in the soil of moving cadmium, using factors such as year, season, zone type and pH (Table 7). The acidity of the soil is not statistically significant as a predictor of the content of moving cadmium, although these indicators are characterized by a statistically significant correlation ($r = 0.42$, $p = 0.00$). In the seasonal aspect, the content of moving cadmium in spring is regularly lower than in autumn.

The ecotoxicological assessment made it possible to establish that after 2009 there was a sharp decrease in cadmium content in the soils of Melitopol, after which there was a steady tendency to increase this indicator.

The analysis of the content of moving cadmium forms in soils showed their excess in comparison with the background indicators. The largest concentrations were observed in the zones of industrial objects (the region of 'Refma' plant, MZTG factory, 'Avtokoliorlyt' and MeMZ plants), the smallest concentrations - in the zones of recreational territories (IIG, CP) and residential areas (MHD, DNM), but here they were 2–3 times higher than the background level (Table 8).

By reducing the total pollution index Z_c, the studied functional zones made the following list: region of the 'Refma' plant → the area of the plants 'Avtokoliorlyt' and MeMZ → the area of the MZTG factory → Berdyansk bridge → Kiziyarskaya beam → Pishchanaya → Southern crossing → Institute of irrigated gardening → Microdistrict → Telecentre → Airfield → Location of Hotel Melitopol → District of cottages in New Melitopol → City Park (Table 8).

The decrease in the vitality of mesopedobionts depends on the total indicator of soil contamination level (Fig. 1).

Analytically, this dependence can be expressed by the following equation:

$$\bar{G}_m = 1.72 - 58.16 * \log_{10} Z_c.$$

The conducted studies allowed to carry out an ecotoxicological assessment of the ecological state of the soil in Melitopol and to compare the results with the data of the biodiagnostic research.

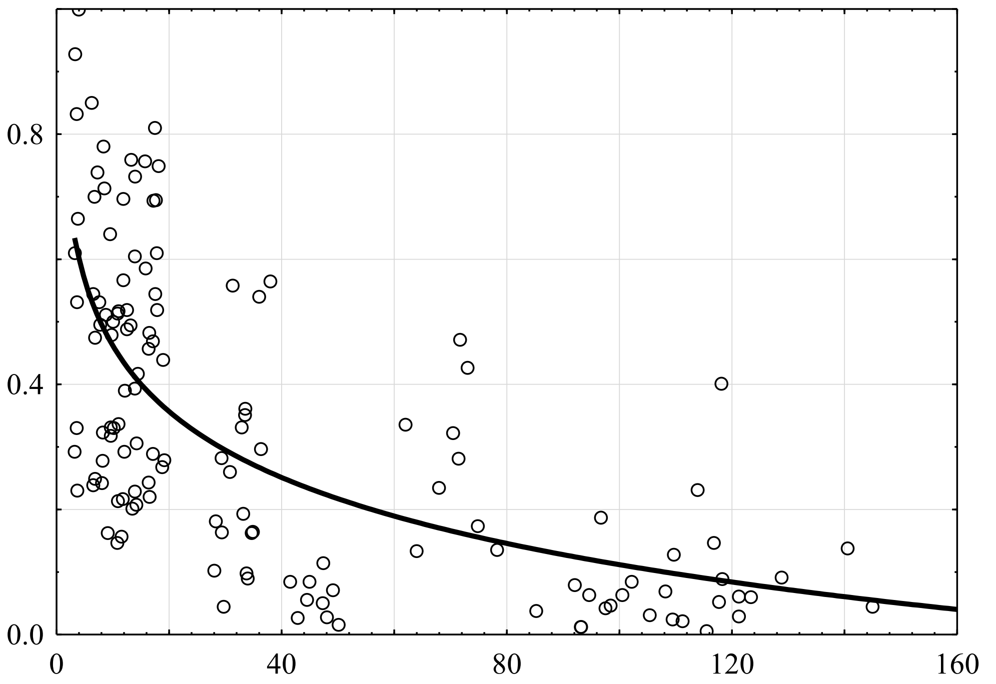

Fig. 1. Dependence of the decrease in the vitality of mesopedobionts from the total indicator of soil contamination level.

The high alkalinity of the soils of Melitopol urbosystem is due to the arrival of suspended particles from the highways (Ca and Mg carbonates), as well as dust. According to Dmitrenko (2016), in alkaline medium, Cu, Zn, Cd have weak mobility, and Pb is practically immobile. In the functional zones where the alkaline soils predominate, the zones of anomalies of chalcopylic elements are recorded (Kalabekov, 2003).

Sverlova N. (2004) indicate that in alkaline soils, a predominance of calcefils – stomach molluscs – has been noted, which allows them to be used to indicate the level of alkalization of soils. Berger and Dallinger (1993) believe that ground-based mugs are effective indicators of contamination of edaphotops by heavy metals.

According to the vitality of the mesophane groups (Batdyev, 2007), the quality of the soil of the urbosystem is evaluated. Thus, the ecological state of the functional zones can be recognized as favourable for 1 functional zone (6.7%), stress – for 4 functional areas (26.7%), critical – for 3 functional areas (20.0%), crisis – for 3 functional areas (20.0%) and catastrophic – for 4 functional zones (26.7%). The obtained data indicate that the total soil pollution index of the 8 functional zones of the city (53.3%) are classified as admissible level of pollution, 2 – as moderately dangerous level (13.3%), 5 – as dangerous level (33.34%).

It should be noted that the total indicator of soil contamination is based on the assumed non-toxicity of the toxic influence of heavy metals, which is a rather general idea. Indeed, there is, of course, synergism and antagonism of the influence of heavy metals on the grouping of soil invertebrates (Dai et al., 2004; Kohler, 2002; Kunah , 2016; Mohammadein et al., 2013).

The dependence of the decrease of the mesopedobionts' vitality index on the total indicator of soil contamination level indicates the presence of the stability in the groups of soil invertebrates. With increased level of pollution, the decrease in the vitality of mesopedobionts is inhibited, which can be explained by the activation of homeostatic mechanisms in the group (Zhukov, Shatalin, 2016; Zadorozhnaya, 2018).

Some authors emphasize (Kohler, 2002; McKinney, 2006) that in anthropogenically altered areas, the population of zoophages increases, there is homogenization of the cenomorphic composition of the main groups of mesopedobionts with the dominance of certain species.

Conclusion

As a result of the ecotoxicological and biodiagnostic assessment of the soil condition of Melitopol urbosystem, it was found that:

- For lead and zinc, there is a steady and statistically significant tendency to increase their content. During the years, the statistically probable trends of change in the content of moving copper forms have not been established. After 2009, there was a sharp decrease in the cadmium content in soils, after which there was a steady tendency to increase this index.
- In spring, the content of lead, zinc, copper and cadmium is lower than in autumn. The main source of soil contamination of the urbosystem by lead is vehicles.
- On the basis of the complex of bioindicative researches, which foresee the determination of the indicators of the vitality of the soil mesophane, an ecological state of edaphotops of the urbosystem of Melitopol was conducted.
- It has been proved that in anthropogenically altered areas, the population of zoophages increases, homogenization of the cenomorphic composition of the main groups of mesopedobionts with the dominance of certain species is observed. In alkaline soils, the predominance of calcefils – polygons, woodlice, stomach molluscs – has been noted, which allows them to be used to indicate the level of alkalization of soils.

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EFFECT OF LANDSCAPE USE ON WATER QUALITY OF THE ŽITAVA RIVER

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Abstract

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Intensification of landscape use brings along the negative effects on environmental components. These include surface water pollution. The aim was to determine the effect of landscape use on the water quality of the Žitava river. It was assumed that an area with the high proportion of anthropogenic activity would negatively affect water quality. At the same time, we assumed that an area with the lower proportion of anthropogenic use and with the higher proportion of natural and semi-natural elements contributes to self-cleaning ability of the watercourse. At the four observed sites, ammoniacal nitrogen (NH_4-N), nitrate-nitrogen (NO_3-N), phosphate-phosphorus (PO_4-P) and water conductivity were monitored. Landscape use was analysed using the database of land cover based on the CORINE Land Cover methodology. Subsequently, it was observed how the landscape use affects the water quality. It was found that the very good state, represented by the Class I water quality, is according to the measured indicators mostly present in the areas predominantly covered by forests along with extensive use of elements of the agricultural land. The area with predominance of agricultural and urbanised sites where the anthropogenic influence prevails is characterised by average water quality. As the overall water quality of the Žitava river reaches the average, it is necessary to eliminate the pollution by constructing the sewer systems in the villages through which the watercourse is passing and, in agriculture, to ensure the adherence to the legislation concerning the protection of surface water against pollution from agricultural sources.

Key words: land cover classes, water quality indicator, ammoniacal nitrogen, nitrate-nitrogen, phosphate, watershed.

Introduction

Water quality of the watercourses is influenced by numerous factors. Anthropogenic pollution as a result of landscape use is significant amongst them. Important findings were published already in 1970s (Rimer et al., 1978). The relationship between the landscape use and pollution is observed in the works of Basnyat et al. (1999), Buck at al. (2004), Ahearn et al. (2005), Chang (2008), Wan et al. (2014), Ding et al. (2016), Peng et al. (2017) and others. Akasaka et al. (2010), Lu et al. (2015) and Muchová and Tárníková (2018) point out that ensuring good surface water quality plays an important role in the protection of biotopes, ecological stability, agriculture, food processing industry, and protection of public health. In Slovakia, the relationship between the landscape use and water quality was studied in the past, for example, by Mendel et al. (1994) and Pekárová, Pekár (1996). The works that are coming to the foreground in the recent years are mainly the ones that evaluate the water quality depending on the effects of natural factors (Babošová et al., 2017; Vanková, Petluš, 2014; Pratt et al., 2012) or only on selected pollution indicators (Jurík et al., 2013; Húska et al., 2013; Šulvová et al., 2009). An important part of knowing the relationship between landscape use and water quality is the simulation of pollution processes using IT systems (Maillard, Santos, 2008; Sahu et al., 2009; Li et al., 2015; Oliveira et al., 2016 etc.).

According to the data published at the website of Enviroportal (2017), the surface waters in Slovakia have long been of poor quality or of bad state. At present, they are gradually improving; however, a major effort is needed to meet the main environmental objective that arises from Directive 2000/60/EC on the good state of all water bodies. One of the steps to take remedial action is to analyse the landscape use in individual river basins, to identify and, subsequently, to eliminate sources of water pollution.

As part of the evaluation, we work with the hypothesis that the area with high proportion of eco-stabilising landscape elements positively affects the water quality of the watercourse.

The aim is to determine the effect of landscape use on water quality of the Žitava river based on the level of selected indicators of water pollution. The basis for the evaluation is the analysis of the landscape use within the individual watersheds of the Žitava river and the analysis of pollution indicators in water sampling sites.

As part of the evaluation, we assume that the territory with a high proportion of landscape elements in the landscape will positively affect the water quality of the watercourse.

The objective is to determine the impact of land use on water quality of the Žitava river based on the values of selected indicators of water pollution. The basis for the evaluation is the analysis of the use of the landscape within the individual watersheds of the Žitava river and the analysis of the pollutants at the site sampling locations.

Material and methods

The Žitava river and its basin

Total length of the watercourse is 69 km. The area of the Žitava river basin is 907 km^2, of which the assessed area represents 53.5% (485.21 km^2). It is a river basin area that flows into the lowest placed site sampling location, approximately 4 km north of the town Vráble (Fig. 1). According to the typology of bodies of surface water elaborated for the implementation of the Water Framework Directive, the lower course of Žitava river is classified as the medium-sized river of the Pannonian Basin; the remaining part belongs to small rivers in the Carpathians.

In the assessed part of the basin, the total length of the watercourses with a catchment area bigger than 10 km^2 is 211.3 km. Geomorphologically, the area belongs to the parts of Tribeč, Pohronský Inovec and the Danubian Hills. The geological base is predominantly the core mountains of Tribeč and volcanic rocks of Pohronský Inovec. The clastic rocks are predominant in the Danubian Hills.

The Žitava river flows through several types of landscape. In its upper course, the forest landscape, an extensive agricultural landscape and the settlements predominate. In the middle and lower course of the river prevails the intensive agricultural landscape with rural and two urban settlements. For the purpose of comparing the effect of landscape use on level of water pollution, the area was divided into four watersheds. The site sampling locations of the surface water were at the mouth of the watersheds.

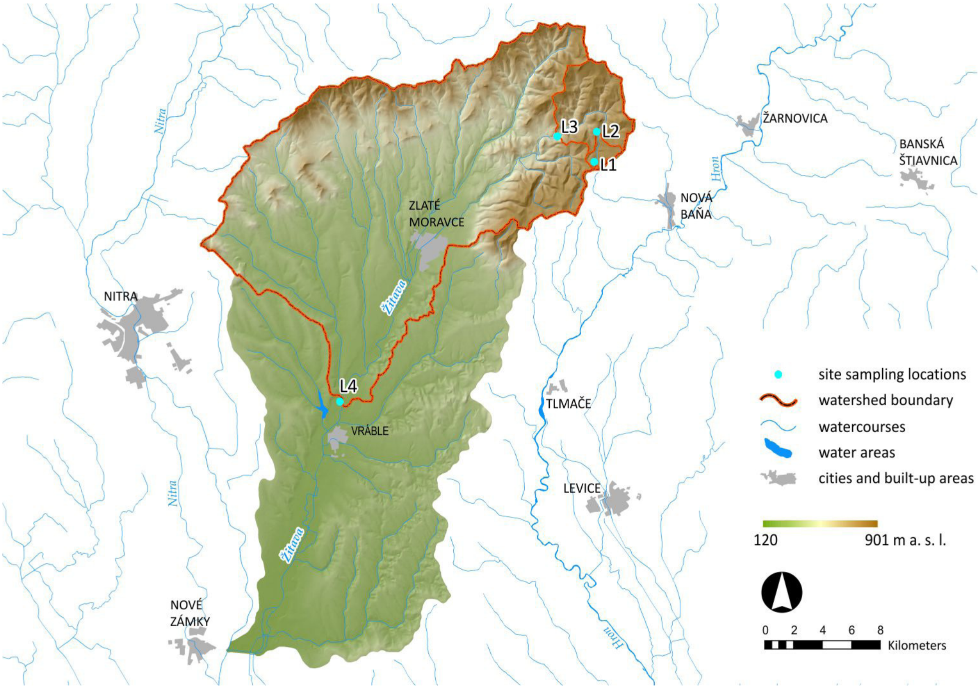


Fig. 1. Delimitation of watersheds and site sampling locations within the Žitava river basin (source of underlying layers: Digital Layers of Landscape Atlas of the Slovak Republic Landscape Atlas, 2002).

Location 1 (48,4498386N; 18,5612372E; 635 m above sea level, 69 rkm) – it has the character of spring area located on the border of cadastral area of the village Veľká Lehota (district Žarnovica), about 650 m north-east of spot height Kamennývrch (720 m above sea level). The site is located on the border of built-up area of the village, on a slope with large-scale arable land (currently grassed) and gardens of family houses. Botanically, the habitat can be characterised as highly herbaceous community on wet meadows (hygrophilous tall-herb fringe communities of plains and of the mountain to alpine belts).

Location 2 (48,4705192N; 18,5609244E; 535 m above sea level, 66.37 rkm) – located approximately 150 m north of the built-up area of the village Veľká Lehota (part Dolina). The width of the water flow at the sampling point is about 1.5 m. The site is located on the border of a built-up area near inoperative wastewater treatment plant built on the watercourse. Nowadays, it has the character of successively growing wet meadow accompanied with developed vegetation of woody plants with *Alnus glutinosa and Salix caprea*.

Location 3 (48,4652222N; 18,5193611E; 360 m above sea level, 59.65 rkm) – the cadastral territory of the village Jedľové Kostoľany outside the built-up part of the village 80 m north-east of the ruins of Živánska tower on the verge of the road II/1622. It has the character of mountain stream. Stony stream bed is about 3.5 m wide. It flows mostly through forested part of the landscape with well-developed vegetation of woody plants with *Alnus glutinosa*. There are mowed mesophilic meadows nearby.

Location 4 (48,2759625N; 18,3124114E; 150 m above sea level, 27.99 rkm) – the cadastral area of the town Vráble, part Horný Oháj, approximately 230 m south-west of water reservoir Nová Vesnad Žitavou. It has the character of slowly flowing river deeply cut below the level of the surrounding flat relief. The width of the stream bed is around 5 m at the site sampling location. It flows through intensively used agricultural landscape with prevailing large-scale arable land from which the watercourse is separated by a strip of woody bank vegetation with *A. glutinosa, Salix viminalis* and *Negundo aceroides.*

Methods

Landscape use analysis

Landscape use was analysed using the database of land cover based on the CORINE Land Cover methodology (CLC, 2012). The area was evaluated in terms of the CORINE Land Cover legend, identifying 18 classes of landscape cover (Table 1).

T a b l e 1. The landscape covers identified according to CORINE Land Cover (2012).

Level 1	**Level 2**	**Level 3**
Artificial surfaces	1.1 Urban fabric	1.1.2 Discontinuous urban fabric
	1.2 Industrial, commercial and transport units	1.2.1 Industrial or commercial units 1.2.2 Road and rail networks and associated land
	1.3 Mine, dump and construction sites	1.3.1 Mineral extraction sites 1.3.3 Construction sites
	1.4 Artificial, non-agricultural vegetated areas	1.4.1 Green urban areas 1.4.2 Sport and leisure facilities
Agricultural areas	2.1 Arable land	2.1.1 Non-irrigated arable land
	2.2 Permanent crops	2.2.1 Vineyards 2.2.2 Fruit trees and berry plantations
	2.3 Pastures	2.3.1 Pastures
	2.4 Heterogeneous agricultural areas	2.4.2 Complex cultivation patterns 2.4.3 Land principally occupied by agriculture, with significant areas of natural vegetation
Forest and semi natural areas	3.1 Forests	3.1.1 Broad-leaved forest 3.1.2 Coniferous forest 3.1.3 Mixed forest
	3.2 Scrub and/or herbaceous vegetation associations	3.2.4 Transitional woodland-shrub
Water bodies	5.1 Inland waters	5.1.2 Water bodies

Landscape use was analysed in individual watersheds. The watershed is the basic (hydrologically) contributing area belonging to the site sampling location. When defining the watersheds, the digital relief model DMR 10 was used with a raster size of 10 m, generated from the Basic contour maps of Slovakia 1:10000.

Determination of selected water quality indicators

In water samples at the four monitored locations, ammoniacal nitrogen (NH_4-N), nitrate-nitrogen (NO_3-N) and phosphate-phosphorus (PO_4-P) were determined using the spectrophotometer Spectroquant Move 100. Selected indicators of surface water indicate the inorganic anthropogenic pollution of surface water, for example, by agriculture. Subsequently, the device Hana II 991301 determined the conductivity (EC) that indicates the concentration of mineral substances in water. High values refer to possible presence of pollution. The temperature and pH of the water had to be measured for the optimal determination of the indicators and their interpretation. At the same time, the amount of oxygen dissolved in water was determined using Oximetra WTW Oxi 3310. Oxygen ration affects significantly the processes in water environment. The water analysis was carried out at monthly intervals from July 2016 to June 2017. The values were used in research of relationship between water quality and landscape use. At the same time, based on the Government Regulation No. 269/2010Coll., water quality class and state of the Žitava river were determined.

The data obtained from the analysis of landscape use in individual watersheds and values of indicators measured at site sampling locations were used as an input for research of the effects of landscape use on water quality. On the basis of the input data, the changes in concentrations of measured values of the NH_4-N, NO_3-N and PO_4-P; the changes in conductivity over the monitored period; and the seasonal changes in the concentration of indicators were observed in individual locations. The findings were confronted with the analysis of landscape use in individual watersheds.

The significance of the differences between locations and seasons was tested with factorial analysis of variance. Where the main factors were significant, the Tukey test was used. A significance level of 0.05 was used for both the analyses. All calculations were made in R software (R Core Team, 2017) using packages ggplot2 (Wickham, 2009), lsr (Navarro, 2015) and heplots (Fox et al., 2017).

Results

Landscape use in the evaluated part of the Žitava *river basin*

For the analysis of landscape use, the four watersheds were determined. The landscape use in the individual watersheds is given in Table 2.

The representation of land cover classes was influenced significantly by the size of watersheds. In watershed of location 4 that had the largest area, all land cover classes were identified. On the other hand, in watershed of location 1, only 2 classes were found (Fig. 2).

The grasslands that were created by grassing of arable land used mainly for the growing of cereals prevails in watershed of location 1. Nowadays, they are used as pastures. Urban fabric consists of residential houses, roads and gardens. The representation of land cover classes in watershed of location 2 is similar. However, here are prevailing lands occupied by agriculture that are currently used as pastures, with significant areas of natural vegetation, that is represented by successive linear or group-scattered woody vegetation. In this watershed, throughout the watercourse, the urban fabric is in contact with the river. In the watershed of location 3, there are mainly forest and semi-natural areas. The class of broad-leaved forests with woody areas prevails. There are oak-hornbeam forests represented, and in the higher altitudes, there are beech-oak forests. The vegetation with *Alnus glutinosa* was found in the bank along the watercourse. Texture of forests is complemented by pastures, transitional woodland-shrubs and scattered settlement. In watershed of location 4, the agricultural land slightly prevails over the forests (609.94 ha, 1.27%). Site sampling location is situated in the southern part of watershed where only the agricultural land is represented, which include intensively used arable land. In this part of watershed, right tributaries flow into the river collecting the surface water from the part of Tribeč. During the period of research, maize (*Zea mays* L.), rapeseed (*Brasica napus* L. *var. napus*) and common wheat (*Triticum aestivum* L.) were cultivated on both the riverbanks in the immediate proximity of the site sampling location. Vineyards, scattered, mainly linear vegetation, meadows, baulks, individual agricultural buildings and farms are all parts of the agricultural land.

T a b l e 2. Landscape use in the evaluated part of the Žitava river basin.

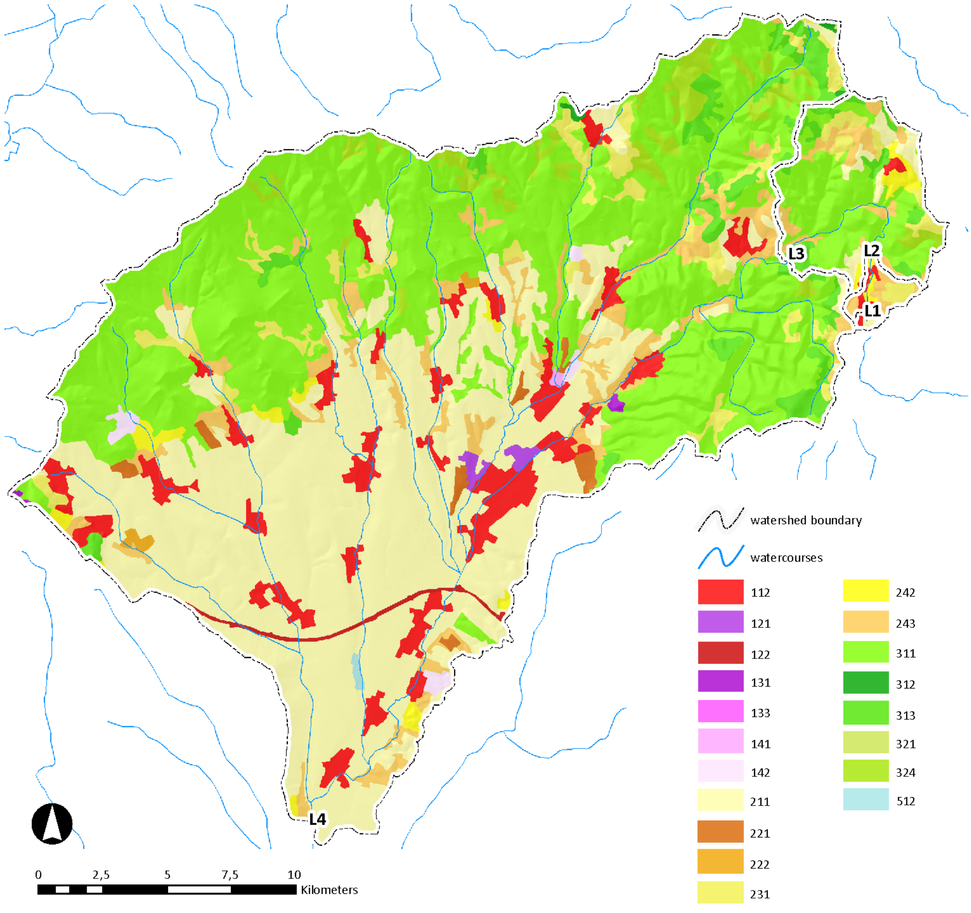
	Location 1		Location 2		Location 3		Location 4	
Class	**ha**	**%**	**ha**	**%**	**ha**	**%**	**ha**	**%**
1.1.2	10.54	21.19	68.45	17.53	110.88	3.15	2,781.76	5.73
1.2.1	-	-	-	-	-	-	135.46	0.28
1.2.2	-	-	-	-	-	-	131.15	0.27
1.3.1	-	-	-	-	-	-	47.76	0.10
1.3.3	-	-	-	-	-	-	43.02	0.09
1.4.1	-	-	-	-	-	-	25.08	0.05
1.4.2	-	-	-	-	-	-	214.38	0.44
Total	**10.54**	**21.19**	**68.45**	**17.53**	**110.88**	**3.15**	**3,378.61**	**6.96**
2.1.1	-	-	51.89	13.29	337.96	9.60	17,101.55	35.25
2.2.1	-	-	-	-	-	-	313.29	0.65
2.2.2	-	-	-	-	-	-	83.54	0.17
2.3.1	31.72	63.78	84.97	21.76	333.04	9.46	1,843.99	3.80
2.4.2	-	-	39.95	10.23	185.86	5.28	566.54	1.17
2.4.3	7.47	15.02	145.25	37.19	548.30	15.57	2,947.63	6.07
Total	**39.19**	**78.80**	**322.06**	**82.47**	**1,405.16**	**39.91**	**22,856.54**	**47.11**
3.1.1	-	-	-	-	1,588.43	45.11	19,074.87	39.31
3.1.2	-	-	-	-	4.95	0.14	62.26	0.13
3.1.3	-	-	-	-	332.09	9.43	1796.91	3.70
3.2.1	-	-	-	-	-	-	0.30	0.00
3.2.4	-	-	-	-	80.06	2.27	1312.26	2.70
Total	**-**	**-**	**-**	**-**	**2,005.53**	**56.95**	**22,246.6**	**45.84**
5.1.2	-	-	-	-	-	-	38.91	0.08
Total	**-**	**-**	**-**	**-**	**-**	**-**	**38.91**	**0.08**
In total	**49.73**	**100.00**	**390.51**	**100.00**	**3,521.57**	**100.00**	**48,520.66**	**100.00**

Notes: 1.1.2 – discontinuous urban fabric; 1.2.1 – industrial and commercial units; 1.2.2 – road and rail networks and associated land; 1.3.1 – mineral extraction sites; 1.3.3 – construction sites; 1.4.1 – green urban areas; 1.4.2 – sport and leisure facilities; 2.1.1 – non-irrigated arable land; 2.2.1 – vineyards; 2.2.2 – fruit trees and berry plantations; 2.3.1 – pastures; 2.4.2 – complex cultivation patterns; 2.4.3 – land principally occupied by agriculture, with significant areas of natural vegetation; 3.1.1 – broad-leaved forests; 3.1.2 – coniferous forest; 3.1.3 – mixed forest; 3.2.4 – transitional woodland-shrub; 5.1.2 – water bodies; - – the class is not present in the location.

Water quality of the Žitava river

The state and development of selected indicators was observed during the year based on the measured values. Significant monthly or seasonal differences were not observed, which was reflected as well in the classes of water quality in the individual indicators at all locations. The water temperature that influence the changes in the water quality varied in individual locations between 2.6 and 15.5 °C (location 1), 2.3 and 21 °C (location 2), 1.8 and 20.3 °C (location 3) and 3.6 and 23.3 °C (location 4). The average pH was 7.72 at all locations. The lowest value was 7.19, and the highest was 8.7. The measured values of water pollution indicators, dissolved oxygen and water quality classes according to the Government Regulation

Fig. 2. Land cover classes in the watersheds of monitored locations.



Notes: 1.4.2 – sport and leisure facilities; 2.1.1 – non-irrigated arable land; 2.2.1 – vineyards; 2.2.2 – fruit trees and berry plantations; 2.3.1 – pastures; 2.4.2 – complex cultivation patterns; 2.4.3 – land principally occupied by agriculture, with significant areas of natural vegetation; 3.1.1 – broad-leaved forest; 3.1.2 – coniferous forest; 3.1.3 – mixed forest; 3.2.4 – transitional woodland-shrub; 5.1.2 – water bodies; - – the class is not present in the location.

No. 269/2010 Coll. are given in Table 3. The amount of oxygen dissolved in water can be estimated as an average at all locations (Class III). It met the requirements for surface water quality only during the spring, which is related to the greater discharge of water in watercourse. It was caused by melting of snow and more precipitation during the spring. The lowest measured values were those of NH4-N, which reached optimal values during the whole observing period. Only in one case (February 2017, location 4), it exceeded the limit value of 1 mg/l, so the requirement for the surface water quality was not met. Locations showed predominantly

T a b l e 3. Values of water pollution indicators and water quality classes of the Žitava river.

	Jul 2016	Aug 2016	Sep 2016	Oct 2016	Nov 2016	Dec 2016	Jan 2017	Feb 2017	Mar 2017	Apr 2017	May 2017	Jun 2017
	MV/ WQC	MV/ WQC	MV/ WQC	MV/ WQC	MV/ WQC	MV/ WQC	MV/ WQC	MV/ WQC	MV/ WQC	MV/ WQC	MV/ WQC	MV/ WQC
	Location 1											
NH_4-N (mg/l)	0.19/I	0.19/I	0.24/I	0.26/I	0.19/I	0.01/I	0.04/I	0.12/I	0.04/I	0.01/I	0.03/I	0.01/I
NO_3-N (mg/l)	1.2/I	4.5/III	0.7/I	1.3/I	0.8/I	0.4/I	1.8/II	1.2/I	0.7/I	0.5/I	1.2/I	0.5/I
PO_4-P (mg/l)	0.09/II	0.44/III	0.06/II	0.04/I	0.02/I	0.01/I	0.25/III	0.27/III	0.19/II	0.02/I	0.02/I	0.02/I
O_2 (mg/l)	0.3/III	0.34/III	0.06/III	0.06/III	0.13/III	0.53/III	0.81/III	1.56/III	4.1/III	2.3/III	8.66/I	3.5/III
EC (mS/m)	170/III	690/III	150/III	120/III	170/III	150/III	210/III	290/III	180/III	160/III	170/III	30/I
	Location 2											
NH_4-N (mg/l)	0.19/I	0.19/I	0.24/I	0.63/II	0.18/I	0.21/I	0.14/I	0.4/I	0.26/I	0.32/I	0.22/I	0.01/I
NO_3-N (mg/l)	1.1/I	4.5/III	0.7/I	4.5/III	1.6/II	1.5/II	1.6/II	1.2/I	1.7/II	1.5/II	2.0/II	1.5/II
PO_4-P (mg/l)	0.42/III	0.44/III	0.06/II	0.54/III	0.34/III	0.18/II	0.16/II	0.17/II	0.15/II	0.33/III	0.29/III	0.02/I
O_2 (mg/l)	0.34/III	0.34/III	0.06/III	0.06/III	0.17/III	0.43/III	0.23/III	3.2/III	25.7/I	9.51/I	9.42/I	8.5/I
EC (mS/m)	250/III	690/III	150/III	290/III	230/III	190/III	160/III	16/III	160/III	210/III	220/III	150/III
	Location 3											
NH_4-N (mg/l)	0.18/I	0.19/I	0.24/I	0.27/I	0.16/I	0.02/I	0.05/I	0.12/I	0.07/I	0.01/I	0.07/I	0.09/I
NO_3-N (mg/l)	0.7/I	4.5/III	0.7/I	1.6/II	0.5/I	1.1/I	1.8/II	1.3/II	0.7/I	0.4/I	0.9/I	0.9/I
PO_4-P (mg/l)	0.08/II	0.44/III	0.06/II	0.17/II	0.03/I	0.05/II	0.06/II	0.04/I	0.04/I	0.03/I	0.05/II	0.02/I
O_2 (mg/l)	0.46/III	0.34/III	0.06/III	0.07/III	0.19/III	0.45/III	1.3/III	1.5/III	3.41/III	10.33/I	10.48/I	8.5/I
EC (mS/m)	310/III	690/III	150/III	240/III	280/III	230/III	170/III	180/III	20/I	220/III	20/I	150/III
	Location 4											
NH_4-N (mg/l)	0.19/I	0.19/I	0.24/I	0.82/II	0.27/I	0.53/II	0.13/I	1.02/III	0.36/I	0.05/I	0.14/I	0.09/I
NO_3-N (mg/l)	4.5/III	4.5/III	0.7/I	4.5/III	1.2/I	3.1/II	3.5/II	2.2/II	2.5/II	2.3/II	2.2/II	0.9/I
PO_4-P (mg/l)	0.44/III	0.44/III	0.06/II	0.26/II	0.22/II	0.19/I	0.13/I	0.18/I	0.13/I	0.15/I	0.23/II	0.02/I
O_2 (mg/l)	0.34/III	0.34/III	0.06/III	0.08/III	0.16/III	0.4/III	2.91/III	1.94/III	5.22/III	8.82/I	7.9/I	8.5/I
EC (mS/m)	690/III	690/III	150/III	690/III	70/I	630/III	520/III	40/I	640/III	570/III	530/III	150/III

Notes: MV – measured value; WQC – water quality class according the Government Regulation SR No. 269/2010Coll.

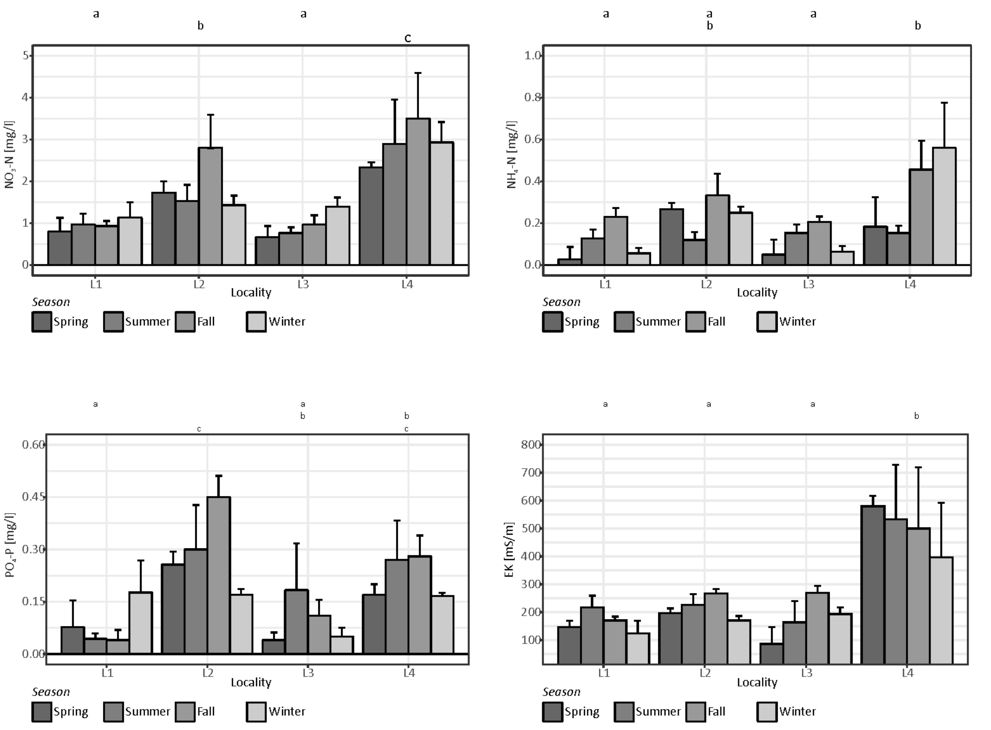
high EC values that exceeded the permitted values of 110 mS/m, which confirmed the presence of a high number of dissolved pollutants in water. On the basis of the measured values obtained from locations during the whole research period, water quality of the Žitava river reached Class III, which represents the average water quality state of the watercourse.

Effect of landscape use on water quality of the Žitava *river*

The values of water pollution indicators in individual locations show the differences in water quality. This is related to the concentration of individual pollutants and the placement of site sampling locations that are affected by the landscape use in the watersheds. Pollution in watercourses is affected by the current use of the area as well, for example, agricultural use. Therefore, the seasonal concentrations of pollutants at site sampling location were also monitored (Fig. 3).

A factorial analysis of Variance (ANOVA) was separately conducted to compare the main effects of season and location and the effect of the interaction between season and location on the NH_4-N, NO_3-N, PO_4-P and EC. Location included four levels (L1, L2, L3 and L4), and season consisted of four levels (Spring, Summer, Fall and Winter) (Table 4).

Fig. 3. Seasonal concentrations of pollutants at site sampling locations.



T a b l e 4. Analysis of variance of the effect of season and location on NH_4-N, NO_3-N, PO_4-P and EC.

		NH_4-N [mg/l]			NO_3-N [mg/l]			PO_4-P [mg/l]			EC [mS/m]		
Source of variation	df	MS	F		MS	F		MS	F		MS	F	
Season	3	0.08	2.99	*	0.98	1.33		0.02	1.49		15,406	0.61	
Location	3	0.14	5.11	**	10.48	14.17	***	0.12	8.65	***	306,339	12.07	***
Season x Location	9	0.03	1.22		0.42	0.57		0.02	1.32		9,981	0.39	
Error	32	0.03			0.74			0.01			25,392		

Notes: MS – mean square. Significance: *** – ≤0.001; ** – ≤0.01; * – ≤0.05.

Statistical analysis shows that the locations significantly affect the concentration of water quality indicators (NH_4-N: F (3.32) = 5.11, p = 0.005, NO_3-N: F (3.32) = 14.17, 0.001, PO_4-P: F (3.32) = 8.65, p <0.001, EC: F (3.32) = 12.07, p <0.001). On the basis of the Tukey post hoc test, it is clear that location 4 was notably different at all evaluated indicators. Concerning the indicators NO_3-N and NH_4-N, the difference was observed in location 4 compared to location 1 (NO_3-N: p = 0.011, NH_4-N: ps<0.001) and location 3 (NO_3-N: p = 0.015; NH_4-N: ps<0.001). Concerning the EC, the differences were observed compared to locations 1, 2 and 3 (all ps< 0.001). Concerning PO_4-P, the test showed that location 4 was different from location 1 (p = 0.039) and location 2 was different from location 3 (p = 0.002). Influence of the seasonality proved as significant only concerning NH4-N (p = 0.045). In the tests, the relationship between the locations and seasonality proved to be insignificant (NH_4-N: p = 0.313; NO_3-N: p = 0.814; PO_4-P: p = 0.265; EC: p = 0.929), indicating that the locations were not polluted differently during the seasons.

The results stated so far show that the highest concentrations are those of NO_3-N. They are particularly elevated during autumn in locations 2 and 4 (not statistically proven). Locations are characterised by increased anthropogenic use that affects the presence of NO_3-N in water. A similar pattern is evident in the concentrations of the NH_4-N indicator (statistically proven). Their development is related because the nitrogen forms undergo biochemical transformation, which decomposes NH_4-N to NO_3-N or to nitrites (NO_2-N). Municipal pollution from sewage water is the source of pollution in location 2, where NH_4-N is a part of physiological waste. The autumn fertilisation of winter cereal – wheat and rape – that were cultivated nearby is the source of pollution in location 4. This type of pollution was shown also concerning PO_4-P. Locations 2 and 4 are also characterised by high concentrations of PO_4-P during whole monitored period (mainly during the autumn). This is related to the faecal waste that is being released into the watercourse along with sewage water with the addition of washing powders and various detergents because the village Veľká Lehota does not have a sewer system. On the basis of the presence of anthropogenic pollution, which is expressed by conductivity, it is evident that location 4 is the mostly used watershed where the biggest pollution during the whole monitored period was observed. The water quality indicators monitored detect mainly anthropogenic pollution that is related to the landscape use. Comparing the landscape use in the individual watersheds belonging to site sampling locations, the watershed of location 4 is the most intensively used. There are represented all identified classes of land cover, mainly artificial surfaces and agricultural areas with arable land, which represent 54.07% of total area of watershed. Intensive landscape use affects water quality in the watercourse. Intensive human activity was also reflected in the watershed of location 2, where only artificial surfaces and agricultural areas are represented. In terms of landscape use, the evaluated locations are similar. The low water quality at site sampling locations in the watercourse was also similar. In the watershed of location 1, there are mainly agricultural areas with extensive pastures with significant areas of natural vegetation (78.80%) that do represent the risk of anthropogenic pollution. It was reflected in the average water quality at site sampling location. Location 3 is represented mainly by forests (56.95%) and agricultural areas used as meadows, pastures and complex cultivation patterns with significant areas of natural vegetation (30.31%). These classes of land cover do not require intensive human intervention, thereby reducing the potential water pollution. This affected significantly the water quality that was several times at all evaluated indicators of Class I water quality, such as Location 1. Locations 1 and 3 are similar in terms of landscape use. In locations 1 and 3 (compared to locations 2 and 4) were the measured values of NH_4-N, NO_3-N and also PO_4-P were lower, which is connected with the higher proportion of natural elements and low proportion of anthropogenic activity.

Discussion

The results of the work point out the effect of landscape use on water quality of the Žitava river. The results of measurements show that the very good state represented by Class I water quality is most represented in the area where the forests prevail along with extensively used elements of agricultural lands (they account for almost 88% of total area of the corresponding watershed). On the contrary, the watersheds with prevailing agricultural areas and urban fabric where the anthropogenic effect is dominating are characterised by the average water state. On the basis of the results, it can be stated that the forests and extensively used agricultural land have the positive effect on water quality and contributes to the self-cleaning ability of the watercourse. It is clear that the forest (location 3), which fulfils the water protection function, has the positive effect on water quality as the site sampling location situated below the village (location 2) showed only the average water quality state. The municipality has no sewer system, and sewage water and faecal waste from the households are being released into the watercourse. The results of this study are in compliance with the researches (Li et al., 2009; Tu, 2011; Jurík et al., 2013; Wan et al., 2014) that point out the correlation between the presence of nitrogen and phosphorus compounds and an intensive human activity. Thong and Chen (2002) stated that nitrogen compound pollution is related to the commercial use of land for agricultural and residential purposes. The impact of human activity was the lowest on location 1, which was situated at the river spring. There was almost no presence of NH_4-N and NO_3-N, and only a slight increase in PO_4-P. PO_4-P pollution might be caused by livestock breeding nearby the spring that can be washed to the spring after precipitation and concentrated in slowly flowing water. The location is characterised by an inappropriate oxygen regimen. It is related with the slow waterflow that was caught in the tank from where it flow only slowly. Low values of NH_4-N and NO_3-N indicate the extensive landscape use around the site sampling location. The opposite effect of pollution was observed in location 4 situated in lower course of the river where the agricultural areas and urban fabric are represented. In this area, the presence of intensive agricultural activity significantly affects the concentration of nutrients that soak to the soil by excessive fertilisation. They reach the watercourse by washing off, erosion and seepage, proven as well by the works of Ongley et al. (2010), Johnson at al. (2013), Húska et al. (2013) and Zhang et al. (2014). During the monitored period, the grain maize and common wheat were cultivated in the proximity of watercourse. Both crops require high nutrient intake in the form of inorganic fertilisers as well as pesticide use. These contribute to the increase in the local production of corps; however, they have negative effect on soil and water, many times also at regional level.

Conclusion

Water quality of the Žitava river is significantly affected by the landscape use. It has been confirmed that an area with a high proportion of anthropogenic activity negatively affects the water quality. It is possible to assume the high degree of water self-cleaning ability in the watercourse because in location 3, where the forests prevail, the water had a good quality. On contrary, in location 4 and in its immediate proximity, there is a high proportion of land cover with intensive effect of human activities and the water quality was not at appropriate level. Substantial water pollutant of the Žitava watercourse is the pollution by sewage water from households. Many municipalities do not have public sewer system; households release the sewage water directly to the watercourse. The current situation should change after 2021. By this time, the municipalities have a duty to allow the households to connect to a public sewer system. Another major polluter is an intensive agricultural activity focused on plant production. To eliminate the pollution in this area, it is necessary to respect the requirements and regulations in force that are part of the cross-compliance in agriculture and to ensure the protection of water from pollution from the agricultural sources, for example, by creating the buffer zones along the watercourses where industrial or organic fertilisers that can be considered as potential source of surface water pollution will not be used.

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THE BIOINDICATION EVALUATION OF GROUND BEETLES (COLEOPTERA: CARABIDAE) IN THREE FOREST BIOTOPES IN THE SOUTHERN PART OF CENTRAL SLOVAKIA

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Abstract

Langraf V., Petrovičová K., David S., Nozdrovická J., Petrovič F., Schlarmannová J.: The bioindication evaluation of ground beetles (Coleoptera: Carabidae) in three forest biotopes in the southern part of Central Slovakia. Ekológia (Bratislava), Vol. 38, No. 1, p. 25–36, 2019.

Ground beetles (Carabidae) were used to evaluate the bio indication environmental incidence. The ground beetle material (2,341 individuals, 30 species) was collected between 2015 and 2017 using pitfall traps in three types of forest habitats with different disturbance rates. The comparison of carabid's sensitivity as bio indicators has been evaluated by using three methods: (i) community index of ground beetles (IKS), (ii) ellipsoid biovolume (EV) and (iii) flight ability of the carabids. Using the Monte Carlo permutation test, we did not record the statistically significant changes in IKS values, nor does a change in the representation of carabids in the bioindicative group A, E and R. On the contrary, we confirmed the statistically significant changes in the average values of ellipsoid biovolume in biotopes and between biotopes (the Friedman and Kruskal-Wallis test - ANOVA (p-value = 0.00)). A higher number of macropterous species were recorded in biotopes with high disturbance as compared to the biotopes with low disturbance.

Key words: carabids, bio indicators, community index of the ground beetles, ellipsoid biovolume, flight ability, Slovakia.

Introduction

Approximately 80% of the human population of industrialized countries live in towns. It is important to know what the impact of human activity is on cultural aspects, and to identify factors that influence species biodiversity for biodiversity conservation in town surroundings. It is also important to find out and test the indicators of the biodiversity status, as well as its causes and changes (Pickett et al., 2001). The most commonly used bioindicators from invertebrate fauna are the orders of Araneae (Buchar, 1983), Diplopoda, Chilopoda (Tuf, Tufová, 2008), Odonata (David, 2001) and Coleoptera (Boháč, 2007). The Coleoptera order – especially the Carabidae family – is rich in species. These are species with well-known autecology, inhabiting various habitat types. They react sensitively to the presence of different toxic substances, and to pH and soil moisture change (Cárcamo, Spence, 1994; Stork, 1990).

In forest ecosystems, the carabids react to the changes derived from the character of the tree layer. The structure of their communities change due to tree cutting intensity but also with forest restoration (Šteffek et al., 2008). The clear-cut of trees changes the microclimate of habitat and its light conditions, and thus reflects the species composition and phenology of herbal communities (Heithecker, Halpern, 2006). Forest clear-cutting have caused a decline in some specialized forest species of the Carabidae. Eurytopic species that are typically found in open areas, ruderal habitats and fields (Elek et al., 2001; Finch, 2005; Wiezik et al., 2007) have replaced these species. This species exchange is typical in locations such as oak forests and beech-fir forests, at up to approximately 900 m a. s. l. At higher altitudes, there is a reduction in species exchange because there is a reduction in the occurrence of the areas cultivated; and the field (segetal) species (Šustek, 2005). Šteffek et al. (2008) proposes that these changes are a reflection of the ecological degradation of ecosystems and are associated with human activities in the environment. Stluka (2013) confirmed the carabid response to tree cutting in spruce forests using the Community Index of the Ground Beetles (IKS). He considers that the intensity of management increases the number of euryvalent species in the forest ecosystem. Rajová (2007) also recorded a higher proportion of adaptable species compared to the eurytopic species found in the intact Klánovický Forest (the Czech Republic). The results of Langraf et al. (2016) also confirm that the anthropogenic influence on the forest deteriorates the living conditions of the adaptable and relict species. These conclusions also apply to the undisturbed mountain meadow biotopes in the Veporské vrchy hills. There was a predominance of eurytopic species (bioindication group E) in the intensively influenced forest and meadow biotopes of the Juhoslovenská kotlina basin. Another indicator, which determines the environmental pollution level, is the change in body size (ellipsoid biovolume) and vagility (distributing the species in a certain area) (McGeogh, 1998). Szyszko (1983) formulated and confirmed the hypothesis 'the decrease of environmental disturbance allows for a larger than average body size', while he was studying ground beetles during the restoration of a pine forest. Šustek (1987) pointed out the decreasing body size of the Carabidae in areas that are under intensive anthropogenic disturbance. The body size of a Carabidae is associated with flight ability, which is related to the appearance of apterous and brachypterous species. (Majzlan, Frantzová, 1994). The reverse is also true – macropterous species have a smaller than average body size in biotopes. Porhajášová, Šustek (2011) confirmed that the species that live in stable ecosystems, have lost their flight ability. Flight ability endures within those species that come from ecosystems exposed to cyclical changes. Rainoi, Niemalä (2003) recorded a trend for the Carabidae, which shows that the number of apterous species decreases with the increasing disturbance, and on the contrary, the number of macropterous species increases. Similarly, Shibuya et al. (2014) also discovered that macropterous beetle species dominated in grass ecosystems and apterous and brachypterous species dominated in forest ecosystems.

These results show that the predominance of apterous and brachypterous species indicates significant environmental stability, and macropterous species indicates a less stable environmental ecosystem.

The aim of our paper is to evaluate the changes in the values of the Index of community of the ground beetles (IKS), body size (ellipsoid biovolume), and flight ability of the Carabidae in the three biotope types between 2015 and 2017. We focused on evaluating the three hypotheses: 1) the Index of community of the ground beetles (IKS) values decrease with the increasing intensity of biotopes' disturbance; 2) the average body size value (EV) of ground beetles decreases with the increasing intensity of biotopes disturbance; and 3) the number of macropterous species increases with the increasing intensity of biotopes disturbance.

Material and methods

Ground beetle research took place from 2015 to 2017 in the three localities that represent the three types of biotopes with varying intensities of anthropogenic influence: The Culture of *Picea abies*, Carpathian oak-hornbeam forest and Carpathian turkey oak forest. In 2015, the traps were set from 17th April to 23rd October; in 2016 from 7th May to 30th October; and in 2017, from 15th April to 30th October. The material was collected seven times in each year at regular three-week intervals. We used the pitfall traps (720 ml) (Novák et al., 1969), five pitfall traps were set in one line per each biotope in 10 metres distances. As a fixation fluid, we used 4% saline. We identified the ground beetles according to Hůrka (1996), the nomenclature and flight ability of the species from Carabidae (apterous (A), brachpterous (B) and macropterous (M)) follow Hůrka (1996).

Study area

The study areas are located in the southern part of Central Slovakia near the town of Lučenec and Poltár and the village of Utekáč (Table 1).

T a b l e 1. Location data of the study localities.

Geomorphological unit	**study site**		**C. a.**	**m a. s.l.**	**Biotope**	**G. C.**
Veporské vrchy hills	1	Lichovo	Utekáč	518	Culture of *Picea abies*	48°36′27″N 19°48′23″E
Juhoslovenská kotlina basin	2	Kúpna hora	Poltár	300	Carpathian oak-hornbeam forest	48°26′02″N 19°49′31″E
	3	near Ľadovo	Lučenec	258	Carpathian turkey oak forest	48°19′49″N 19°37′06″E

Notes: C. a. – Cadastral area; m a.s.l. – metres above sea level; G.C. - geographic coordinates.

The study plot 1 (Lichovo) is characterised by black berries (*Rubus fruticosus* agg.) in the undergrowth of approximately 20 years forest cover of old Norway spruce (*Picea abies*). During 2016, a small number of trees, which the great spruce bark beetles (*Ips typographus*) has attached themselves to and infested them, were finally cut. They were at a distance of 3 to 5 m away from the trap lines. In study plot 2 (Kúpna hora), the 50–60 years old oak-hornbeam forest was formed by the species of hornbeams (*Carpinus betulus*), black locusts (*Robinia pseudoacacia*), pedunculate oaks (*Quercus robur*), and sessile oaks (*Q. petraea*). Thin shrub undergrowth consist of privet (*Ligustrum vulgare*), spindle tree (*Euonymus europaeus*) and especially younger hornbeams (*Carpinus betulus*), black locusts (*Robinia pseudoacacia*), pedunculate oaks (*Quercus robur*), in the height up to 3 m. The ground zone consists of leaf litter without vegetation. In 2016, forest tree cutting took place 60 m from the trap lines. Study site 3 (near Ľadovo) is the Carpathian turkey oak forest, which is 80–100 years old. This tree zone is represented by species of field maple

(*Acer campestre*), hornbeam (*Carpinus betulus*), Turkey oak (*Quercus cerris) and pedunculate oak (Q. robur*). Field maple and hornbeam (*Acer campestre* and *Carpinus betulus*) dominate in the shrub zone. Coralroot (*Dentaria bulbifera*), fumeworts (*Corydalis* spp.) and cleavers (*Galium aparine*) dominate in the herb zone. Intensive forest tree cutting took place 40 m from the trap lines during the years 2016 and 2017.

The following methods were used for the bioindication evaluation of ground beetles at the localities: the community index of the ground beetles (IKS) (Nenadál, 1998), ellipsoid biovolume (EV) (volume – body size) (Brauna et al., 2004) and the flight ability of the Carabidae (Hůrka, 1996) and (Majzlan, Frantzová, 1994).

Computation of the Carabidae Ellipsoid biovolume (EV)

The morphometric signs were measured for each individual using a digital microscope (0.1 mm accuracy): (i) the length – dorsal length between the upper lip (labium) and the terminal part of elytra, (ii) the width – dorsal length between the maximum width of the elytra, and (iii) the height – the maximum dorsoventrally thickness of the left side of the body. Each parameter was measured three times to minimize error, and the final value is their arithmetic average. According to Braun et al. (2004), the ellipsoid biovolume (EV) from our measured morphometric signs (length, width, height) used the formula:

$$EV = (\pi/6) \times L \times H \times W$$

where: L = individual length, H = individual height, W = individual width.

Computation community index of the ground beetles (IKS)

Ground beetles we divided into three bioindication classes according to Farkač et al. (2006):

- Group R – relicts, stenotopic species, narrow ecological valence – mostly rare and endangered species of natural ecosystems.
- Group A – adaptable species which colonize semi-natural habitats, they occur in secondary, good regenerating biotopes and its ecotones.
- Group E – eurytopic species without special requirements on the character and quality of environment. They occur in unstable and changing biotopes with strong anthropogenic influence.

The Index of Community of ground beetles (IKS) is calculated according to Nenadál (1998) based on the division of the *Carabidae* into bioindication groups (A, E, R). We use the following formula:

$$IKS = 100 - (\Sigma E + 0.5 \times \Sigma A)$$

where E = percentage of individuals in group E (E%), A = percentage of individuals in group A (%).

The IKS index includes the values ranging from zero to 100. In cases where the index value is close to zero, we identified mostly species of group E. Conversely, when the value of index is close to 100; there are mostly species from group R. The final values included five classes according to the Nenadal's (1998) classification scale of human influence on habitat: I (0–15) strongly influenced, II (10–35) significantly influenced, III (30–50) influenced, IV (45–65) marginally influenced and V (65–100) not influenced.

Data analyses

For the analysis of morphometric parameters, Ellipsoid biovolume (EV), flight ability and community index of the ground beetles (IKS), were used statistic methods (StatSoft, 2004; Ter Brak, Šmilauer, 2004). Distribution normality (the Shapiro-Wilk´s W test), homogeneity of variance (the Levene's test), compliance of average values (the Friedman test – ANOVA), (the Kruskal-Wallis test – ANOVA) correlation of years to EV values and correlation of biotope types to IKS values and bioindication groups (A, E, R) (the Monte Carlo permutation test) were analysed by the methods of inductive statistics. We used data matrix of all species with the number of individuals at the sites and matrix of species of bioindication groups A, E, R and IKS values.

Thanks to the level of significance $p_\alpha = 0.05$ (if $p > p\alpha$, we cannot reject H_0 according to the level of significance $p_\alpha = 0.05$). H_0 hypotheses was tested - (i) Random selection comes from a set of normal values distribution; (ii) Random selection comes from a set of normal values dispersion; (iii) In the years 2015 and 2017, there is no difference in the average value of EV in all localities; (iv) Linear regression model is statistically significant.

Results and discussion

During the research, we found 2,341 individuals (1,111 males, 1,230 females) belonging to 30 species (Table 2). According to the values of index of community of ground beetles (IKS), the largest species representation from all found specimens belonged to group A – adaptable (21 species; 2,294; individuals = 70%). A smaller percentage of species belonged to group E – eurytopic (7 species; 34 individuals = 23.33%). Group R – relicts was represented by two species and 13 individuals = 6.67%. Rajová (2007) recorded a higher representation of group A species in intact stands of the Klánovický Forest (the Czech Republic) compared to the localities located on the edge of the forest in contact with the meadow and stream where the species from group E prevailed.

According to the classification scale of anthropogenic influence on habitat, the biotopes belong to class III (influenced) or IV (lower influenced). IKS values over the three years between the beetle assemblages in localities did not differ significantly. The following summarises the IKS values we recorded in the forest: pine stand of *Picea abies* (IKS = 49), Carpathian oak-hornbeam forest (IKS = 48) and Carpathian turkey oak forest (IKS = 46). The IKS values in study sites 1 and 2 decreased during 2016, due to the cutting of invaded trees there. In 2017, there was a small increase (Table 2) of IKS values. On the contrary, the highest decrease in IKS values were found in 2017 at the study site Carpathian turkey oak forest, which was due to the continuing cutting of trees. Using the IKS (Stluka, 2013) also confirmed that tree cutting has strong anthropic impact. We found a significant decrease in IKS values in the tree cutting forest and the lowest in the spruce forest. Langraf et al. (2016) noted the predominance of group E (eurytopic) species in a habitat in the tree cutting forest. We assume that after removing most of the trees in biotope Carpathian turkey oak forest, the carabids from group E would replace the species of group A. The lower IKS value in this study site was influenced by the presence of a higher number of individuals *Calathus fuscipes* and *Pseudoophonus rufipes* belonging to group E. These species are typical in arable lands, which surround this locality. There was also tree cutting there and newly created open area offered to carabids to penetrate there.

The difference in the representation of the Carabidae bioindication groups of A, E, R and IKS values among the study sites over the years 2015 and 2017 was evaluated by a redundancy analysis (RDA, the highest value of lengths of gradient = 1.38) (Fig. 1). RDA analysis explained the variability of species data in the first ordination axis (76.1%) and in the second ordination axis (90%). Variability of species data explained by the environmental variables in the first ordination axis was 71.6%; and in the second axis, it was 85%. The maximum value of inflation factor was 1,551. We confirmed the species of group A correlated with carabids from the study biotopes pine stand *Picea abies* and Carpathian turkey oak forest, where they were represented mostly. We expected the binding of group A species, although intensive tree cutting prevails carabids form the study biotope Carpathian turkey oak forest and the flying of macroporous species belonging to group E also occurs. The complete exchange of groups would only occur after the forest was cut. The vectors, which show the individual years (2015–2017) for this group, did not deviate significantly, indicating only small changes in the number of species for group A. The species of group R correlated with carabids from

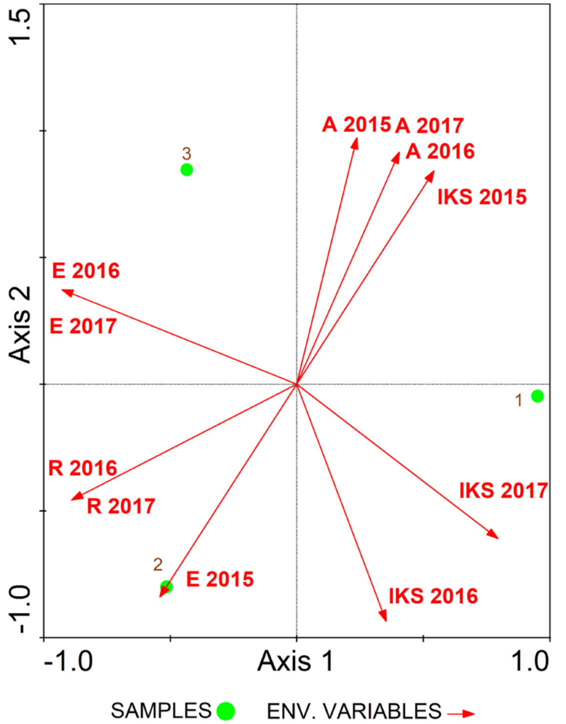
T a b l e 2. Distribution of the Carabids based on bioindication groups of flight ability in the study sites.

species	KBS	F.A.	Study site		
			1	2	3
Abax ovalis (Duftschmid, 1812)	A	B	12	-	-
Abax parallelepipedus (Piller & Mitterpacher, 1783)	A	B	145	54	115
Abax parallelus (Duftschmid, 1812)	A	B	51	19	26
Amara familiaris (Duftschmid, 1812)	E	M	-	1	-
Amara saphyrea Dejean, 1828	A	M	-	-	3
Aptinus bombarda (Illiger, 1800)	R	B	-	2	9
Calathus fuscipes (Goeze, 1777)	E	M	-	-	4
Calosoma inquisitor (Linnaeus, 1758)	A	A	-	-	2
Carabus cancellatus Illiger, 1798	A	A	6	-	-
Carabus convexus (Fabricius, 1775)	A	A	5	-	1
Carabus coriaceus Linnaeus, 1758	A	A	19	75	60
Carabus glabratus Paykull, 1790	A	A	237	-	2
Carabus granulatus Linnaeus, 1758	E	B	-	-	4
Carabus hortensis Linnaeus, 1758	A	A	332	368	212
Carabus intricatus Linnaeus, 1761	A	A	15	20	3
Carabus nemoralis O.F.Müller, 1764	A	A	45	5	43
Carabus violaceus Linnaeus, 1758	A	A	168	27	22
Cychrus caraboides (Linnaeus, 1758)	A	A	12	-	-
Cymindis humeralis (Fourcroy, 1785)	A	B	2	4	1
Harpalus rubripes (Duftschmid, 1812)	E	M	-	-	1
Leistus rufomarginatus (Duftschmid, 1812*)*	R	M	-	2	-
Molops elatus (Fabricius,1801)	A	B	-	-	2
Molops piceus (Panzer, 1793)	A	B	87	2	21
Nebria brevicollis Fabricius, 1792	A	M	-	-	4
Notiophilu biguttatus (Fabricius, 1799)	A	B	-	2	-
Ophonus azureus (Fabricius, 1777)	E	B	3	-	-
Pseudoophonus rufipes (De Geer, 1774)	E	M	-	3	17
Pterostichus melanarius (Illiger, 1798)	E	B	-	1	-
Pterostichus niger (Schaller, 1783)	A	M	20	-	1
Pterostichus oblongopunctatus (Fabricius, 1787)	A	M	1	14	29
Σ species	-	-	17	16	22
Σ species KBS-A/flight ability A	21	10	16/9	11/5	17/7
Σ species KBS-E/flight ability B	7	11	1/6	3/6	4/6
Σ species KBS-R/flight ability M	2	9	0/2	2/5	1/9
IKS value in 2015	-	-	50	50	50
IKS value in 2016	-	-	49,1	47,2	46,3
IKS value in 2017	-	-	49,2	47,8	43,1
Total IKS value for the years 2015–2017	-	-	49	48	46

Notes: KBS- categories of bioindication groups A, E and R; F.A.- flight ability of the Carabids: apterous (A), brachypterous (B), macropterous (M); 1- locality 1 (Culture of *Picea abies*), 2 - locality 2 (Carpathian oak-hornbeam forest), 3- locality 3 (Carpathian turkey oak forest).

localities two and three; the vectors did not change over the years 2016 and 2017. For the year 2015, the vector is not representative due to the absence of the group R species. Biotopes Carpathian oak-hornbeam forest and Carpathian turkey oak forest were mostly represented by species from group E, as shown by the correlation of this group among 2015–2017. The vectors markedly deviated between 2015 and 2016, indicating a change in the number of species from group E. The vectors for IKS values have deviated significantly between 2015 and 2016. Between 2016 and 2017, there was also a separation of the vectors, which was not as significant as the year before. The above-mentioned fact, the deviation of vectors for IKS values and the number of species from group E points to the tree cutting of wood in biotope Carpathian turkey oak forest, which had begun in 2016 and continued until 2017. In 2015, group R did not occur in study localities; therefore, it is not in the chart and Monte Carlo permutation test. The maximum value of inflation factor was = 4.73. Using the Monte Carlo permutation test, we did not confirm statistical significance of IKS values and bioindication groups (A, E, R) for 2015 to 2017.

Fig. 1. RDA analysis of species representation of groups A, E, R and IKS values from 2015 to 2017.



Notes: 1, 2, 3 – locality number. R 2015–2017 species of indicator group R for 2015 to 2017, E 2015–2017 species of indicator group E for the years 2015 to 2017, A 2015–2017 species of indicator group A for 2015 to 2017, IKS 2015–2017 values of community index of ground beetles for the years 2015 to 2017.

The Carabidae were divided into three bioindication groups according to their flight ability: apterous (A), brachypterous (B), macropterous (M). The largest species spectrum belonged to the group B (11 species 36.67%; 562 individuals), a smaller presence of the species was in the group A (10 species = 33.33%; 1679 individuals); in the group M, were 9 species = 33% (100 individuals) (Table 2). The slight prevalence of brachypterous species above theapterous species were recorded in all the study sites as was also found by Farkač et al. (2006) too. The predominance of macropterous species was recorded in the biotope Carpathian turkey oak forest due to the intensive tree cutting of wood and prevalence of species that prefer arable land and meadows: *Calathus fuscipes*, *Harpalus rubripes*, *Nebria brevicollis* and *Pseudoophonus rufipes*. In our study of carabids in three different sites, there has been a decline in the apterous species that indicates greater stability of the environment. Subsequently, they have been replaced by the macropterous species indicating a less stable environment. In the biotope Carpathian oak-hornbeam forest, there was tree cutting of wood during a particular year (2016); therefore, the number of macropterous species was lower than in the biotope Carpathian turkey oak forest. Shibuya et al. (2014) find that apterous and brachypterous species dominated over macropterous species in forest ecosystems. He confirmed that when the forest vegetation is disturbed, there is an increase in the number of macropterous species. During the study of spatial structure (Porhajášová, Šustek, 2011) of carabids in wetland area, the authors found that macropterous species live in ecosystems exposed to cyclical changes and the predominance of apterous species indicates significant environmental stability. Rainoi, Niemalä (2003) pointed to the reduction in the number of apterous species due to the increasing disturbance. On the contrary, the number of macropterous species has increased due to disturbance.

The ellipsoid biovolume (EV) value was determined based on our measured morphometric analyses (length, thickness and width of body) of all the individuals. The total EV value of carabids represented 1,756,503 mm^3 (1.7 l) per 2,431 individuals and 30 species. EV values for the period under review were following: study site 1 = 773 269 mm^3 (0.77 l), study site 2 = 549 332 mm^3 (0.54 l) and study site 3 = 433 901 mm^3 (0.43 l).

A non-parametric Friedman test for testing H_0 hypothesis was used because of distribution normality data disruption (the Shapiro-Wilk´s W test [p-value = 0.00]) and homogeneity of variance disruption (the Levene's test [*p*-value = 0.00]). The result of testing the average compliance of EV values is H_0 rejection (*p*-value = 0.00) during 2015 and 2017 in each locality. This means that the EV average values are statistically different (Fig. 2) for all the years in each locality. The statistically significant difference in individual localities in EV values for 2015–2017 confirmed the Kruskal-Wallis test. Results are following: biotope pine stand of *Picea abies* (p-value = 0.00), biotope Carpathian oak-hornbeam forest (p-value = 0.00), biotope Carpathian turkey oak forest (p-value = 0.00). The decrease in the EV average value was recorded in the study site 3, which was affected by intensive tree cutting of wood. In biotopes of pine stand of *Picea abies* and Carpathian oak-hornbeam forest, the EV value decreased in 2016, but had a subsequent increase in 2017. Szyszko (1983) also formulated and confirmed the hypothesis that the decrease of environmental disturbance allows for a bigger average EV value, while he was studying ground beetles during the restoration of a pine forest. Šustek (1987) confirmed the same fact. The predominance of apterous and brachypterous species, which have a larger average size than macropterous species, was recorded in all three forest biotopes confirmed Majzlan, Frantzová (1994) as well.

The correlation coefficient was high r = 0.99, indicating a very strong relationship of the measured EV values to the years of collection. The confidence coefficient $r^2 = 0.99$, explains the capture of 99% of the EV variability during the years 2015–2017. The overall suitability of the regression model is statistically significant (*p*-value = 0.03) and so the result confirms the effect of the species spectrum in years trapping on the EV values. We can predict (Fig. 3) the EV value for 2018, which would be 28,020 mm^3. EV values for the period under review were: 2015 = 903 299 mm^3, 2016 = 563 433 mm^3 and 2017 = 289 770mm^3. Significant decline in EV values during the period under review – 2015–2017 and the predicted year 2018 – is due to the tree cutting of wood in biotopes Carpathian oak-hornbeam forest and Carpathian turkey oak forest.

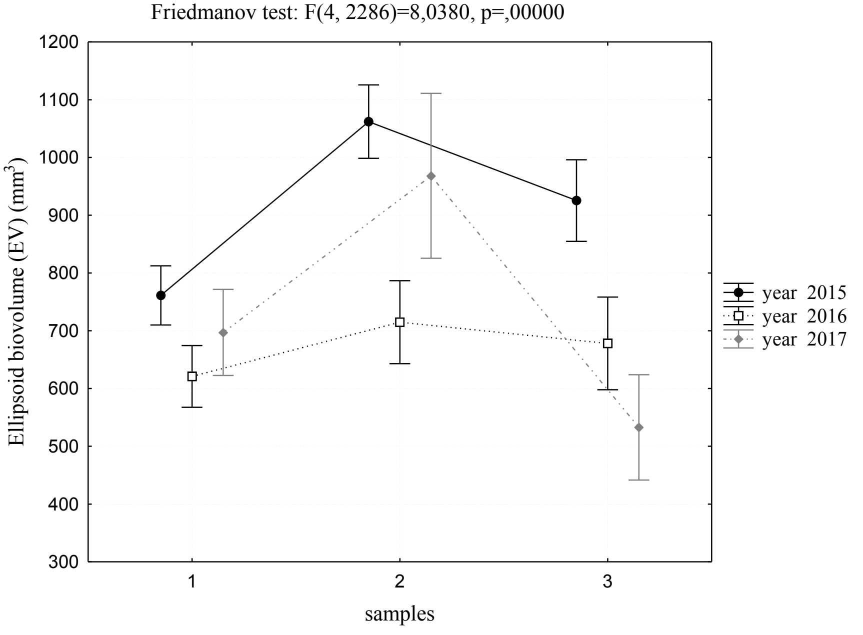


Fig. 2. Analysis of variance (Friedman test (ANOVA)) of the Carabidae species average EV values during 2015–2017 in each study site with 95% confidence.

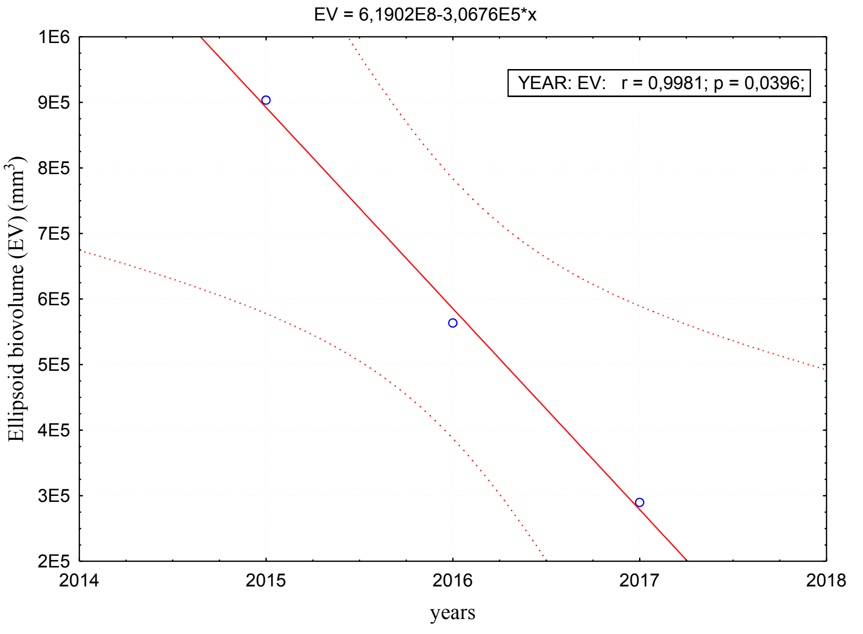


Fig. 3. The linear regression model of EV values for years 2015–2017, with 95% confidence.

In study sites, there is likely to be a decline in the apterous species, which have their food optimum in biotopes and indicate greater stability of the environment. Subsequently, they will be replaced by macropterous species, which will seek food because of their lack of it. All these indicate a less stable environment. Šteffek et al. (2008), Elek et al. (2001), Finch (2005) and Wiezik et al. (2007) pointed to a change in the structure of the Carabidae community due to tree cutting of wood or its renewal. Šustek (2005) remarked that such a species exchange is typical for the locations from oak forests to beech-fir forests, approximately up to 900 m a. s. l. Our research took place in the range from 258 to 518 m a. s. l.

Conclusion

The different intensity of anthropogenic influences (tree cutting of wood) on the Carabidae species were evaluated in three study sites in Slovakia (three types of forest habitats).

Using the Community Index of Ground Beetles (IKS), we did not confirm the statistically significant changes in values over the years 2015–2017. No statistically significant changes in the number of bio-indicating species (A, E, R categories) were confirmed, while the total representation of the species included in the bioindication groups was significant (A - 21 species; E - 7 species; R - 2 species). Statistically significant decrease in IKS values in the direction from the less disturbed biotope (study site 1) to a more disturbed biotope (study site 3) were not confirmed. Consequently, we did not confirm our first hypothesis.

The highest human activity were found in the Carpathian turkey oak forest. Based on the evaluation of the Carabidae flight ability, a higher number of macropterous species, we can declare the high impact of intensive tree cutting. This is associated with the occurrence of species that prefer the open landscape (field and meadow species): *Calathus fuscipes*, *Harpalus rubripes*, *Nebria brevicollis* and *Pseudoophonus rufipes*. There were 10 apterous species, 11 brachypterous and 9 macropterous species.

The decrease in EV values during the years 2015–2017 and predicted year 2018 is caused by tree cutting. In the study of carabids at the three study sites, there is a decline in apterous species, which indicate greater stability of the environment. Subsequently, they were replaced by the macropterous species, which indicate a less stable environment. The statistically significant decrease in the average EV values in the direction from the less disturbed biotope to a more disturbed biotope was confirmed. A higher number of macropterous species was recorded in the biotope Carpathian turkey oak forest 3, which was affected by intensive tree cutting that confirmed our third hypothesis.

The valuation of ecological stability is considered on the basis of the present status evaluation, such as future alternatives of land use. Ground beetles are a very important model bioindicative organisms that reflect environmental changes and they may be used for landscape planning documents in Slovakia (e.g., development of environmental systems). Bioindication evaluation using EV and flight ability of carabid beetles can be used as one of the assessment approaches to the environmental quality and the intensity of human activity impact on the landscape.

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FACTORS ASSOCIATED WITH HABITAT SEGREGATION AMONG THE FOUR SPECIES OF CERVIDS IN THE CHITWAN NATIONAL PARK, NEPAL

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Abstract

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Study of habitat segregation among the four species of cervids was conducted in the Chitwan National park of lowland Nepal. This study aimed to investigate the possible mechanisms of habitat partitioning among the four cervids - chital, sambar deer, hog deer and northern red muntjac using discriminant analysis and canonical correlation analysis. Present study considered four major niche dimensions - habitat, human disturbance, presence of predators and seasons. The data were collected by walking along the line transects that encompasses the different habitats, varying degree of human disturbances and frequency of predator's presence. Results showed the significant effect of season on the habitat segregation among these cervids. There was higher niche overlap during summer season as compared to winter season. Habitat overlap between chital and muntjac was higher and unstable than others, which showed that they were the competitors of the same resources as enlightened by their generalist nature. Therefore, maintaining habitat heterogeneity and minimizing human disturbances will be better solutions for the coexistence of herbivores in the Chitwan National Park and can be an example for similar areas of lowland Nepal.

Key words: habitat segregation, Chitwan, deer, bengal tiger.

Introduction

Investigations of habitat utilization by large mammals, as well as their relationship with their sympatric species and the environment, are important in understanding the mechanisms that influence large mammalian community structure. In general, the sympatric species with similar niche dimensions may compete for common resources and coexist either by resource partitioning or geographical area partitioning (Schaller, 1967). Habitat selection and the niche theory explains that similar species with similar niches should be allopatric or some of their behavioural aspects that separate them spatially or temporally within the same range. The coexistence of competitive species cooccurs in the same habitat as a result of the resource partitioning (Hardin, 1960). Competition can be considered as the bioforce that cause differentiation in the use of resources by coexisting species (Pianka, 1976). Predation or different responses of species to environmental factors may also lead to resource partitioning (Wiens, 1977). For example, similar body sized sympatric species can also compete with each other to avoid predators and such an interaction is known as 'apparent competition' (Werner et al., 1983) or competition for 'enemy-free space' (Jeffries, Lawton, 1984), and consequently, may try to adopt different escape tactics that sometimes leads to habitat or resource partitioning. In territories of large carnivores like tiger and leopard, the competition may be prevented by predation, which keeps the population of the competitors below the level at which food resources become limiting (Hutchinson, 1968; Putman, 1986). Sometimes, predation and competition come together and can affect prey community assemblage in multiple ways that often interact (Schoener, 1977; Werner et al., 1983).

The habitat segregation among the wild prey communities have been studied widely (Gordon, Illius, 1989; Voeten, Prins, 1999); however, the underlying mechanisms that initiate such partitioning remain rare. The analysis of niche differences reflects the evolutionary adjustments in a biotic community, designed to facilitate the coexistence of ecologically similar species (Dueser, Shugart, 1978; Reinert, 1984). Sometimes, similar analyses may concern the limits of ecological similarity that necessitate the resource partitioning for coexistence of multiple species in a Gaussian framework (May, 1973). It is believed that coexisting sympatric species segregate primarily by habitats and subsequently by dietary and temporal specialisations (Schoener, 1974, 1983; Toft, 1985) and also by the predators and human disturbances in the edges of habitats. The use of multivariate statistical methods like Discriminant analysis (DA) and Canonical Correlation analysis (CCA) are a popular tool for representing niche geometry and studying natural communities (Green, 1971; Dueser, Shugart, 1978; Reinert, 1984; Edge et al., 1987; Marnell, 1998; Wei et al., 2000). Here, we studied the niche dimensions of four species of cervids in the Chitwan National Park (CNP). The habitat use patterns of chital (*Axis axis*), sambar (*Rusa unicolor*), hog deer (*Axis porcinus*) and northern red muntjac (*Muntiacus vaginalis*) in different habitats were taken as the variables to measure their niche dimensions and habitat segregation by using DA and CCA.

Material and methods

Study area

The Chitwan National Park (Fig. 1) is located in the lowland Terai region of Nepal. It is one of the major habitats of tigers in the Indian subcontinent (CNP, 2018; Dhakal et al., 2014). It covers an area of 952.63 km^2 and is surrounded by a buffer zone of 729.37 km^2 (including 55% of agricultural land and 45% of community forest). The park consists of diverse ecosystems ranging from early stages of succession on alluvial floodplains along the Narayani, Rapti and Rew watersheds to the climax forest in the foothills and on the slopes of the Churia range. The forests here are composed predominantly of deciduous and semi-deciduous species. Sal forest covers over 70% of the park. Similarly, grasslands (both tall and short grasslands and riparian flood plains) make up to 20% of the park area. Sal *(Shorea robusta)* dominates in the Chitwan National Park, while the lowland areas along the rivers are covered by a mosaic of riverine forests dominated by *Bombax ceiba*, *Trewia nudiflora* and tall grasslands (Dhakal et al., 2014).

This park hosts the highest density of large mammals, including the Bengal tiger and greater one-horned rhinoceros, in South Asia. It also covers the Terai-Duar Savanna and Grassland Ecoregion, which is listed among the 200 globally important areas of biodiversity in the world, because of its rich diversity of large mammals (Wikramanayake et al., 2001). There are at least 70 species of mammals in the CNP, including tiger (*Panthera tigris tigris*), sloth bear (*Ursus ursinus*), gaur bison (*Bos gaurus*), greater one-horned rhinoceros (*Rhinoceros unicornis*) and Asian elephant (*Elephas maximus*) (Bhattarai, Kindlmann, 2012; CNP, 2018). This park supports a high diversity of ungulates (important tiger prey species) such as gaur bison, sambar (*Rusa unicolor*), chital (*Axis axis*), hog deer (*A. porcinus*),

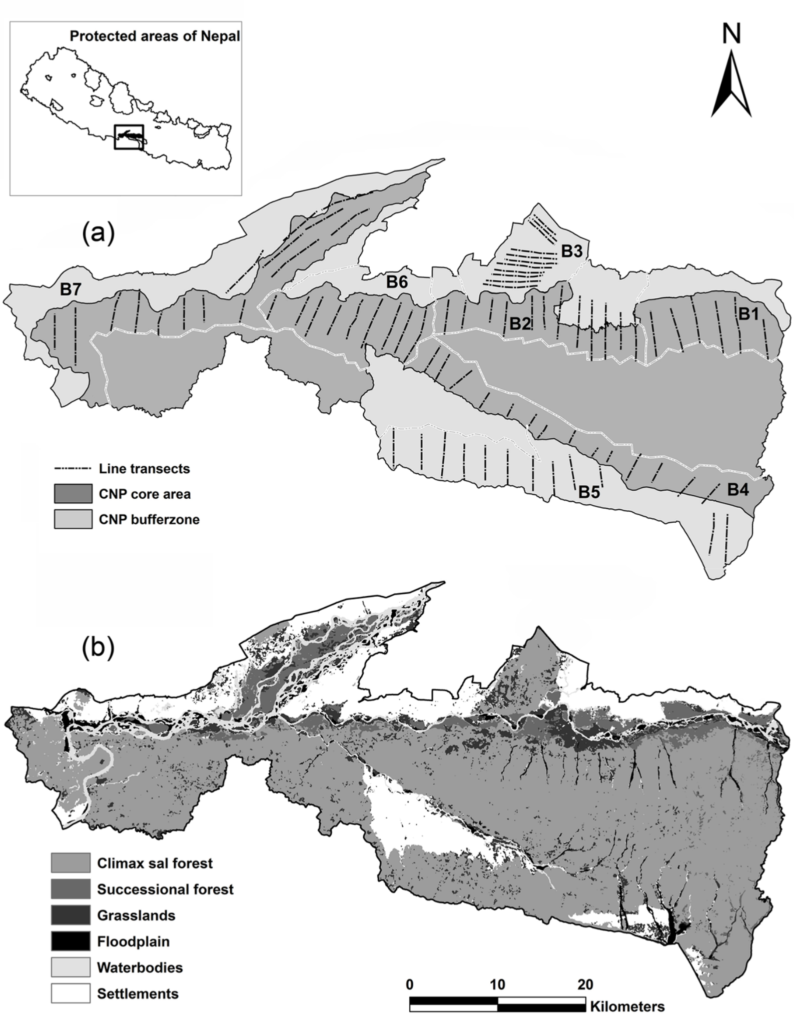

Fig. 1. Map of the study area showing different habitats and location of transects.

northern red muntjac (*Muntiacus vaginalis*), wild boar (*Sus scrofa*), common langur (*Semnopithecus entellus*) and rhesus monkey (*Macaca mulatta*) (Stoen, Wegge, 1996; Smith et al., 1999; CNP, 2018).

Model species

The cervids (deer), the major prey species of tiger in the tropical Asia, are the model species for this study. There is considerable variation in the body size, habitat selection and range of these species. Sambar deer is the large sized prey and distributed throughout the reserves and parks of the Terai (Mishra, 1982). Climax forest is the most preferred habitat of sambar deer and feed mainly at night and retires into heavy cover at daybreak and do not usually come out till dusk (Prater, 1998). Chital is a medium sized prey of tiger and it is found throughout the Terai, with major concentrations in the parks and reserves. Newly burned grasslands are the major feeding habitats and dense forest habitats are the resting places during the hot periods of a day for ungulates including chital (Mishra, 1982). Another medium sized deer in this area is the hog deer, which mainly inhabits the alluvial grasslands of lowlands (Dhungel, O'Gara, 1991; Mishra, 1982) and its range is decreasing. Northern red muntjac is the smallest deer in this area that mostly prefers dense forests and usually grazes in the open forest edges nearby the human settlements (Pokharel et al., 2015).

Data collection

The distribution of the four species of cervids were determined by direct observation in line transects. We walked 80 transects, twice for the year 2013 summer (April, May, June, July) and winter (November, December 2013 and January, February 2014) that covered 1154 km. The location and length of transects were defined by the accessibility on foot. During the walks on transects, we recorded the name of cervids, their group size, presence signs of predators (tiger and leopard), habitat parameters and disturbance variables associated with them (Table 1). This sampling was carried out at every 100 m interval along the transect and data on the habitat gradient for each sampling point was visually recorded in 100 m radius plot as forest cover (Dense or Mild dense or Open); plane or gentle slope and as topography and distance to the waterholes. The distance between animal and waterholes was measured by using the topographic map (1:50,000 scale by the Survey of Nepal toposheets) of the study area. Human disturbance was enumerated by recording the signs of people and livestock presence in the same transects. The presence of signs of people were enumerated by recording the numbers of lopped trees, logged trees, grass cutting sites and the presence signs of livestock were enumerated by recording the faeces of livestock. Altogether, we had data on 18 habitat variables (Table 1) for each season. We then used these data to measure the niche dimensions for each of these cervids.

Table 1. Description of the habitat variables collected in Chitwan National Park during the two seasons of 2013–2014.

Variables	**Details of variables**
Habitat types	
SF	Sal forest
MF	Mixed forest
RF	Riverine forest
TGl	Tall grassland
SGl	Short grassland
FPl	Flood plain
Forest cover	
Open	Open habitats
Closed	Closed habitats
Topography	
Plain	Plane areas
Gslope	Gentle slope areas
Disturbance	
Peop	Presence of people: number of loped and logged trees and grass cutting sites
Livs	Presence of livestock: number of faecal matter of livestock
Others	
DW	Distance to waterhole
PP	presence of predators

Statistical analysis

The habitat segregation among the four species of cervids was analysed by comparing their sightings data with the habitat, disturbance and predator presence across two seasons. We first carried out the multivariate analysis of variance (MANOVA) for testing the hypothesis of equality of the four group centroids (Reinert, 1984; Schneier, 1993) using Pillai's trace as the test statistic (Venables, Ripley, 1994). Again, we also performed a pair-wise multiple comparison of different groups of cervids as chital-muntjac, chital-hog deer, chital-sambar deer, muntjac-hog deer, muntjac-sambar deer and sambar deer-hog deer by using the Hotelling's T-square test. Suggested by the results of MANOVA, the identified distinct groups of cervids were later examined and tested by the stepwise Discriminant Function Analysis (DFA) to know how these species were separated with each other in terms of difference in habitat use (Green, 1971; Dueser, Shugart, 1978; Reinert, 1984; Edge et al., 1987; Marnell, 1998; Wei et al., 2000). We adopted the stepwise method in DFA to support and maximise the Mahalanobis distance between the group-centroids (Edge et al., 1987). The degree of habitat overlap was obtained from the scores of Discriminant Function of a secondary DFA model for all four species (May, MacArthur, 1972; May, 1973, 1975). Furthermore, the box's modification of Bartlett's test was used to evaluate the homogeneity of covariance matrices.

Analyses were carried out with data from two seasons using S-Plus (Venables, Ripley, 1994) and CANOCO (CANOCO v. 4.5; ter Braak, Šmilauer, 2002). We used CCA to visualize how these four species of cervids associated with the habitats, disturbances, predator presence across two seasons. CCA is a form of canonical ordination, which uses multivariate ordination and multiple regression statistical techniques to relate the species abundance data with the multiple environmental factors (ter Braak, 1986; ter Braak, Prentice, 1988)). In addition to the graphical representation of data spread in a biplot (MacFaden, Capen, 2001), a CCA reveals the relative contribution of each explanatory variable to the variance in the response variable. We selected CCA because it is robust to analyse with multiple correlated variables (Palmer, 1993). We used automatic forward selection procedure during the CCA in CANOCO, to identify the variables that best explained the variance in the data. Monte Carlo permutation test (using 499 unrestricted permutations) was performed to identify the environmental variables that significantly explained the variation in the distribution of animals.

Results

The study recorded 352 groups of chital, 124 sambar deer, 44 hog deer and 83 groups of muntjac. Based on these sightings, the results showed that these four species of cervids utilised significantly different habitat features (MANOVA- Winter: *Pillai's trace = 0.08, F(15, 837) = 21.93, P<0.0001*; Summer: *Pillai's trace = 0.12 F(15, 837) = 21.93, P < 0.0001*). The results obtained from *Hotelling's T-square test* revealed that there were four distinct groups of cervids and used different habitat features in each season (Table 2). To evaluate the homogeneity of covariance matrices, we used Box's modification of Bartlett's test and found that the

T a b l e 2. Pair-wise comparison by Hotelling's T-square test for equality of group-centroids of four species in Chitwan National Park, in terms of habitat-use; across two seasons.

Species pair	F- value		Hotelling's T-square probability	
	Winter (df = 15,126)	Summer (df = 15, 158)	Winter	Summer
Chital–hog deer	15.18	0.71	< 0.0001	0.492
Chital–sambar deer	13.51	2.2	< 0.0001	0.117
Chital–muntjac	17.07	7.78	< 0.0001	0.001
Muntjac–hog deer	8.33	8.25	< 0.0001	< 0.0001
Muntjac–sambar deer	7.53	9.55	0.001	< 0.0001
Sambar–deer-hog deer	4.35	2.57	0.014	0.079

covariance matrices were not equal for both seasons (Winter: *Box's M = 123.8, F(18, 73928) = 6.70, P < 0.0001*; Summer: *Box's M = 52.6, F(18, 49558) = 3.89, P < 0.01*), suggesting that four species of cervids exhibit different patterns of variation with respect to original variables.

Four different discriminant functions were constructed as followed by the results of MANOVA. The cervids showed the significant Discriminant Function for each season independently (Table 3). These results implied that chital segregated from other cervid species by riverine forest, short grassland, flood plain, distance to waterhole and presence of predators during winter season. While during summer season, chital segregated from other species by mixed forest, short grasslands, predator presence and human disturbances (Table 3). Likewise, muntjac segregated from other species by mixed forest and riverine forest during winter, while it segregated from other species by mixed forest and predator presence during summer season. Sambar deer was segregated from other cervids by mixed forest and predator presence during winter, while mixed forest, predator presence and disturbance during summer season. Hog deer was segregated from other species by tall grassland, floodplain and predator presence during winter while tall grassland, open canopy habitats and predator presence during summer season (Table 3). Besides, niche overlap and differences in resource

Table 3. Summary of significant Discriminant Functions developed by stepwise.

Results	Chital		Muntjac		Sambar deer		Hog deer	
	Winter	**Summer**	**Winter**	**Summer**	**Winter**	**Summer**	**Winter**	**Summer**
Eigenvalue	0.26	0.14	0.03	0.032	0.08	0.09	0.08	0.07
CC	0.454	0.345	0.15	0.18	0.257	0.29	0.27	0.26
Chi-square	96.37	52.82	9.06	12.73	28.62	34.7	30.05	28.3
df	5	6	2	2	2	3	3	3
p- value	< 0.0001	< 0.0001	0.011	0.002	< 0.0001	< 0.0001	< 0.0001	< 0.0001
SF	0.14	-0.116	-0.554	-0.19	-0.114	-0.072	-0.339	-0.209
MF	0.133	**0.417**	**0.701**	**0.781**	**0.578**	**0.458**	-0.125	0.046
RF	**-0.228**	-0.048	**0.543**	-0.149	-0.138	-0.075	-0.307	-0.134
TGl	0.024	-0.147	-0.362	-0.101	-0.08	-0.125	**0.512**	**0.394**
SGl	**0.265**	0.373	-0.101	-0.007	-0.042	0.002	-0.066	-0.023
FPl	**-0.289**	-0.157	-0.153	-0.041	-0.138	-0.027	**0.7**	0.089
Open	0.058	-0.104	-0.104	-0.129	0.016	-0.114	0.082	**-0.32**
Closed	-0.057	0.104	0.101	0.129	-0.014	0.114	-0.083	0.32
Plain	-0.065	0.088	0.169	0.142	0.024	0.089	0.091	0.147
Gslope	0.065	-0.088	-0.169	-0.142	-0.024	-0.089	-0.091	-0.147
DW	**0.304**	-0.07	0.133	-0.034	0.207	-0.026	-0.06	-0.007
PP	**0.856**	**0.582**	0.064	**0.677**	**0.859**	**0.822**	**0.252**	**0.784**
Livs	-0.023	**-0.376**	-0.046	-0.075	0.014	0.0001	0.092	-0.058
Peop	-0.063	**-0.407**	0.003	-0.044	-0.036	-0.025	0.111	0.044

Notes: DFA to differentiate between the four species of cervids (chital, sambar, hog deer and muntjac) of Chitwan National Park, for two seasons. Significance tests were carried out for those variables (highlighted) by the absolute size of correlation within function. CC, Canonical correlation; df, degrees of freedom and details of other variables are explained in Table 1.

a)

b)

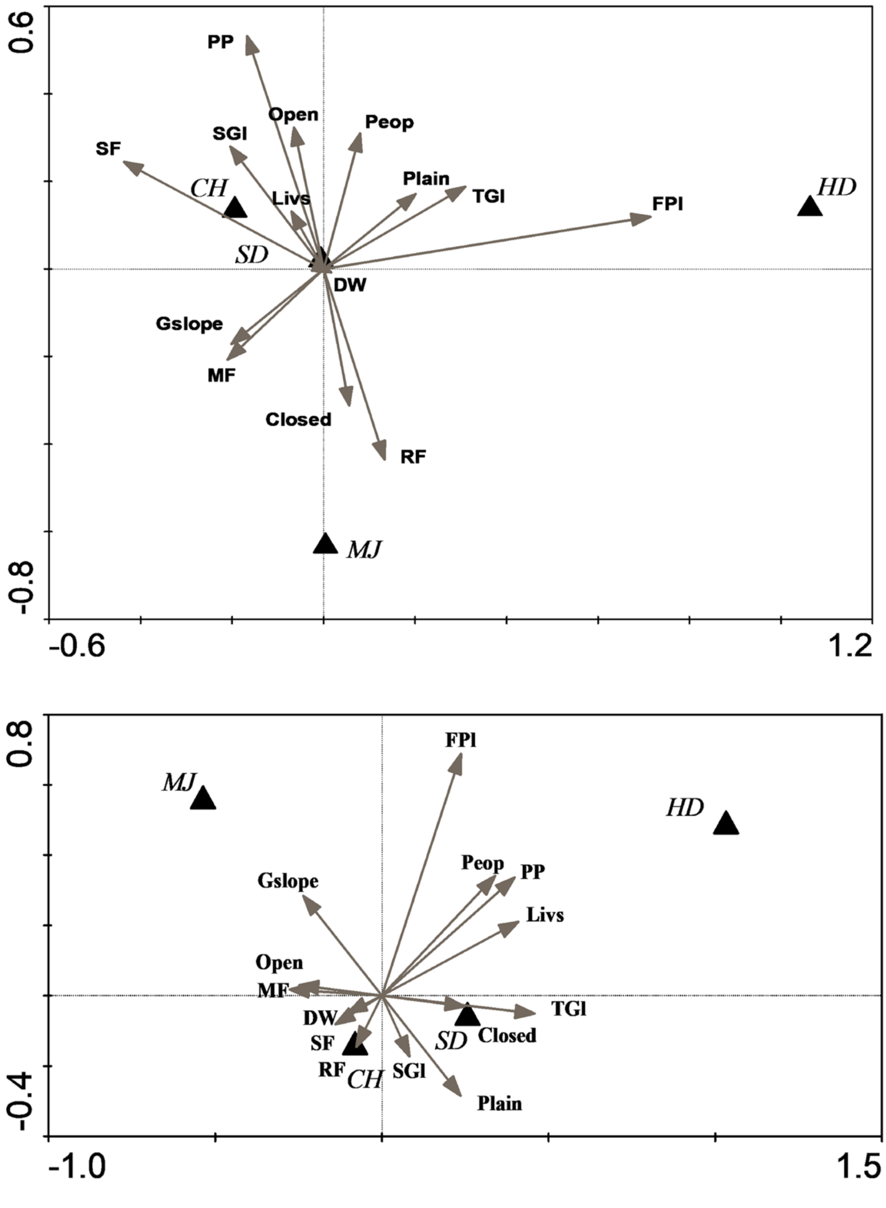

Fig. 2. CCA ordination diagram showing habitat separation among four species of cervids in the Chitwan National Park for two seasons. Monte-Carlo permutation test of significance of all canonical axes (a) winter season: *Trace = 0.20, F = 2.24, P = 0.002* (with 499 permutations). First two axes are displayed. The first axis explains 58.7% and the second axis explains 32.4% of the total variability. (b) summer season: *Trace = 0.21, F = 2.01, P = 0.002* (with 499 permutations). First two axes are displayed. The first axis explains 52.2% and the second axis explains 30.3% of the total variability.

availability also influence the reproductive rates of some deer species (Green et al., 2017). The results of discriminant function analysis were also supported by the CCA. It gives the clear picture of the relationship among the species in terms of habitat use. Figure 2 (a and b) showed that the species exhibits significant habitat separation in both the seasons. In these CCA diagrams, sambar deer and chital are close with each other compared to muntjac and hog deer, which are separated from each other as well as with the chital and sambar deer.

Discussion

Habitat separation

The habitat segregation helps to reduce both interference and competition, and facilitates coexistence of ecologically similar (sympatric) species (Pianka, 1976), like four species of cervids in the CNP. In general, the sympatric ungulates tend to use different habitats (Gordon, Illius, 1989). However, these species are ecologically similar to each other, a closer examination in this study revealed that there were in fact four groups or 'guilds' (Table 2). If the preference and the avoidance of a habitat by one species differs with the others, then habitat segregation may occur. Chital and sambar were close to each other in terms of habitat use as compared to muntjac and hog deer (Table 3). Chital segregated from other species by riverine forest, short grassland, floodplain, distance to waterhole and presence of predator during winter season; while during summer, it segregated from others again from short grasslands and predators' presence, mixed forest and human disturbances. It was mostly recorded in the ecotones such as forest and grassland border (Schaller, 1967; Eisenberg, 1981; Bagchi, 2001). The sambar deer is the largest deer in terms of body mass and it has a long distribution range as compared to the other species, and was segregated from others by mixed forest and predator presence during summer, while mixed forest, predator presence and disturbance during summer season. Sambar mostly occurred in the forested areas, which is also supported by its oriental origin and has evolved in forested environments (Schaller, 1967; Corbet, Hill, 1992). The smallest deer in this area is muntjac, which is adapted to live near human settlements in forest edges, and is segregated from other larger cervids by mixed forest and riverine forest during winter; while it is segregated from other species by mixed forest and predator presence during summer season (Pokharel et al., 2015). Among the four cervids, hog deer has quite a different preference in terms of habitats. It was segregated from other species by tall grassland, floodplain and predator presence during summer, while tall grassland, open habitats and predator presence during summer season. Some earlier studies on diet and resource partitioning at various scales suggest that resource partitioning occurs mainly at the diet level (Endo et al., 2017) and less at spatial level, but the differences are possible in small-scale habitat use (Tobler et al., 2009). Such patterns of habitat segregation among these cervids suggested a useful insight into the evolutionary history of these species (Schaller, 1967; Corbet, Hill, 1992; Eisenberg, 1981).

Habitat overlap

The multivariate approach of habitat segregation and overlap (May, MacArthur, 1972) among the four ecologically similar cervids in the Chitwan National Park of Nepal was studied by using the DA and CCA, instead of using univariate measure of the habitat overlap. This study implied that the habitat selection and overlap among the ungulates not only depend on the habitat types but also depend on the other factors associated with the habitats such as open or closed canopy, distance to waterhole, topographic features and human disturbances (Wang et al., 2018). This study also considered the predator presence as the principal factor that has a significant impact on the separation of the habitats because these four species of cervids are the principal prey species of tiger and leopard in this area. The results obtained from the measurement of habitat overlap among these four cervids by taking the ratio of distance between group centroids (*d*) to the variance along the resource axis (*w*). For these data, *d* was the difference between mean discriminant scores and *w* was standard deviation of the scores for each species that are derived from the second DFA model created with all four groups (May, MacArthur, 1972). The study found an asymmetrical habitat-overlap matrix of species that may be due to different habitat-breadths. The habitat overlap decreases with an increase in the magnitude of the ratio (*d/w*) and it has been theoretically determined to approximate or exceed 1.0 for stable coexistence in a community (May, MacArthur, 1972; May, 1973). This ratio also explains the competition coefficient, as the magnitude of d/w is inversely related to the competition coefficient and May (1973) used this model for multi-species interaction in ecological communities by non-linear differential equations. It means that the habitat overlap matrix (Table 4) is analogous to the community-matrix of Levins (1968) and May (1973, 1975). Hence, these explanations suggested that lower the values of *d/w*, the higher is the *competitive coefficient* and consequent effects on population of interacting species. However, if $d > w$, then there is minimal competitive interaction (May, 1973) and subsequent population stability. If so, the instability was found in the overlap between sambar and chital in both seasons (ratio: 0.19 to 0.39) and between sambar and muntjac in winter and summer seasons (ratio: 0.38, 0.49). Likewise, the instability was also found in between muntjac and chital in winter season (ratio: 0.49) and between hog deer and chital (ratio: 0.15) and hog deer and muntjac (ratio: 0.30) during winter season (Table 4). This apparent instability between sambar deer with chital and muntjac can potentially cause fluctuations in the latter's population because chital occurs in much higher densities than other deer in this park. There is increasing evidence that semiarid ungulate assemblies are disequilibrial (Ellis, Swift, 1988; Illius, O'Connor, 1999; Bagchi, 2001; Wang et al., 2018) and these data seem to suggest that the extent of ecological similarity might be a determinant of theoretically predictable population fluctuations. But the relationship between chital and sambar is likely due to forage limitations during winter and might not be a permanent feature in the community

T a b l e 4. Asymmetrical habitat-overlap matrix of the four species of cervids in the Chitwan National Park for two seasons.

Seasons	**species**	**Niche overlap**			
		Chital	Muntjac	Sambar	Hog deer
Winter	Chital	-	2.06	5.38	6.83
	Muntjac	0.49*	-	2.62	3.32
	Sambar	0.19*	0.38*	-	1.27
	Hog deer	0.15*	0.30*	0.79	-
Summer	Chital	-	1.26	2.58	1.86
	Muntjac	0.79	-	2.05	1.47
	Sambar	0.39*	0.49*	-	0.72
	Hog deer	0.54	0.68	1.39	-

(as suggested by the high ratio in summer than winter season, Table 4). Such a situation can arise due to seasonal fluctuations in forage quality and quantity in such semiarid environments of tropical and subtropical forests. However, heterogeneity in the habitats can be the better options under such circumstances as there is considerable variability in forage availability in different habitats with respect to different seasons (Bhattarai, Kindlmann, 2012).

Conclusion

In Chitwan National Park, the four species of cervids showed different niche primarily according to forest types. The overlap between chital and sambar deer occurs due to scarcity of forage in dry season. The study found unstable habitat overlap between chital and muntjac that was due to difference in their body size and significantly unequal populations. Niche overlap and competition among the four species of cervids were found to be lower in the areas with high habitat heterogeneity. Such areas can provide multiple resources and facilitate a stable state of coexistence of sympatric species. Present results help to improve the knowledge about the niche ecology of four major cervids of lowland Nepal that directly link with the conservation of large predators like tiger and leopard. These findings suggest a possible relation between niche-overlap and population fluctuations among cervids. Further studies on population dynamics of these species would help to develop a detailed understanding about the functioning of such tropical and subtropical ecosystems of lowland Nepal. Maintaining high diversity in the habitats and minimizing human disturbances will help to build the conservation strategies for the long term coexistence of these four species of cervids in the Chitwan National Park.

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FOREST FIRE TREND AND INFLUENCE OF CLIMATE VARIABILITY IN INDIA: A GEOSPATIAL ANALYSIS AT NATIONAL AND LOCAL SCALE

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Abstract

Ahmad F., Goparaju L.: Forest fire trend and influence of climate variability in India: a geospatial analysis at national and local scale. Ekológia (Bratislava), Vol. 38, No. 1, p. 49–68, 2019.

Climate change and its severity play an important role in forest fire regime. Analysing the forest fires events becomes a prerequisite for safeguarding the forest from further damage. We have made an assessment of the long-term forest fire events at the district level in India and identified the forest fire hotspot districts. The spatial seasonal (January to June) district wise pattern and forest fire trend were analysed. In the second part of the study area (central part of India), we have evaluated the forest fire events in grid format with respect to the climatic/weather datasets, and the statistical analysis Cramer V coefficient (CVC) was performed to understand its association/relationship with forest fire events.
The study revealed that Karbi Anglong and North Cachar Hills districts of Assam of India have the highest forest fire percent among all districts equivalent to 3.4 and 3.2% respectively. Dantewada district of Chhattisgarh and Garhchiroli district of Maharashtra of India occupied 3rd and 4th rank with value 3.1 and 3.0% respectively. The grid-based evaluation (local scale) revealed that most of the fire equivalent of 80% was found in the month of March and April. Forest fire frequency of the month of April is spread over 88 % of the grids over the study area. The 11 years average seasonal month-wise (February to June) maximum temperature, wind velocity, relative humidity, and solar radiation were found in the range of (25.9 to 40.6), (1.69 to 2.7), (0.301 to 0.736) and (14.21 to 22.98) respectively. The percentage increase (in the month of March) of maximum temperature, wind velocity, and solar radiation were 36, 39 and 62% respectively, when compared with the preceding month; whereas, a 60% decrease to relative humidity that was observed in the same month is usually the major cause of forest fire events in the month of March onwards.
The evaluation of Cramer V coefficient (CVC) values of rainfall, relative humidity, potential evapotranspiration, maximum temperature, wind velocity, and solar radiation were in decreasing order and in the range of 0.778 to 0.293. The highest value of rainfall (0.778) showed its strongest association with the forest fire events. In the month of June, these areas receive adequate rainfall, which leads to an increase in the soil moisture and a reduction in forest fuel burning capacity by absorbing the moisture and it is a strong reason for less forest fire events during this month.
Geospatial technology provides an opportunity to evaluate large datasets over various spatial and temporal scales and help in decision making/formulating various policies.

Key words: forest fire events, forest fire hotspot, meteorological and climatic data, Cramer's V coefficient, India.

Introduction

Fire regimes (frequency, intensity, size, pattern, season, and severity) are important contributors in many ecosystems (Bowman et al., 2009; Bond, Keeley, 2005; Gill, 1975), which can change the structure and function of forest landscapes (Mouillot et al., 2002; McKenzie et al., 2004). The climate of a region plays a vital role in regulating the forest fire regimes (Harrison et al., 2010). Climate is one of the most influential factors that decides the vegetation patterns globally and has a significant role in distribution, structure, composition, and ecology of forests (Kirschbaum et al., 1996). Climate variables interact between themselves and with vegetation (Flannigan, Harrington, 1988). Fire activity mostly depends on four factors: fuels load accumulation, local climate/weather condition (i.e., dry, hot, and/or windy periods), source of ignition and people activity (Bond, van Wilgen, 1996; Flannigan et al., 2005; Moritz et al., 2005; Bradstock, 2010).

Although the amount of fuel/ fuel load, its continuity, and fuel distribution pattern (vertical and horizontal) within the forest affect fire activity (Finney, 2001), fuel moisture by and large determines whether fuels can sustain or withhold ignition (Littell et al., 2009), and therefore, it determines its spread (Blackmarr, 1972; Wotton et al., 2010), and these parameters have been found to be an important deciding factor in the amount of area burned (Flannigan et al., 2005). Fires need fuel to burn, heat to ignite and oxygen to feed to carry out their chemical reaction. Weather condition and severity plays a key role in determining all of these necessary conditions to start and spread a forest fire and making fuel available with the percent of moisture content in forest ecosystem (Swetnam, Betancourt, 1998; Littell et al., 2009). A long period without rain leads to drought, which dries out the existing vegetation, making it easier to burn and thus becomes a better fuel source of fire (Pausas, Fernandez-Munoz, 2012). High solar radiation, and thus, high maximum temperature during the summer makes the humidity low by enhancing the evapotranspiration and makes the forest prone to fire (Vicente-Serrano et al., 2010). Winds play a crucial role in starting and spreading a fire (Song, Lee, 2017) by manoeuvring the flames of the initial spark and it provides fresh oxygen so that it can also stir the fire to the new areas in the potential fuel sites.

Some long-term/short-term studies conducted in the past revealed that fire activities have a strong relationship with climate of a region (Krawchuk, Moritz, 2011; Littell et al., 2009; Westerling et al., 2003), whereas seasonal trends in maximum temperature, precipitation, and drought severity (Wells et al., 2004) is a major player in wildfire frequency and the extent of destruction. Forest fires and its intensity have a unique relationship to global warming. The increase in the frequency of wildfires will lead to an increase in global warming (Brown et al., 2004; Running, 2006). Various studies show that global warming increases the temperature (Hansen et al., 2010) especially during summer and this phenomenon increased the weather severity (Sinha Ray, De, 2003) during the fire season by increasing temperature, decreasing relative humidity, increasing evapotranspiration and so on. These all-weather activities increase the fuel's load burning capability, which leads to an increase in the forest fire season span (Vorobyov, 2004) and its severity. The rainfall deficit of preceding year creates a drought-like condition, which further deteriorates the overall forest fire situation. In contrast, forest fire is also contributing to global warming by burning carbon-storing vegetation adding a huge amount of carbon dioxide to the atmosphere (Reddy et al., 2017).

The forest fire has some positive impact on ecosystem (http://www.positivenegativeeffects.com/wildfires), whereas in most of the cases, it destroys the natural vegetation and reduces the forest cover (Roy, 2003); leads to loss of valuable timber resources (Rodriguezy Silva et al., 2012); destroys the wildlife habitat (Engstrom, 2010) and leads to reduction of wild life species; effects the micro climate, degrades the soil and water catchment areas (Ferreira et al., 2008); causes loss of biodiversity (Secretariat of the convention on biological diversity, 2001) of forest; enhances the air and haze pollution (Srivastava, Singh, 2003; Vadrevu et al., 2011) in atmosphere that can degrade air quality (Riebau, Fox, 2001), leads to vegetation succession and alters the nutrient and global carbon cycles (Kutiel, Inbar, 1993; Capitanio, Carcaillet, 2008); steers the climate change (Ramanathan et al., 2005; Crutzen, Andreae, 1990), leads to global warming; and very adversely affects the socioeconomic condition of the poor inhabitant community/villagers/tribal people, whose life revolves around forests for livelihoods (Aggarwal et al., 2009).

India is one of the mega-biodiversity countries of the world, where forests occupy more than one-fifth of the geographical area. There are nearly 173,000 villages classified as forest villages in India largely occupied by ethnic communities – mostly the tribal people that fully depend on forest resources (Kishwan et al., 2009) and generate revenue for the government by collecting the Minor Forest Products.

Several studies have been carried out in the developed countries regarding forest fire events and their relationship to various environmental parameters. Wotton et al., 2010 studied the fire events and climate/weather parameter in Canada and predicted an increase in fire occurrence of 25% by 2030 and 75% by the end of the 21st century due to the impact of climate change. Tian et al. (2012) studied the climate change variation and impact on forest fire events in China. They used temperature and precipitation of the study area in the baseline period and suggested that the potential burned areas would increase in future due to climate change. Pinol et al. (1998) conducted a study in Europe between the period 1941−1994, which revealed that the fire hazard and risk show an increasing trend and further concluded that climate warming will lead to an increase in a number of wildfires over this area. Tapper et al., 1993 studied the impact of meteorological parameters, such as temperature, relative humidity, wind speed and preceding rainfall when combined with fuel characteristics for fire risks modelling. The study of Krusel et al., 1993 in southern Australia suggested that mean maximum daily temperature and maximum relative humidity are good parameters to predict high fire activities. Antonovsky et al. (1989) study revealed that the chance of fire is strongly correlated to the mean air temperature, total rainfall and the maximum period between two successive rains over the fire season.

Forest fires are adequately studied for risk analysis (Belgherb et al., 2018), to predict the fire damage using FORKOME model (Kozak et al., 2014) and for analysing the soil property due to the fire severity (Šimanský, 2015). Reddy et al. (2017) evaluated the total burnt area extent and CO_2 emissions for the whole country India. Giriraj et al. (2010) identified the high fire-prone zones. Vadrevu et al. (2008) analysed the spatial patterns on fire events across diversified geographical, vegetation and topographic gradients. Vadrevu et al. (2013) analysed the various fire regimes over the various diverse geographical regions of India. Ahmad and Goparaju (2017) identified the forest fire hotspot districts at the local level. Ahmad et al. (2017) evaluated the forest fire points and delineated the forest fire hotspot area. The relationship of forest fire events with climate parameter utilizing the Cramer's V coefficient (CVC).

There are no comprehensive studies for forest fire regime analysis and its relationship with respect to various climatic and weather parameter of India, which creates a lacuna in policy implementation. The present study has utilized the nine years' forest fire data for India (point data of forest fire location) and analysed it in the GIS domain towards visualization and evaluating the spatial/temporal dimension of fire pattern district wise and its monthly trend over the fire season. We have also evaluated the forest fire events with grid spacing 0.3 x 0.3° with climate datasets in the second part of the study area to understand their relationship.

The objectives of the present study are as follows:

1. The analysis aims to manifest forest fire hotspot district of India at the national scale and to evaluate the spatial variation (seasonal) district wise and its trend.
2. To analyse the forest fire events using the grids at a local scale to examine its distribution/variation with respect to the meteorological datasets and to examine the association/relationship of these based on the statistical analysis 'Cramer V coefficient' (CVC).

Material and methods

Study area

The study area was the country India, with the total geographical are equivalent to 3,287,263 km^2 and falls between 6° 44' N to 35° 30' N latitude and 68° 07' E to 97° 25' E longitude (Fig. 1). India retains a forest cover of 21.34% of the total geographical area of the country (FSI, 2015) and these forests are extremely diverse and heterogeneous in nature along the various geographical and climatic gradient. Forest Survey of India (FSI) defined forest as 'all lands, more than one hectare in area, with a tree canopy density of more than 10%' (FSI, 2009). Champion and Seth, 1968 classified the forest of India into 16 distinct forest types and further into subtype based on criteria such as physiognomy, structure, phenology, function, plant association, flora, climate, topography, soil, and biotic factors. Natural vegetation occupies 29.36% of total geographical area of India, whereas the predominant forest types, that is, the tropical dry deciduous and tropical moist deciduous, occupy 68% of the total forest cover of India (Reddy et al., 2015). A large part of India is dominated by tropical dry deciduous forest which shed their leaves by the end of January and the dead leaves and litter further increases the fuel load on the forest floor.

The reason for forest fires are anthropogenic (Joseph et al., 2009) caused accidentally due to negligence and intentionally. The local people clear the land for specific purposes. In tropical dry deciduous forests, the tribal/villagers start clearing the ground for collecting the mahua (*Madhuca indica*) flower from the end of February, whereas people/contractor deliberately light fire to enhance the flush of tendu (*Diospyros melanoxylon*) leaves that fetch them more money in the form of revenue. Shifting cultivation, which is largely practiced in the North Eastern states of India by the tribal ethnic groups, are the major reason of forest fire to this region. Decrease in forest area due to shifting cultivation is equivalent to 23.0% of the total deforestation in India (Manhas et al., 2006).

Winter season in India is roughly from December to February, followed by the summer season from March to May. During summer, it is noticed that the forest fire incidents are high, which coincides with the period of high amounts of fuel load available on the forest floor.

The meteorological parameters and forest fire events are evaluated at the local level. The area is chosen in the central part of India because it is dominated by deciduous forest, tribal population, and frequent fire incidence.

Data pre-processing and analysis

We used the forest fire counts datasets for the year 2008 to 2016 provided by the Forest Survey of India (FSI) as a free download. FSI has been analysing the forest fires events (from the year 2005 onwards) regularly across the

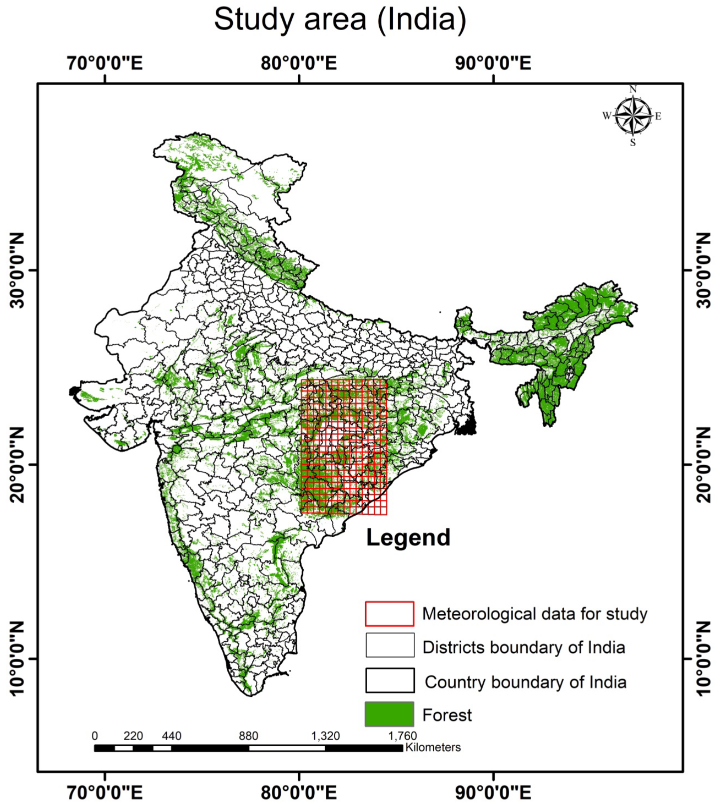


Fig. 1. The location of the study area (India).

country boundary using inputs received from MODIS satellite system by a collaboration with NASA and Geography Department of University of Maryland (http://nidm.gov.in/pdf/pubs/forest%20fire.pdf). The MODIS based active forest fire point is further masked by FSI using the existing forest cover, which eliminates non-forest fire points. The location wise forest fires points of the latitude and longitude were downloaded (http://fsi.nic.in/forest-fire.php) was in MS-EXCEL format. The ARC/GIS Software was used to export the MS-EXCEL file to point the shapefile. The dates of the forest fires points' shapefile were split into a day, month and year column for further evaluation. In this study, we generated the district wise forest fires hotspots for the whole of India at the national level utilizing all the forest fire datasets (2008–2016). The hotspot area considered in this study was on the basis of the highest forest fire frequency brought into a percentage. The forest fire events of each district were converted into percentage considering the total forest fire events of India as 100%. The forest fire spatial trends (district wise) were also evaluated based on the month wise forest fire data from February to June. We have utilized the Land use and land cover (LULC) data (2005) having 100 m resolution for India (Roy et al., 2015). LULC map categories representing the forest were merged (except plantation, grassland, and scrubland) for forest mask is given in the Fig. 1.

Climate datasets (maximum temperature, wind velocity, relative humidity and solar radiation) grid wise (1-1-2004 to 31-7-2014) was downloaded from the website (globalweather.tamu.edu) in one of the forest fires hotspot area, which retains the grid spacing 0.3 x 0.3° provided by the National Centers for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR).

In this study, the averages of four parameters (maximum temperature, wind velocity, relative humidity, and solar radiation) independently were analysed month wise in the fire season (February to June) and maps were generated based on the 'kriging' interpolation technique. Each grid polygon was evaluated based on the monthly (February to June) forest fire events. We have also downloaded the district wise the monthly (February to June) rainfall, potential evapotranspiration data from 1993 to 2002 from Indian Water Portal 2016 (http://www.indiawaterportal.org/met_data/). The average annual monthly rainfall and potential evapotranspiration data from February to June (fire season) for 10 years were used in this study. Cramer's V coefficient (CVC), as suggested by Liebetrau (1983) for statistical analysis was executed to see the relationship of the climatic parameters with forest fire events.

Result and discussion

Overall forest fire assessment

The hotspot district wise map over India is given in Fig. 2. The total forest fire events over India were found approximately 1.95 lakh over the period 2008 to 2016. The highest ten forest fire districts in India were Karbi Anglong (Assam), North Cachar Hills (Assam), Dantewada (Chhattisgarh), Garhchiroli (Maharashtra), Lunglei (Mizoram), Churachandpur (Manipur), Bastar (Chhattisgarh), Mamit (Mizoram), Kandhamal (Orissa) and Tamenglong (Manipur) having the forest fire frequency percent equivalent to 3.4, 3.2, 3.1, 3.0, 2.8, 2.4, 2.2, 2.0, 1.9 and 1.6% respectively, considering the total forest fire percent of country as 100%. These results have their own significance as they were evaluated based on district boundary (an administrative unit), which was the research gap in the past. We have separately evaluated the contribution to forest fire occurrence of northeast region, which are so-called as the 'Seven Sister States'. The forest fire occurrence in the north-eastern states were found to be the highest in Mizoram (27.4%) followed by Assam (20.4%), Manipur (16.7%), Meghalaya (11.7%), Nagaland (10.1%), Tripura (8.2%) and Arunachal Pradesh (5.5%). Similarly, we have also analysed the central part of the Indian states (Orissa, Chhattisgarh, Madhya Pradesh, Maharashtra, Telangana, and Andhra Pradesh) of India falls in forest fire hotspot, mostly dominated by dense and open dry and moist deciduous forest. The study revealed that Chhattisgarh state had the highest number of forest fire incidences followed by Orissa, Madhya Pradesh, Maharashtra, Andhra Pradesh, and Telangana states.

Forest fire trend

We have also evaluated the forest fire trend monthly to understand its spatial pattern. The forest fires trend over the month of January, February, March, April, May, and June are given in the Figs 3–8 respectively. The seasonal forest fire frequency % over the month of February to June at the national level was separately evaluated. The forest fires frequency percent in the months of February, March, April, May, and June are found to be 8, 56, 28, 7, and 1% respectively (at the national scale) considering the total forest fire frequency between these periods (February to June) as 100%. Although the forest fire frequency in the month January was very less, while analysing the trend in the same month revealed that the forest fires were found to be the highest in the districts of North-East state of India such as Mon (Nagaland) and Tirap (Arunachal Pradesh) with frequency 116 and 98 respectively. The South Indian state of Telangana

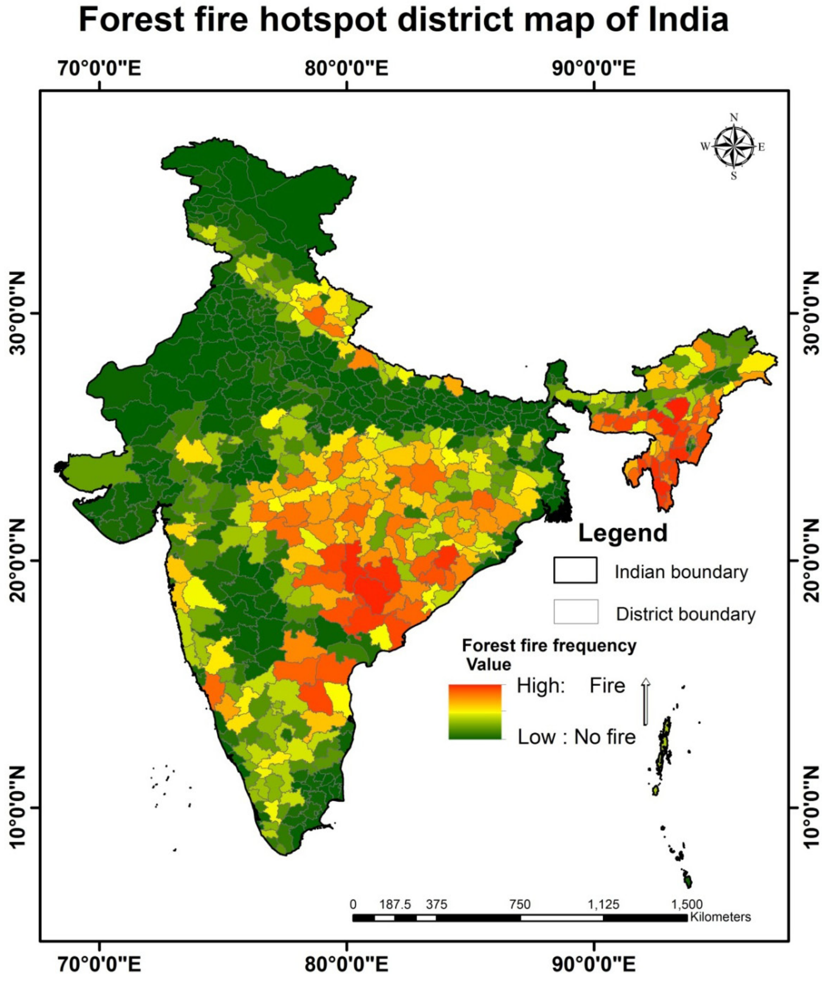


Fig. 2. The forest fire hotspot districts of India.

such as Adilabad district witnessed the frequency value 96 occupied the 3rd position. Forest fires took a grippe in the southern states of India during the month of February mostly adjoining forest district of state Maharashtra (Garhchiroli), Telangana (Khammam, Warangal), and Chhattisgarh (Dantewada). The forest fire frequency was found to be the highest in the Khammam district, whereas in the other three districts, the forest fire frequencies were in the range of 669 to 602.

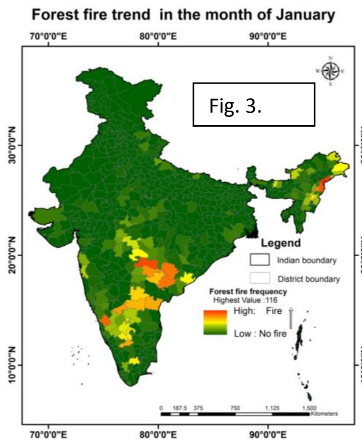
The highest forest fire frequency in the month of March was in the range of 4637 to 1492, and was observed in the 15 highest forest fire districts. The 13 districts out of these 15 districts were from the northeast states of India. In the southern part of

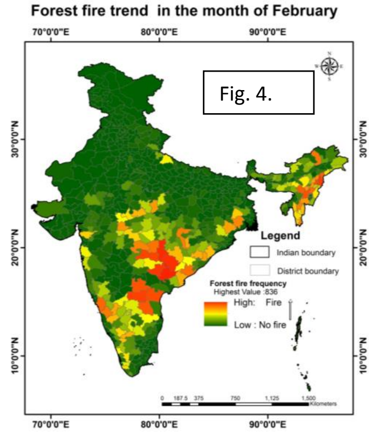
India, the forest fire in the month of March were more concentrated in the same districts where the forest fires were the highest in the month February extending further to the new area up to north (Jharkhand state) and northwest (Madhya Pradesh state). In the month of April, the forest fires were found concentrated on the same areas with low forest fire frequency when compared with March, whereas the fires were further intensified in the new areas towards the north side of Pauri Garhwal district of Uttarakhand state of India. In the month of April, the 141 districts of India showed and increasing forest fire frequency trend, whereas 284 districts of India showed a forest fire frequency decreasing trend when compared to the preceding month. The three top districts that showed an increasing trend in the month of April were Pauri Garhwal (Uttarakhand), Karbi Anglong (Assam), and Naini Tal (Uttarakhand) with the difference (increase) fire frequency value as 850, 750, and 504 respectively when compared with the preceding month. Roughly, during the month of May in most of the districts of India, the forest fire frequency showed a decreasing trend except in Jammu and Kashmir, Uttarakhand, Punjab, and Himachal Pradesh, mostly in northern part of India. The forest fire frequency in the month of May roughly reduced to a large extent in the northeast state of India. In the month of June, the forest fire fully disappeared in the northeast because of the active monsoon phenomenon there, whereas it only remained active in the northern states of India because of the late arrival of monsoon. The pre-monsoon showers in the month of June in most parts of India were largely responsible for reducing the forest fire events in this month.

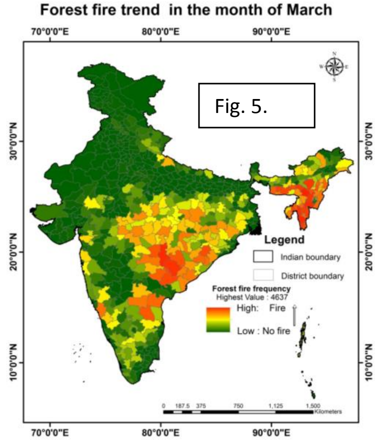
Grid based climatic and fire events data evaluation

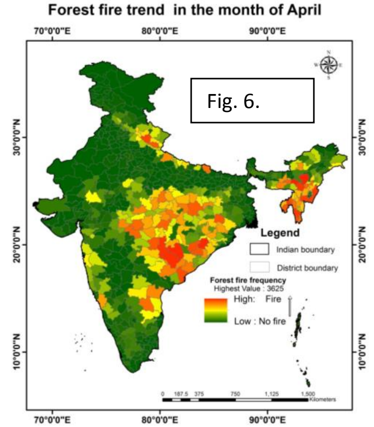
In this study, we have created grids equal to the spacing of climatic point data onto the rectangular area (in the central part of India), where each grid retains the climatic data points falling inside the grid. There were 308 grids with 22 rows and 14 columns. Here, our objective was to study the month wise impact of climate (maximum temperature, solar radiation, relative humidity, and wind velocity) on forest fire events/occurrence depicted in Figs 9, 10, 11, 12, 13. The grids were evaluated based on the total forest events (2008 to 2016), month wise (from February to June). The forest fire events were depicted with dots. The bigger dots mean higher forest fire events. The green dots mean no forest fires occurrence. Table 1 shows the forest fire events month wise over the rectangular study area at local scale.

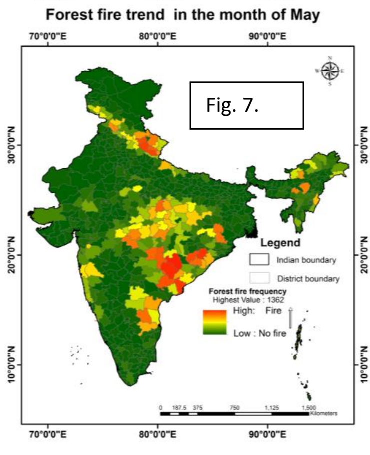
This table shows that roughly 80% of forest fire events are in the month of March and April, whereas the month March retains the highest forest fire events roughly equal to 50%. The evaluation of grid wise forest fire events in the month of February revealed that forest fire frequency was more in the southwestern side. The forest fire frequency in the month of March was spread over 90% of the grids, whereas out of the total grids, 51 grids (in the count) showed the fire frequency >= 151 mostly dominated in the southern portion. Similarly, the forest fire frequency in the month of April was spread over 88 % of the grids, whereas out of the total grids, 18 grids and 7 grids (in the count) showed the fire >= 181 and >=320 respectively. A large concentration of fire grids were found in the southern region, concentrated on three pockets shown in Figure 11(a). In May, seven grids (in the count) were showing the

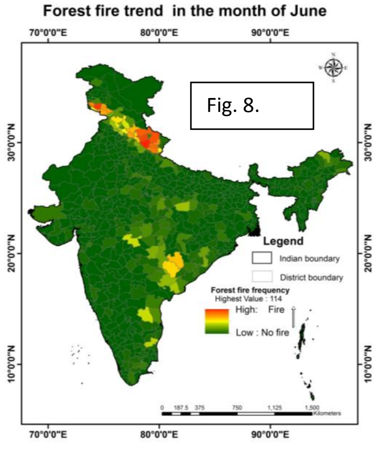












Figs. 3, 4, 5, 6, 7, 8. Month wise forest fire trend from January to June.

forest fire frequency >=178, whereas the large concentration of fire grids were found in the southern/southwest region.

The evaluation of maximum temperature (°C) revealed that the temperature in the month of February was roughly in between 21 to 30, approximately showing high concentration in the central western portion of the grids. The sudden jump in temperature (°C) was observed in the month of March and was found to be roughly in the range of 26 to 41° C, whereas high temperature was concentrated in the southwestern portion of the grids. The temperature (°C) further showed an increasing trend in the month of April was found in between 28 to 46° C. The temperature also showed an increasing trend in the month of May and approximately manifested high concentration in the northern region of the grids.

Analysis of relative humidity (fraction) grid wise revealed that the relative humidity in the month of February was roughly in the range of 0.56 to 0.94. The relative humidity was further decreased in the month of March, whereas the lower value decrease was found the highest from 0.56 to 0.18 (Fig. 10d). The higher value of relative humidity was found the lowest in all the month in April equivalent of 0.79, whereas it improved in June and was equivalent of 0.83. The overall relative humidity trend showed that in all the months, the low relative humidity was observed over the northern/ north-western portion of the grids.

Study of wind velocity (meter/second) grid-wise revealed that the wind velocity in the month of February was roughly in between the range of 1.04 to 3.07. The wind velocity further intensified in March and was found in the range of 0.98 to 7.64. The highest wind velocity was observed in the month of April, mostly concentrated in the central western part of the grids equivalent of 7.83 (highest among all months), whereas it reduced in the month of May and found in the ranges of 1.43 to 4.63.

The solar radiation (MJ/m^2) grid wise analysis showed that the increasing trend with the highest value from February to May whereas, it reduced slightly in June. The lowest value of solar radiation range was found the highest in March, equivalent of 21.38 among all months (Fig. 10c).

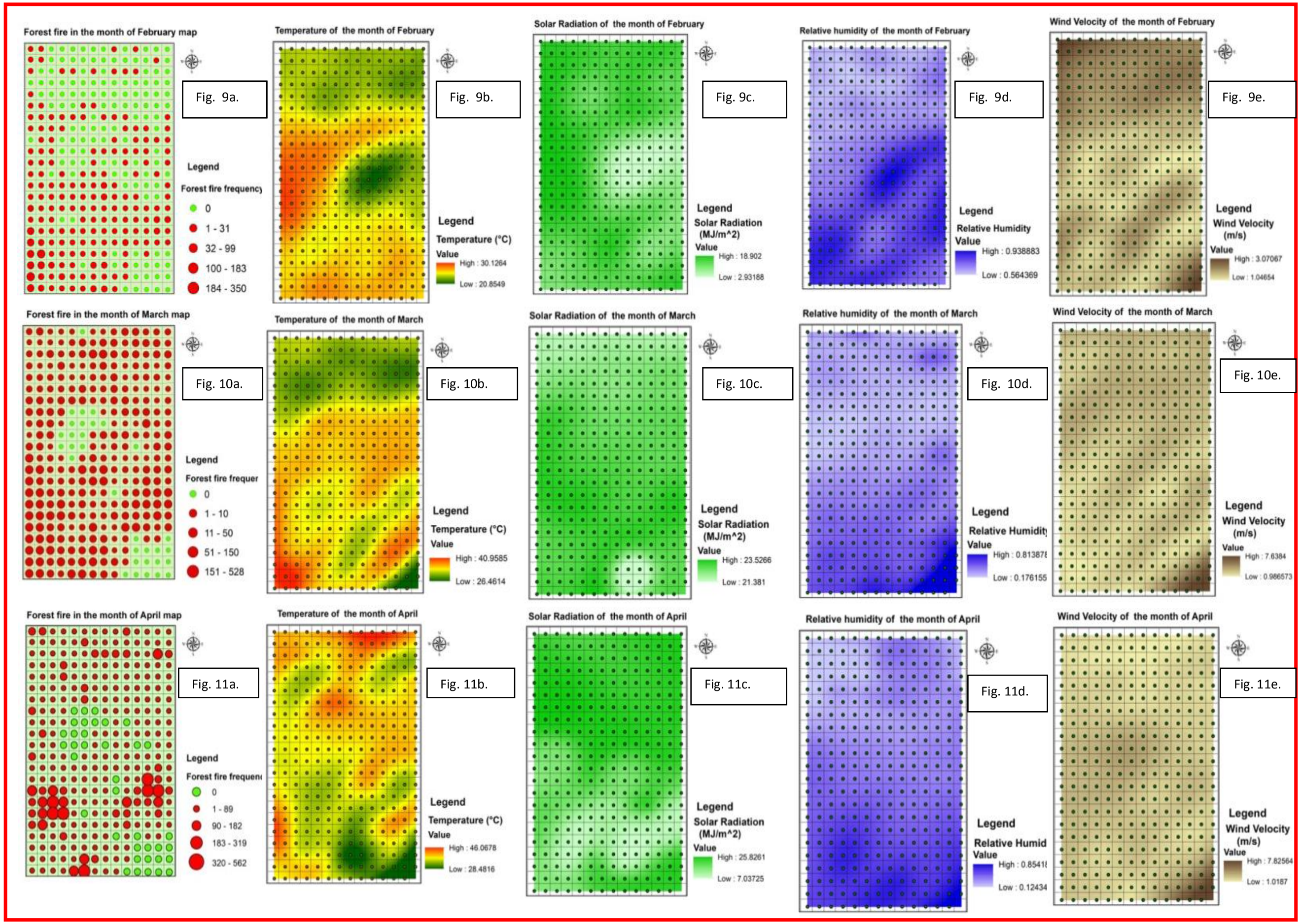
Rainfall and evapotranspiration trend and intensity analysis

The rainfall shows a strong relationship between the area burned and annual rainfall during summer season (Pausas, 2004). The precipitation and evapotranspiration are important parameters widely used for drought index modelling (Vicente Serrano et al., 2010) and highly useful for forest fire analysis (Wells et al., 2004; Flannigan et al., 2005).

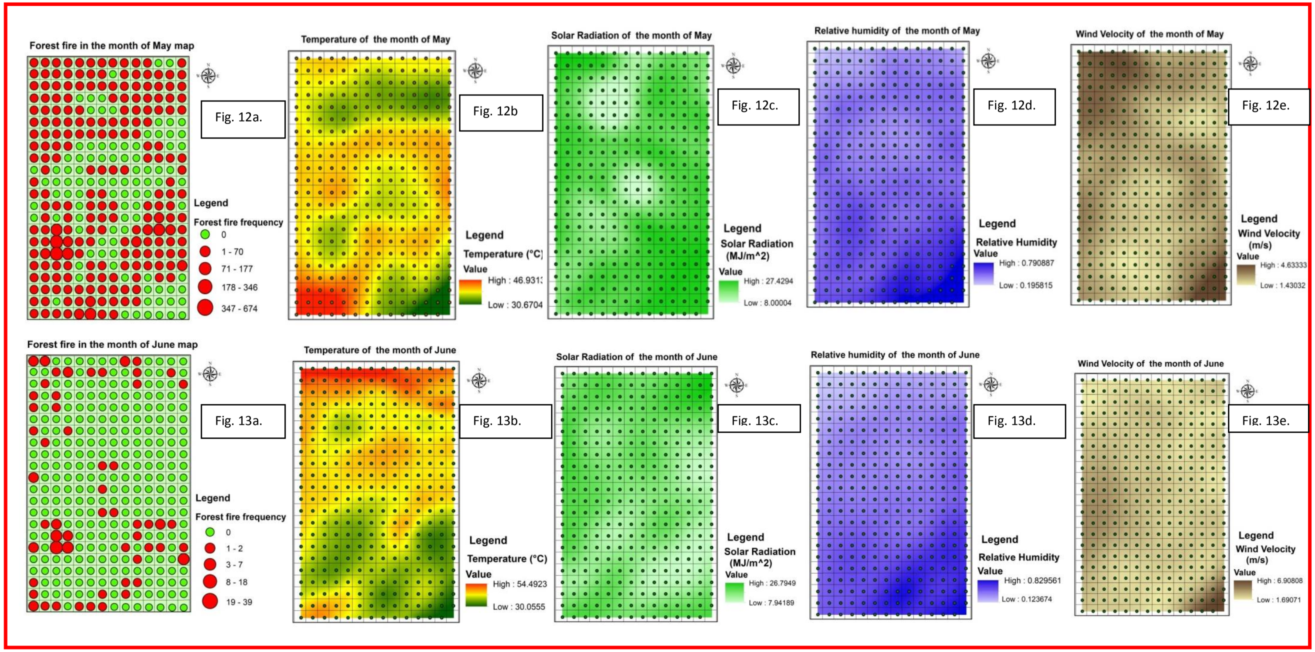
The average monthly rainfall and the potential evapotranspiration over the central part of India during summer season were analysed and depicted in the Figs 14, 15. In this study, we have used 15 districts' data for the evaluation. The rainfall data showed that in the month of June, the areas received good rainfall due to the pre-monsoon and monsoon showers, whereas the

T a b l e 1. Month wise forest fire events.

Month	Feb.	March	April	May	June
Forest fire events (Frequency)	3614	24 629	16 444	5640	176
Forest fire %	7.2	48.8	32.6	11.2	0.3



Figs 9, 10, 11. Showing the trend (9-February, 10-March, 11-April) (a-forest fire events, b-maximum temperature, c-solar radiation, d-relative humidity, e-wind velocity).



Figs. 12, 13. Showing the trend (12-May, 13-June) (a-forest fire events, b-maximum temperature, c-solar radiation, d-relative humidity, e-wind velocity).

potential evapotranspiration data showed an increasing trend from February to May, but decreased in the month of June. Potential evapotranspiration increase showed the weather severity towards dryness, which leads to an increase in fuel load inflammability available in the forest. Carcaillet, Richard (2000) also highlighted in their study of seasonal precipitation variability over fire occurrences. The month wise data were further evaluated for statistical analysis.

Statistical analysis

In this case, the objective was to evaluate the month wise climate/weather data for statistical analysis (Crammer's V coefficient) and find out their relation/association with forest fire frequency. The climatic datasets, maximum temperature, wind velocity, relative humidity, and solar radiation were analysed month wise and the averages were calculated. The average monthly basis observations from February to June are recorded in Table 2. The maximum temperature, wind velocity, relative humidity, and solar radiation were found in the range of (25.9 to 40.6), (1.69 to 2.7), (0.301 to 0.736), and (14.21 to 22.98) respectively. The maximum temperature was showing the increasing trend from February to June, whereas the maximum increase of temperature was observed in the month of March with the increased value of 9°C. A rapid climate change was observed that favoured the forest fire events in the month of March onward. The percentage increase (compared with the month of February) noticed in maximum temperature, wind velocity, and solar radiation were 36, 39 and 62% respectively in the month of March, whereas a 60% decrease was observed in the relative humidity in the same month. The CVC values of different meteorological parameter (driving factors) are given in Table 3.

Here, the CVC value of rainfall, relative humidity, potential evapotranspiration, maximum temperature, wind velocity, and solar radiation were found in a decreasing order and in the range of 0.293 to 0.778 (Table 3). Except for solar radiation (although it retains the

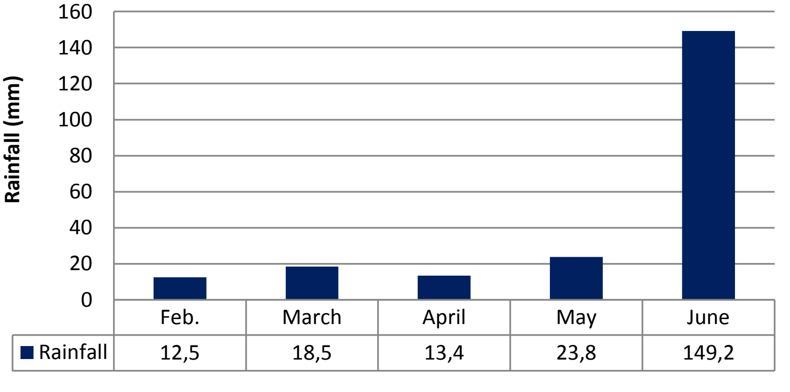


Fig. 14. The Rainfall trend during forest fire season.

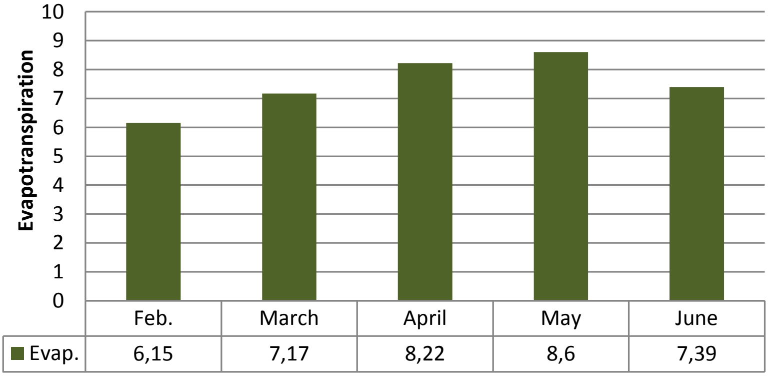


Fig. 15. The potential Evapotranspiration trend during forest fire season.

value roughly 0.3), all the other climatic parameter showed strong association with forest fire events. The CVC value of rainfall was found the highest equivalent to 0.78, which showed its strong association/relationship with fire events. The rainfall significantly increased the soil moisture and reduced forest fuel burning capacity by absorbing moisture in it. Wang et al., 2016 also described the value greater than 0.3 of CVC and shows strong relationships with the driving factor for their study. A similar finding has been observed by Ahmad et al., 2017.

Climate anomalies and its impact

In recent years, the potential impacts of climate change and variability have been widely discussed and received a lot of attention from the researchers around the globe. Fire and climate have strong linkages (Swetnam, Betancourt, 1990; Marlon et al., 2008; Aldersley et al., 2011), climate-related disruptions to fire activity will occur in many old and new areas. By various research findings, it has been well proved that climate plays a significant role, which decides the fire behaviour (Flannigan et al., 2000; Fried et al., 2004) attributing it to the forest fire events (Stephens, 2005; Westerling et al., 2006) anomalies. Studies conducted by Pinol et al. (1998), Tian et al. (2012), and Wotton et al. (2010) revealed that forest fire events will be more severe in the future.

A study conducted by NASA also revealed that the global temperature increased by roughly 1 °C in the year 2016, whereas it shows a continuous increasing trend after the year 1978 (https://climate.nasa.gov). The average temperature increase by approximately 1 °C will increase the duration of the fire season by 30% (Vorobyov, 2004). Increase in summer temperature maneuvered by an induced climate change leads to influencing the forest fire regime in a direct or indirect way (Wells et al., 2004). In the above study, it was also observed that the temperature significantly increased in the summer month (April, May).

A warmer climate in summer leads to higher rates of evapotranspiration in the forest ecosystem. These processes, in association with a shifting pattern of precipitation, will affect the spa-

Table 2. Meteorological average data on monthly basis from February to June.

Average of 11 years (2004–2014)	Feb.	March	April	May	June
Maximum Temperature (°C)	25.9	35.1	39.5	40.2	40.6
Wind Velocity (m/s)	1.69	2.35	2.21	2.26	2.7
Relative Humidity(fraction)	0.736	0.301	0.429	0..412	0.442
Solar Radiation(MJ/m^2)	14.21	22.98	19.72	21.6	16.53

Table 3. Crammer's V coefficient (CVC) values of forest fire driving factors.

Meteorological variable (Driving factors)	Forest fire frequency Crammer's V coefficient (CVC)
Maximum Temperature	0.399
Solar Radiation	0.293
Wind Velocity	0.383
Relative Humidity	0.415
Potential Evapotranspiration	0.414
Rainfall	0.778

tial and temporal distribution of soil moisture, relative humidity and increase the probability of droughts. The severity of drought plays a significant role in the wildfire frequency and extent of damage (Wells et al., 2004) and also the increase in forest fire season (Flannigan et al., 2005). Various studies show that India will face climate change in the future. A study conducted by Chaturvedi et al. (2011) on the impact of climate change over India based on an assessment on climate projections. Model scenarios revealed that the many forest dominant states of the central part of India such as Chhattisgarh, Karnataka, and Andhra Pradesh (including Telangana) are projected to undergo a change in forested grids. The study conducted in North East region of India by Jhajharia et al. (2009) suggested that the two parameters, viz. sunshine duration (solar radiation) and wind speed, strongly influenced, which leads to changes in evaporation at various sites, whereas the study by Jain et al. (2013) at the same region showed all four temperature variables, viz. maximum, minimum, and mean temperatures and temperature range had a rising trend. These trends will further enhance the fire frequency and occurrences in the forest fire hotspot area of North East region, which is already more fragile as far as forest fire is concerned. This was also proved in our study.

Dry deciduous forests of India are more vulnerable to forest fire (FAO, 2001). The area of the central part of India are largely occupied by deciduous forest and provide shelter to large population of marginalized ethnic tribes/weaker sections and have integrated linkages to their livelihood seem to be the forest fire hotspots are also experiencing a decreasing trend of rainfall and in number of rainy days (Kumar, Jain, 2011) and need immediate policy intervention to cope with future challenge. These above studies of climatic anomalies over Indian region will lead to an increase in forest fire events in future and are a major policy concern towards its prevention and control. Finally, we can conclude that more studies are required based on participatory and cross-disciplinary approach (Meinke, Stone, 2005) at the national level in India on climate change anomalies and its impact on forest fire events, and its hidden linkage with tribal population, livelihood and food security must be addressed adequately by research studies to closely monitor their relationship/impact and suggesting/implementing long-term strategies to reduce its impact on forests.

Conclusion

This study has analysed the long-term forest fire events at the district level of India and identified the high forest fire districts and its temporal trend. We have also evaluated the relationship between forest fire events and climate datasets supported by statistical analysis based on the values of Crammer's V coefficient (CVC) at the local level. This research revealed that the climate parameters have a strong correlation with forest fire occurrence especially in summer. This was supported by several research findings especially in the developed countries, whereas this is a research interstice in the Indian region in the prevalent climate change scenario. Bowman et al. (2009) rightly said, 'We're most concerned that fire has not been rigorously and adequately incorporated in the climate models.'

In this study, we have found that several districts of India have significantly high forest fire events. Thus, there is an urgent need to formulate and implement the forest fire policy by the Indian government keeping in mind the socio-economic conditions of the local inhabitants. Furthermore, weather forecast and an alarm system should be warranted on a daily basis during forest fire periods. The weather severity and its trend should be sent to respective administrative headquarters, which will significantly help them to take adequate preventive measures to control the extent of its damage.

Our study showed 6 out of 10 highest forest fire districts of India falls on the northeast region. These forest dominated area harbour significantly high percentage of the tribal population and they are facing acute poverty due to diminishing livelihood condition. Shifting cultivations are widely practiced by them due to their very poor socioeconomic status. The government bodies, NGO, and local administration should initiate such programs to enhance the livelihood of the local people practicing shifting cultivation by involving them in forest afforestation, conservation, and protection activity through empowered village forest management committees (VFMCs) on the line of joint forest management (JFM).

The forest fires are significantly high in some of the districts and will continue to increase in future due to climate change. Thus, there is a need of a new division in the forest department, especially in forest fire hotspot areas, headed by a forest officer who will look into all the activities related to fire prevention, control, and its conservation planning and future strategy. There is a need for adequate support of manpower, funds, equipment, and technology to increase the effectiveness for fire prevention and control. Furthermore, the fire awareness and educational activities should be initiated in and around the high forest fire zone/district involving the local community and other groups in a fire management programme and including them as a responsible partner.

Climate plays a significant role in forest fire regime, whereas comprehension of their interaction is very poor in the Indian subcontinent. Thus, there is a need for more future research in the field of a forest fire, climate change and socio-economic linkage of the tribal community that will give better understanding and knowledge. Furthermore, there is a need to develop fire risk predictive models utilizing fire events, meteorological and other dependent parameters in this region, which will work as future research strategies.

Geospatial technology has enormous capability and can be potentially used in mapping, monitoring of forest health (quantitative and qualitative) and its disturbance. Its vital role cannot be ignored, and thus, should be incorporated in decision making so that appropriate conservation related policy/decisions are taken in time.

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ECOLOGICAL MEASURES IN THE LAND CONSOLIDATION PLANNING OF THE VILLAGE OF KOCURANY

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Abstract

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This paper deals with the application of ecological proposals within the land consolidation project process in Slovakia. Ecological proposals form part of the Local Territorial System of the Ecological Stability project, which is a compulsory material for developing land consolidation projects. The Local Territorial System of Ecological Stability for the cadastral unit of Kocurany village was worked out in 2013. Within the area, 31 localities were selected for the implementation of ecological proposals with a total area of 154.34 ha, namely 3 biocorridors, 2 biocentres, 9 interacting elements, 8 ecostabilising elements and 9 localities with the need of anti-erosion soil cultivation, or delimitation to permanent grasslands. The main task was to analyse the rate of acceptance of the proposed measures. It was found that only 20 localities with a total area of 119.37 ha were accepted into the land consolidation project. In order to improve all the landscape functions, the integration of quality ecological proposals from the Territorial System of Ecological Stability into the land consolidation projects is necessary.

Key words: Territorial System of Ecological Stability, land consolidation, ecological proposals, local level.

Introduction

Land consolidation (LC) in the Slovak Republic and in most European Union countries constitutes an activity whose objective is to aid purposeful and rational organisation of the agricultural landscape. Additionally, it helps in the protection and development of this landscape. In different countries and regions, the aims and methods of LC are influenced by specific conditions, their historical and current political and social development, their natural conditions, as well as the official (information) price of agricultural land (Eichenauer, Joeris, 1994; Bonfanti et al., 1997; Borec, 2000; Crecente et al., 2002; Sklenička, 2002; Gorton, White, 2003; Muchová et al., 2018).

The current state of LC planning in Slovakia is especially affected by specific historical developments within the former Czechoslovakia. After the year 1948, LC was dealt with on the basis of regulations, so-called economic and technical modifications in Czechoslovakia. Their meaning was subordinated to the economic aims, agricultural industrialisation and political demands of that period. The regulations principally involved the formation of large blocks of land. The prior ownership of this land was not considered, and a sensitive approach to the landscape was often absent. The agricultural landscape was transformed considerably, especially in intensively cultivated agricultural areas (Kaulich, 2012). The Slovak landscape underwent a big reorganisation. Areas that were originally divided into several-hectare fields, were transformed into large, several hundred hectare blocks of arable land by the process of collectivisation in the 1950s. During this process, the 'dividing' elements were removed from the landscape. These elements included important biotic elements such as vegetation of balks, hedges, ecotones and verges alongside roads. After their removal, a considerable decrease in biodiversity and overall ecological stability occurred across large areas of the landscape. The changes in the spatial landscape organisation were also felt in the form of an increase in some negative processes on arable land – especially soil erosion. The overall reaction of the landscape to agricultural activities is different on big blocks and on small blocks of land. Moreover, large areas of agricultural land are usually owned by several landholders (fragmentation of landholding). This does not allow an independent use of land parcels by individual landholders. Access from public or local roads is not ensured to every parcel. Several land parcels are of unsuitable shape and have a small surface area. The land parcels are often co-owned by several landholders. For these reasons, they are left for rent to a common user. Bigger fragmentation of landholding and related limitations on use lead to farming on larger blocks of agricultural land. Due to these factors, the landscape becomes more homogeneous, and therefore, less stable and less ecologically valuable.

However, if the landholders own land parcels, whose surface area and shape enable their individual use or rental, the agricultural landscape is divided into a lot of smaller blocks of arable land. The land parcels create a varied landscape mosaic. They are separated by balks, hedges, ecotones and verges, which fulfil many important ecological and environmental functions (Urban et al., 2013).

Such linear elements are important landscape elements affecting biodiversity. They allow different kinds of plants and animals to move among fragmented biotopes (Forman, Baudry, 1984; Opdam et al., 1995; Bennet, 1999). Motion of different kinds of plants and animals down the corridors has been demonstrated by many authors (e.g., Mann, Plummer, 1995; Rosenberg et al., 1997; Roy, Blois, 2008). They are considered to be sustainable landscape elements and they should have their own administrative management (Baudry et al., 2000).

The current organisation of landholding by LC enables the execution of property rights and users' relations to the land parcels in Slovakia. The variety within the landscape is thus increased and its ecostabilising, retentive, anti-erosional and biotic functions and other biodiversity supporting functions are improved and 'greening of the landscape' is performed. From this viewpoint, the Territorial System of Ecological Stability (TSES) is an important tool in the process of LC in Slovakia (Law No. 330/1991 Coll.). The concept of the TSES in Slovakia is fully convergent with other laws, which have been created and applied to landscapes internationally (e.g., Buček, Lacina, 1979; Buček et al., 1986; Löw et al., 1988; Míchal et al., 1991; Míchal, 1992; Buček, Lacina, 1993; Forman, Godron, 1993; Smith, Helmund, 1993;

Bastian, Schreiber, 1994; Jedicke, 1994; Naveh, Lieberman, 1994; Lammers, Zadelhoff, 1996; Bani et al., 2002; Izakovičová, Swiader, 2017).

The TSES represents an ecological network that contains spatially related, ecologically stable segments of the landscape. These elements are functionally distributed on the basis of their functional and spatial criteria. Methodologies of this specialisation are known all over the world (Cook, van Lier, 1994; Brandt, 1995; Jongman, 1995; Sepp, Kaasik, 2002; Jongman et al., 2004; Wrbka et al., 2005; Fabos, 2005; Jongman, 2008). It is a modern concept for the protection of nature and biodiversity, based on the principles of protection of conditions and forms of biota, that is, geobiodiversity protection (Miklós et al., 2011). The TSES consists of biocentres (ensuring a food chain, conditions for reproduction, recreation and shelter), biocorridors and interacting elements (allowing migration and exchange of genetic information, as well as interactions of different ecosystems of different stability). It is processed at three hierarchical levels: local, regional and national. A local level of the TSES (LTSES) is important for the land consolidation.

Several authors deal with the importance of a LTSES in LC, and with the principles of creation of LTSES projects for the needs of LC, for example, Dumbrovský, Kolářová, 1995; Izakovičová et al., 2000; Zelinka, 2001; Ružičková, 2006; Muchová et al., 2013; Kocián, 2013; Belaňová, Diviaková, 2015; Doubrava, Martének, 2015; Julény et al., 2017. The areas of the Natura 2000 network of protected European sites are fully or partially considered in relation to the land consolidation (Hootsmans, Kampf, 2004; Ružičková, 2006).

A guidance framework for the creation and implementation of LTSES projects inland consolidation includes a methodological manual for land consolidation planning, issued by the Ministry of Agriculture and Rural Development of the Slovak Republic (2004) and the Methodological Standards for Designing Land Consolidations (Muchová et al., 2009).

The project of land consolidation is worked out within the LC district in the following steps: introductory materials, proposal of new arrangement of land parcels, implementation of the project. The proposal of the LTSES and ecostabilising measures is a part of the proposal of the General Principles of Functional Organisation of the Territory (GPFOT). These proposals are worked out during the preparation of introductory materials of the land consolidation project.

This paper deals with the protection and development of the agricultural landscape in the LC project district of the village of Kocurany. It focuses on the proposal of structure of the LTSES and anti-erosion measures, and subsequently, it monitors the integration of ecological measures into the proposal of GPFOT.

Material and methods

The area under discussion belongs to the district of the LC project of the village of Kocurany (latitude of 48°46′17″N; longitude of 18°32′35″E). It is situated in the north-western part of the Slovak Republic, in the region of Prievidza (Fig. 1). The total area of the land parcels in the area is 332.48 ha. Geological conditions are determined by the area's position in a border part of the Hornonitrianska kotlina basin of characteristic tectonic composition. The basin is filled with neogene and paleogene sediments. There are Mesozoic and Crystalinicum rocks of Malá Magura in their bedrock. Cambisols predominate among the soil types, and adjacent to the watercourses, there are fluvisols and fragmental rendzinas. According to the phytogeographical structure (Miklós, Hrnčiarová, 2002), the area belongs to the beech zone, Crystalline-Mesozoic area and to the region of the Hornonitrianska kotlina basin. The following units of potential natural vegetation were identified (Michalko et al., 1986): bottomland forests, lowland forests, oak and hornbeam Carpathian forests, oak and silverweed forests, oak and European turkey oak forests. The area is an open agricultural landscape. Permanent grasslands, forest vegetation and arable land are dominant. Formations of non-forest woody vegetation are the important elements of the landscape structure. In the area under discussion, there are the following types of biotopes (Ružičková et al., 1996): oak and hornbeam Carpathian forests (*Carici pilosae-Carpinenion betuli*), submontane alder bottomland forests (*Stellario-Alnetum glutinosae*), blackthorn scrubs (*Ligustro-Prunetum*), shrub covers of mesophilic forest covers, lowland and submontane oatgrass meadows (*Arrhenatherion*), poor submontane and montane meadows (*Polygalo-Cynosurenion)*, reed communities of still water and marsh and submontane stream. Two watercourses flow through the territory: Trebianka and Jeleškový streams. The territory is drained by the river Nitra.

The agricultural production is realized through the Kolesi cooperative. The forests are managed by Forest and Land Association Kocurany. The following stress factors have been identified in the territory: large-scale arable land, Route III. classes, horse-breeding grounds, line equipment of technical infrastructure (telecommunication lines, water mains, gas pipelines and electric conduits), deforestation, air pollution, soil contamination, surface water pollution and soil damage by water erosion. The coefficient of ecological stability in the area is 2.79 (average ecological stability).

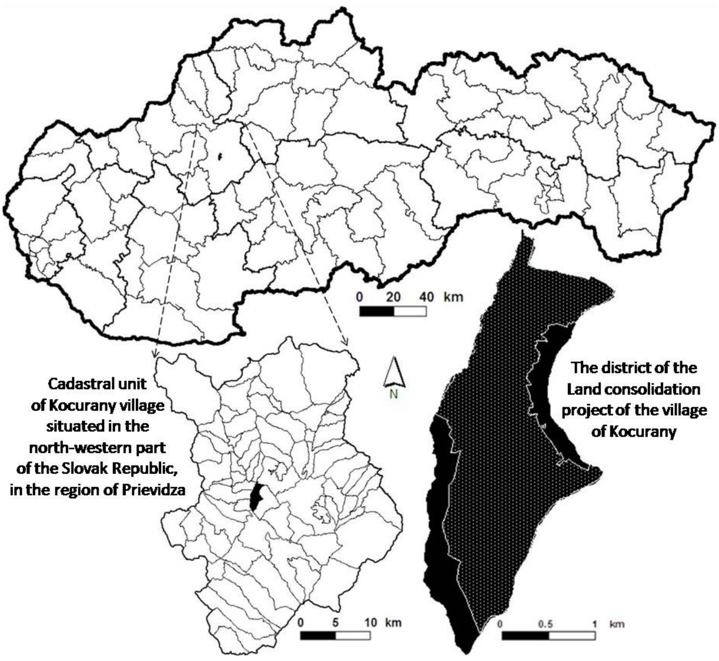

Fig. 1. The location of the area under discussion within the administrative organisation of the Slovak Republic.

The project of LTSES Kocurany for the purposes of LC (Diviaková et al., 2013) was worked out in accordance with the Methodological Standards for Designing Land Consolidations (Ministry of Agriculture and Rural Development of the Slovak Republic, 2004). The working procedure consisted of 3 basic parts:

- analysis of accessible materials, natural conditions and the current landscape structure,

- syntheses and evaluations focused on areal and spatial organisation of positive and negative elements and phenomena, and on the assessment of ecological stability and landscape structure,
- proposal of the TSES structure and anti-erosion measures.

The proposal of General Principles of Functional Organisation of the Territory was worked out by the project architects of LC within the Kocurany LC project (Krchňavá et al., 2013) on the basis of the proposal of the TSES structure and anti-erosion measures, with the specification based on more detailed knowledge and proposals, as well as comments and requirements of the participants of the LC.

From the introductory materials of the LC project, the elements of the structure were analysed in the first part (biocenters, bioccoridors and interacting elements), along with the proposal for anti-erosion measures in the LTSES project. Subsequently, the proposal for GPFOT was analysed. In the last step, the rate of integration of ecological measures from the LTSES to GPFOT was assessed.

Results

Analysis of the proposed structure of the Local Territorial System of Ecological Stability and anti-erosion measures

In the district of the Kocurany land consolidation project, one biocorridor of regional importance (RBc1) was reflected in the proposed structure of the LTSES from the project of Regional Territorial System of Ecological Stability Prievidza (Múdry et al., 1994). RBc1 Šútovský stream and its environs, ecotones Háje, represent a regional hydric and terestric biocorridor (only a part of the biocorridor is involved in the district of the LC project). The biocorridor is created by submontane watercourse and its bank cover. In the northern part, it borders the western frontier of the discussed area, and in this part, the watercourse is not regulated. It is created by natural bank cover (*Alnus glutinosa, Salix* sp., and *Corylus avellana* in some parts of the undergrowth). Bank cover on the right side changes continuously into forest cover. Cover of submontane firs, undermined by water, is a part of the northern part of the biocorridor. In the southern part of the area, the biocorridor goes through ecotone communities of the forest cover.

13 existing elements of local importance were set aside: 2 local biocentres (LBcr2 Nádavky, LBcr3 Háje), 2 local biocorridors (LBc4 Homôlky, LBc5), 9 interacting elements (IE6 Slivčina, IE7 Slivčina, IE8 Zadné diely, IE9 Zadné diely, IE10 Zadné diely, IE11 Lány, IE12 Zadné diely, IE13 Krížne cesty, IE14 Zadné diely). LBcr2 Nádavky represents a terrestrial local biocentre, created by the formations of non-forest woody vegetation, forest cover and partially grass and herbaceous covers with woody plant succession. In the formations of non-forest woody vegetation, Scots pine (*Pinus sylvetris*) and European hornbeam (*Carpinus betulus*) are dominant; the ecotone is created by blackthorn (*Prunus spinosa*). There are also other species, for example, field maple (*Acer campestre*), common oak (*Quercus robur*), old man's beard (*Clematis vitalba*), wild privet (*Ligustrum vulgare*), common hazel (*Corylus avellana*), rubus (*Rubus* sp.), common hawthorn (*Crataegus monogyna*), rowan (*Sorbus aucuparia*), wild service tree (*S. torminalis*), whitebeam (*S. aria*), common dogwood (*Swida sanquinea)*, European beech (*Fagus sylvatica*), silver birch (*Betula pendula*), common juniper (*Juniperus communis*), dog rose (*Rosa canina*), aspen (*Populus tremula*), European wild pear (*Pyrus pyraster*) and so on. Due to the variety of communities, the local biocentre is an important biotope in the discussed area, which provides permanent conditions for the

existence of biota of the area. It is also an important ecostabilising element. LBcr3 Háje is a local biocentre comprising forest, partially grass and herbaceous covers, with the occurrence of formations of non-forest woody vegetation. The forests contain predominantly pine and oak covers. The main woody plants are: sessile oak (*Quercus petraea*), common oak (*Q. robur*), Scots pine (*Pinus sylvestris*) and European hornbeam (*Carpinus betulus*). The ecotone of these communities consists mainly of blackthorn (*Prunus spinosa*). The local biocentre in the discussed area is an important biotope, providing permanent conditions for the reproduction, shelter and nutrition of living organisms and for the conservation and natural development of their communities. LBc4 Homôlky is a local terestric biocorridor. It is a large multi-level formation of non-forest woody vegetation of linear shape, stretching into the upper part of the discussed area along its western border. Species composition of the woody plants and shrubs is varied, including taxa from the surrounding forest covers, as well as attractive species from the point of view of fruit production serving as a source of food for animals (*Prunus spinosa*, *Pyrus pyraster* etc.). The element gives ideal conditions for the migration of different fauna. During the field research, several species of birds were registered and migrations of animals including wild boar (*Sus scrofa*), fallow deer (*Dama dama*), European roe deer (*Capreolus capreolus*) were observed. With respect to wider relations, the local biocorridor forms a large part of the immediate regional biocorridor RBc1. Together, they form one of the most important ecological and stabilising segments of the discussed area. The described formation of non-forest woody vegetation also fulfils a significant anti-erosion function. LBc5 Jeleškový potok stream forms a local hydric and terestric biocorridor (only a part of the biocorridor reaches the district of the LC project). It is a submontane watercourse with a gentle slope, which forms part of the north-eastern border of the discussed area. The watercourse is not regulated. In its immediate surroundings, there are narrow lines of bank covers, which contain common alder (*Alnus glutinosa*) and shrubs (*Rosa* sp.) scattered in the undergrowth. Near the watercourse, the soil is undermined by water in some places, with the presence of rushes (*Juncus* sp.). Interacting elements (IE6, IE7, IE8, IE9, IE10, IE11, IE12, IE13, IE14) predominantly represent formations of non-forest woody plant vegetation, forest covers, or meadows with a certain proportion of non-forest woody plant vegetation. They are connected with biocentres and biocorridors and they ensure their favourable effect on the surrounding parts of the landscape, which have been transformed or otherwise affected by people (especially arable land and intensively used meadows and pastures). They fulfil a lot of ecological functions and complete the local ecological network. They consist predominantly of Scots pine (*Pinus sylvestris)*, sessile oak *(Quercus petrea)* and European hornbeam (*Carpinus betulus*), and in the undergrowth, there are common privet (*Ligustrum vulgare*), dog rose (*Rosa canina*), Rubus (*Rubus* sp.), common dogwood (*Swida sanquinea)*, field maple (*Acer campestre*), wild service tree (*Sorbus torminalis*), hawthorn (*Crataegus monogyna*), common hazel (*Corylus avellana*), blackthorn (*Prunus spinosa*), common spindle (*Eonymus europaeus*) and others.

Most ecological measures of the selected biocorridors and biocentres dealt with the conservation of the current state and eliminating human interferences. Size parameters were suitable in the majority of the elements. Only for the element LBc5 Jeleškový potok stream, it was proposed to broaden the bank covers on both banks of the stream to the minimal length of 5 m by means of leaving natural succession and reduction of interferences into bank covers when working (mowing) the surrounding land parcels. Species composition of all the elements was suitable too, and all the localities represented natural communities. The majority of proposals of management measures of interacting elements were focused on keeping size parameters and conservation of ecotone communities on the borders of forest covers. It was necessary to broaden some of them by directly planting of suitable woody plants (*Quercus*

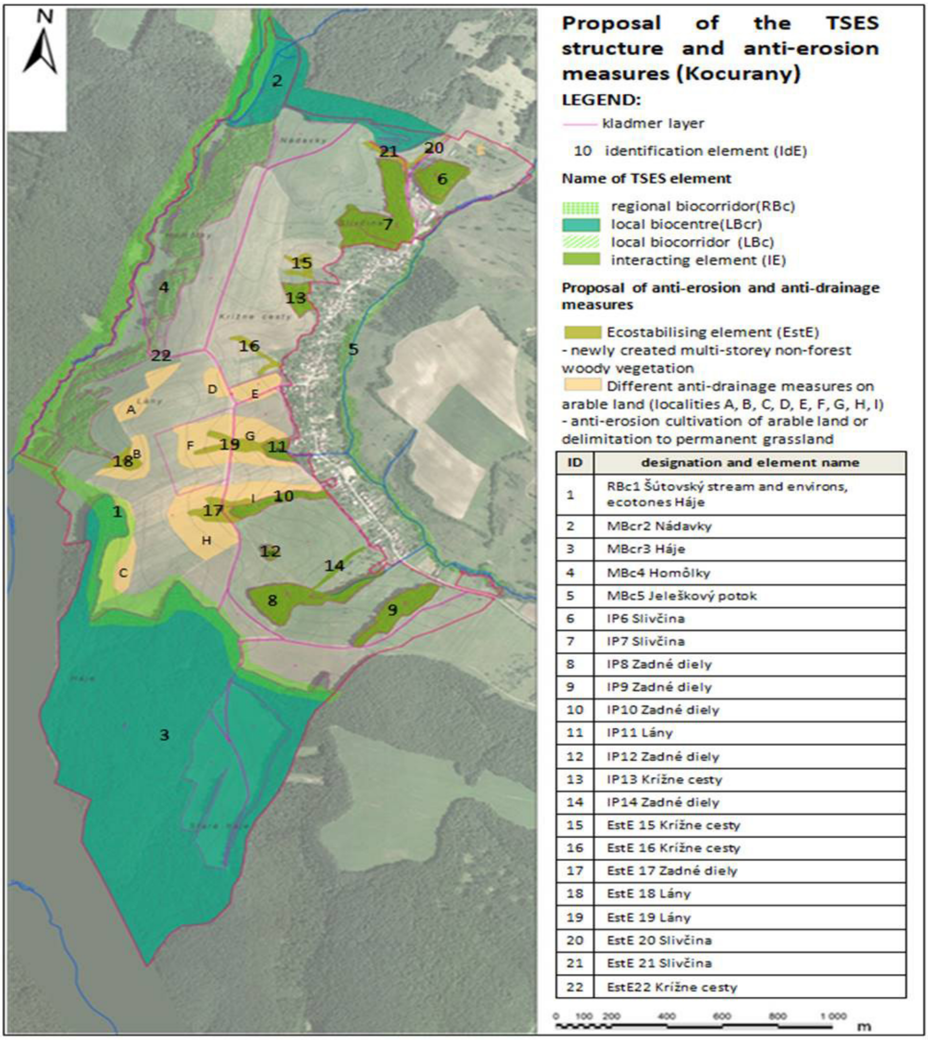

Fig. 2. Proposal of the TSES structure and anti-erosion measures worked out within the project of the Local Territorial System of Ecological Stability for the land consolidation project of the cadastral unit Kocurany (Diviaková et al., 2013).

robur, *Acer campestre*) or with the support of succession. It was necessary to remove illegal landfills in some interacting elements.

In the district of the LC project Kocurany, locations were proposed for 8 new ecostabilising anti-erosion elements (EstE15, EstE16, EstE22 - Krížne cesty, EstE17 Zadné diely, EstE18, EstE19 - Lány, EstE20 and EstE21 - Slivčina). These were mainly locations of groups and belts of non-forest woody vegetation, which were multi-layered, created by various species of natural woody plants (*Carpinus betulus, Quercus petraea, Acer campestre, Tilia cordata* and others), with the formation of noticeable ecotone communities on the borders of proposed elements. The aim of this group of proposals was to improve the overall ecological spatial stability. It was important to propose ecostabilising elements that would improve the retention ability of the landscape: deceleration of water runoff from the landscape, increase of self-cleaning ability of the landscape, ensuring anti-erosion protection of the landscape and so on.

In the localities of arable land with a high threat of water erosion, or at a risk of flooding (near the village area), anti-erosion and drainage measures were proposed. 9 localities were specified (A, B, C, D, E, F, G, H and I) with a need for anti-erosion cultivation (arable land with multi-year fodder plants), or delimitations to permanent grasslands.

6 sites (A, B, D, E, F, G) were to the west of the central part of the intravilan in the local part of the Lány and the remaining 3 (C, H, I) were defined southwards in the neighbouring local part of the Zadné diely.

You can see the proposal of ecological measures of the LTSES project for Kocurany village in Fig. 2.

Currently, there is only intensive agricultural production in some parts of the discussed area. The majority of the permanent grassland is used extensively; it is being overgrown with self-seeding of woody plants (oak, beech, juniper) and with the extension of succession covers (blackthorns, hawthorn, briars, blackberries, etc.).

Due to the change of traditional territory administration, the disappearance of important landscape structures is becoming a serious environmental problem, as well as threatening spatial stability and biodiversity. Species reliant on open areas are especially concerned, because this space is kept as agricultural landscape (by mowing and grazing). Incorrect management or the end of farming lead to overgrowth by succession self-seeding, changing species composition and leading to a decline of sensitive and protected species.

It is, therefore, necessary to implement the following management measures in order to optimally use agricultural land parcels:

- conservation of remaining natural mowing submontane meadows (in the locality of Nádavky),
- conservation of ecotone communities on the border of forest covers,
- conservation of grass and herbaceous communities with the presence of non-forest woody vegetation,
- creation of new ecostabilising elements on agricultural soil with varied species of multilayered non-forest woody vegetation,
- anti-erosion soil cultivation and planting only perennial fodder plants on arable land,
- ensuring protection of bank covers,

- creation of a protective belt of soil along water streams as a form of delimitation of adjacent land parcels, these belts being registered as having a different functional use to the adjacent land parcels, thereby preventing cultivation up to the edges of water surfaces,
- conservation of the current state with the prevention of modification to bank covers and limitation of crossing Šútovský streambed by vehicles.

On the land parcels that are used for other non-agricultural purposes, it will be necessary to provide the following management measures:

- conservation of natural forest covers of natural woody plants composition,
- conservation of old cemetery with no interventions to vegetation,
- determination of individual projection units next to the urban land and their consequent transfer to the ownership of the village, so they will correspond with the zones designated for residential construction based on the conclusions from the updated local plan of the village.

Analysis of the proposal of general principles of functional organisation of the territory

In the district of the LC project Kocurany, several types of land parcels underwent the process of delimitation, that is, integration into a new category of functional use. Their total area (82.16 ha) represented nearly 25% of the total area of the LC project. The largest area for delimitation (41.18 ha) consisted of arable land, located in the local areas of Lány and Zadné diely, which was transferred to the category of permanent grasslands. Some of the land parcels, registered as other surfaces (2.33 ha) or forest land (2.01 ha), were also transferred into the category of permanent grassland. Certain land parcels, which had been registered as permanent grasslands (9.55 ha) and other surfaces (1.41 ha), underwent the process of delimitation and were transferred for use as arable land. Furthermore, over a considerable area, the process of delimitation was undergone on land parcels, which has previously been categorised as other surfaces around the Jeleškovský potok, (19.09 ha) and permanent grasslands (0.32 ha), but actually consisted of the forest covers, as well as some parcels of arable land (0.01 ha) over which the forest had spread to such an extent that it was not possible to characterise it as self-seeding woody plants. All these land parcels were re-categorised as forest land parcels. Existing areas of non-forest woody vegetation are still registered as other surfaces. These included covers on the slopes beyond the urban area, which do not have forest characteristics, and also bank covers beside streams. Newly proposed areas for non-forest woody vegetation with ecostabilising function on permanent grasslands (0.1 ha), on forest land parcels (0.05 ha) and on arable land (0.001 ha) were, from the point of view of land recording, transferred into the category of other surfaces. Due to its position, the village did not have any areas of development or zones determined for residential construction. Therefore, the demand for the development of residential construction was included in the proposal of GPFOT in compliance with the land plan of the village (Szalay et al., 2013). Land parcels registered as permanent grasslands (3.51 ha), arable lands (2.43 ha), other surfaces (0.11 ha) and forest land parcels (0.06 ha) in areas above the urban area of the village were delimited into the category of built-up area. Consequently, it was necessary to ensure the transfer of these projection units into the ownership of the village during the implementation of the LC project.

In the process of the GPFOT proposal creation, the requirements of the Land and Forest Department of the Prievidza District Office were accepted. The proposals of the association of participants of the LC were taken into consideration, and those of people farming on land parcels within the LC project (Agricultural cooperative of shareholders in Koš and the Kocurany Forest and Land Association). Regarding the new proposal, the majority of the landholders agreed that their new land parcels will be rented to the Agricultural cooperative of shareholders in Koš or to another user that has not been established yet. On 21 March 2012, the contract on the establishment of the Kocurany Forest and Land Association was concluded at the general assembly. In compliance with the Forest Management Programme and under the supervision of a professional forest manager, the association wanted to achieve rational management of common land. Based on this, large projection areas of forest land parcels were selected in the GPFOT proposal so that blocks in co-ownership could be projected. At the same time, the closest areas of adjoining cadastral units were taken into consideration. Thus, it will be possible to continue these proposals when projecting the LC of surrounding villages in the future.

In order to prevent or protect against water erosion, three groups of proposals of anti-erosional soil protection were created (anti-erosional organisation of the territory, anti-erosional protection using ecostabilising elements, anti-erosional soil cultivation). Anti-erosional organisation of the territory consisted of the proposal of optimal shape, volume and positional distribution of agricultural land parcels in the landscape. Anti-erosional arable land cultivation in the form of planting perennial fodder plants only was proposed in 5 localities (E, F, G, H, I). There were locations of arable land at A high risk of erosion located in the local parts of Lány (E, F, G) and Zadné diely (H, I) with the total area of land parcels of 9.61 ha. Anti-erosional protection by ecostabilising elements (EstE15, EstE16, EstE22, EstE23 - Krížne cesty, EstE20, EstE21 - Slivčina) was proposed in 6 localities. It was a proposal of new or extension of existing elements of non-forest woody vegetation on the land parcels with a total area of 2.14 ha. The role of ecostabilising elements is to provide a barrier to water erosion and, during periods of torrential rain, to ensure flood protection of the village urban area.

In order to increase ecological stability and biodiversity, the network of 6 existing TSES elements was established over an area of 99.97 ha (RBc1, LBcr3, LBc4, IE10, IE11, IE13). It was a proposal from a group of measures for the protection of the environment, the aim of which was to ensure connectivity of biotic elements at the local level: hydric and terestric regional biocorridor, local biocentre (forest cover), terestric local biocorridor and the interaction of these 3 elements. From water management measures, the management of hydric and terestric regional biocorridor Šútovský potok and its environs, ecotones Háje (RBc1) was proposed. It was a proposal of maintaining the current state and elimination of interventions to bank covers, as well as a restriction to the crossing Šútovský stream by vehicles.

Land parcels for public facilities were proposed, having a total area of 0.49 ha on two localities (an old cemetery in the southern part of the discussed area and a garden next to a kindergarten). It was necessary to convert the ownership of these parcels so that they became the property of the village.

Only 20 localities (total area 119.37 ha) were reflected in the GPFOT proposal compared to 31 localities (total area 154.34 ha) in the TSES structure and anti-erosion measures proposal. Due to the specific requirements of the village, a new ecostabilising element with an anti-erosional function was created in GPFOT (EstE23 element). It was an ecological measure created with an area of 0.22 ha, which was situated on permanent grasslands with the local name Krížne cesty (between the elements IE13 and EstE16).

The following ecological measures were incorporated into GPFOT from the LTSES:

- 6 TSES elements (elements RBc1 Šútovský potok, LBcr3 Háje, LBc4 Homôlky, IE10 Zadné diely, IE11 Lány, IE13 Krížne cesty),
- 5 ecostabilising elements (elements EstE15, EstE16, EstE22 - Krížne cesty, EstE20, EstE21 - Slivčina),
- 5 localities of arable land with the need of anti-erosional soil cultivation (localities E, F, G - Lány and H, I - Zadné diely),
- 4 localities of arable land with the need of delimitation to permanent grasslands (localities A, B, D - Lány and C - Zadné diely).

Of those ecological measures, the following were incorporated into GPFOT but with an adjustment to their areal extent:

- 4 ecological measures (IE10 Zadné diely, IE11 Lány, EstE20 Slivčina, EstE22 Krížne cesty) were incorporated with a 1.47 ha larger areal extent than determined in the LTSES, having a total area of 4.01 ha,
- 7 ecological measures (IE13, EstE15, EstE16 - Krížne cesty, EstE21 Slivčina, locality G - Lány, localities H, I - Zadné diely) were incorporated with 7.57 ha lesser areal extent than determined in the LTSES, having a total area of 6.77 ha.

The absence of 11 other localities can be considered as the biggest deficiency of the GPFOT. These localities were proposed in the LTSES for the implementation of ecological measures (total area 29.09 ha), but were not incorporated from the LTSES into GPFOT:

- 8 TSES elements (elements LBcr2 Nádavky, LBc5 Jeleškový potok, IE6, IE7, IE8, IE9, IE12, IE14 - Zadné diely),
- 3 ecostabilising elements (elements EstE17 Zadné diely, EstE18, EstE19 - Lány).

An overview of the ecological measures, specified in the LTSES and consequently incorporated or not into GPFOT, is shown in Table 1 and Table 2.

Discussion

In the LC project in the village of Kocurany, the process of creation of LC project documents was, to a large extent, influenced by specific social demands. They were discussed during the whole process of the LC. The proposals were considered and reviewed with the concerned parties. In the process of determining the rate of acceptance of ecological measures, it was found that only 6 elements (out of 14) of the LTSES structure were incorporated into the

T a b l e 1. Localities of ecological measures incorporated from the LTSES to GPFOT.

		LTSES for LC purposes		GPFOT		**Changes in area from LTSES to GPFOT**
		Proposal of the TSES structure and anti-erosion measures		Proposal of GPFOT		
Ecological measures	Abbreviation	Name	Area [ha]	Name	Area [ha]	**Area [ha]**
Measures for environmental protection	Bcr	LBcr3 Háje	49.54	LBcr3 Háje	49.54	**0.00**
	Bc	RBc1 Šútovský stream and environs, ecotones Háje	25.81	RBc1 Šútovský potok and environs, ecotones Háje	25.81	**0.00**
		LBc4 Homôlky	19.30	LBc4 Homôlky	19.30	**0.00**
	IE	IE10 Zadné diely	1.54	IE10 Zadné diely	1.77	**+ 0.23**
		IE11 Lány	0.73	IE11 Lány	1.37	**+ 0.64**
		IE13 Krížne cesty	1.09	IE13 Krížne cesty	1.08	**- 0.01**
Anti-erosion measures	EstE with anti-erosion function	EstE15 Krížne cesty	0.68	EstE15 Krížne cesty	0.51	**- 0.17**
		EstE16 Krížne cesty	0.58	EstE16 Krížne cesty	0.44	**- 0.14**
		EstE20 Slivčina	0.23	EstE20 Slivčina	0.63	**+ 0.40**
		EstE21 Slivčina	0.57	EstE21 Slivčina	0.10	**- 0.47**
		EstE22 Krížne cesty	0.04	EstE22 Krížne cesty	0.24	**+ 0.20**
	Anti-erosion and anti-drainage measures on arable land	Locality A: anti-erosion arable land cultivation or delimitation to permanent grasslands	1.90	Locality A: arable land delimited to permanent grasslands	1.90	**0.00**
		Locality B: anti-erosion arable land cultivation or delimitation to permanent grasslands	2.27	Locality B: arable land delimited to permanent grasslands	2.27	**0.00**
		Locality C: anti-erosion arable land cultivation or delimitation to permanent grasslands	3.70	Locality C: arable land delimited to permanent grasslands	3.70	**0.00**
		Locality D: anti-erosion arable land cultivation or delimitation to permanent grasslands	0.88	Locality D: arable land delimited to permanent grasslands	0.88	**0.00**
		Locality E: anti-erosion arable land cultivation or delimitation to permanent grasslands	1.27	Locality E: arable land with anti-erosion cultivation	1.27	**0.00**
		Locality F: anti-erosion arable land cultivation or delimitation to permanent grasslands	3.70	Locality F: arable land with anti-erosion cultivation	3.70	**0.00**
		Locality G: anti-erosion arable land cultivation or delimitation to permanent grasslands	3.00	Locality G: arable land with anti-erosion cultivation	2.46	**- 0.54**
		Locality H: anti-erosion arable land cultivation or delimitation to permanent grasslands	5.96	Locality H: arable land with anti-erosion cultivation	0.22	**- 5.74**
		Locality I: anti-erosion arable land cultivation or delimitation to permanent grasslands	2.46	Locality I: arable land with anti-erosion cultivation	1.96	**- 0.5**

Notes: LTSES – Local Territorial System of Ecological Stability; GPFOT – General Principles of Functional Organisation of the Territory; LC – land consolidation; Bcr – biocentre; LBcr – local biocentre; Bc – biocorridor; RBc – regional biocorridor; LBc – local biocorridor; IE – interacting element; EstE – ecostabilising element.

GPFOT (i.e., 43% integration rate) and 15 anti-erosion measures out of 17 were incorporated into the GPFOT (i.e. 88% integration rate). This incomplete projection was most likely the result of the demands of users or landholders of the land parcels concerned.

T a b l e 2. Localities of ecological measures not incorporated from the LTSES to GPFOT.

		LTSES for LC purposes		GPFOT		**Changes in area from LTSES to GPFOT**
		Proposal of the TSES structure and anti-erosion measures		Proposal of GPFOT		
Ecological measures	Abbreviation	Name	Area [ha]	Name	Area [ha]	**Area [ha]**
Measures for environmental protection	Bcr	LBcr2 Nádavky	8.80	-	0.00	**- 8.80**
	Bc	LBc5 Jeleškový stream	1.10	-	0.00	**- 1.10**
	IE	IE6 Slivčina	2.37	-	0.00	**- 2.37**
		IE7 Slivčina	5.83	-	0.00	**- 5.83**
		IE8 Zadné diely	4.06	-	0.00	**- 4.06**
		IE9 Zadné diely	2.80	-	0.00	**- 2.80**
		IE12 Zadné diely	0.27	-	0.00	**- 0.27**
		IE14 Zadné diely	0.44	-	0.00	**- 0.44**
	EstE	EstE17 Zadné diely	1.41	-	0.00	**- 1.41**
		EstE18 Lány	0.72	-	0.00	**- 0.72**
		EstE19 Lány	1.29	-	0.00	**- 1.29**
		-	-	EstE23	0.22	**+ 0.22**

Notes: LTSES – the Local Territorial System of Ecological Stability; GPFOT– General Principles of Functional Organisation of the Territory; LC – land consolidation; Bcr – biocentre; LBcr – local biocentre; Bc – biocorridor; LBc – local biocorridor; IE – interacting element; EstE – ecostabilising element.

T a b l e 3. Rate of integration of ecological measures from the LTSES into GPFOT in selected municipalities of the region of Prievidza.

District of the LC project of a municipality		**Nováky**		**Pravenec**		**Horná Ves**	
Documents of the LC project		LTSES	GPFOT	LTSES	GPFOT	LTSES	GPFOT
ARTSES	Bcr	0	0	0	0	0	0
	Bc	0	0	0	0	1	1
RTSES	Bcr	2	2	1	0	3	3
	Bc	3	3	2	1	4	4
LTSES	Bcr	17	17	3	3	11	11
	Bc	10	8	4	4	11	11
	IE	15	12	25	10	65	65
Ecological measures - total		47	42	35	18	95	95
Integration [%]		-	**89**	-	**51**	-	**100**

Notes: ARTSES – Above-Regional Territorial System of Ecological Stability; RTSES – Regional Territorial System of Ecological Stability; LTSES – Local Territorial System of Ecological Stability; GPFOT– General Principles of Functional Organisation of the Territory; LC – land consolidations; Bcr – biocentre; Bc – biocorridor; IE – interacting element.

Similar issues of the implementation of ecological measures in the LC projecting were also encountered in other cadastral units of the region of Prievidza (Belaňová, 2014). 3 cadastral territories were compared and in 2 of them, an incomplete rate of integration was identified (Table 3). With the focus on the creation of the TSES structure, several imperfections of spatial and planning practice were identified in the practical verification and application of the LTSES in LC planning in model territories. Project architects of land consolidations had quality materials from the processed project documentations of the LTSES for the LC purposes, which were integrated to different extent into each LC project.

More positive conclusions were drawn from a study of the rate of ecological measure integration into the LC in selected municipalities within the regions of Žilina and Zlaté Moravce, in the northern and south-western parts of the Slovak Republic (Belaňová, Diviaková, 2015). From the 8 municipalities compared, an incomplete rate of integration of ecological measures was identified in only 2 of them. In one municipality, even more localities were selected for the implementation of ecological measures than were proposed in the LTSES.

Currently, the LC plans have been completed for only 421 cadastral units out of 3538 cadastral units in Slovakia, that is, only 12% (http://www.kpu.sk/komplexne-pu/prehladna-mapa-pozemkovych-uprav-v-sr). The existing pace of the LC implementation does not provide even a theoretical possibility of a complete organisation of landholding in Slovakia within two or three decades.

This 'complex' LC has been financed by the Rural Development Programme, which represents the assistance from EU funds and aims to solve many of the problems concerning the countryside in a single project. This complexity leads to time and financial difficulties with these local projects. Another reason for the small number of the completed LC projects in Slovakia is that the current situation is convenient for landholders, who buy these land parcels cheaply or rent them using teams of lawyers and dealers (https://miroslavziak1.blog.sme.sk/c/465635/pozemkove-upravy-vlastnikom-pody-pomozu-ale.html). The solution may be to better define the time and financial schedule of the LC, with reasonably set technical parameters, as well as ensuring LC financing from several sources. This is considered as a key step necessary for the larger implementation of the LC into practice (http://www.kpu.sk/aktuality/komplexne-komasacne-jednoduche-pozemkove-upravy).

These solutions would also result in a more reliable rate of integration of quality proposals of ecological measures into the LC projects. It can then be stated that TSES projects (a base of ecological measures), as a compulsory material for the LC, are very reliable documents for the implementation of ecological measures into the landscape. This is proved by several practical outputs of the LTSES projects for the LC, which have been published from different points of view. Ružičková et al. (2010) dealt with the problem of fragmentation of natural biotopes and the importance of renewal of ecological networks, especially via the local TSES proposed in the LC. They compared two distant municipalities (Tuchyňa - western Slovakia, Štôla - eastern Slovakia).

In the 3 villages of western Slovakia (Hájské, Veľké Vozokany, Kanianka), which were of different geomorphological types of relief, the development of landscape structure was studied chronologically. In the latter of the three studied time periods, they observed positive changes in the landscape due to the implementation of the TSES proposals into the LC projects. New landscape elements were created using the LC and it lead to a diversity increase within landscape, which positively affected the ecological stability of the landscape and ensured prevention of destructive processes in the landscape (Muchová, Petrovič, 2010).

Within the intensively used landscape in the cadastral unit of Klasov, Moyzeová and Kenderessy (2015) focused on the creation of an ecological network through revitalisation of existing fragments of natural biotopes and creation of new ones, as well as system of ecostabilising measures and their management. They presented a functional framework of the TSES in the territory, whose implementation through the LC will contribute to an increase of territorial diversity and improvement of spatial ecological stability. The TSES project for the purposed LC is presented as a tool, which contributes to adaptation to climate changes, to support economic, territorial and social cohesion and to strengthen protection of natural and cultural heritage.

Muchová et al. (2016) pointed to problems within the Žitava river basin, which restrict rural development (low ecological stability of landscape, frequent flooding, increase of soil erosion, etc.). They highlighted the main problems of water resource management and environmental protection. They graphically presented basic topics that are important for the assessment and proposal of ecostabilising measures, which could protect the area from natural disasters.

Conclusion

There is a constant development in the landscape, which is more and more influenced by human activity. Landscape components are mutually affected and it continuously gains new structure and properties. Efforts to improve structure, as well as use of agricultural land parcels are very urgent in many cases. A decrease was observed in the ecological stability of the landscape, an increase of water and wind erosion and degradation of soil cover, due to the use of excessive amount of chemicals. The increase of concentration of production leads to other harmful impacts on the environment, for example, eutrophication of water courses, increase of nitrates in underground water and so on. It is obvious in these cases that from the point of view of infrastructure, the territory is not economically organised and used, or it is necessary to implement anti-erosion or other ecological measures within it, which require interventions to the landscape and change of proprietary rights and relations of use. It is not possible to successfully apply proposals and measures following from planning processes without the arrangement of ownership and implementation of several acts at the level of land registry. For the realisation of individual proposals and measures in specific areas, the land parcels must have owners. The most suitable method is to have a new organisation of land parcels and ensure that there are no problem accessing them. The solution to these problems is land consolidation, which – in compliance with the law on LC – enables the rational spatial organisation of the land parcels via the LC project. The LC project is implemented in accordance with the requirements and conditions of environmental protection, sustainable development principles and creation of the TSES structure.

The TSES concept in Slovakia can be considered as the most important intersection of landscape and ecological principles into real ecological policy and into spatial and planning practice. The main contribution of the TSES for the LC project is its implementation stage when the TSES at the local level becomes a real tool for protection and design of the landscape, or revitalisation and ecologisation of agricultural landscape. Based on this, the TSES implementation has multifunctional and society-wide importance.

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TRADITIONAL VILLAGE SYSTEM – CASE STUDY FROM THE KREMPNA COMMUNE (POLAND)

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Abstract

Kozak I., Balaniuk I., Szelenko D., Balaniuk S., Kozak H. Traditional village system – case study from the Krempna commune (Poland). Ekológia (Bratislava), Vol. 38, No. 1, p. 87–100, 2019.

The study was conducted within the actual area of Krempna commune in Jaslo county Podkarpackie voivodeship in Poland. Historical data and maps were analysed using the ArcGIS 10.3 program. The changes in the number of villages, householders and human population were presented. Religious composition for the year 1785 and ethnic composition for the year 1939 were evaluated. Only in the case of Ukrainian population, the Moran's test has shown dispersed distribution (Index Moran's for Ukrainians = −0.478664; Z = −1.684100; P = 0.092162). The total number of householders increased from 915 in the year 1785 to 1,409 householders in the year 1939 and decreased to 349 in the year 1965 and 333 in the year 2018. The traditional village system (TVS) of Krempna commune was depopulated after World War II. As a result, the agricultural abandonment and forest succession developed. Class area (CA) of settlements decreased from 1174.02 ha in the year 1939 to 248.13 ha in the year 1965 and 240.2 ha in the year 2018, and CA of forests increased from 7,268.20 ha in the year 1939 to 15,465.20 ha in the year 1965 and 15,841.3 ha in the year 2018. Villages that had begun the core of TVS together with tserkvas and chapels in the centre of village, roadside crosses and traditional private farms were lost. The scale and results of such changes are interesting for future research, mainly in terms of change in TVS infrastructure and culture.

Key words: land use, cultural landscape, dynamics, GIS.

Introduction

An important part of the world's landscapes were managed by local and indigenous communities (Stevens, 1997). Such cultural landscapes were based on a traditional village system (TVS) with centre-periphery zoning from houses, gardens, fields, mowed grasslands and grazed grasslands to forests. It is analogous to the ancient system with domus, hortus, ager, saltus and silva (UNESCO, 1999; Elbakidze, Angelstam, 2007). TVS carried traditional knowledge, innovations and practices of indigenous and local communities. Such systems were gained over long time and were adapted to the local culture and environment. They help to sustain production of various goods and services providing livelihoods safety and value of life. The TVS supplies to feature natural and ethnic cultural heritage and traditions (Angelstam et al., 2003; Agnoletti, 2006; Parrotta et al., 2006).

On the other hand, the TVS integrated economic, ecological and socio-cultural extent of landscapes in space and time (Bourguignon, 2006). Cultural heritage and traditional knowledge of TVSs have been accepted and promoted at an international level in a number of worldwide agreements (World Conference, 1982; European Landscape Convention, 2000; MCPFE, 2003). Nevertheless, the TVS with its feature cultural landscape were threatened by political, socio-economic and technological changes (Antrop, 2005; Angelstam, 2006).

The Krempna commune study region had landscape resources of high economic value and retained both cultural and natural biodiversities (Angelstam, 2006). This region was also home to ethnographic group of Ukrainians – Lemkos – who have been determining mountain landscapes for centuries and have created a rich economic (Denysjuk, 1938) and cultural heritage with 13 tserkvas.

The role of TVS in terms of Ukrainian Carpathians is evaluated in the context of sustainable forest management (Elbakidze, Angelstam, 2007). The analysis of the social and cultural aspects of TVS is a current issue and requires the development of new approaches.

Cultural landscapes in Krempna commune, of course, were related to the TVS, which is characterised by a specific zoning from the centre (building with the tserkvas) through farmland, hayfields, pastures and forests (Elbakidze, Angelstam, 2007) to the periphery. The understanding of the definition of the TVS lies in the fact that such a system united local communities, which for centuries created a rich Ukrainian cultural heritage (cultural and educational societies such as 'Ridna szkola', 'Prosvita', 'Sokil', tserkvas, schools, libraries, co-operatives and craft workshops), and adapted to mountainous conditions and the environment. The consequences of the loss of such a system require a more detailed study.

The results of depopulation of Krempna community were agricultural abandonment (MacDonald, 2000; Van Vliet, 2015) and loss of landscape attractiveness and landscape heterogeneity as well as its cultural heritage (Pazur et al., 2014).

Agricultural abandonment is widespread in the world (Cramer et al., 2008), including post-socialist countries of central and Eastern Europe (Kuemmerle et al., 2008; Lieskovsky et al., 2015). In post-socialist countries, agricultural abandonment dominates mainly after the year 1989. Some time earlier, this process occurred in Slovakia (in the years 1950–1970) and brought changes in agricultural land use structure (Masný et al., 2017). The agricultural abandonment led to a decrease in agricultural production and often also to rural migration (Muller et al., 2009).

But, in Krempna commune, we can observe the process of agricultural abandonment earlier. It happened after the deportation of Ukrainians – Lemkos – in the years 1944–1946 (Gil, 2004) and after the loss of TVS. Agricultural abandonment and expansion of forest were the result of TVS loss. Expansion of forest and shrub at the grasslands was the result of traditional agricultural practice reduction (Riecken et al., 2002).

The aim of the study was to analyse the loss of the TVS in Krempna commune and to show the changes in villages and forest areas and also changes in ethnic, religious, cultural and economic components.

Materials and methods

The changes in land cover, dynamics of settlements, human population, religion and cultural aspects as the elements of TVS in the landscape within current borders of Krempna commune, in Jaslo county, Podkarpackie voivodeship in Poland, were objects of this study.

The number of householders and inhabitants based on the religious and ethnic composition was added for each of settlements in Krempna commune. Data from the years 1785 (Budzyński, 1993) and 1939 (Kubijovyč, 1983); maps from the years 1785, 1855 and 1939; and maps of 'WMS-Web Map Service, Geoportal' from the years 1965 and 2018 have been used. Changes in the number of villages and population dynamics for Greek Catholics, Latins and Jews for the year 1785 and Ukrainian ones in comparison with the number of Poles and Jews for the year 1939 were evaluated by applying ArcGIS 10.3 program. The corresponding layers in the ArcGIS 10.3 program (Urbański, 2010) have been completed. Ethnic and religious composition from the second half of the 18th century to the second half of the 20th century and the character of settlements distribution in Krempna commune have been evaluated based on the study of spatial distribution of settlements with the use of spatial statistics (spatial autocorrelation global Moran's test, standard deviational ellipse and mean center) executed in ArcMap program (Urbański, 2010), Scott, Janikas, 2010).

This study focuses on the role of the TVS to support sustainable landscape management. The TVS is defined by the land uses of pre-industrial cultural landscapes and a spatial structure with zones of land satisfying different cultural, social and economic needs (Elbakidze, Angelstam, 2007). The character of householders distribution in Krempna commune in the years 1785, 1855, 1939, 1965 and 2018 has been evaluated.

The changes in land cover based on maps and using the following indices (metrics) have been estimated and calculated on class level. Principles of landscape metrics (Forman, Godron, 1981) were applied in studies of different regions (Klaučo et al., 2013; Baran-Zgłobicka, Zgłobicki, 2012). For this study, three indexes (area metrics) have been chosen: class area (CA, in hectares); number of patches (NumP) and mean patch size (MPS, in hectares).

We respect present actual situation in Krempna commune using actual maps (2018) and conduct SWOT (strengths, weaknesses, opportunities, threats) analysis.

Analyses of published statistical data and recent original statistics were used to quantify the status and trends of economic and socio-cultural development of the Krempna commune. To evaluate the current TVS, we used spatial traditional village zoning structure (houses, gardens, fields, mowed grasslands, grazed grasslands and forests), traditional land use associated with cultural landscapes, types of natural resources used by local people and the goods and services produced by local land users.

Results

The analysis shows that the number of householders (Table 1) increased up to the year 1939 for Krempna commune. It can be concluded that the increase in the number of householders in the years 1785–1939 took place virtually for all localities, which could have been caused by the good economic development of TVS. The total number of householders increased from 915 in the year 1785 to 1,291 in the year 1855, and the highest value was obtained for the year 1939 with the result equal to 1,409. The total number of householders decreased to four times in the year 1965 (349 householders) that confirm the loss of TVS in Krempna commune. The number of householders decreased to zero in Tychania, Ostryshne, Rozstajne and Svirzhova Ruska villages. Only few householders remained in Hrab, Vyshevatka, Ozhynna, Kotań and Zhydivske villages where State Agricultural Farms and prisons were created in 1950s–1970s. Families from other regions were settled in abandoned Lemko houses, for example, in Mytsowa and Polana. But even after that, the total number of householders in Krempna commune decreased (Table 1) in the year 2018, which means that TVS has not renewed itself.

Calculations in the present work, conducted based on the data published by Budzyński (1993), are the evidence that in Krempna commune in the year 1785, Greek Catholic (Ukrainians) population amounted to 95.69%, Latins to 2.60% and Jewish to 1.70% (Table 2).

However, it should be noted that Budzyński by the term Latins, except Poles, also meant Ukrainians, who spoke Ukrainian language, however, in order to participate in mass service went to the church (kościół). As a result, the term 'Latins' is incorrect. A correct manner is to identify two different terms: Roman Catholics (Poles) and Latins (Ukrainians), as it had been done before (Kubijovyč, 1983).

The previous is well illustrated on the example of villages such as Svirzhova Ruska and Polyany. In the year 1785, in the village of Svirzhova Ruska, there lived 266 Greek Catholics and 30 Latins according to Budzynski (1993). According to Kubiiovych, in the year 1939, there lived 475 Ukrainians and 5 Poles (Kubijovyč, 1983). In the village of Polyany, there lived 678 Greek Catholics, 115 Latins and 11 Jews in the year 1785 (Budzyński, 1993), whilst there lived 1,225 Ukrainians, 5 Jews and 60 Poles in the year 1939 (Kubijovyč, 1983). That decrease in the number of Poles in statistics for the year 1939 confirms the inaccuracy of data presented by Budzyński. Consequently, Ukrainian dominance is quite clear, meaning the dominance of Greek Catholics and Ukrainians (Table 2). It has been confirmed by the following data analysis in the year 1939 when 96.18% commune's population were Ukrainians, 3.31% were Poles and 0.51% were Jews (percentage of Germans was lesser than 0.01% and was not analysed).

T a b l e 1. Number of householders in villages of Krempna commune in the years 1785–2018.

No.	Village name in English, Ukrainian and Polish	Years				
		1785	1855	1939	1965	2018
1	Tychania, Тиханя, Ciechania	52	53	61	0	0
2	Hrab, Граб, Grab	76	102	111	22	11
3	Huta Polyanska, Гута Полянська, Huta Polańska	51	47	45	10	0
4	Kotan, Котань, Kotań	37	53	52	5	54
5	Krampna, Крампна, Kręрna	74	108	101	25	89
6	Mystsova, Мисцова, Myscowa	66	196	197	90	44
7	Ostryshne, Остришне, Ostryszne	50	48	49	0	0
8	Ozhynna, Ожинна, Ożenna	66	54	54	16	16
9	Polyany, Поляни, Polany	134	171	185	93	43
10	Rozstajne, Розстайне, Rozstajne	48	65	52	0	0
11	Svyatkova Mala, Святкова Мала, Świątkowa Mała	35	43	54	18	18
12	Svyatkova Velyka, Святкова Велика, Świątkowa Wielka	90	179	174	35	36
13	Vyshevatka, Вишеватка, Wyszowadka	40	44	38	5	22
14	Svirzhova Ruska, Свіржова Руська, Świerzowa Ruska	43	55	175	0	0
15	Zhydivske, Жидівське, Żydowskie	53	73	61	12	0
	Total	915	1,291	1,409	349	333

This situation demonstrates the dominance of Ukrainians before World War II. The placement ellipses analysis (Fig. 1) showed that in the year 1785, ellipse for Greek Catholics (black) is broader and covers a large area. This indicates a natural and more equilibrist distribution of Greek Catholics within Krempna commune. The ellipse for Latins has not been possible to create because Latins were living only in two villages (115 people in Polyany and 30 people in Svirzhova Ruska villages).

The mean center for Greek Catholics (black square) shows a more central distribution comparing to the mean center for Latins (grey triangle), which was located within 5.2 km to the North–East in comparison to the mean center of Greek Catholics. The ellipse for Jews (grey line) and mean center (grey hexagon) shows a similar central distribution comparing to the ellipse and the mean center representing Greek Catholics. It means common and the similar distribution of Greek Catholics and Jews.

In all settlements of Krempna commune (numbers on the figures correspond to the settlement number and settlement name in the table), Greek Catholics dominated in the year 1785. After the year 1785, the number of Greek Catholics increased (Blażejowskyj, 1995). In the year 1939 (Fig. 2), distribution ellipse for Ukrainians (black) did not change in compari-

T a b l e 2. Religious and national distributions of settlements in Krempna commune.

No.	Name in English, Ukrainian and Polish		1785			1939	
		Greek Catholics	**Latins**	**Jews**	**Ukrainians**	**Poles**	**Jews**
1	Tychania, Тиханя, Ciechania	305	0	7	425	5	0
2	Hrab, Граб, Grab	450	0	9	680	0	0
3	Huta Polyanska, Гута Полянська, Huta Polańska	-	-	-	-	-	-
4	Kotan, Котань, Kotań	213	0	10	345	5	0
5	Krampna, Крампна, Kręрna	440	0	6	620	125	5
6	Mystsova, Мисцова, Myscowa	1,023	0	10	1,310	10	0
7	Ostryshne, Остришне, Ostryszne	-	-	-	-	-	-
8	Ozhynna, Ожинна, Ożenna	395	0	3	360	0	0
9	Polyany, Поляни, Polany	678	115	11	1,225	60	5
10	Rozstajne, Розстайне, Rozstajne	280	0	8	320	0	10
11	Svyatkova Mala, Святкова Мала, Świątkowa Mała	205	0	4	320	0	0
12	Svyatkova Velyka, Святкова Велика, Świątkowa Wielka	528	0	14	820	5	5
13	Vyshevatka, Вишеватка, Wyszowadka	240	0	0	245	0	5
14	Svirzhova Ruska, Свіржова Руська, Świerzowa Ruska	266	30	6	475	5	0
15	Zhydivske, Жидівське, Żydowskie	310	0	7	405	5	10
	Total	5,333	145	95	7,550	220	40

Note: - represents lack of data.

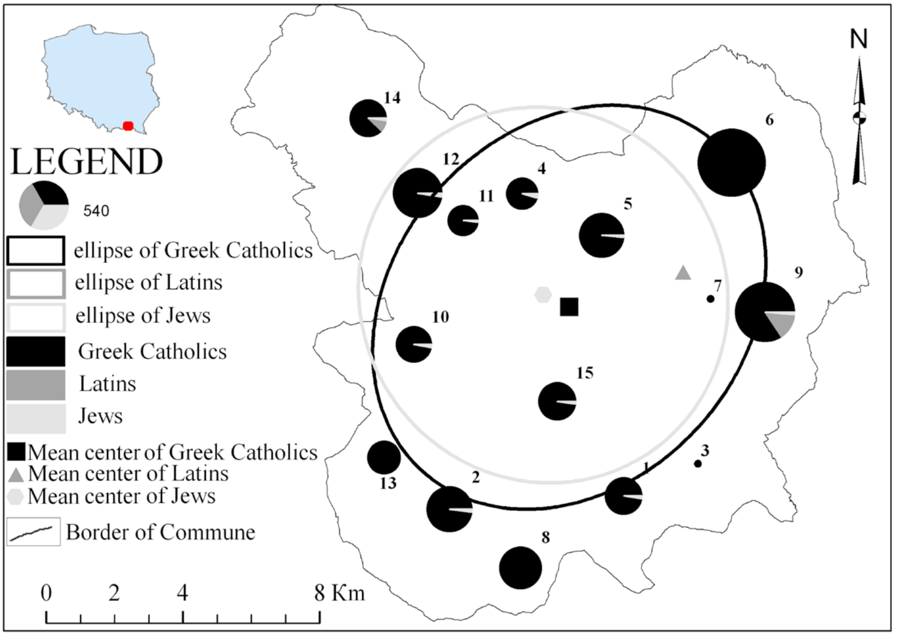

Fig. 1. Religious structure of settlements in Krempna commune in the year 1785.

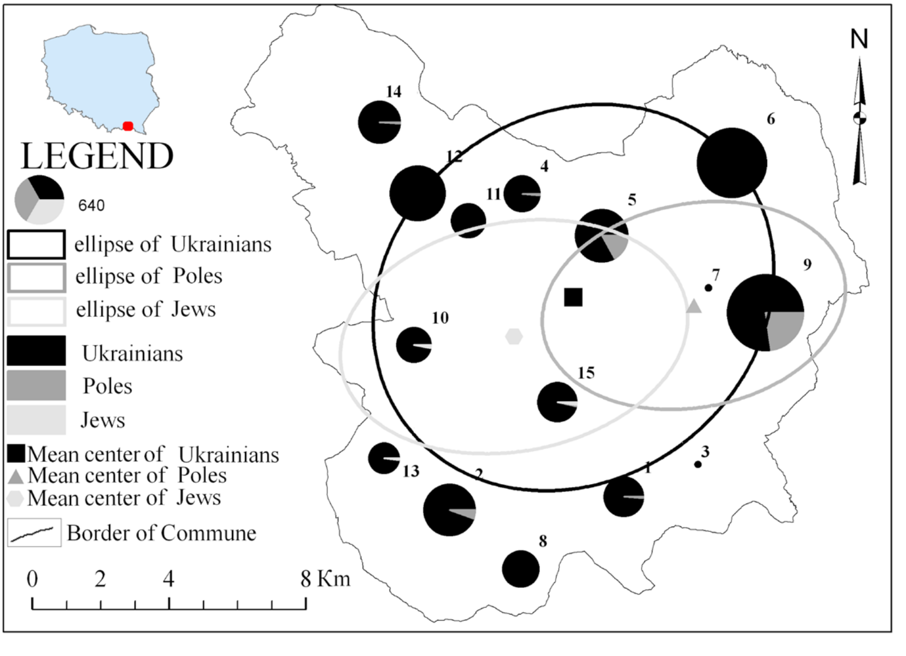

Fig. 2. National structure of settlements in Krempna commune in the year 1939.

son with the ellipse for Greek Catholics in the year 1785. This tendency confirms the stability and durability of their settlement on the territory of Krempna commune.

In the year 1939, ellipse for Poles (dark grey) is smaller, elongated oval (Fig. 2) and distributed more to the North–East, comparing to the ellipse for Ukrainians (black). Ellipse representing Jews (light grey) moved to the West. Mean center (grey hexagon) representing Jews moved to the West and mean center representing Poles (grey triangle) moved to the East.

The analysis of Moran's test results leads to the conclusion that there was a random distribution of ethnic composition in the year 1939 for Poles and Jews. Only in case of Ukrainian population, the Moran's test has shown dispersed distribution (Index Moran's for Ukrainians = −0.478664; Z = −1.684100; P = 0.092162) and confirmed that the probability of their distribution being a result of randomness is less than 10%.

At the end of the 18th century, from the data of Josephine Metrics (1785) in the villages, the share of peasant arable land, meadows and pastures was quite high. For example, in the largest village of Polana, arable land occupied 833 ha (33.8%) and meadows and pastures 1,612 ha (64.6%). In smaller towns, as in Svyatkova Velyka, arable land occupied 573 ha (34.5%) and meadows and pastures 801 ha (48.3%), and in even smallest villages, as in Kotań, arable land occupied 241 ha (38.9%) and meadows and pastures 302 ha (48.9%). The share of forests varied from 21 ha (1.6%) in Polana to 12.2% in Kotań and 17.2% in Svyatkova Velyka. The high share of arable land, meadows and pastures provided opportunities for the development of TVS until the year 1939.

The current traditional land use is not associated with cultural landscapes, and spatial traditional village zoning structure (houses, gardens, fields, mowed grasslands, grazed grasslands and forests) are destroyed. Types of natural resources are not used by local people, and the goods and services are not produced by local land users.

All settlements within Krempna commune area were destroyed after depopulation. Complete (100%) destruction of householders occurred in villages such as Tychania, Ostryshne, Rozstajne, Ożenna, Zhydivske and Svirzhova Ruska. In many other settlements, the level of destruction reached more than 80%. It should be noted that the level of destruction that occurred in 1950s was the highest and contributed to the loss of TVS. The comparison of the data from the years 1939 and 1965 showed a sharp decrease in the number of householders from 1409 in the year 1939 to 349 units in the year 1965.

Before World War II, the area of Krempna commune was densely populated. In the year 1785, the density level reached 27.38 persons for 1 km^2. In the year 1939, it reached 38.56 persons for 1 km^2. According to the Central Statistical Office of Poland, in the year 2011, there were 2,004 persons (1,059 men and 945 women) on the area of 203.58 km^2 and the density level decreased to 9.84 persons for 1 km^2 (Statistics Poland, 2011). For the year 2018, the number of inhabitants in the commune decreased to 1,950. At present, the decreasing trend of the population in the commune persists.

In the year 1875, in Krempna commune, there lived 5,573 people. The majority of them, therefore, 5,333 of 5,573, were Ukrainian Greek Catholics. In the year 1939, there lived 7,850 people in the commune, including 7,550 of Ukrainian nationality. In the year 1965, the population of commune amounted to 1,250 people but with no Ukrainians amongst them. By analysing this situation, it is clear that without Ukrainians, Krempna commune has lost the TVS, which was rich in cultural, social and economic traditions.

Before World War II, the character of traditional land use practices (two field rotating system, a combination of tillage and livestock products in one sector, crops rotation, mechanical devices for cultivation and weed control, protection of soil from erosion using special methods of ploughing) was completely dependent on the availability of local natural sources and kept in a sustainable and balanced relationship with the environment and minimal use of resources and energy of the region (Utrysko, 1984). Rural settlement livelihoods reflect spatial–temporal form of organisation of life. These settlements were inherent with traditional way of building for villages, features of wooden architecture, location and structure of agricultural land. Rural life was the basis of Ukrainian ethnographic identity.

After World War II, the Krempna commune was depopulated. The area of buildings, arable land, pastures and grasslands decreased. The structure of the land and forests has changed dramatically. The private forests and lands were transferred to the state property. Economic activities carried after 1950s were not always consistent with the management of traditional systems. These changes reduced the variety of structural elements such as hedges, gardens and individual trees in various areas of TVS. People who moved into the commune from low-lying areas till these days do not feel the spirit of that place (genius loci) and spirit of this mountainous area. The local use of natural resources should be considered as a weakness. There are no satisfying practices of traditional land use. As it was shown by SWOT analysis for Krempna commune, at present, there may be identified unfavourable conditions for its development, such as little access to historical documentation; no tradition and, therefore, connection with its origins; no indigenous population; lack of access to religious sites (other than Roman Catholic); inconvenient architectural forms as to the landscape conditions; and lack of work. In the destroyed villages, remaining tserkvas, crosses, Lemko houses and cemeteries are attractive for tourists at the present time.

Names of villages, which originally came from Ukrainian etymology, were changed into Polish: Kręmpna appeared instead of the name Krampna (from the name of ukr. «крам» – goods), Ożenna instead of Ozhynna (from the name of ukr. «ожина» – blackberry), Ciechania instead of Tychania, Wyshowadka instead of Vyshevatka and Grab instead of Hrab. At the present time, on the territory of Krempna commune, there does not exist any link between generations. Villages that had been the core of Ukrainian TVS, together with tserkvas and chapels in the centre of village, roadside crosses and traditional householders, were lost. The Lemko Ukrainian tserkva that dominated on the area of the commune are considered as sacred and unique monuments of national wooden architecture, preserved in the centre of old Ruthenian traditions and became an element of Ukrainian and European cultural and religious foundation. Ukrainians have always preserved their cultural values (in every tserkva, except religious icons, there were also icons of Prince Volodymyr and Princess Olga to whom Ukrainians prayed and with whom they linked their confidence and hope). Tserkva, because of its form and building material, perfectly inscribed into the landscape and complemented it.

In Krempna commune, there were 13 tserkvas located in the following villages: Krempna, tserkva of Kosma and Damyan from the year 1782; Svirzhova Ruska, tserkva of Ivan Chrestytel from the year 1894; Hrab, tserkva of Kosma and Damyan from the year 1809; Svyatkova Velyka, tserkva of Archanhel Myhayil from the year 1757; Svyatkova Mala, tserkva of Archanhel Mychail from the year 1700; Mystsova, tserkva of St. Paraskeva from the year 1796;

Polyany, tserkva of St. Ivan Zolotoustyj from the year 1900; Kotan, tserkva of Kosma and Damyan from the year 1800; Ozhynna, tserkva of Vasylij Velykyj from the year 1867; Rozstajne, tserkva of Kosma and Damyan from the year 1600; Tychanya, tserkva of St. Mykolaj from the year 1790; Vyshevatka, tserkva of (unknown name) from the year 1700; Zhydivske, tserkva of Voznesinnya Chrysta from the year 1828.

After World War II, there remained only 6 of the 13 tserkvas in Krempna commune in Svyatkova Velyka, Svyatkova Mala, Mystsova, Polyany, Kotan and Krempna that currently were taken over by the Roman Catholic Church (Luboński, 2015). Four tserkvas in villages of Hrab, Rozstajne, Tychanya and Zhydivske were destroyed in the years 1945–1947. Three tserkvas in villages of Svirzhova Ruska, Vyshevatka and Ozhynna were demolished in the post-war period – during 1950s. The area of settlements was sharply reduced (Fig. 3c and e) compared to the year 1855 (Fig. 3a; numbers on the figure correspond to settlement number and settlement name in the Tables 1 and 2). In the year 1965 and actual in the year 2018, the forests appeared on the site of the lost TVS with buildings, tserkvas, fields, meadows and pastures (Fig. 3d and f).

Metric analysis confirmed the destruction of settlement elements in Krempna commune. The CA of building area was 617.97 ha in the year 1785, 1,131.61 ha in the year 1855 and 1,174.02 ha in the year 1939. CA building area decreased to 248.13 ha in the year 1965 and to 241.23 ha in the year 2018. The MPS index (represents average patch size for settlements) was 47.54 for the year 1785, 80.83 for the year 1855 and 71.60 for the year 1939. The MPS index decreased to 19.09 in the year 1965 and 18.17 in the year 2018, and this value points to the fragmentation of landscape mosaic.

On the other hand, CA for forest increased from 5,827.48 ha in the year 1855 to 7,268.62 in the year 1939, 15,465.20 in the year 1965 and 15,930.49 in the year 2018, and the MPS index increased too. In Krempna commune, an increasing trend of especially forest category was observed.

Discussion

On the present state of Krempna commune, landscape in the south-eastern Poland influences not only the geological processes (Kondracki, 2002) and climate by shaping the terrain and vegetation (Ziemońska, 1973) but also historical events that resulted in a reduction of population and their settlement area and the TVS lost. This, however, provoked the agricultural abandonment and intensified spontaneous forest succession processes in the landscape.

The analysis of settlements and population in Krempna commune presents domination of Greek-catholic and Ukrainians before World War II (WWII), which was also confirmed in the literature (Holly, 2014). The agricultural abandonment and intensive forest succession (Wolski, 2007; Klich et al., 2013), the process of depopulation of Ukrainians (Ardan, 2011) and the destruction of tserkvas in Lemkos and Bojkos region (Stępień et al., 2011) were also confirmed by studies from other parts of Carpathians. The analysis of the literature on TVS shows how such systems contribute to characteristic natural and cultural heritage (Agnoletti, 2006).

The loss of cultural heritage of TVS presented in Krempna commune has been recognised and promoted at a global level in a number of international agreements and programmes (World Conference, 1982; UNESCO, 1999; European Landscape Convention 2000; Antrop,

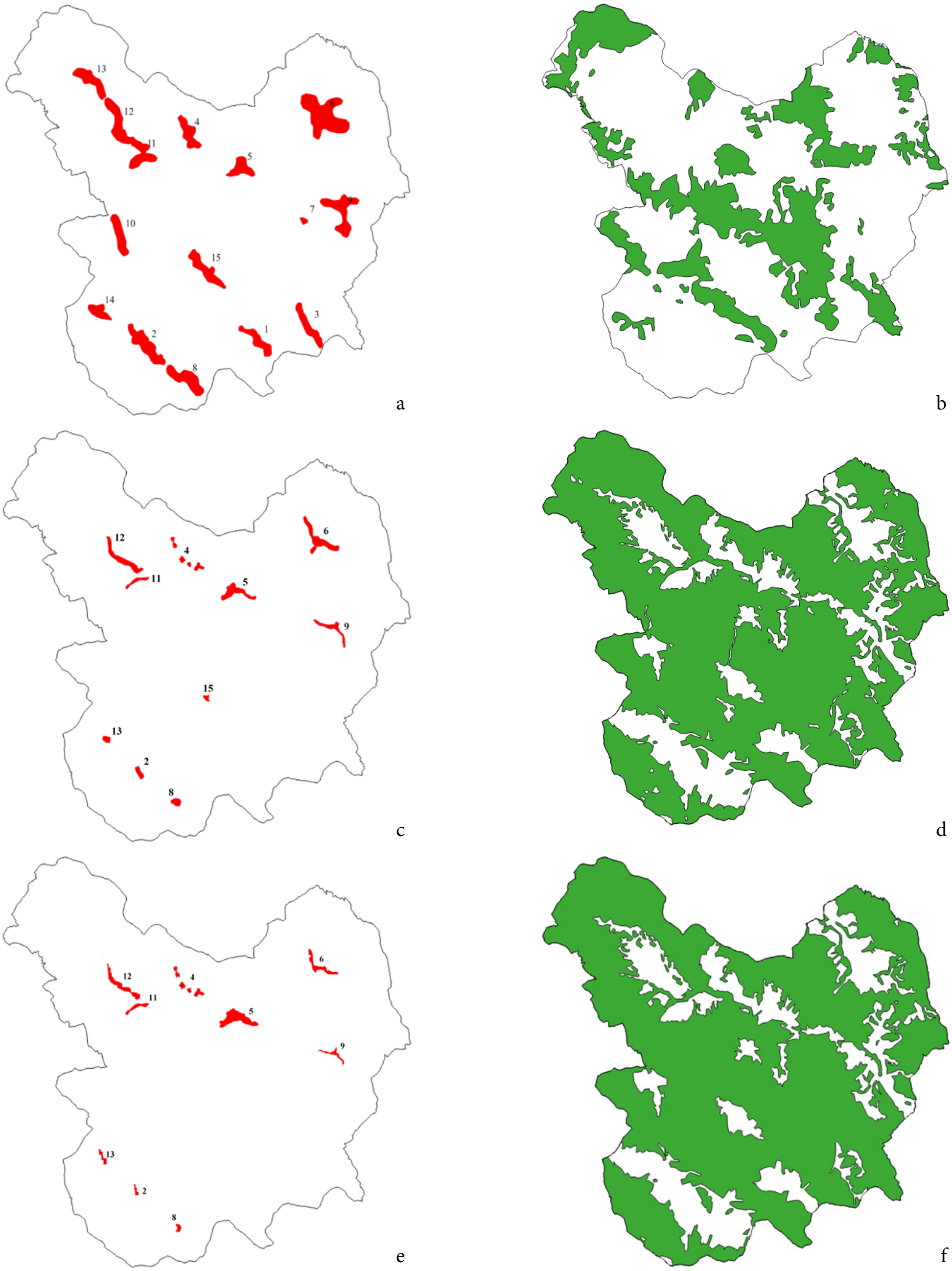

Fig. 3. Settlements (a, c and e) and forests (b, d and f) in the years 1855 (a, b), 1965 (c, d) and 2018 (e, f).

2005). However, the TVS with its cultural landscape is often threatened by political decision, socio-economic and technological changes in agriculture, industrial forestry and particular nature conservation strategies (Agnoletti, 2006; Antrop, 2005).

After World War II, it is difficult to consider settlements as those that perform traditional role of rural systems. In fact, destroyed TVS had the traditional spatial structure, satisfying different needs of people. Research shows that lack of such system negatively affects the social and cultural aspects of sustainable management of the studied region. An increase in forestation and a decrease in land use (because of the decrease in number of population within that area) has been observed in the region. Eventually, natural succession process took advantage over the lack of human activity and land use practices (Ambrozy, Wika, 1998).

Objective historical information on the loss of TVS is also important for touristic purposes. Analysing the value of the landscape without Ukrainians, on the example of former Ruthenian (Ukrainian) Boryslavka village (currently nonexistent) in Sanotsko-Turchansky mountains (Fredropol commune), confirmed the sudden and radical changes in the characteristics of most landscape: the loss of its identity and the loss of spirit of the place (genius loci) of mountain terrain (Affek, 2011).

Historical statistical data is not always objectively shown in terms of ethnic and religious composition of the whole Galicia population (Kubijovyč, 1983) and the study area of Krempna commune. On the basis of this situation, it may be considered that evaluation of national origins and religious data is quite significant for a research within Krempna commune. As mentioned above, it is also important in terms of rural cultural landscapes. Such cultural landscapes are usually associated with TVS with centre-periphery zoning from houses, gardens, fields, mowed grasslands and grazed grasslands to forests (Elbakidze, Angelstam, 2007). Actually, the Krempna commune is one of the most forested regions in Poland (with 78% of forested land). The consequences of losing such a TVS require a more detailed study.

According to the European Landscape Convention (European Landscape Convention, 2000), it is a loss of social and cultural values on local and regional level. The convention defines landscape as a zone or an area in the perception of local residents or visitors where visual signs and symbols of the landscape are a result of natural and cultural factors, historical stratifications for a long time. The most important is its identity, tradition and material culture in the human landscape (European Landscape Convention, 2000). Next, according to the World Conference on Cultural Policies (World Conference, 1982), for example in Recommendation number 64 on the page 100, we can see that folk culture, a fundamental component of a nation's heritage, should not be restricted solely to the productions of folk arts but should also take in aspects such as language, oral tradition, beliefs, celebrations, dietary habits, medicine and technology. Those elements were lost in the Krempna commune. The above-mentioned conducts to the degradation of the landscape, which constitutes a coherent entity, where natural and cultural components are closely interrelated.

Conclusion

The study has been performed within the border zone between Poland and Slovak Republic at the region of Krempna commune. We analysed the Krempna commune in terms of the changes in settlements and maps used for the analysis of changes in its structure by applying the ArcGIS program.

In Krempna commune, TVS was an example of sustainable co-existence of man and nature, natural and cultural heritage and social capital and was successful for centuries for achieving both common economic as well as cultural development of Lemkos people's in Poland with the traditional type of land use activity in cultural landscape and with the production of traditional goods and services by local land users.

The current land use is not associated with cultural landscapes, and spatial traditional village zoning structure is destroyed. The present land use clearly indicates that the present type of land use activity is not similar to the TVS. the present type of land use activity is not similar to the traditional, with reductions in diversity of all characteristics.

The change in land use observed in the study periods does not mean only the loss of agricultural land but also a decrease in the landscape diversity. It was a very negative phenomenon. Especially in a spatial context of the sustainable development of Krempna commune, that was an excellent region of harmony between human utilisation and landscape conservation.

The TVS was basic unit of the Krempna commune landscapes up to WWII. The analysis showed reduction in the number and area of settlement and loss of TVS. From the years 1939 to 2018, the area of settlements decreased in 4.9 times (CA decreased from 1,174.02 ha in the year 1939 to 241.23 ha in the year 2018). The MPS decreased from 71.6 in the year 1939 to 18.17 in the year 2018.

The Lemko Ukrainian tserkva – which dominated on the area of the commune, is considered as sacred and unique monuments of wooden architecture, preserved in the centre of old Ruthenian traditions and became an element of Ukrainian and European cultural and religious foundation – was destroyed (7 tserkvas).

Support of TVS (as a good indicator of sustainable landscapes) and socio-cultural functions and land use systems including fields, wooded grasslands and forests must be the milestones for sustainable development of this region.

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