Changes in the fragmentation and ecological stability of the Morava River floodplain forest in the course of the 20th century

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ABSTRACT: This paper presents the results of an analysis of the changes in the fragmentation and ecological stability of the floodplain forest geobiocoenoses in the Protected Landscape Area Litovelské Pomoraví, Czech Republic. Using GIS methods, it was determined that the fragmentation within the study area had increased slightly and the ecological stability of the landscape had decreased slightly between the years 1938 and 2006, although the latter remained on a fairly high level. The data reflect the anthropogenic conditionality of the floodplain forest ecosystem and show that an anthropogenically conditioned geobiocoenosis may attain a relatively high level of ecological stability, this being particularly characteristic of floodplain forest geobiocoenoses in Central Europe. The results of the study contribute to the documents that will be used in drawing up a management plan for the locality important at the European level which is a part of the Natura 2000 system.

Keywords: ecological stability; floodplain forest; fragmentation

The process of fragmentation is considered a core theme in landscape ecology (Wilcove et al. 1986; Farina 2007) which is closely connected with themes arising within landscape conservation biology (Saunders et al. 1991). Fragmentation usually proceeds continuously. Although fragmentation is usually connected with the theory of island biogeography (MacArthur, Wilson 1967), this theory is not capable of sufficiently explaining all the influences of fragmentation on the island patches. From the perspective of landscape ecology, a number of other factors need to be considered, such as connectivity, the question of metapopulation, the presence of ecotones and corridors (Gu et al. 2002).

During the process of forest fragmentation, the initially continuous, homogeneous and large area of a forest stand is divided into smaller patches, usually by means of non-forest matrices or corridors. This process is accompanied by a decrease in the initial total size of the area (Fahrig 2003). The fragmentation of the forest habitats is considered as one of the most serious dangers to forest biodiversity (Kaennel-Dobbertin 1998; Rochelle et al. 1999; Larsson 2001). When fragmentation influences key species, the impact of the fragmentation may also affect those species that are not directly affected by changes in the landscape (Angelstam 1997). The forest ecosystem fragmentation, for example, significantly increases susceptibility to the invasion of allochthonous herb species (Vitousek et al. 1996). According to Wade et al. (2003), in a quarter of the tropical rainforests, more than a half of the broad-

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leaved and mixed forests of the temperate zone and only 4% of the boreal forest biome are fragmented as a result of anthropogenic influences. Since the beginning of the Middle Ages fragmentation has had a significant impact on the present Central European cultivated landscape, which has been described in a number of studies. For example, Wilcove et al. (1986) carried out a research in the Warwickshire county dealing with the fragmentation of the initial forest landscape matrix between 400 and 1960. As a result of the fragmentation of Central European forests, the population of large mammals that need large home territories is reduced (Peterken 1996). The ecological consequences of fragmentation are very important for measures related to nature protection and landscape planning (Collinge 1996).

Newton (2007) summarized the methods and measures used to measure the fragmentation of forest ecosystems. To analyze forest fragmentation at the landscape level GIS methods and distant landscape examination are used (e.g. Fuller 2001).

Forest fragmentation increases the edge effect due to an increase in the relative largeness of the edges compared to the total area of the forest environment. The ecological characteristics of the edges of the fragmented areas in the forest environment usually differ significantly from the characteristics of the inner environment (Matlack, Litvaitis 1999). The length of the edges in the fragmented forest environment closely correlates with the overall heterogeneity of the forest geobiocoenoses and their ecological stability significantly influencing the ecological stability of the forests (Míchal et al. 1992).

Fragmentation is especially challenging for European floodplain forests because they are endangered ecosystems with unusually high biodiversity (Klimo, Hager 2001; Klimo et al. 2008), which are significantly anthropogenically conditioned at the same time (Řehořek 2001). The development dynamics of Central European floodplains is very quick (Lipský 2008), from which follows a very dynamic ecological stability in the floodplain forests themselves. This was described by Buček and Lacina (1994) as the "dynamic fluvial seral section of floodplain biotopes".

This paper assesses the development of fragmentation and changes in the ecological stability of the floodplain forest geobiocoenoses in the Litovelské Pomoraví Protected Landscape Area (PLA) (Czech Republic) during the 20th century. The aim of this paper is to contribute more detailed knowledge of the anthropogenic processes that have formed the present state of the floodplain forest and provide a basis for a management plan for this type of biotope which is ranked as important at the European level in the Natura 2000 system.

MATERIAL AND METHODS

Study area

The study area of the floodplain forest in the Litovelské Pomoraví Protected Landscape Area is located in the floodplain of the Morava River in the western part of the Czech Republic. The altitude of the area is 228–237 m a.s.l., the geographical coordinates are 17°03'E, 49°42'N. From the biogeographical aspect, the study area belongs to the bioregion of Litovel (for a more detailed profile of the biotic conditions and biota see Culek et al. [1996]).

According to Zlatník (1976), the floodplain forest geobiocoenoses of the Litovelské Pomoraví area belong to the 2nd forest altitudinal zone. Table 1 shows an overview of the basic geobiocoenological units (Buček, Lacina 1996) defined within the study area. The area of interest is situated in a warm continental climatic region with a long and dry summer and short dry winter with minimal snow coverage. The geological bed of the area is formed by the Quaternary valley terrace of the Morava River, which consists of pit-run gravel coming from the Würm period and 4–6 m thick alluvia. These are covered

Table 1. Groups of geobiocene types (GGT) in the floodplain forests in Litovelské Pomoraví PLA

Abbreviation of GGT	Name of GGT	Proportions of GGT in PLA (ha)	Proportions of GGT in PLA (%)
A B-C 5a	*Saliceta albae* sup.	86.2	3.6
2 B-C (4) 5a	*Querci roboris-fraxineta* sup.	302.8	12.9
2 C (4) 5a	*Ulmi-fraxineta populi* sup.	340.1	14.5
2 BC-C (3)4	*Ulmi-fraxineta carpini* sup.	1,512.3	64.6
S BC 5b	*Alni glutinosae-saliceta* sup.	98.5	4.4

by recent alluvial soil layers that are up to 3 m thick. Several levels of river terraces forming the edge of the bottomland can be distinguished. The basic geomorphological feature of the floodplain in Litovelské Pomoraví is an inland river delta. The basic form is forked, consisting of active or empty canals of the main channel of the Morava River and its side streams, meanders in various developmental stages, connecting and compensating channels. The canals are sunk deeply into the sediments themselves. Recent geomorphological research (Kirchner, Ivan 1999) has discovered the presence of a special type of river net, so-called anastomosis. The anastomosis river system of the Morava River in Litovelské Pomoraví is characterized by the dominant meandering main stream of the Morava River with a system of side canals (popularly known as "smoha" in Czech). The side canals are flooded periodically during spring floods. The valley terrace of the Morava River is covered by Holocene alluvial soil, Fluvisols. There is a constant pedogenetic process of the sedimentation of fluvial soil in the regularly flooded parts of the alluvial forest in Litovelské Pomoraví.

The planned forest management dates from 1754, when the geodetic location of the forests was carried out. The network of forest paths set up at that time has remained virtually without change to the present day. The detailed characteristics and biotic descriptions of study area can be found in Machar (2008b). According to the Czech Natura 2000 biotope typology (Chytrý et al. 2001), these floodplain forests belong to the biotope type hardwood and softwood floodplain forests of plain rivers. The total area of the Protected Landscape Area is 9,600 ha, of which 2,655 ha constitute the study area (Fig. 1).

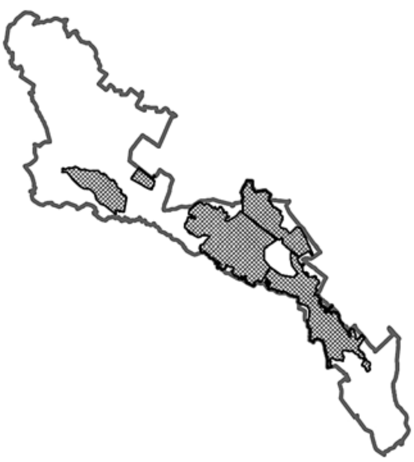


Fig. 1. Extension of floodplain forests in the Litovelské Pomoraví PLA

The analyzed attributes and data sources

With the help of GIS methods, the following attributes related to the landscape change were analyzed for the years 1938, 1953, 1990 and 2006: total area of individual types (categories) of land use (in ha) and its percentage representation, number of patches, total length of patch edges (in m), relative length of patch edges (in m/ha), average size of patches (in ha) and the variability of patch size. The landscape heterogeneity index (V) was calculated according to Mimra (1993):

$$V = \frac{N}{\sqrt{A}} \times \frac{H}{H'} \qquad (1)$$

where:
N – total area of the mosaic elements,
A – value of the total area of the mosaic (elements and matrix),
H – actual type diversity of elements,
H' – potential type diversity of elements.

The calculations of conventional diversity indices were carried out by the classical equation for index diversity:

$$H = \sum_{i=1}^{j} p_i \times \log p_i \qquad (2)$$

where:
p_i – relative number of elements in the matrix i^{th} combination of the given characteristics,
j – total number of present combinations.

Furthermore, the anthropic impact coefficient K_{aov} (Löw et al. 1995) was identified:

$$K_{aov} = \frac{I + II + III + IV + V}{VI + VII + VIII + IX + X} \qquad (3)$$

In this equation I–X are the values of relative anthropic influence on vegetation. In order to analyse changes in the ecological stability of the study area, the degree of ecological stability of the forest stands was identified by Buček and Lacina (1996). A six-point scale is used to evaluate the significance of the existing communities from the aspect of ecological stability: 0 – no significance, 1 – very little significance, 2 – little significance, 3 – medium significance, 4 – great significance, 5 – extraordinary significance. The ecological stability coefficient (K_{ES}) was determined in two ways, i.e. according to Míchal (1985):

$$K_{ES} = \frac{S}{L} \qquad (4)$$

(S is the total area of ecologically stable landscape structures, L is the total area of ecologically unstable landscape structures) and according to Miklós (1986):

$$K_{ES} = \frac{p_a \times k_{pn}}{P} \qquad (5)$$

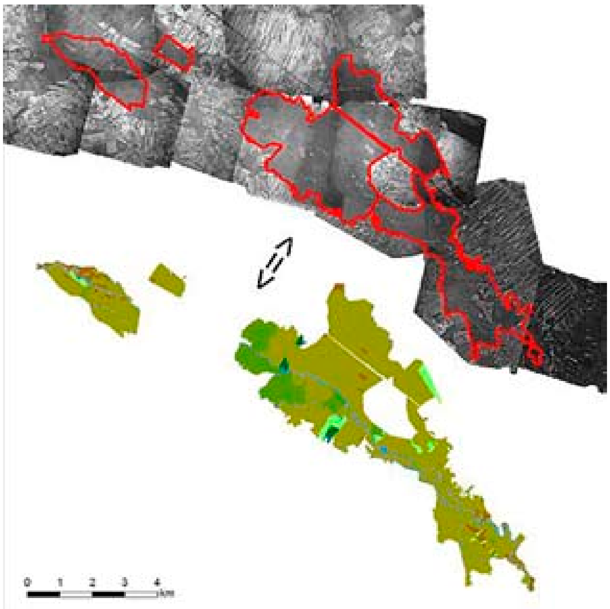
where:
p_a – area of land-use categories,
k_{pn} – coefficient of ecological importance of land-use categories,
P – range of study area.

Coefficient k_{pn} was altered by Lipský (2000): arable land has the value 0.14, meadows 0.62, pastures 0.6, gardens 0.68, orchards 0.3, forests and water bodies 1.0, others 0.1.

Analysis was carried out of aerial photographs from the years 1938, 1953, 1990 and 2006, of forest stand maps at the 1:10,000 scale from the archives of the Forest Management Institute, Brandýs nad Labem, and topographic maps at 1:10,000. The data were scanned as raster display, digitalized and subsequent-

Table 2. Statistics of the landscape coverage in the study area

Year	Land use	Total area (ha)	Total area (%)	Amount of patches	Total length of edges (m)	Relative total length of edges (m/ha)	Average area of patches (ha)	Variability of patch size
1938	Water body	89.4	3.4	22	140,448	53.6	4.1	10.2
	Unstocked forest land	153.0	5.8	91	81,894	31.3	1.7	2.6
	Young plantation	80.2	3.1	16	20,936	7.9	5.0	7.9
	Small pole stage and pole-stage stand	296.3	11.3	11	28,812	11.0	26.9	35.3
	High forest and mature stand	24.7	0.9	3	5,510	2.1	8.2	2.4
	Coppice with standards	1,975.4	75.4	65	239,248	91.4	30.4	64.6
1953	Water body	43.6	1.7	12	60,674	23.2	3.6	5.00
	Unstocked forest land	131.7	5.0	93	73,240	28.0	1.4	2.6
	Young plantation	142.5	5.5	29	40,844	15.6	4.9	7.6
	Small pole stage and pole-stage stand	119.1	4.6	11	26,288	10.0	10.8	13.0
	High forest and mature stand	3.3	0.1	2	1,570	0.6	1.7	0.3
	Coppice with standards	2,172.6	83.2	44	200,904	76.9	49.4	123.6
1990	Water body	55.4	2.2	14	94,578	36.9	3.9	6.9
	Unstocked forest land	218.2	8.5	130	124,538	48.7	1.7	2.5
	Clearcut area	121.8	4.8	52	59,814	23.4	2.4	3.2
	Young plantation	560.8	21.9	122	195,762	76.5	4.6	7.4
	Small pole stage and pole-stage stand	372.7	14.6	88	123,096	48.1	4.2	6.4
	High forest and mature stand	1,229.5	48.1	88	240,612	94.1	14.00	27.3
2006	Water body	62.3	2.4	24	86,994	32.8	2.6	7.1
	Unstocked forest land	120.3	4.5	120	79,330	29.9	1.0	1.9
	Clearcut area	396.6	14.9	155	166,592	62.7	2.6	4.7
	Young plantation	536.6	20.2	153	199,900	75.3	3.5	5.4
	Small pole stage and pole-stage stand	382.0	14.3	110	141,108	53.2	3.5	5.1
	High forest and mature stand	1,157.3	43.6	75	233,436	87.9	15.4	28.9



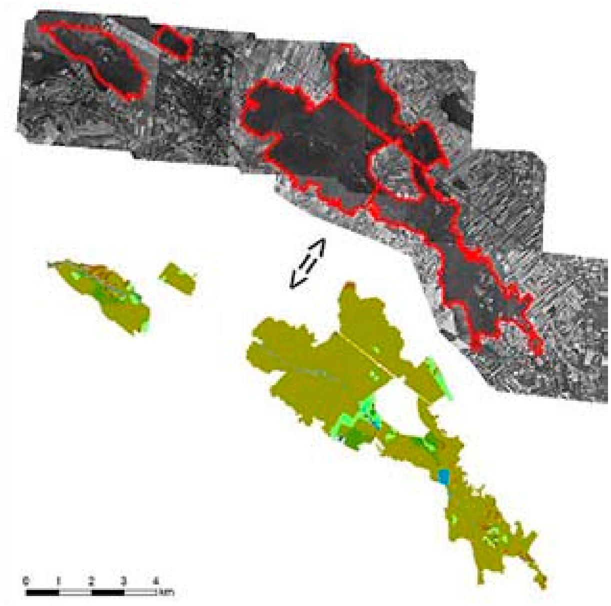


Fig. 2. Land use and fragmentation of floodplain forests in the study area in 1938

Fig. 3. Land use and fragmentation of floodplain forests in the study area in 1953

ly analyzed using common statistical devices in a GIS environment (Topol programme version 5.5.).

RESULTS

Figs. 2–5 show the development of the landscape cover within the study area according to land-use categories for the years 1938, 1953, 1990 and 2006. As the figures clearly show, the area of the floodplain forest remained virtually unchanged from 1938 to 2006. The stable state of the forest area in Litovelské Pomoraví during the 20th century is conditioned by regular floodings in the floodplain of the Morava River. The floodplain forest area is bordered (from the surrounding agricultural land) by a complex of earthen flood-control dams that turn the floodplain forest into a natural polder. The polder fills with water during the virtually annual floods on the Morava

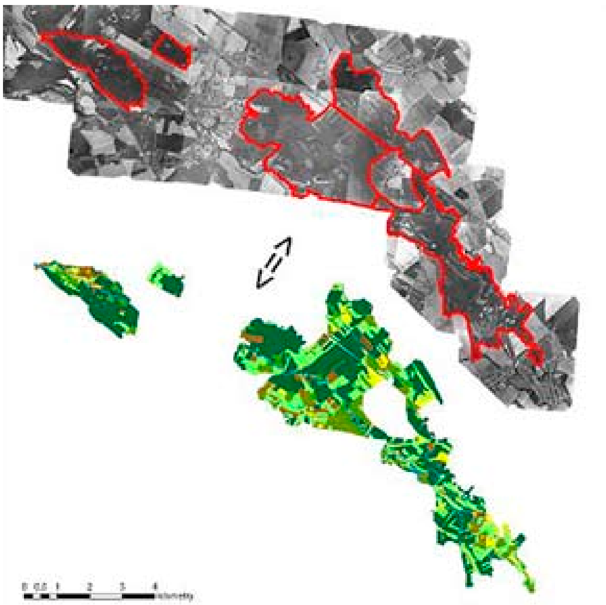


Fig. 4. Land use and fragmentation of floodplain forests in the study area in 1990

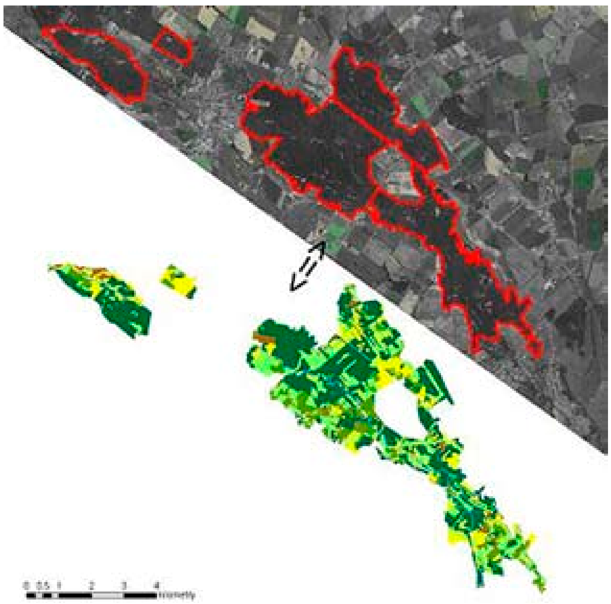


Fig. 5. Land use and fragmentation of floodplain forests in the study area in 2006

Table 3. The development of the landscape structure in the study area

Year	Shannon's diversity index	Simpson's diversity index	Shannon's equitability index	Simpson's equitability index	Index of landscape heterogeneity	Total area of forest land (ha)	Total length of edges (km)
1938	0.9	0.4	0.5	0.5	9.3	957.9	47.4
1953	0.7	0.3	0.64	0.4	7.2	971.8	36.5
1990	1.4	0.7	0.8	0.8	12.9	834.3	58.4
2006	1.5	0.7	0.8	0.9	15.2	950.4	53.9

River and has thus served as natural protection to the surrounding villages practically since the Middle Ages (Machar 2008b). Based on an analysis of aerial photographs that correlates with the data obtained during historical forest research (Hošek 1987), a significant change in forest management in the 1950s can be identified. Figs. 2 and 3 show that in 1938 and 1953 the prevailing land-use category was coppice with standards. In 1990 and 2006, that category was no longer extant due to a change to a high production forest type at the end of the 1950s and throughout the 1960s. This change in inner forest fragmentation is well documented when compared to aerial photographs from 1953 (Fig. 3) and 1990 (Fig. 4). The change in the forest management of the floodplain forest (the transition from the coppice with standards type to the high production type) is apparent when other changes in landscape attributes are considered: the overall number of permanent landscape structures increases – this applies both to patch size and edge length (Table 3). The same trend is observable in the average patch size: whereas the average size of one segment in the coppice with standards forest in 1938–1953 is between 30 and 50 ha, the same parameter for the mature production timber forest in 1990–2006 failed to reach even a half of the previous value, i.e. 14–15 ha (Table 2). The increasing inner fragmentation of the floodplain forest is mirrored by a continuous increase in the landscape heterogeneity index, which increased by 63% between 1938 and 2006 (Table 3). The increase in landscape heterogeneity is in line with the development of both the analyzed indices of landscape diversity, which rose between 19938 and 2006, while having retained high balance values (Table 3).

The development of the ecological stability changes in the landscape of the study area is expressed by means of the temporal development of the ecological stability coefficients (K_{ES}) as calculated by two different methods (Table 4). The table clearly shows that all values of the individual K_{ES} for the study area decreased continuously between 1938 and 2006. The aerial photographs from 1990 and 2006 (Figs. 4 and 5) document the most significant of the anthropogenic changes in the study area during the 20th century – the corridor of the highway leading from Olomouc to Hradec Králové, which was built in the 1970s and which divides the study area. The location of the highway caused changes in the ecological stability as a result of anthropogenic influences between 1953 and 1990 (see Table 4). Despite the slight decrease of K_{ES} in the observed period, the ecological stability of the study area remains exceptionally high. During the entirety of the period observed the critical K_{ES} value according to Míchal (1985) indicates a balanced and ecologically highly stable landscape. The same applies to K_{ES} values according to both Miklós (1986) and Lipský (2000), which indicate a mini-

Table 4. Changes in the ecological stability of the study area

Year	Landscape stability index K_{ES} by Míchal (1985)	Landscape stability index K_{ES} by Miklós (1986) and Lipský (2000)	Coefficient of anthropic impact K_{aov} by Löw et al. (1995)	The degree of ecological stability of the forest by Buček and Lacina (1996)
1938	5.63	0.78	11.77	5
1953	5.43	0.76	11.33	5
1990	4.23	0.73	14.02	5
2006	4.39	0.73	14.11	5

mally disturbed highly ecologically stable landscape for the whole 1938–2006 period. When the values of the anthropogenic conditioning of the vegetation K_{aov} are analyzed, the result is a very slight anthropic conditioning of the geobiocoenoses. The level of ecological stability of the forest stand (Table 4) remains at the maximum, value 5, throughout 1938–2006, even when both versions of K_{ES} and K_{aov} change. It would seem that the level of ecological stability of the forest stand is not very useful in describing temporal changes in the forest geobiocoenoses stability allowing instead only a rough estimation.

DISCUSSION

Determining whether a particular landscape is fragmented or homogeneous always depends on the level at which the landscape is observed (Wiens 1994). In the case of the study area in Litovelské Pomoraví, when observed at the landscape macroscale (i.e. tens to hundreds of hectares), the entire PLA may be considered a continuous green floodplain area surrounded by deforested agricultural land of Haná. When the same area is observed at the level of hundreds and tens of hectares, it is possible to identify clearly the inner fragmentation (groups of forest stand, meadows, water stream corridors etc.). From the perspective of North American landscape ecology, fragmentation is chiefly understood as the process that leads to the division of large natural habitat to a number of smaller parts, which is accompanied by an overall decrease in the total area (Reed et al. 1996). However, Newton (2007) points out that while studying fragmentation, it is necessary to distinguish two different processes: habitat loss and the inner fragmentation of the location, the total area of which remains the same. The habitat loss has a negative impact on the biodiversity (Walker 2006), whereas inner fragmentation may have both positive and negative influences on biodiversity. The presented fragmentation development of the Litovelské Pomoraví floodplain forests represents the former case, i.e. inner fragmentation that leads to the changes in the inner heterogeneity of the floodplain forest, but does not result in an areal loss of biotope. Some studies imply that this type of forest fragmentation leads to an increase in its biodiversity, which nevertheless concerns the edges and the non-forest "open land" types, at the expense of the inner forest types (e.g. Machar 2008a).

Habitat edges are generally defined as borders between various types of patches. Therefore, the definition of an edge depends on the definition of the patch (Ries et al. 2004). The forest edge may be defined by means of various attributes, such as e.g. length, width, shape, vertical and horizontal structure or density, as shown by Brändli et al. (1995) during the national forest inventory in Switzerland. In the case of the floodplain forests of Litovelské Pomoraví, it shows that the total length of the forest patch edges slightly increased during the 20th century. This is necessary to assess with regard to the particular forest management forms. Forest management in the floodplain forest based on the high production forest type leads to the increased length of patch edges in a more significant way than forest management of the coppice with standards forest type does (Figs. 2–5). Research results of the edge effect presented in literature are always influenced by the method chosen, e.g. length of the studied transect or the number of landscape categories studied. For this reason, comparison with data obtained by other authors is complicated and misleading (examples: Fraver 1994; Cadenasso et al. 1997; Harper, MacDonald 2001).

When conducting a landscape-ecological analysis, the obtained values of K_{ES} coefficient must be taken as complementary to the statistical data concerning the development of permanent landscape structures. This is apparent especially in the case of the anthropic assessment of the vegetation K_{aov}, which has only a rough informational value for the study area. It is so because its calculation reflects direct and identifiable changes in the areas of various land-use types, leaving aside the indirect anthropic influences (e.g. influences related to the water regime which are particularly significant within the study area – see Machar 2008b). The same applies to the level of ecological stability of the forest stand (Buček, Lacina 1996), used during the definition of environmental systems of ecological stability, that does not have a detailed informational value when analyzing the temporal changes of ecological stability. However, the data concerning the development of landscape ecological stability obtained using the above-mentioned coefficients are in line with the statistical changes in the landscape cover carried out in the GIS environment (Tables 2 and 3). The result of the analysis of the study area condition between 1938 and 2006 is a slight decrease in its ecological stability (Table 4). This does not contradict the general trends of the landscape changes in the Czech Republic in the course of the 20th century (Czech Statistical Office, 1999). According to Kiliánová (2001), the ecological stability of the Morava River floodplain landscape decreased significantly in the course of the 20th century. However, the results of the analysis concern the landscape of the entire the

Morava River floodplain which is predominantly deforested. The same applies to Sklenička (2002), who found a significant decrease in the landscape heterogeneity and shortening of the total length of permanent landscape structure edges (which he considers as important landscape characteristics for assessment of changes in the ecological stability of landscape) in the landscape of north Bohemia (in the Ohře River basin) which is subject to intensive agricultural cultivation.

The non-significant decrease in the ecological stability of the floodplain forest landscape in Litovelské Pomoraví during the 20th century is probably conditioned by the area of the floodplain forest complex that has remained virtually the same and by the forest management measures which have not changed the species composition and character of the forest biotopes. The present richly structured floodplain forest stand in the area of the Litovelské Pomoraví PLA is demonstrably a result of intensive forest management (Hošek 1987). The result of the intensive and centuries-old forest management processes in the floodplain of the Morava River is a conditionally natural state of the floodplain forest geobiocoenoses with unusually high biodiversity (Maděra et al. 2008) and with a relatively high degree of ecological stability.

CONCLUSION

Forest management in the Litovelské Pomoraví floodplain forest during the 20th century led to a continuous and steady slight increase in the fragmentation of the forest geobiocoenoses, which was accompanied by increasing heterogeneity and by a virtually steady state of high ecological stability. This is a contrary tendency when compared to the general developmental trends of the cultivated rural landscape in the Czech Republic, where the overall landscape heterogeneity and ecological stability increased during the 20th century (Lipský 1995; Sklenička 2002). The change in the observed landscape attributes within the study area in the first half of the 20th century was triggered by the transition from the coppice with standards forest type to that of a high production forest. The changes in the value of the ecological stability coefficient and the coefficient of the anthropogenic conditioning of the vegetation were impacted by the building of the new highway which was a significant anthropogenic interference within the area. This change corresponds in time with the marked turn in the cultivated landscape development in the Czech Republic in the 1950s, the main reason for which was the collectivization of agriculture.

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Změny fragmentace a ekologické stability lužních lesů v nivě řeky Moravy v průběhu 20. století

ABSTRAKT: Článek prezentuje výsledky analýzy změn fragmentace a ekologické stability geobiocenóz lužního lesa v Chráněné krajinné oblasti Litovelské Pomoraví (Česká republika). S využitím metod GIS bylo zjištěno, že v průběhu období od r. 1938 do r. 2006 se ve studovaném území mírně zvýšila fragmentace lužního lesa a mírně poklesla ekologická stabilita krajiny, přestože se udržuje na stále vysoké úrovni. Zjištěná data podporují názory o antropogenní podmíněnosti ekosystému lužního lesa a zároveň ukazují, že i antropogenně ovlivněné geobiocenózy mohou dosahovat relativně vysokého stupně ekologické stability, což je právě pro středoevropské geobiocenózy lužního lesa charakteristické. Výsledky studie jsou příspěvkem k vytváření podkladů pro plán péče o evropsky významnou lokalitu v soustavě Natura 2000.

Klíčová slova: ekologická stabilita; lužní lesy; fragmentace

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