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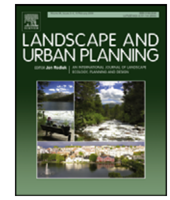

Assessing landscape change and biodiversity values of the Middle Vistula river valley, Poland, using BIO-SAFE

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ABSTRACT

This paper deals with the relation between legally protected biodiversity and riverine ecotopes and with the assessment of biodiversity values of the Middle Vistula river valley (Poland). Furthermore, it describes the effects of landscape change on spatial distribution of ecotope patches and biodiversity values in Kazimierski Landscape Park. Biodiversity values were calculated using BIO-SAFE, a model meant to quantify biodiversity and to value ecotopes based on legally protected species. Dissimilarity indices depict high uniqueness of ecotope types regarding their species assemblages (e.g., river dunes, banks and bars). The actual biodiversity values of the river valley in Kazimierski Landscape Park are high in comparison with floodplains of lowland rivers in Western Europe. GIS analyses of remotely sensed ecotope maps show remarkable differences in number, acreage and patchiness of ecotopes for the years 1953 and 2003. The total number of patches increased by almost 44%. Side channels and floodplain lakes became fragmented. The average and total surface area of bush, forest and arable land increased, but decreased for bare soil, pioneer vegetation and grassland. These landscape changes indicate natural vegetation succession, intensification of agriculture and progressive impacts of river regulation. The Vistula river valley still represents high biodiversity values for higher plants, birds, herpetofauna and fish. However, current landscape changes negatively affect potential values for protected and endangered species. Assessments with BIO-SAFE can help to balance biodiversity conservation, river management and landscape planning.

1. Introduction

The Vistula is the largest river in Poland, crossing the whole country from the Carpathian Mountains in the south to the Baltic Sea in the north (Fig. 1). Several large towns and industrial complexes are located along the river. In spite of floodplain embankment for urbanisation, industrialisation and agriculture, the river still shows rather natural hydro-morphological characteristics with sandy islands, braided-meandering channels and species-rich riverine vegetation (Kajak, 1993). At national and European scale the Vistula river valley functions as an important ecological corridor for biodiversity (Kajak, 1993; Nienhuis et al., 2000; Romanowski, 2007).

The Central-European river landscapes were subjected to intense land use changes (Kaligarič et al., 2008). Recently, Poland has been faced with severe floods of the Vistula river which caused huge economic and social damage (Nienhuis et al., 2000; Cyberski et al., 2006). Therefore, sustainable flood protection became an important river management issue. Flood risk management and landscape changes, however, may threaten the actual and potential biodiversity values of the river corridor.

Polish river management and spatial planning must comply with the European Union Birds and Habitat Directives. These directives require strict protection of endangered flora and fauna species and their habitats (De Nooij et al., 2008). Furthermore, the European Water Framework Directive aims at integrated and sustainable management of the river basin and to safeguard a good ecological status (Nilsson and Langaas, 2006). Therefore, the question is raised how flood risk management and landscape planning relate to (inter)national nature protection legislation and guidelines. In

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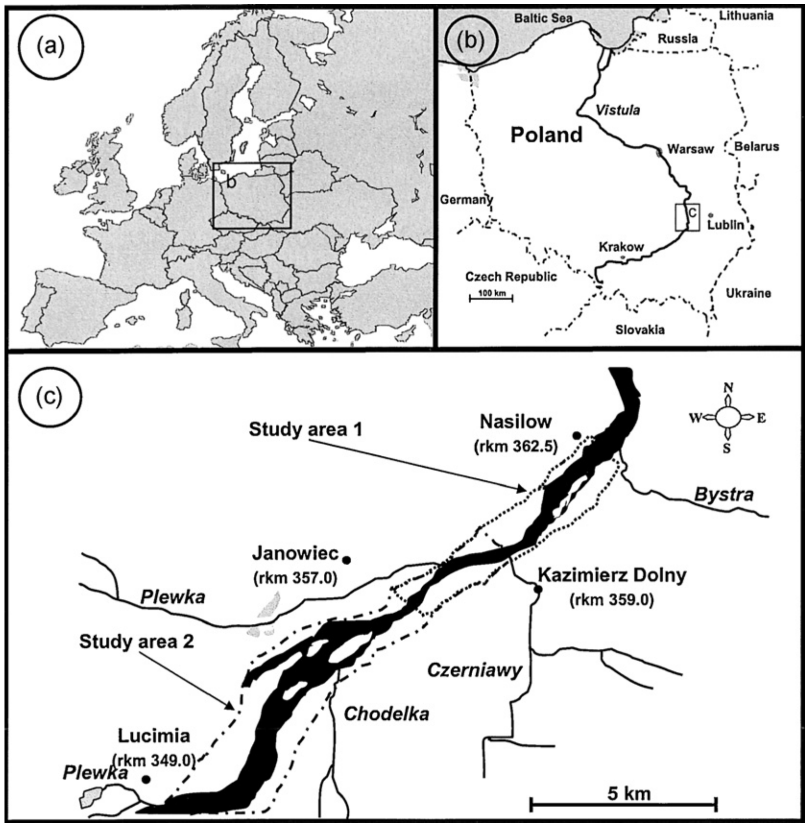

Fig. 1. (a) Location of study area within central Europe; (b) Vistula river Poland; (c) Middle Vistula river floodplains in Lubelski Province (study area 1: assessment of actual biodiversity values; study area 2: analysis of landscape change; rkm: river kilometre).

order to get more insight in the potential effects on nature values, biodiversity has to be surveyed and assessed. BIO-SAFE is a model that provides means to assess the impact of landscape change and physical reconstruction measures on actual and potential biodiversity values in terms of legally protected species (Lenders et al., 2001; De Nooij et al., 2004). The model has been developed for the rivers Rhine and Meuse, but can easily be adapted for sustainable flood risk management and biodiversity conservation of other lowland rivers. This paper addresses the following research questions, using an especially for the Vistula river developed version of BIO-SAFE:

- What are the potential biodiversity values of various riverine ecotopes of the Vistula river based on political and legal criteria for biological conservation?
- What are the actual biodiversity values of the Middle Vistula river valley in Kazimierski Landscape Park?
- What are the effects of recent landscape changes in the Middle Vistula river valley on biodiversity values, using ecotopes as indicators?

The implications of our results for river management and landscape planning will be discussed.

2. Material and methods

2.1. Study area

The source of the Vistula river is located in the Beskidy Mountains in the south of Poland (the northern slope of the Carpathian Mountains). The river flows to the Baltic Sea in northwest Poland (Fig. 1a and b). The river length is 1047 km and the width of its lowland reaches varies between 300 and 1000 m (Kajak, 1993; Brinkmann et al., 2000). The total drainage area is 194,400 km^2 of which 168,600 km^2 (nearly 87%) is located in Poland. The Vistula river is the largest Polish river and it drains circa 54% of the country.

Our study concerns the Middle Vistula river in the Kazimierski Landscape Park, Lubelski Province (Figs. 1c and 2). This river section is regarded as a separate physical–geographical region: Vistula's Małopolska Gorge (Plit, 2004). Here the Vistula river crosses the gap in the Małopolska uplands and flows into the Mazovian plain (glacial uplands). The riverbed is relatively unregulated. Therefore, it is an interesting area to study biogeomorphological interactions and landscape change. However, this river section is extensively used for navigation. Moreover, the water pollution is rather high

Fig. 2. View on the Middle Vistula river valley in Kazimierski Landscape Park (Photo was taken in 1999 by T.J. Chmielewski).

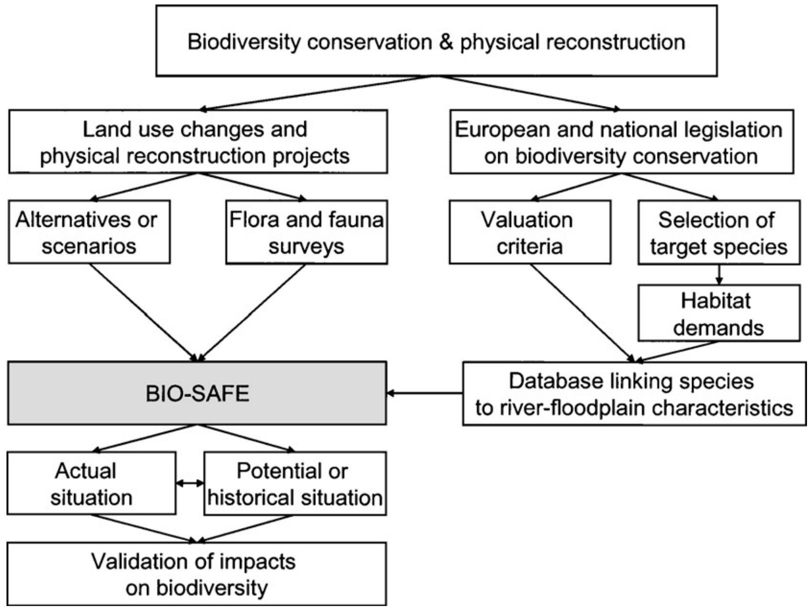

Fig. 3. Conceptual framework of the model BIO-SAFE (for explanation see text).

due to heavily populated and industrialised areas along the upper reaches (Kajak, 1993). In spite of a high status of nature and landscape protection of the landscape park, over recent decades large scale land use changes were indicated (Chmielewski et al., 2004).

Taking into consideration high ecological and landscape values, availability of aerial photographs for analyses of landscape changes and availability of scientific data on distribution of higher plants and fauna, two sites were selected for our case studies: (1) The Vistula river valley between the villages Janowiec (50°9′N, 21°11′E) and Nasiłow (51°20′N, 21°57′E) (river kilometres 357–363; 482 ha) for assessment of actual biodiversity values; and (2) The Vistula river valley between the villages Lucimia (51°17′N, 21°50′E) and Kazimierz Dolny (51°19′N, 21°57′E) (river kilometres 249–359; 1107 ha) for analysing effects of landscape change on biodiversity values. Both study areas are relatively unimpaired with braided and meandering channels, steep banks, sandbars, numerous islands, and the confluents of the Chodelka, Zwoleńka, Plewka and Bystra streams (Maruszczak, 1997). The islands vary in character, from low, bare sandy islets to larger and higher islands. The larger islands and riverine areas are covered by semi-natural meadow vegetation (hay meadows and pasture), shrubs, forests of willow (*Salix* spp.) and poplar (*Populus* spp.) (Kajak, 1993). The eastern river bank is bordered by a dike, but near Janowiec village the floodplain is confined by a scarp with a height between 45 and 50 m (Fig. 2). On the western bank, the research area is delineated by embankments of floodplains. Near the villages Podgórz and Męcimierz the river bed is confined by a scarp with a height between 80 and 90 m. The average slope of the river bed between the villages Lucimia and Pulawy is – 0.252‰ (Maruszczak, 1997). This slope value is expressed as the fall of the river bed per unit distance (in metres per kilometre). The average and maximal flow are 541 and 7820 $m^3\,s^{-1}$, respectively (Kajak, 1993). High discharges usually occur at early spring snow melting, but sometimes also in summer. The subsoil of the river valley mostly consists of course-grained sandy-clay soils.

2.2. Conceptual framework of BIO-SAFE

The conceptual framework of BIO-SAFE (Fig. 3) concerns the political and legal dimensions of biodiversity at the level of species and their habitats in river–floodplains systems (Lenders et al., 2001; De Nooij et al., 2004, 2008). The basis of this model is formed by the (inter)national political and legal protection status of species that are characteristic of river ecosystems. The assignment of values to species allows one to valuate an actual situation of, for example, a floodplain or river valley on the basis of data on species presence in that particular area. Through the species-habitat demands, values can also be assigned to ecotopes or other landscape–ecological or land use units, thus allowing the user to valuate these units. This linkage of species to landscape–ecological units is also the basis for valuation of the biodiversity potential in a particular area since specific landscape–ecological units comprise potential habitats for (protected) species. Land use changes and physical reconstruction measures for flood risk management, river rehabilitation or spatial planning alter hydrological, morphological and biological conditions of river–floodplain systems. Changes of the actual and potential biodiversity values can be quantified using various indices of BIO-SAFE.

2.3. Model description

BIO-SAFE 1.0 links species to various riverine ecotopes. Ecotopes are described as spatial units which are relatively homogenous in terms of vegetation structure and succession stage, and abiotic site factors (e.g., flooding and grazing regime) that are relevant for plant growth (Klijn and Udo De Haes, 1994). Ecotopes at four levels of scale were used (De Nooij et al., 2004): the CORINE land cover classification units of the European Commission (level 1; scale 1:100,000); units of the biotope typology that is developed by the International Committee for the Protection of the Rhine (level 2; scale 1:50,000); units of the Dutch River Ecotope System (levels 3 and 4 with scales 1:25,000 and 1:10,000, respectively). This ecotope typology allowed aggregation of assessment results on low levels of spatial scales to higher spatial scales and the use of input data of various scales. Ecotopes types at levels 1 and 4 are compatible to Polish land cover classification using a methodology elaborated by Chmielewski (2001, 2004). Although only one of the possible approaches towards biodiversity, the hierarchical approach provides a theoretical basis for understanding biodiversity patterns in river systems as spatially nested in the catchment structure and being a result of the processes that play a role on and across various spatial and temporal scales. Klijn and Udo De Haes (1994) investigated the possibilities of a hierarchical approach to ecosystems and its implications for ecological land classification and exemplify that the approach is particularly valuable as a comprehensive tool for scientific analysis on behalf of environmental policy.

In linking species to ecotopes, the habitat demands of all life cycle stages were considered. The information on species and habitats was derived from a thorough survey of scientific literature (atlases, reports, books and journal articles describing the distribution of flora and fauna in relation to landscape characteristics), supplemented by expert judgement. The model includes 177 species that meet both criteria: (1) indigenous to Poland and characteristic of the Vistula river valley; and (2) relevant in terms of national and international policy or legislation concerning nature conservation. The latter category comprises the so-called endangered and protected species that are mentioned at least in one of the following policy and legal instruments:

(a) Red Lists of the International Union for Conservation of Nature (IUCN) and Poland on threatened species.
(b) Enactments of the Polish Minister of Environment concerning wild plant and animal conservation during the entire year or specific periods (Statute books 04.168.1764 and 04.220.2237).
(c) Annex I of the Bird Directive 79/409/EEC of the European Commission on the conservation of wild birds.
(d) Annexes II and IV of the Habitat Directive 92/43/EEC of the European Commission on the conservation of natural habitats and of wild fauna and flora.
(e) Appendices I or II of the Bonn Convention 1.XI.1983 on the conservation of migratory species of wild animals.
(f) Appendices I or II of the Bern Convention on the conservation of European wildlife and natural habitats of the Council of Europe.

The taxonomic groups of selected species comprise higher plants, birds, mammals, herpetofauna (amphibians and reptiles), fish, butterflies and odonates (dragonflies and damselflies). An international panel of experts assigned weights to the policy and legal instruments (i.e., valuation criteria), according to their judgements of the relative importance of these instruments to biological conservation policy (De Nooij et al., 2004). Based on this study, weights factors were assigned to the above-mentioned policy and legal instruments (Red Lists of susceptible and vulnerable species: 1; Red Lists of endangered, critically endangered and extinct species: 4; Polish legislation: 4; Bird Directive: 4; Habitat Directive annexes II and IV: 1 and 4, respectively; Bonn Convention: 1; Bern Convention: 1). Each species was assigned the summed weights of policy and legal instruments that mention the species (species-specific score; *S*-score).

For this study two indices of BIO-SAFE were used: the *Taxonomic group Ecotope Importance* (TEI) constant and the *Taxonomic Biodiversity Saturation* (TBS) index. The TEI constant is calculated on the basis of two other constants: the *Potential Taxonomic group Biodiversity* (PTB) and the *Potential Taxonomic group Ecotope* (PTE) constants (Eq. (1)). In order to make it possible to calculate taxonomic group level biodiversity assessment, the *S*-scores of species belonging to a particular taxonomic group are summed to yield the PTB. For each ecotope type, the *S*-scores assigned to the species linked to that ecotope are summed per taxonomic group, yielding the PTE constant. Subsequently, this PTE constant is related to the PTB constant, resulting in TEI constant ranging from 0 to 100 per ecotope type. TEI therefore represents the relative importance of a particular ecotope for a particular taxonomic group from the viewpoint of political and legal protection.

$$\mathrm{TEI} = \mathrm{PTE} \times \frac{100}{\mathrm{PTB}} \qquad (1)$$

TEI *Taxonomic group Ecotope Importance* constant;
PTE *Potential Taxonomic group Ecotope* constant;
PTB *Potential Taxonomic group Biodiversity* constant.

For the calculation of the TBS indices the above-mentioned PTB constants and the *Actual Taxonomic group Biodiversity* (ATB) scores are used (Eq. (2)).

$$\mathrm{TBS} = \mathrm{ATB} \times \frac{100}{\mathrm{PTB}} \qquad (2)$$

TBS *Taxonomic group Biodiversity Saturation* index;
ATB *Actual Taxonomic group Biodiversity* score;
PTB *Potential Taxonomic group Biodiversity* constant.

Data on actual presence of species in a particular area can be used to calculate the biodiversity indices at the taxonomic group level. For this purpose the *S*-scores of the species actually present in an area are summed, yielding an ATB score. This score reflects the actual value of the area per taxonomic group. TBS thus represents the level of saturation of a particular area regarding the presence of politically and legally protected species of a particular taxonomic group.

Assessment of impacts of land use change on potential values of each taxonomic group are calculated by multiplying the TEI scores per ecotope type by the relative surface area of that particular ecotope type. The relative surface area of ecotopes were derived from remotely sensed ecotope maps, using ArcGIS 9.0 (see Section 2.5). This results in the *Taxonomic group Floodplain Importance* score (TFI; Eq. (3)).

$$\mathrm{TFI}_y = \sum \left(\left(\frac{\mathrm{SA}_{\mathrm{ecotope}\,x}}{\mathrm{SA}_{\mathrm{floodplain}}} \right) \times \mathrm{TEI}_x \right) \qquad (3)$$

TFI_y *Taxonomic group Floodplain Importance* score for taxonomic group *y*;
$\mathrm{SA}_{\mathrm{ecotope}\,x}$ surface area of ecotope *x* present in the floodplains;
$\mathrm{SA}_{\mathrm{floodplain}}$ surface area of the floodplains;
TEI_x *Taxonomic group Ecotope Importance* score for ecotope type *x*.

A detailed explanation of the species selection process, the value assignment, the development of the ecotope typology and the linkage of species to ecotopes, including a full description of the functionalities of the BIO-SAFE model, can be found in De Nooij et al. (2004, 2006b). De Nooij et al. (2006a) tested the validity of the BIO-SAFE approach by comparing effects of landscape changes predicted by the model on the diversity of protected and endangered species with observed changes in species diversity in reconstructed floodplains. A statistically significant correlation ($p < 0.01$) was found between predicted and observed effects. Moreover, quantification of sensitivity of model output to value assignment shows that the model is not very sensitive to assignment of values to different policy and legislation based criteria (De Nooij et al., 2006a). Arbitrariness of the value assignment therefore has a very limited effect on assessment outcomes. However, the decision to include or exclude specific valuation criteria (e.g., Red List status of species) does lead to significant differences.

2.4. Biodiversity data

Actual distribution data of species present in the Vistula river valley were used for calculations of biodiversity value (i.e., TBS) with BIO-SAFE. Higher plants data for the period 1996–2001 were obtained from Kucharczyk (2001, 2003). Bird data were available for the period 1984–2000 (Tomiałojc, 1993; Tomiałojc and Stawarczyk, 2003; Sidło et al., 2004). Data on fish (Wisniewolski et al., 2004), mammals and herpetofauna (Wołoszyn and Furtak, 2004) and butterflies (unpublished data of J. Buszko and K. Pałka, Maria Curie-Skłodowska University, Lublin) were available for the period 1984–1991. For dragon- and damselflies actual data was lacking. TBS values of the Vistula river were compared with data from four floodplains along strongly regulated lowland reaches of the rivers Rhine and Meuse (De Nooij et al., 2004).

2.5. Landscape change

GIS-based analyses of remotely sensed landscape data were conducted by processing ecotope maps from digital black and white aerial photographs of the National Geodetic and Cartographic Company in Warsaw. Retrospective analyses of remotely sensed riverine landscape maps require similar environmental conditions. For instance flooding and plant growth strongly determines delineation of several types of ecotopes (Leuven et al., 2002; Geerling et al., 2006). Aerial photographs of summer conditions (presence of annual plants) with similar water level (base flow) were only available for the years 1953 (scale 1:15,000) and 2003 (scale 1:13,000). Available photographs of the intervening years showed large differences in momentary river discharge and were excluded from analyses to prevent bias by incomparable environmental conditions.

The photos were scanned into grey-scale image data sets, which then were geo-referenced and merged to one image of the entire research area in ERDAS IMAGINE software. The 2003 image was ortho-rectified using a topographic map of the Polish National Geodetic and Cartographic Institute (Kazimierz Dolny sheet 135.14; scale 1:25,000) and a digital elevation model based on the contour lines. The maximum geo-reference error was about 10 m. ArcGIS 9.0 was used to manually digitise the polygons of the landscape patches (riverine ecotopes) on the screen. To minimize overlay errors, the 2003 ecotope map was created first and used as a basis for the 1953 map. Differences larger than 10 m were considered to be changed ecotope borders (Geerling et al., 2006). Errors in the polygon creation and ecotope labelling process were minimized by stereoscopic verification of original photos and comparisons with topographical colour maps (1: 25,000). The level of detail in remotely sensed landscape images was strongly determined by the quality of aerial photographs. The use of best quality black and white photographs and stereographic interpretation allowed accurate mapping of nine types of ecotopes (landscape units): main channel, side channel, isolated floodplain lakes, bare soil (i.e., sandy banks and sediment deposits without vegetation), pioneer vegetation (i.e. sandy ecotopes sparsely covered by plant species that are able to colonize an area after the soil is disturbed by flooding, sedimentation or erosion), grassland, arable land, bush and forest. They represent important landscape elements used for land use change analysis of river floodplains (Miller et al., 1995; Leuven et al., 2002; Parsons and Gilvear, 2002; Freeman et al., 2003; Chmielewski, 2004; Geerling et al., 2006; Zomeni et al., 2008).

2.6. Characteristics of ecotopes

Ecotopes were classified to seven hydrodynamic classes along the hydrodynamic gradient. The theoretical relation between hydrodynamics and biodiversity is well-known and is exemplified in the flood pulse concept (Junk et al., 1989). The different taxonomic groups have different relations with hydrodynamics in terms of the minimum or maximum number of days flooded per year (De Nooij et al., 2006a). The criteria for the classification of hydroclasses were adopted from De Nooij et al. (2006b).

The dissimilarities in protected species (DS) among pair-wise combinations of various types of ecotopes were calculated using Eq. (4).

$$DS = 1 - \left(\frac{2N_c}{N_a + N_b}\right) \qquad (4)$$

N_a number of species present in ecotope A;
N_b number of species present in ecotope B;
N_c number of species present in both ecotopes.

If DS = 0, then all species are shared among ecotopes; if DS = 1 no species are shared.

3. Results

3.1. Potential biodiversity values

Valuation of riverine ecotopes of the Vistula river shows which ecotopes are important for which species groups (Table 1). The TEI constants vary remarkably for ecotopes and taxonomic groups. Relatively high TEI constants were found for: (a) the summer bed and side channels for fish; (b) lakes and foodplains channels for amphibians; (c) grassland ecotopes for birds and butterflies; and (d) forested ecotopes for mammals. Our results clearly show that habitats of protected species differ remarkably in hydrodynamics. Aquatic ecotopes with high hydrodynamic conditions (classes 1–2) are important for fish. Intermediate hydrodynamic conditions (classes 3–5) are important for higher plants, birds, herpetofauna and butterflies. Ecotopes with low hydrodynamics conditions (classes 6–7) are important for mammals, higher plants species and butterflies.

The dissimilarity in assemblages of protected species among pair-wise combinations of ecotopes is rather high (in particular for higher plants) and differ strongly between ecotopes and taxonomic groups (Table 2), indicating that ecotopes are characterized by unique assemblages of protected species.

3.2. Actual biodiversity values

The mean TBS value for the Vistula river valley in the Kazimierski Landscape Park is 46% (Table 3). The mean TBS value of our study area is comparable with that of the Common Meuse in Belgium, but much higher than the values of the floodplains Rijnwaarden along the Rhine river in the Netherlands and Mouzay area along the Meuse river in France. The rivers Rhine and Meuse are roughly under the same temperate climate regime, but differ remarkably in habitat availability for protected species. In spite of a small acreage, the Vistula river valley shows highest TBS-scores for higher plants, herpetofauna, fish and mammals, indicating a high ratio between the actual and potential values of the landscape park for protected species. However, the TBS-score for birds is relatively low.

3.3. Landscape change and biodiversity values

The number, total surface area and average patch size of ecotopes in the Vistula river valley varied remarkably between the years 1953 and 2003 (Fig. 4, Table 4). The total number of patches increased by almost 44%, mainly due to an increase in the number of side channels and forest patches. Between the villages of Zastów Polanowski and Męcimierz (river km 350–355), the main channel now separates into several (side) channels. The surface area and average patch size of the main channel, isolated floodplain lakes, bare soil, pioneer vegetation and grassland strongly decreased while the average and total surface area of bush, forest and arable land increased. The changes in main and side channels indicate progressive effects of river regulation (e.g. flow regulation by an upstream dam and construction of groynes). Changes in

Table 1
Taxonomic group Ecotope Importance constants (TEI; 0–100) and hydrodynamic classes for ecotopes of the Vistula river in Poland, reflecting their relative importance for protected species (shadings indicate the three highest values for each taxonomic group).

Ecotopes at scale 1:25,000	Hydrodynamic class	BI	BU	DD	FI	HP	MA	RA
Deep summer bed	1	9	0	0	65	0	14	0
Lake	1–7	43	0	43	19	6	39	94
Shallow summer bed	2	6	0	40	100	7	25	10
Floodplain channel	2–7	53	0	83	31	10	39	94
Side channel	3–4	12	0	40	71	6	39	10
Beach, bank, bar	3–4	12	0	40	50	15	37	0
Gravel deposit	3–4	16	11	0	0	0	0	0
Herbaceous marsh	4–5	59	49	60	0	25	21	74
Marsh grassland	4–5	54	67	40	0	14	28	68
Moist grassland	4–5	54	67	40	0	7	28	46
Herbaceous moist floodplain	4–5	51	67	40	0	4	28	44
High-water-free herbaceous area	4–6	15	34	40	0	0	58	52
Softwood alluvial forest	4–6	14	10	0	0	8	83	39
Hardwood alluvial forest	4–6	12	11	0	0	5	83	42
Other forested ecotopes in floodplain	4–6	12	13	0	0	2	88	52
River dune	5–6	17	11	0	0	9	8	40
Levee pastures	5–6	18	34	0	0	5	16	49
Shrubs in floodplain	5–6	16	27	40	0	5	43	29
Shrubs on levee	5–6	14	0	40	0	5	43	42
Forested levee	5–6	18	3	0	0	14	83	52
Herbaceous levee or dyke	7	19	34	40	0	2	56	61
High-water-free grassland	7	17	23	40	0	15	23	0
High-water-free forested area	7	9	1	40	0	16	75	42

BI: birds; BU: butterflies; DD: dragon- and damselflies; FI: fish; HP: higher plants; MA: mammals; RA: reptiles and amphibians; hydrodynamic classes after De Nooij et al. (2006b): 1: deep water; 2: permanently flooded; 3: river bank; 4: flooded >100 days per year; 5: flooded 20–100 days per year; 6: flooded <20 days per year; 7: never flooded.

patchiness of semi-aquatic and terrestrial ecotopes indicate succession from pioneer vegetation to alluvial forest. The acreage of arable land has increased at the expense of grassland. Isolated floodplain waters are subject to succession and/or land reclamation.

The landscape changes in the study area affect potential biodiversity values (Fig. 5). The average TFI score shows a slight decrease (2%) over the period 1953–2003. The TFI scores for fish, birds and odonates show a decrease with 35%, 4% and 2%, respectively. However, the scores for butterflies, mammals, herpetofauna, and higher plants increase with 25%, 14%, 11% and 4%, respectively.

4. Discussion

4.1. Biodiversity assessment

Attuning biodiversity conservation and river management is a major issue in applied ecology and landscape planning (Leuven and Poudevigne, 2002). In several planning procedures it is compulsory to take (habitats of) protected species into consideration (De Nooij et al., 2004). This paper describes the development and application of an operational model for valuation of species, ecotopes, and areas, as well as for assessment of impacts of changes

Table 2
Dissimilarity in protected species for ecotopes of the Vistula river (shadings indicate the three highest values of dissimilarity for each taxonomic group).

Ecotopes at scale 1:25,000	Dissimilarity[a]						
	BI	BU	DD	FI	HP	MA	RA
Deep summer bed	0.24	n.a.	n.a.	0.25	n.a.	0.20	n.a.
Lake	0.13	n.a.	0.15	0.15	0.25	0	0
Shallow summer bed	0.34	n.a.	0	0.25	0.34	0.20	0
Floodplain channel	0.13	n.a.	0.12	0.15	0.25	0	0
Side channel	0.24	n.a.	0	0.28	0.34	0	0
Beach, bank, bar	0.65	n.a.	0	0.43	0.50	0.12	n.a.
Gravel deposit	0.08	0.34	n.a.	n.a.	n.a.	n.a.	n.a.
Herbaceous marsh	0.17	0.07	0.12	n.a.	0.72	0	0.12
Marsh grassland	0	0	0	n.a.	0.67	0	0.12
Moist grassland	0	0.07	0	n.a.	0.67	0	0.20
Herbaceous moist floodplain	0.04	0	0	n.a.	0.67	0	0.20
High-water-free herbaceous area	0.12	0	0	n.a.	n.a.	0.14	0.08
Softwood alluvial forest	0.23	0.17	n.a.	n.a.	0.72	0	0.12
Hardwood alluvial forest	0.15	0.17	n.a.	n.a.	0.46	0	0
Other characteristic forested biotopes in floodplains	0.15	0.34	n.a.	n.a.	0.67	0.04	0.12
River dune	0.08	0.34	n.a.	n.a.	0.78	0.60	0
Levee pastures	0.09	0	n.a.	n.a.	0.50	0.34	0.08
Shrubs in floodplain	0.50	0.25	0	n.a.	0.50	0.24	0.15
Shrubs on levee	0.23	0	0	n.a.	0.50	0.17	0
Forested levee	0.18	0.34	n.a.	n.a.	0.06	0	0.12
Herbaceous levee or dyke	0.09	0	0	n.a.	0.50	0.14	0.08
High-water-free grassland	0.12	0.20	0	n.a.	0.64	0.34	n.a.
High-water-free forested area	0.17	0	0	n.a.	0.06	0.04	0

BI: birds; BU: butterflies; DD: dragon- and damselflies; FI: fish; HP: higher plants; MA: mammals; RA: reptiles and amphibians; n.a.: not applicable, since none of the species belonging to this taxonomic group makes use of the ecotope.

[a] Minimum value of all pair-wise combinations of ecotopes per taxonomic group.

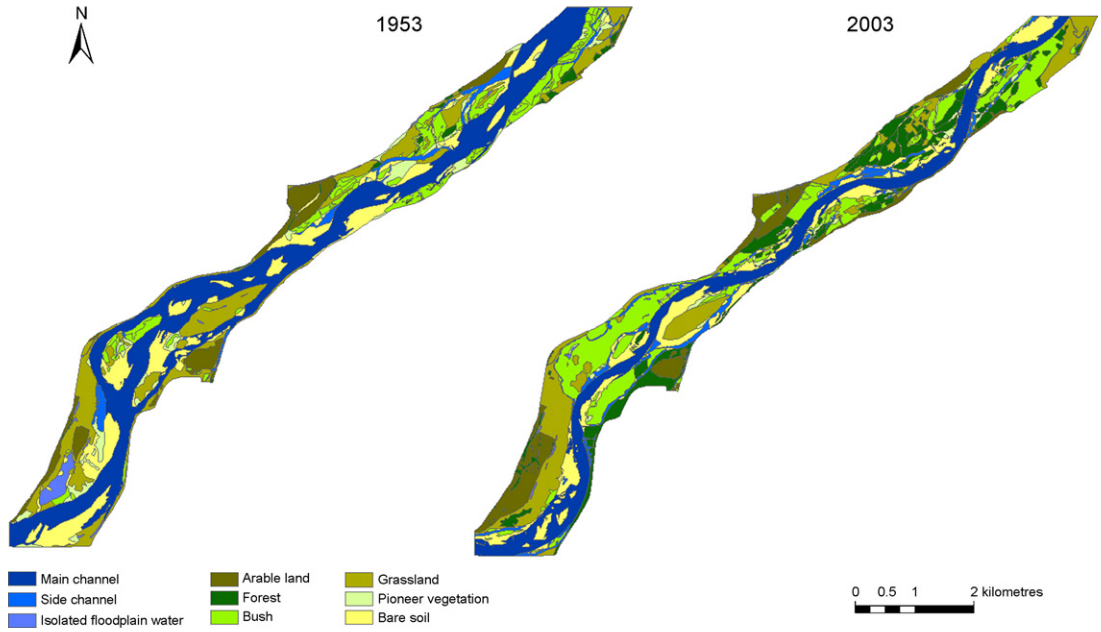

Fig. 4. Land use of the Vistula river floodplains for 1953 and 2003 (river km 349–359).

Table 3
Taxonomic group Biodiversity Saturation indices (TBS; 0–100) for seven taxonomic groups for various lowland river reaches in Europe (highest score per taxonomic group is shaded). Results for Rhine and Meuse rivers after De Nooij et al. (2004).

Taxonomic group	Middle Vistula river valley	River Rhine	River Meuse	
	Kazimierski Landscape Park, Poland (482 ha)	Rijnwaarden, The Netherlands (1100 ha)	Mouzay, France (570 ha)	Common Meuse, Belgium (2365 ha)
Higher plants	66.8	19.2	50.0	58.2
Birds	50.3	62.9	56.6	58.4
Mammals	70.9	52.2	0.0	–
Reptiles and amphibians	43.0	42.2	36.3	–
Fish	31.3	24.1	–	22.6
Butterflies	14.8	0.0	–	–
Dragon- and damselflies	–	8.5	0.0	–
Mean value	46.2	29.8	28.6	46.4

(–) Lack of data.

in river–floodplain ecosystems of the Vistula river, based on legally protected species. BIO-SAFE offers the opportunity to present politically and legally relevant indices on various levels of scale, i.e., (1) species (assemblages) and taxonomic groups, and (2) riverine ecotopes and riverine areas (floodplains). The method links ecological knowledge with (inter)national nature conservation policy goals, by providing insight into ecologically relevant parameters from the viewpoint of protected and endangered species. The model can be

Table 4
Changes in number of patches, total surface areas and average size of ecotopes in the floodplains of the Middle Vistula river valley (river km 349–359).

Ecotope type	Number of patches			Total surface area			Average patch size		
	1953	2003	Change (%)	1953 (ha)	2003 (ha)	Change (%)	1953 (ha)	2003 (ha)	Change (%)
Main channel[a]	1	1	0.0	413.1	237.2	−42.6	413.1	237.2	−42.6
Side channel[b]	13	50	284.6	21.0	57.9	175.7	1.6	1.2	−28.3
Isolated floodplain lakes[b]	22	12	−45.5	22.9	4.1	−82.2	1.0	0.3	−67.3
Grassland[a]	25	23	−8.0	218.8	175.3	−19.9	8.8	7.6	−12.9
Arable land[c]	10	14	40.0	89.9	134.3	49.4	9.0	9.6	6.7
Bush[a]	45	49	8.9	77.7	212.7	173.7	1.7	4.3	151.4
Forest[a]	13	67	415.4	6.4	132.1	1964.1	0.5	2.0	300.5
Pioneer vegetation[d]	30	26	−13.3	55	16.9	−69.3	1.8	0.6	−64.6
Bare soil[b]	51	60	17.6	201.9	136.1	−32.6	4.0	2.3	−42.7
Total	210	302	43.8	1106.6	1106.6	0.0	5.3[e]	3.7[e]	−30.2

Forest: dense and open forest; Bush: dense and open shrub patches; Side channel: flowing side channel, semi-connected floodplain water and stream.
[a] BIO-SAFE level of scale 1.
[b] Level of scale 3.
[c] Level of scale 4.
[d] Level of scale 2.
[e] Weighted average.

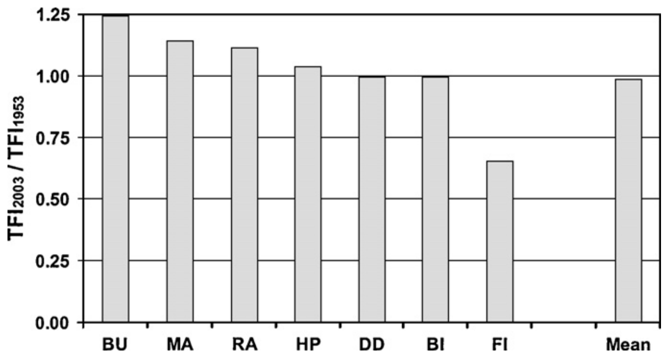

Fig. 5. Changes in potential biodiversity values of the Vistula river floodplains (river km 349–359) over the period 1953–2003 (TFI: *Taxonomic group Floodplain Importance* score; HP: higher plants; BI: birds; RA: reptiles and amphibians; MA: mammals; FI: fish; BU: butterflies; DD: dragon- and damselflies).

used to valuate actual data, historical trends, and results of scenario analyses and physical reconstruction designs.

Traditional biodiversity indices, for example Shannon, Simpson's and Berger-Parker Dominance, are measures for biological diversity that are often poorly understood by policy makers, require quantitative data on species distribution and cannot give insight into the potentials of taxonomic groups and ecotopes or the consequences of reconstruction measures (De Nooij et al., 2004). Assessments by means of BIO-SAFE on the other hand are already possible on the basis of presence–absence data of species and/or riverine ecotopes and can be carried out at several levels of spatial scale. An assessment can be based on international treaties and European Union directives concerning species protection, and national legislation and Red Lists concerning endangered species and on all combinations of these political and legal criteria.

An important step in constructing this model comprised the selection of species. Species selection and relations between species and ecotopes were mainly based on ecological literature and geographic distribution maps of species. Our list of protected and endangered species characteristic of the Vistula river was verified by several experts. Due to lack of literature data, habitat descriptions of some species are based on unpublished monitoring data and personal observations of river ecologists. Selection of species and habitat descriptions always carries a subjective touch. However, there seems to be no way to renounce this subjectivity because there are no data available that allow a selection based on mathematical or logical algorithms.

The species in the model are river characteristic, protected and/or endangered species that are indigenous to Poland. Taxonomic groups involved are higher plants, birds, herpetofauna (reptiles and amphibians), mammals, fish, butterflies and dragon- and damselflies. Taking into account these taxonomic groups, the total number of species in the final selection for the Vistula river is 177 (Table 5). This figure is higher than the number of protected river species selected for the middle and lower reaches of the Rhine river in Germany and the Meuse river in France and Belgium (i.e., 160–173 species), but lower than that of the Rhine-Meuse delta in the Netherlands (i.e., 257 species). Our species selection accentuates that the Vistula river represents highest potential values for butterflies, fish, herpetofauna and mammals. Differences between countries can be explained by biogeographical aspects and differences in environmental pressure on species in each country. In addition, the criteria for selection of Red-listed species differ between countries. The selection criterion 'river characteristic' means that, according to the literature and a panel of experts, the whole population of a species or the largest part of the population is considered to be river-bound or closely associated with riverine areas. Species that are currently not found in the riverine areas because sufficient habitat is lacking have also been considered characteristic of rivers.

The hierarchical ecotope typology used in the model is adapted from De Nooij et al. (2004). It was constructed by integration of various well established landscape–ecological typologies in the context of low land river management in north-western Europe, but also appeared to be useful for the Vistula river valley. This typology is based on abiotic processes such as morphodynamics, hydrodynamics and land use. These processes determine operational factors such as moisture regime, nutrient availability and acidity. The use of ecotopes provides a basis for assessing biodiversity at the landscape level in addition to the species level and gives a clear insight into the spatial consequences of species protection.

4.2. Potential values of riverine ecotopes

The potential values of various riverine ecotopes of the Vistula river differ remarkably for various taxonomic groups (Table 1). Moreover, ecotopes are characterized by unique assemblages of protected species (Table 2). Species and taxonomic groups have specific evolutionary adaptations to hydrodynamics and therefore show different distribution pattern along hydro-morphological gradients in riverine landscapes (De Nooij et al., 2006b). Our study supports the view that for some groups of protected species (e.g., rheophilous fish), it is the high-dynamic parts that are more important, while for other groups (e.g., higher plants, herpetofauna and butterflies), the most important parts are those with low dynamics. Many species of birds, mammals and odonates predominantly use the entire gradient. Most plant species, and to a lesser extent also butterflies and fish, are specifically bound to one or two hydrodynamic classes. Similar patterns are described for hydromorphological gradients along the rivers Rhine and Meuse (De Nooij et al., 2006b).

4.3. Actual biodiversity values

Despite of several anthropogenic impacts and related water pollution, life in the Vistula river and its valley is thriving (Kajak, 1993). The riverine areas function as ecological corridors and offer a refuge for many animal and plant species. Our study reveals that the river valley in Kazimierski Landscape Park still represents relatively high biodiversity values (Table 3). Many nationally and internationally protected species were recorded in recent field surveys. The actual biodiversity values of the Vistula river valley are relatively high in comparison with floodplains along regulated lowland rivers in Western Europe, i.e. the rivers Rhine and Meuse. High biodiversity values are related to a relatively unmodified riverbed with meanders, side channels, steep banks, sandbars, numerous islands and oxbow lakes. The river–floodplain system still shows intact hydrodynamic gradients and high landscape heterogeneity. Therefore, the riverine corridor offers specific habitats for a broad spectrum of aquatic, amphibious and terrestrial species, including many protected and endangered species.

4.4. Analyses of landscape change and effects on biodiversity values

The GIS analyses reveal remarkable changes in distribution of riverine ecotopes over the period 1953–2003 (Table 4). Differences in number, surface area and spatial configuration of ecotopes indicate natural vegetation succession as well as progressive human impact (e.g., intensification of agricultural land use and river regulation).

According to Plit (2004) until the late 18th and early 19th centuries the Middle Vistula river was mainly affected by natural

Table 5
Number of protected and endangered species included in BIO-SAFE. Results for Rhine and Meuse rivers after De Nooij et al. (2004).

Taxonomic group	Country				
	PL River Vistula	NL Rhine-Meuse delta	G River Rhine	F River Meuse	B River Meuse
Higher plants	49	136	60	12	90
Birds	64	60	58	113	38
Reptiles and amphibians	11	9	11	7	4
Fish	17	9	11	7	5
Butterflies	20	20	17	10	16
Dragon- and damselflies	6	17	9	7	15
Mammals	17	6	5	4	5
Total	177	257	171	160	173

PL, Poland; NL, The Netherlands; G, Germany; F, North-eastern France; B, Belgium; Shadings indicate highest value per taxonomic group.

factors, especially the fluctuations of precipitation. The river was still freely meandering in places as late as in the 19th century. The sizes of the bends did not change for several centuries, indicating limited changes in the river regime and sediment load. After the Second World War, the Middle Vistula river became regulated (e.g., construction of lateral embankments and some groynes), which diminished the flooding area, increased the water level at high discharges and also limited channel changes (Maruszczak, 1997; Chmielewski et al., 2004; Cyberski et al., 2006). Several dams and reservoirs in upper reaches near Cracow also affected river flow and sediment balance or the river. Such measures are known to decrease dynamism of rivers, hinder channel development, drain floodplain wetlands, and may cause extensive modification of (semi-)aquatic communities (Nilsson et al., 2005). River regulation tends to eliminate side arms and branches of the river as well as permanent and temporary islands, and to decrease landscape heterogeneity (Kajak, 1993). Our study also reveals that the main channel of the Vistula river changed remarkably over the period 1953–2003 (Fig. 4). The river transformed at river km 350 from two branching channels into one main river bed, and bush vegetation occupied the abandoned channel. Vegetation succession was also observed at the left bank of the river, opposite of Kazimierz Dolny village (river km 358). The main channel at river km 358–360 moved after the creation of the groynes.

Natural retention capacities of the river catchments have diminished markedly due to decreasing area of forests, disappearance of small water bodies and wetlands (Mioduszewski, 2004). Our results indicate a partial reversal of this trend over the period 1953–2003 (Table 4). The decrease of grasslands and steep increase of bush and forest indicate more extensive land use (e.g., reforestation and lower grazing pressure), although in some parts of the floodplains land use still intensifies (mainly increase of arable land). Moreover, according to transition schemes of riverine ecotopes (Tockner and Stanford, 2002; Geerling et al., 2006) our results also indicate natural vegetation succession from bare soil, pioneer vegetation and (herbaceous) grassland to bush and forest.

In spite of relatively high biodiversity values of our study area in comparison with other north-western European river systems, the actual biodiversity values of Kazimierski Landscape Park are not saturated for several taxonomic groups (Table 3). The assessment of recent landscape change with BIO-SAFE shows a decline of the potential values of the Vistula river valley for several groups of protected and endangered species (Fig. 5). The decrease of potential values of the study area for fish and odonates over the period 1953–2003 is mainly related to a decrease in surface area of the main channel and isolated floodplain lakes. The decrease in potential values for birds is mainly related to the ongoing vegetation succession from grassland to bush and forest, combined with an increase in the acreage of arable land. According to Oleksyn and Reich (1994) habitat loss, landscape fragmentation, and intensification of agriculture and forestry indeed contributed to the loss of many protected and endangered species in Poland.

4.5. Implication for river management and spatial planning

The deforestation and conversion to agricultural land in upper reaches enormously reduced the water retention capacity of the Vistula river (Kajak, 1993) and the construction of embankments strongly diminished the flooding area (Cyberski et al., 2006). Economic activities of residents play an important role in land use changes during the recent period of system transformation in Poland (Lowicki, 2008). Our study shows that the number, acreage and patchiness of ecotopes in the Middle Vistula river valley has been changed remarkably due to vegetation succession, intensification of agriculture and progressive impacts of river regulation. These landscape changes negatively affected biodiversity values of the river valley.

Kajak (1993) discussed the relevance of rational planning and organisation of water management and nature conservation for the Vistula river. The biodiversity values of the river and its riparian corridor form a high potential for ecotourism. The Vistula river valley has special importance for recreation due to its central location within Poland. In relation to the high ecological values and tourism purposes it is necessary to combine all data sources (e.g. models, monitoring, remotely sensed data) for improving river management. The current flood protection problems should also be taken into consideration in land development and spatial planning.

BIO-SAFE appeared to be a useful tool for assessment of potential biodiversity values of riverine ecotopes and landscapes and for evaluation of biodiversity data from monitoring programmes of river–floodplain systems. Important recommendations to optimise opportunities for protected and endangered biodiversity in spatial planning and management of the Middle Vistula river valley are: (1) to prevent further conversion of riverine ecotopes with high biodiversity values to arable land; (2) to increase the acreage of (semi-) aquatic ecotopes by counteraction of negative impacts of river regulation; (3) to reduce the ongoing vegetation succession from grassland to bush and forest by semi-natural grazing regimes and cyclic floodplain rejuvenation measures (Geerling et al., 2006). These measures should be considered in the forthcoming management plan for the Natura 2000 PLB 14006 site, nature conservation plan Kazimierski Landscape Park and river basin management plan.

Policy based biodiversity assessment with BIO-SAFE yield complementary information compared to more conventional ecological approaches and has relatively low data requirements (De Nooij et al., 2004). Therefore, it is recommended to apply a multi-approach methodology in monitoring, evaluation and valuation of effects of river management and riverine landscape planning on biodiversity. BIO-SAFE is best used early in planning processes for designing reconstruction scenarios that optimise opportunities for protected and endangered biodiversity, during the fine-tuning of designs in order to determine which ecotopes are in the actual situation the most valuable and should be conserved, and as a tool for evaluation of biodiversity data from monitoring programmes of river–floodplain systems or rehabilitation projects.

5. Conclusions

The potential values of riverine ecotopes of the Middle Vistula river valley are rather high for protected and endangered species of fish, butterflies, reptiles, amphibians and mammals. However, these values remarkably differ for various taxonomic groups. Riverine ecotopes are characterized by unique assemblages of protected species. In particular river dunes, banks and bars show high uniqueness regarding their species assemblages.

The actual biodiversity values of the river valley in Kazimierski Landscape Park are still high in comparison with floodplains of lowland rivers in Western Europe. This study area shows highest Taxonomic group Biodiversity Saturation scores for higher plants, butterflies, fish, amphibians, reptiles and mammals, but lowest scores for birds.

Over the period 1953–2003 the number, acreage and patchiness of ecotopes remarkably changed due to vegetation succession, intensification of agriculture and progressive impacts of river regulation. Current landscape changes negatively affect potential values for protected and endangered species (i.e., odonates, fish and birds).

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