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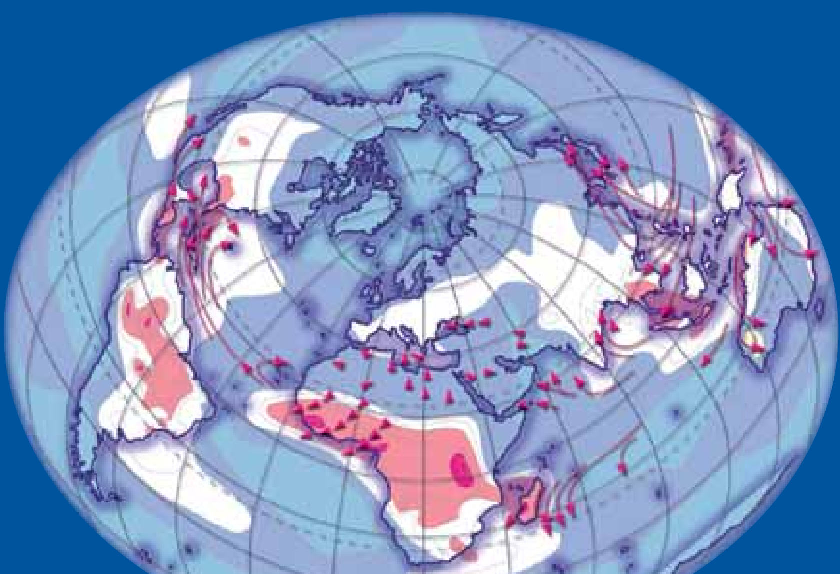

VEGETATION MAPS AS A TOOL IN ENVIRONMENTAL ASSESSMENT AND SPATIAL PLANNING

POLISH ACADEMY OF SCIENCES
INSTITUTE OF GEOGRAPHY AND SPATIAL ORGANIZATION

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COMPLEX MULTI-LAYER VEGETATION MAP AS THE BASIS FOR DETAILED GEOBOTANICAL REGIONALIZATION AND CHARACTERIZATION OF THE SPATIAL STRUCTURE OF LANDSCAPE (A CASE STUDY FROM THE VISTULA RIVER VALLEY, POLAND)

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Abstract: The paper links vegetational microlandscapes distinguished on the basis of differentiation of actual vegetation with geobotanical sub-districts defined on the basis of differentiation of potential vegetation. For each of these microlandscapes an actual and potential vegetation, as well as land-use were analyzed; the analysis being performed for an area of ca. 540km^2 of the Vistula River valley. The spatial structure of these microlandscapes was characterized in terms of various landscape metrics. The analysis reveals that comprehensive treatment allows microlandscapes to be aggregated into typological (and potentially regional) units of a higher rank. However, the relationships between vegetational microlandscapes and geobotanical regionalization, based on potential vegetation are not unambiguous.

Key words: actual vegetation, potential vegetation, landscape metrics, vegetational microlandscapes, Vistula Valley, Poland

INTRODUCTION

In Europe, survey maps of potential vegetation have long been used for landscape typology and division into geobotanical regions (Mücher *et al.* 2003; Marchetti 2004; Wascher 2005). In Poland they have rather been used with respect to small areas, encompassing several hundred km^2 (Plit and Solon 1994a) or some thousand (Plit and Solon 1994b; Solon 1999). More important, though, are the renditions on the scale of Poland as a whole. These may be of a distinctly generalized (Matuszkiewicz W. 1980), or a highly detailed character (Matuszkiewicz J. M. 1993) that are often the basis for further research and mapping. A good example is the natural-silvicultural regionalization that takes into account the geobotanical differentiation of the landscape (Matuszkiewicz J. M. *et.al* 2001).

Large-scale maps of actual vegetation have been used to distinguish landscape units of a local character, through application of the method of landscape mosaic analysis.[1] The units thus distinguished (vegetational microlandscapes) are low level units within the region, that also correspond to distinct landscape units. These units comprise specific abiotic conditions and land

[1] This approach was applied in Poland in the spatial breakdown of part of the river Narew valley (Solon *et al.*1990), of Kampinos National Park and its buffer zone (Solon 2003), the neighbourhood of the town of Pińczów (Solon 1994), and the surroundings of lake Wigry (Solon 1988, 1990; Richling *et al.* 2001).

uses, as reflected in the spatial distribution of associated phytocoenoses and complexes that express the spatial structure of the entire landscape (Solon 2002).

The need for quantitative assessments and analyses of the spatial structure of the landscape was convincingly justified by Jaeger (2000). In his opinion, the quantitative approaches are indispensable in that they provide for: 1) documentation of the development of the landscape and verification of the observations of a qualitative character; 2) assessment of the degree of fragmentation of the area within the confines of a region and the possibility of comparison with other regions; 3) a search for interrelationships between structural features and the functioning and evolution of a landscape; 4) the formulation and testing of hypotheses concerning the presence of quantitative thresholds, and beyond them the type of spatial structure and factors shaping landscape change; 5) concise and unambiguous presentation of a landscape model.

Landscape metrics (McGarigal and Marks 1995) are used as indicators of landscape structure. They represent the configuration and composition of the landscape mosaic. Landscape configuration reflects the physical distribution of patches in space and accounts for relationships among patches with regard to degree of isolation, pattern and variability. The composition of a landscape deals with the differentiation and frequency of occurrence of individual patch types but does not account for their spatial location. Among the multitude of indicators the ones most appropriate to the synthetic presentation of spatial structure are the indices of fragmentation, richness and shape (e.g. O'Neill *et al.* 1988; Turner 1989; McGarigal and Marks 1995; Riitters *et al.* 1995; Solon 2002).

This paper attempts to link vegetational microlandscapes based on actual vegetation in part of the Vistula valley, Poland with the geobotanical sub-districts distinguished by J. M. Matuszkiewicz (1993) based on potential vegetation. In addition, the spatial structure of these microlandscapes is characterized, and any differences or similarities are discussed. The role of selected landscape metrics in the explanation of total variability of spatial structure and their usefulness in the process of identification of regions were also assessed.

DATA AND METHODS

The analyses performed referred to the vegetation map of the Vistula valley (Matuszkiewicz J. M. and Solon 1998), of which small fragments have been published (Romanowski *et al.* 2005). A portion of about 540 km^2 was selected from the map. Over this portion the vegetational microlandscapes were distinguished in accordance with the methods applied previously (Chmielewski and Solon 1996; Solon 2003). For each of the microlandscapes, the following basic indices of spatial structure (landscape metrics) were calculated:

MPS—mean patch size;

PSCOV—patch size coefficient of variance;

ED—edge density (length of boundaries per surface unit);

MPAR—mean perimeter-area ratio;

MSI—mean shape index (calculated on the assumption that, for a given area, the minimum length of perimeter is associated with a circle—in the vector approach, or with a square—in the raster approach).

The work was carried out using ArcView 3.2 software, with the PatchAnalyst extension. Interrelationships between variables were determined on the basis of the Pearson product-moment correlation coefficient. The ordering of variables and determination of their influence was achieved using Principal Component Analysis (Jongman *et al.* 1995). The mutual similarity of the spatial structure of landscapes was determined on the basis of the dendrogram obtained from Ward minimum variance clustering algorithm, based on the dissimilarity matrix containing standardized Euclidean distances. In the majority of statistical analyses the Statistica 5.0 and KyPlot 2.0 software packages were used.

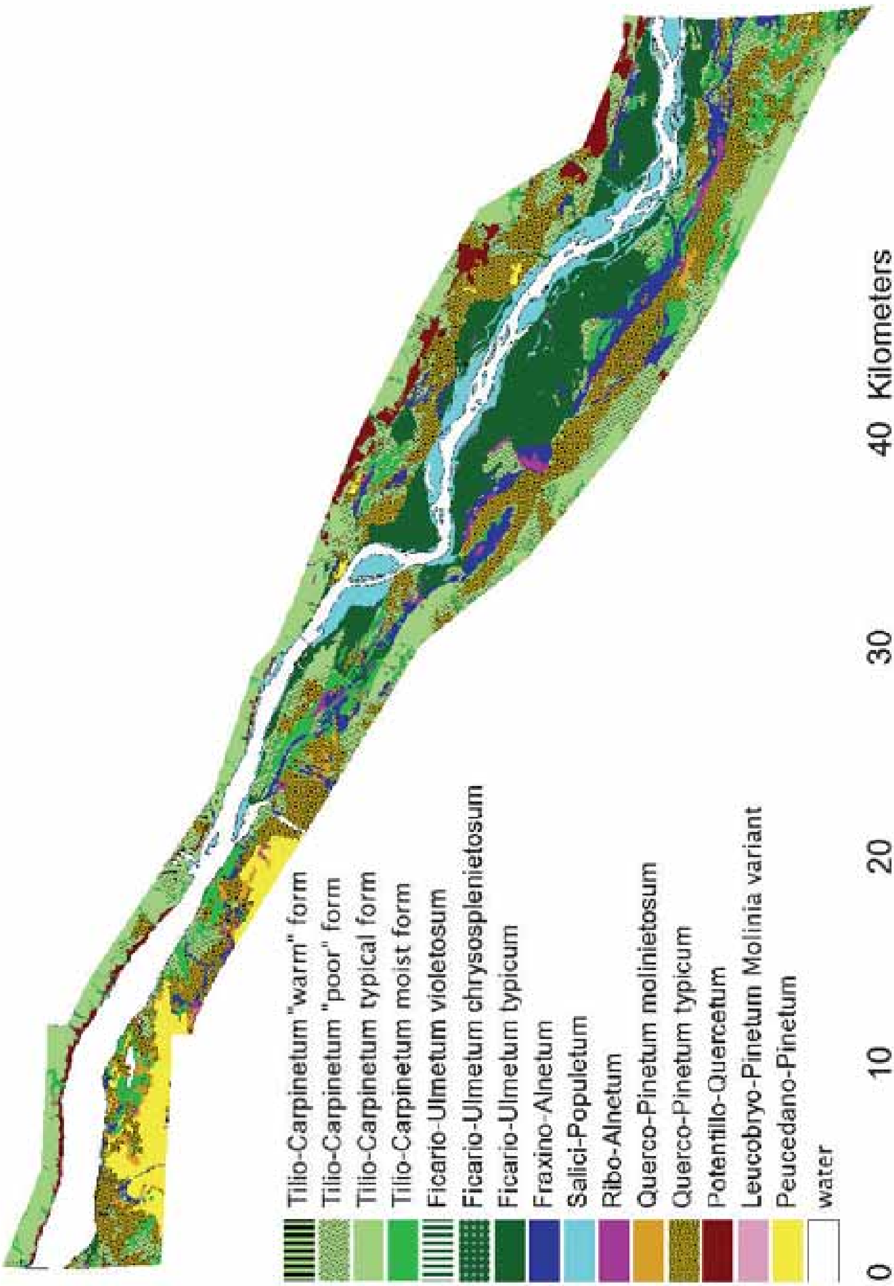

Figure 1.1. Potential vegetation of the analyzed fragment of the Vistula Valley (after Matuszkiewicz and Solon 1998)

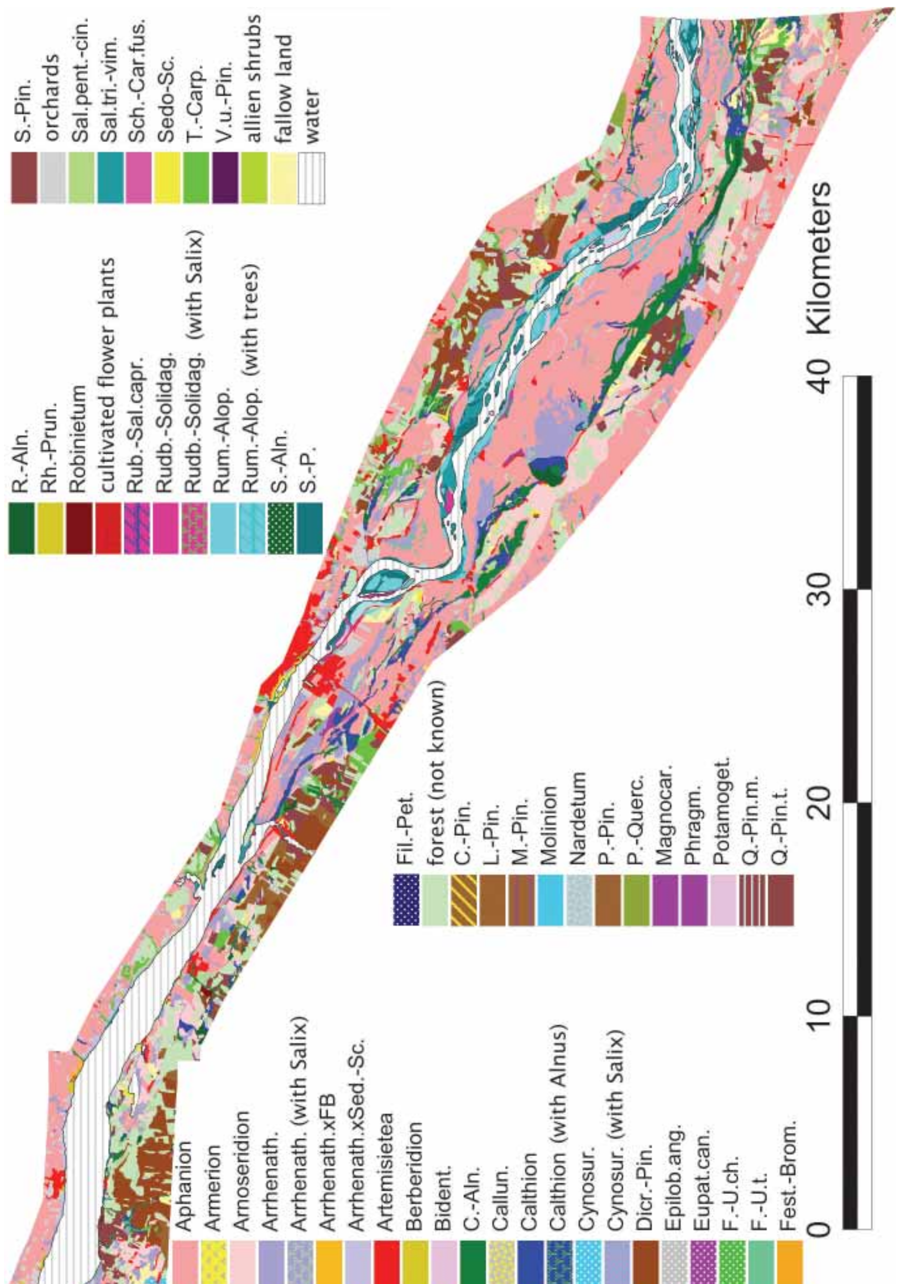

Figure 1.2. Actual vegetation of the analyzed fragment of the Vistula valley (after Matuszkiewicz and Solon 1998)

RESULTS

VEGETATIONAL MICROLANDSCAPES AND THEIR ROLE IN THE PROCESS OF DIVISION INTO GEOBOTANICAL REGIONS

Fifteen types of potential vegetation were distinguished in the study area, including four habitat forms of the oak-hornbeam forest habitat (Figure 1.1). The richness of the actual vegetation is much greater and encompasses 76 community types, including only 38 types that have well defined syntaxonomic status (most often corresponding with associations or alliances) (Figure 1.2). On the basis of differentiation in the distribution and adjacency of patches of the particular types of actual vegetation, it was possible to identify 13 vegetational microlandscapes, of which only two are entirely contained within the area in question, and all the remainder occurring far beyond the study area. Analysis of the course of the boundaries to microlandscapes and the characterization of their potential vegetation allowed for classification of the units distinguished into 9 geobotanical sub-districts, as distinguished by Matuszkiewicz (1993) (Figure 1.3). However, it should be emphasised that the unique assignment of a microlandscape to a geobotanical sub-district in some cases required a modification of the course of the boundaries to the sub-districts. This applies, in particular, to units E.1.8.e, E.1.8.d and E.2a.3.b, whose boundaries have clearly been moved in a westerly direction on the border with the bottom of the valley of the Vistula river. Likewise, sub-districts E.2a.4.a and E.2a.4.c were enlarged. Only in the case of the microlandscape no. 11 was it neither possible nor sensible to move the boundaries of the sub-districts. That is why, of necessity, this unit was partly classified within sub-districts E.1.6.f and E.1.6.g. Despite the divergences mentioned, the differences in the course of the boundaries are not very significant and result largely from the diverse degree of detail of characterizing the initial data.

THE DIVERSIFICATION OF VEGETATIONAL MICROLANDSCAPES

Each of the 13 distinguished vegetational microlandscapes displayed distinctly individual features, the mutual similarity depending upon the set of attributes considered. In terms of spatial diversity, it was possible to distinguish three groups based on the values for indices of diversity of potential vegetation, H(E), and actual vegetation, H(P). The four landscapes (2, 16, 17 and 22), which are least differentiated, are associated with the oak-hornbeam forest habitats of a field character situated far from the bed of the Vistula River. On the other hand, the most internally diverse group of landscapes encompassing five units (4, 11, 12, 13 and 110), was associated with the mosaic of humid and dry habitats (Table 1). Two measures sufficed in the assessment of interrelationship between the differentiation of actual vegetation and of habitats (expressed in terms of potential vegetation), namely the diversity of the actual vegetation H(P) and the index W=1—[H(E)/H(E,P)] (Solon 2002). In accordance with this assumption the analyzed microlandscapes were divided into four distinct groups (Figure 1.4). The first included units 16, 17 and 22 and was characterized by low values of both indices that indicated low habitat diversity with the habitat areas occupied by few types of plant community, indicating limited fragmentation of the area and limited differentiation of land-use forms. The second group encompassed landscapes 4, 5, 11, 14 and 110. These units were, in turn, characterized by high values for both indices, indicating a high level of habitat diversification, with each habitat characterized by marked diversification of the actual vegetation, meaning intensive fragmentation of habitat areas, differentiated human influence and diverse land-use forms. The third group included microlandscapes 12 and 13 only. These were characterized by high values of the H(P) index and the medium values of the index W indicating strong habitat diversification and land-use that is clearly specific with respect to habitat types, ensuring that each habitat is occupied by several vegetation types. The remaining microlandscapes (forming the fourth group) were characterized by intermediate values for both indices.

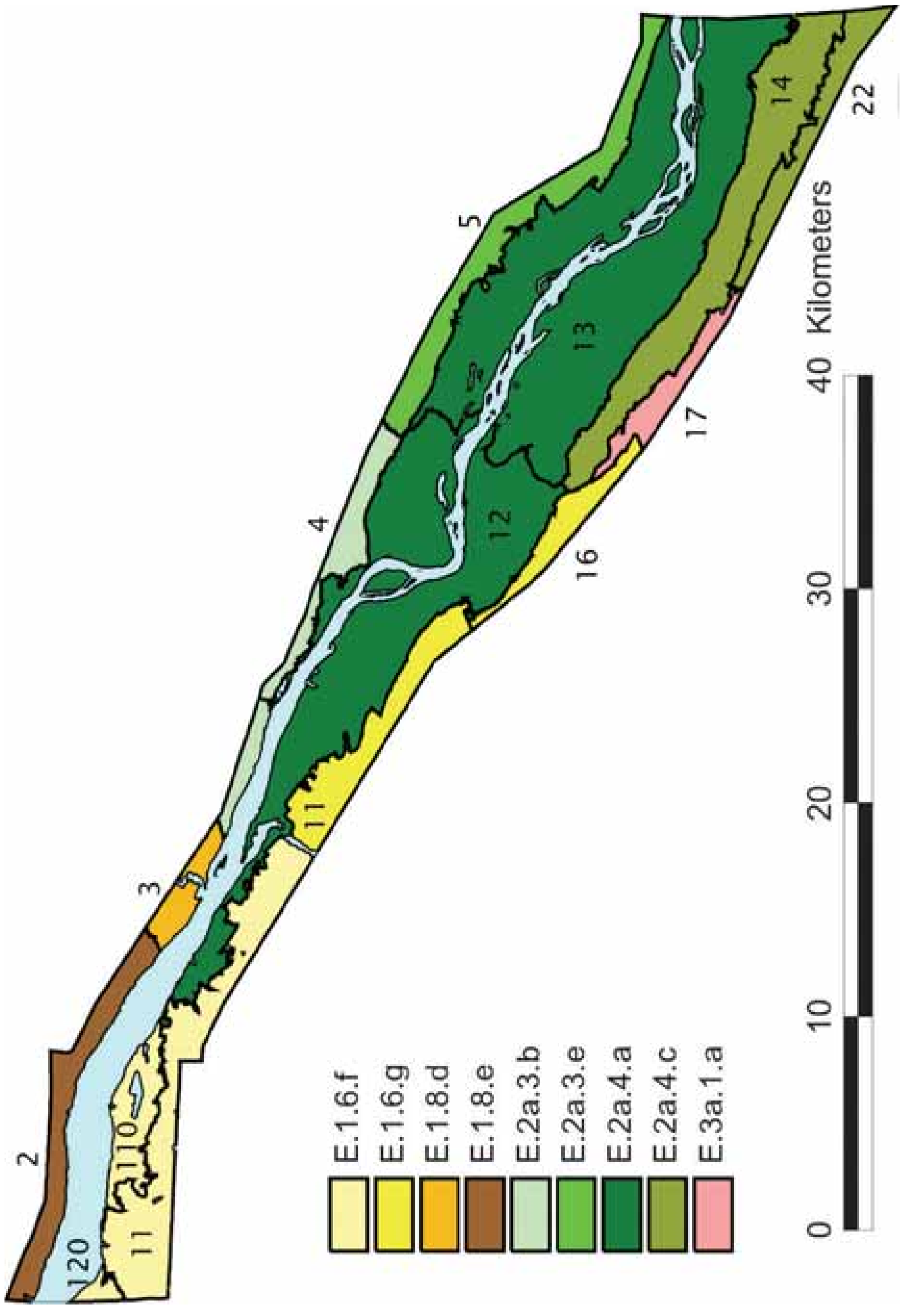

Figure 1.3. Vegetational microlandscapes and their relationship with geobotanical sub-districts (the latter after Matuszkiewicz 1993)

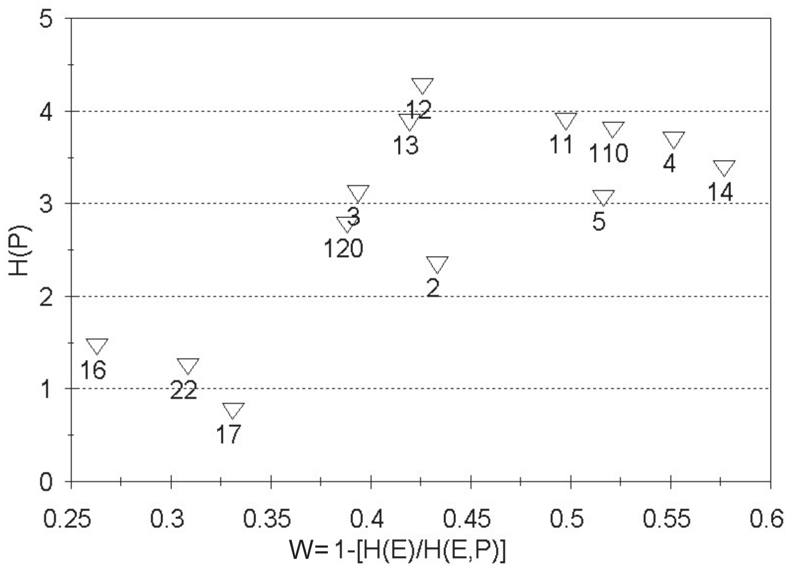

Figure 1.4. Typological diversity of actual and potential vegetation in microlandscapes

From the point of view of the degree of fragmentation of the actual vegetation three groups of landscape unit could be distinguished. The first comprised just two microlandscapes, associated with the floodplain forest habitats in the immediate vicinity of the river. They were characterized by the appearance of patches of elongate shape and a high density of boundaries per unit area. The second group (composed of three microlandscapes) stood out against the third group in its clearly greater mean patch size and much greater patch size coefficient of variance (Table 1). A somewhat different division into groups resulted from analysis of the fragmentation of the potential vegetation. A group of four microlandscapes was clearly distinct, characterized by a higher value for the mean patch size, and more elongate, but less fragmented shape in comparison with the remaining landscape units (Table 1). Yet another pattern resulted from the joint analysis of the degree of fragmentation of actual and potential vegetation (Table 1, Figure 1.5). The lowest values for both indices were characteristic of the microlandscapes situated on the cliff in the vicinity of the town of Płock, while the highest were for the agricultural microlandscapes in oak-hornbeam forest habitats.The variability of the mean shape index in particular microlandscapes was largely independent of mean patch size (Table 1, Figure 1.6). In these terms, the valley microlandscapes, in which the mean shape index values for the potential and actual vegetation were the highest were distinguishable.

From the point of view of spatial shares of particular types of habitat, all the microlandscapes could be divided into two groups. The first group encompassed five units (11, 12, 13, 14 and 110) and was characterized by a low (below 35%) share of oak-hornbeam forest habitats while in the remaining microlandscapes the share always exceeded 50% (Table 1).The division with respect to land-use structure was largely independent of the diversification of landscape metrics and role of particular types of potential vegetation. Three well-pronounced groups could be distinguished, namely four microlandscapes (2, 16, 17 and 22), in which cultivated field areas prevailed and shares of forests were below 15%, five microlandscapes (3, 5, 11, 14 and

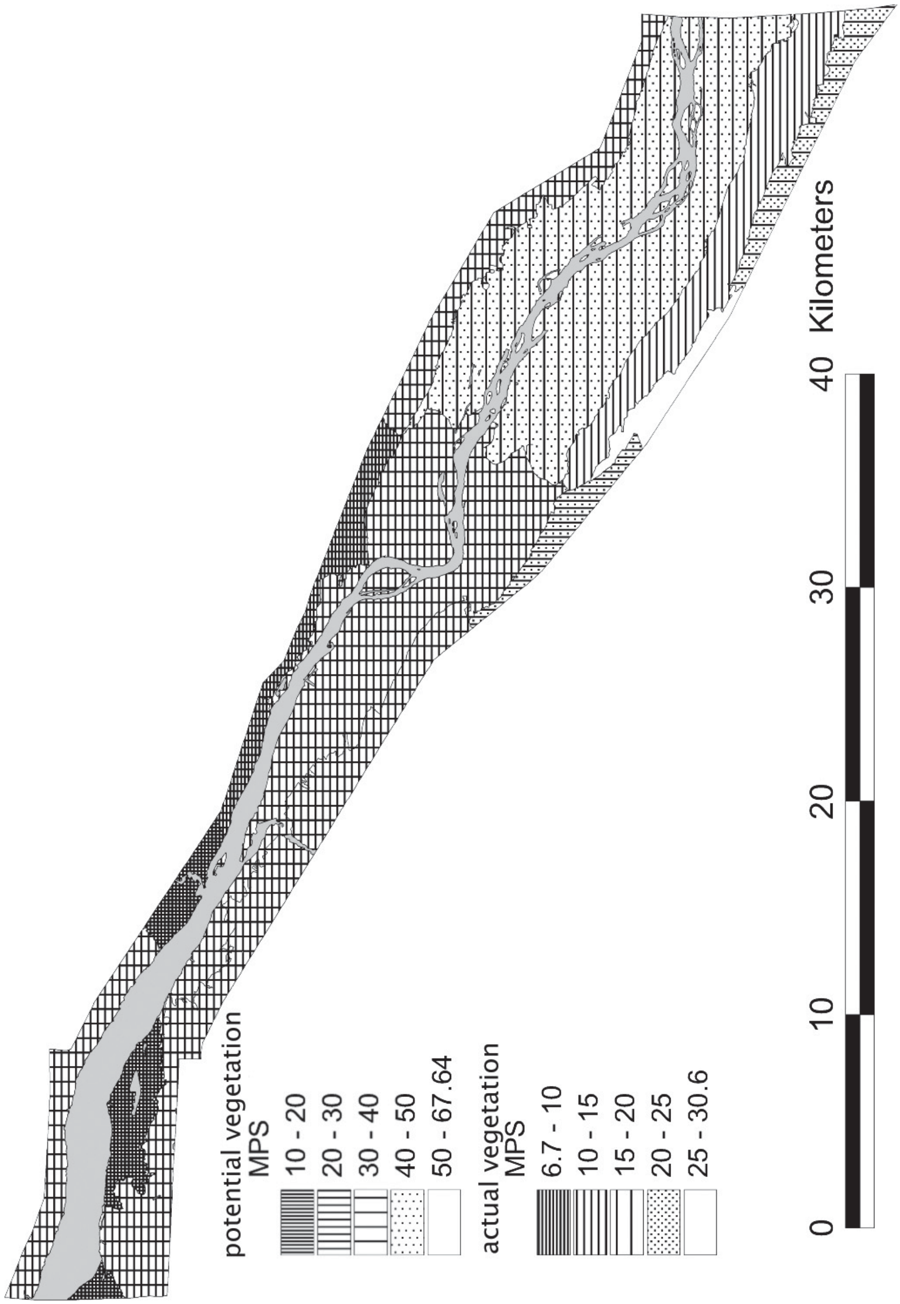

Figure 1.5. Mean Patch Size of actual and potential vegetation in microlandscapes

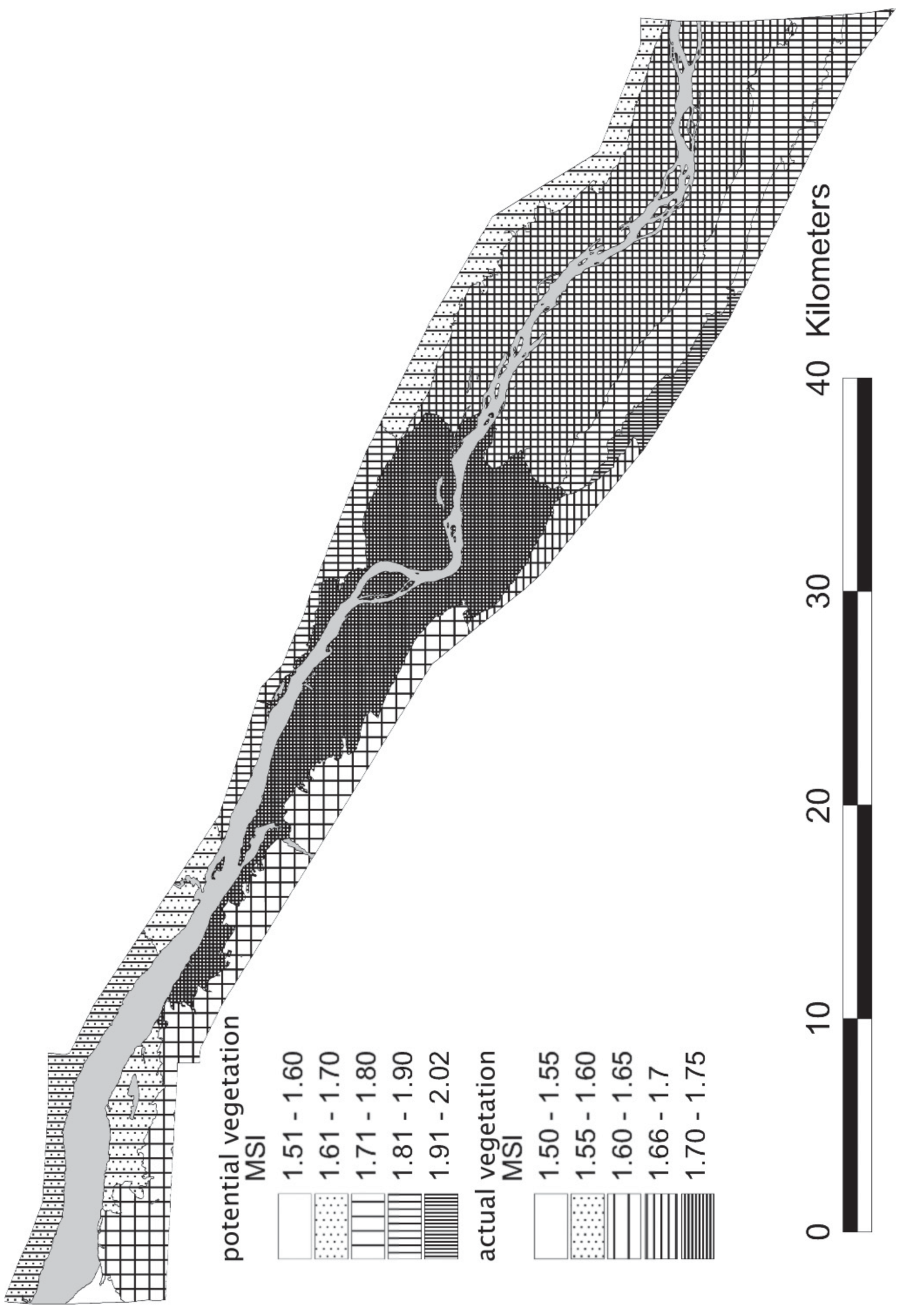

Figure 1.6. Mean Shape Index of patches of actual and potential vegetation in microlandscapes

Table 1. General characteristics of micro-landscapes

		micro-landscape number												
		2	3	4	5	11	12	13	14	16	17	22	110	120
diversity	H(P)	2.34	3.11	3.69	3.06	3.89	4.27	3.88	3.38	1.46	0.76	1.24	3.80	2.77
	H(E)	1.45	2.14	2.08	2.05	2.31	2.79	2.42	1.54	1.68	1.01	1.77	2.26	2.00
	H(E.P)	2.56	3.53	4.64	4.24	4.60	4.86	4.17	3.64	2.28	1.51	2.56	4.72	3.27
actual vegetation	MPS	11.67	7.46	9.64	13.61	12.30	12.89	16.24	12.21	20.87	30.55	23.16	7.29	6.65
	PSCoV	327.84	261.80	258.68	311.12	276.32	261.06	592.22	211.85	363.45	434.89	448.70	203.42	194.72
	ED	5.25	2.35	5.43	5.93	16.37	28.14	31.72	13.40	1.93	1.33	2.51	4.60	0.76
	MSI	1.58	1.60	1.62	1.58	1.61	1.71	1.70	1.63	1.66	1.62	1.64	1.56	1.54
	MPAR	363.27	380.74	317.49	322.39	303.14	310.48	310.39	313.26	350.69	348.51	417.27	306.05	576.96
potential vegetation	MPS	34.03	13.90	23.72	34.73	31.60	35.35	45.24	57.15	28.62	67.64	38.01	15.83	10.13
	PSCoV	318.81	256.90	234.05	169.12	329.13	253.12	481.80	309.68	229.73	209.99	233.69	188.45	138.74
	ED	3.31	1.95	3.50	4.27	9.64	18.00	20.05	6.41	1.79	1.21	2.33	3.46	0.58
	MSI	1.87	1.77	1.82	1.76	1.73	1.92	1.82	1.89	1.78	2.02	1.81	1.75	1.51
	MPAR	370.81	319.34	300.43	243.78	288.19	268.07	289.38	253.07	314.46	201.99	259.31	274.47	648.96
potential and actual vegetation together	MPS	11.22	6.95	8.54	11.58	11.78	12.16	15.64	11.74	17.89	23.67	16.66	6.64	6.08
	PSCoV	325.79	253.84	223.65	232.56	277.87	258.24	601.30	201.53	282.15	334.01	244.59	146.28	135.95
	ED	5.36	2.48	5.73	6.63	16.66	28.92	32.30	13.78	2.16	1.68	3.46	4.85	0.79
	MSI	1.58	1.59	1.61	1.57	1.60	1.71	1.69	1.63	1.68	1.65	1.68	1.55	1.53
	MPAR	358.59	372.17	314.45	315.49	301.72	308.14	309.34	312.64	323.05	309.84	353.12	302.79	545.87
land use (%)	arable lands	58.79	38.54	31.07	52.12	20.31	41.84	46.72	44.45	79.82	91.03	83.11	24.53	26.76
	forests	11.01	49.21	24.20	42.56	68.56	23.29	20.77	43.58	12.17	3.98	5.39	57.34	16.66
	meadows and grasslands	13.77	4.32	8.15	1.38	7.93	26.45	31.39	9.54	6.96	2.62	0.47	15.26	42.60
	built-up areas	16.43	7.93	36.58	3.93	3.21	8.42	1.13	2.44	1.06	2.37	11.03	2.86	13.98

dominating actual vegetation (>10%)	Aphanion field complex	58.65	36.14	29.69	50.74	8.41	18.19	10.32	17.11	77.95	90.43	81.26	7.53	26.76
	gardens and orchards	11.91	7.19	12.01	0.97	0.07	1.85	0.00	0.00	0.00	0.49	8.08	0.00	9.44
	pine plantation	2.68	23.70	2.31	6.71	0.76	1.03	1.25	13.69	8.70	1.33	0.40	24.67	4.12
	cultivated flower plants	2.95	0.00	13.42	0.00	0.00	0.21	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Dicrano-Pinion	0.00	0.71	2.45	4.43	19.47	0.43	4.15	2.90	0.35	0.00	0.00	7.69	0.00
	Querco roboris-Pinetum typicum	0.00	3.59	2.09	2.06	11.87	0.90	3.39	14.57	0.00	0.00	1.13	0.97	6.16
	Aphanion with Oxalido-Chenopodietum field complex	0.14	0.00	0.24	0.00	0.00	14.73	33.47	0.00	0.00	0.00	0.00	0.00	0.00
	Arrhenatherion	4.55	3.86	4.57	1.31	3.92	11.16	7.67	6.52	3.55	2.62	0.47	8.10	35.33
	Arnoseridion field complex	0.00	0.00	0.67	1.07	9.76	7.54	1.27	24.26	1.29	0.60	1.69	14.15	0.00
potential vegetation (%)	Circaeo-Alnetum	0.42	1.15	0.56	0.42	4.31	9.91	10.57	4.16	0.49	0.66	0.61	3.30	4.87
	Ficario-Ulmetum chrysosplenietosum	0.00	0.00	0.00	0.69	0.08	0.00	0.05	0.00	0.00	0.00	4.68	0.00	0.00
	Ficario-Ulmetum typicum	0.14	0.00	0.67	0.00	0.00	22.52	42.16	0.00	0.00	0.00	0.00	0.00	20.39
	Ficario-Ulmetum violetosum	0.00	0.00	0.98	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Leucobryo-Pinetum. Molinia variant	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Peucedano-Pinetum	0.00	0.00	1.36	0.00	30.14	0.24	0.32	0.14	0.00	0.00	0.00	8.34	0.00
	Potentillo-Quercetum	13.95	5.47	15.20	34.51	0.00	0.00	0.12	0.00	0.00	1.61	0.00	0.00	0.00
	Querco roboris-Pinetum molinietosum	0.00	0.00	0.00	0.00	3.19	0.11	0.01	1.21	0.00	0.00	0.21	12.87	0.48
	Querco roboris-Pinetum typicum	3.17	5.25	5.15	7.99	38.65	18.48	14.68	65.36	12.01	1.46	3.79	44.59	19.71
	Ribo-Alnetum	0.23	0.00	0.00	0.04	1.33	1.95	1.68	0.48	0.00	0.00	0.06	1.29	0.00
	Salici-Populetum	0.51	3.48	1.97	0.00	0.00	13.23	14.57	0.00	0.00	0.00	0.00	1.25	0.43
	Tilio-Carpinetum typical form	70.89	43.65	52.52	29.63	9.31	3.83	0.82	0.36	47.15	17.94	57.29	0.00	0.00
	Tilio-Carpinetum ‘poor’ form	3.59	31.93	19.12	24.33	9.52	17.28	10.91	16.25	34.58	77.66	19.34	6.78	46.89
	Tilio-Carpinetum moist form	7.10	3.36	2.04	2.38	3.37	12.45	4.12	12.05	5.77	0.67	14.02	21.59	7.24
	Tilio-Carpinetum ‘warm’ form	0.00	5.72	0.42	0.00	0.07	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Number of potential vegetation types	9	8	11	8	11	11	13	8	5	6	8	8	7
	Number of actual vegetation types	23	23	33	37	47	70	62	31	20	15	20	32	15

110), in which forests occupied at least 40%, and the remaining microlandscapes that were of a mixed character (Table 1).

Consideration of all the aspects to variability mentioned above, allowed the combining of the distinguished microlandscapes into five groups (Figures 1.7 and 1.8). The first of these comprised two units adjacent to the river bed (12 and 13), situated on the lowest terraces, in which the floodplain forest habitats *Ficario-Ulmetum* and *Salici-Populetum* are prevalent, featuring large, regular patches of habitats and of the actual vegetation. The second group was composed of three microlandscapes (11, 14 and 110), situated on terraces covered with dunes, with high shares of pine forest habitats, occupied by forest associations. The third group, encompassed four microlandscapes (2, 3, 4 and 5), situated on the high right bank of the Vistula. The distinguishing features included the relatively large share of thermophilous oakwood (*Potentillo albae-Quercetum*) habitats, while the land-use and the level of fragmentation of the landscape were highly variable. The subsequent three microlandscapes (16, 17 and 22) were situated on the left (low) bank, and were characterized by a high share of oak-hornbeam forest habitats, the lowest diversity of potential vegetation, high values for the mean patch size, and active agriculture. The last group contained unit 120 only, which was only represented within the study area by a very small fragment. As a result, its characterization is fragmentary, and the specificity of the values for the majority of indices is very clear, although most probably not reflecting the composition and configuration of the vegetational microlandscape in its entirety.

INTERRELATIONSHIPS BETWEEN INDICES OF THE SPATIAL STRUCTURE OF THE LANDSCAPE

The calculated indices are intercorrelated in a variety of ways. Their contributions to the overall variability of structural features of the landscape also vary. Of the 231 correlation coefficients between the 22 variables, only 35 are statistically significant at $p<0.01$ (Table 2). This table shows that all the indicators accounted for can be clustered into four groups. The first group encompasses mean perimeter-area ratio, the spatial share of meadows and the mean patch size index for potential vegetation. The second group is

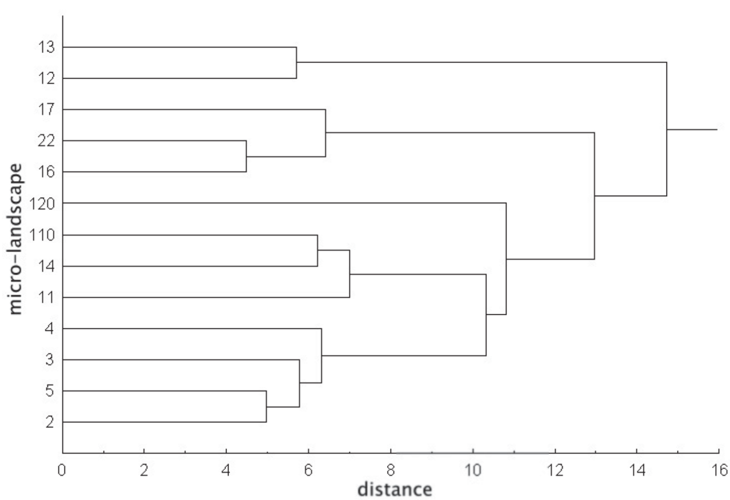

Figure 1.7. Dendrogram of similarity of vegetational microlandscapes based on a joint consideration of all analyzed characteristics

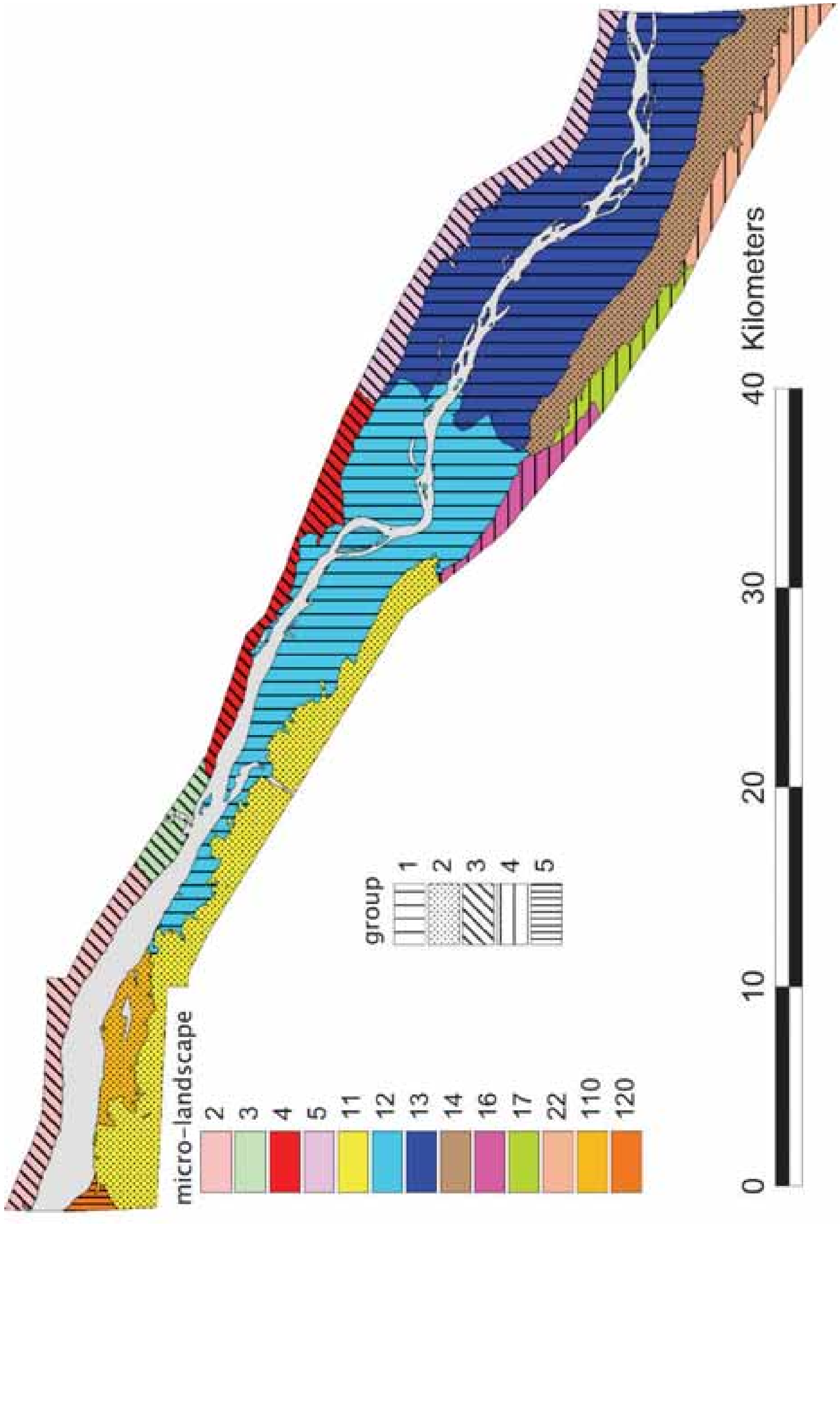

Figure 1.8. Groups of vegetational microlandscapes distinguished on the basis of an analysis of the dendrogram from Figure 7.

Table 3. Results of Principal Component Analysis—Loadings of main factors (Rotation—Varimax normalized). Absolute values > 0.7 in bold.

		Factor 1	Factor 2	Factor 3	Factor 4
HP	diversity index for actual vegetation	**-0,896**	0,421	0,050	0,032
HE	diversity index for potential vegetation	**-0,725**	0,508	-0,089	0,135
HEP	diversity index for combination: potential vegetation—actual vegetation	**-0,901**	0,318	0,147	0,103
MPS1	mean patch size for patches of actual vegetation	**0,892**	0,107	0,317	-0,084
MPS3	mean patch size for patches of combination: potential vegetation—actual vegetation	**0,861**	0,245	0,337	-0,141
POLA	spatial share of arable land weed communities	**0,946**	-0,061	0,216	0,026
LASY	spatial share of forest plant communities	**-0,808**	-0,124	0,284	-0,455
ED1	edge density for actual vegetation	-0,262	**0,938**	0,131	-0,068
MSI1	mean shape index for patches of actual vegetation	0,261	**0,808**	0,337	0,216
PSCOV2	patch size coefficient of variance for patches of potential vegetation	0,021	**0,778**	0,148	-0,240
ED2	edge density for potential vegetation	-0,242	**0,950**	0,120	-0,044
PSCOV3	patch size coefficient of variance for patches of combination: potential vegetation—actual vegetation	0,366	**0,767**	0,073	-0,218
ED3	edge density for combination: potential vegetation—actual vegetation	-0,254	**0,938**	0,139	-0,063
MPAR1	mean perimeter-area ratio for patches of actual vegetation	0,196	-0,330	**-0,883**	0,108
MSI2	mean shape index for patches of potential vegetation	0,440	0,254	**0,738**	0,128
MPAR2	mean perimeter-area ratio for patches of potential vegetation	-0,164	-0,171	**-0,948**	0,102
MPAR3	mean perimeter-area ratio for patches of combination: potential vegetation—actual vegetation	0,006	-0,287	**-0,932**	0,088
LAKI	spatial share of meadow and grassland plant communities	-0,254	0,465	**-0,757**	0,055
ZABUD	spatial share of built-up areas and ruderal plant communities	-0,175	-0,201	-0,125	**0,837**
MSI3	mean shape index for patches of combination: potential vegetation—actual vegetation	0,485	0,668	0,351	0,224
MPS2	mean patch size for patches of potential vegetation	0,599	0,304	0,480	-0,207
PSCOV1	patch size coefficient of variance for patches of actual vegetation	0,661	0,555	0,078	-0,151
Explained variance		7,005	6,526	4,606	1,293
Explained variance (%)		31,8	29,7	20,9	5,9

mostly composed of diversity indices and the mean patch size index of actual vegetation including the spatial shares of fields and forests. The third group contains all the edge density indices, mean shape index of potential vegetation, and the patch size coefficient of variance. The fourth group contains only one index—the share of built-up areas.

Four main axes of variability are distinguishable on the basis of principal component analysis. Analogous to the groups of indicators distinguished on the basis of correlation analysis, these groups together explain more than 88% of total variability of the structural features of the landscape (Table 3). The first of these axes explains almost 32% of total variability and is determined by the typological diversity of potential and actual vegetation, in connection with the main land-use forms. The second of the axes explains almost 30% of total variability and is characterized by edge densities and the patch size coefficient of variance. The third axis explains close to 21% of total variability and represents the degree of complication of shapes assumed by individual patches. The last of the axes is of lesser importance since it explains only some 6% of variability. It is only connected with shares of overbuilt areas and of ruderal plant communities. The factors distinguished through the principal component analysis may be considered new, mutually independent variables, characterizing the structural differentiation of the landscape in a generalized way.

The grouping of microlandscapes on the basis of values of individual factors (principal components) allows for distinguishing of four groups (if microlandscape 120 is considered as a separate group—Figure 1.9). In comparison with the grouping on the basis of absolute values of indices (yielding five well-distinguished clusters—Figure 1.7), the main difference lies in the lack of a separate group composed of microlandscapes situated on the high, right bank of theVistula, and the ones characterized by the relatively high share of thermophilous oak wood habitats (*Potentillo albae-Quercetum*), as well as those with very different land use and level of fragmentation of the landscape.

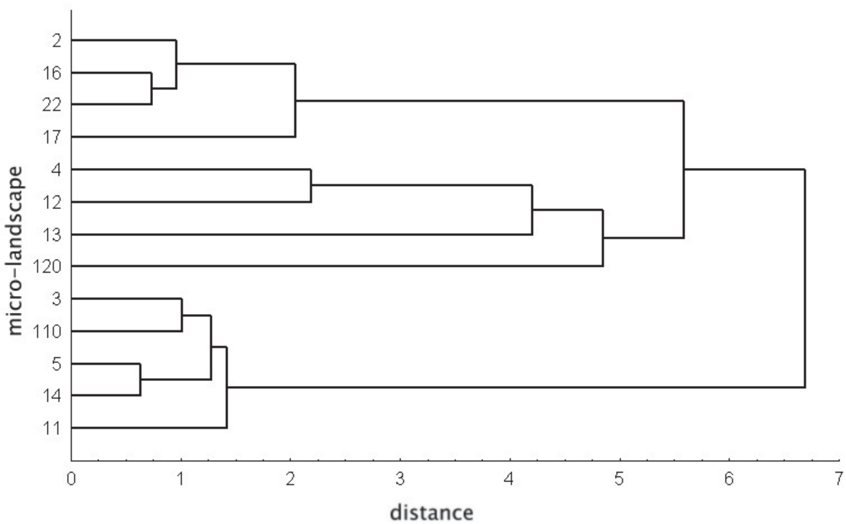

Figure 1.9. Dendrogram of similarity of vegetational microlandscapes on the basis of values for the four first principal components

DISCUSSION

The results obtained can be interpreted in many different ways. The first of these connects with the main aim of the study. A division into vegetational microlandscapes and the description thereof in terms of landscape metrics can be used during the process of regionalization, especially when the ‘ bottom-up’ method is applied. Detailed analyses of interrelationships between different diversity indices have shown that the driving forces responsible for the spatial pattern of ecosystems are organized in a hierarchical way. Habitat types (expressed in categories of potential vegetation) are the main factor, while land use is subordinated. It is worth underlining the fact that the influence of these variables on the spatial pattern (composition and configuration) of ecosystems is varied spatially; an observation is concordant with results obtained elsewhere (Baker 1989; Solon 1990). Generally, the differentiation of forest and scrub ecosystems depends mainly on habitat differentiation, while the spatial pattern to semi-natural and anthropogenic grassy communities results from the land use pattern (Fu and Chen 2000). These relationships make it possible to apply different schemes in joining basic spatial units (vegetational microlandscapes) into units of the higher rank, in line with the general aim of different divisions into regions.

The other direction of applicability of landscape metrics used in this work is connected with landscape evaluation and monitoring. Many (mainly diversity and fragmentation indices) are widely used as surrogate indicators in the description of stability, human pressure, and biotic richness and diversity (Ares *et al.* 2001; McAlpine and Eyre 2002). The relationship between the diversity of landscape mosaics and the diversity of flora and fauna has been shown for many areas and for many systematic groups (Duelli 1997; Favila and Halffter 1997; Pearce 1997; Rejmánek 1997; Fahrig and Jonsen 1998; Natuhara *et al.* 1999). On the other hand, fragmentation indices, shape indices, and compound indices relating the potential and actual vegetation diversities show the level of human pressure, ecosystem disturbance and the level of landscape synanthropization (Iverson and Prasad 1998; Solon 2002). It is worth underlining that these relationships, although general in nature, present specific regional forms, such that their application needs supporting via additional sampling in key areas (Solon 1995; Petit *et al.* 2004).

SUMMARY

Each vegetational microlandscape can be characterized through various indices belonging to several distinct groups, of which the most important are:

- indices of composition (of potential and actual vegetation, as well as land use);
- spatial diversity indices;
- area fragmentation indices (including edge density indices and mean patch size indices);
- patch shape indices and indices of the degree of edge complication.

The analysis showed that, despite the specific character of the individual landscape indices, their comprehensive treatment allows for the joining of microlandscapes into typological (and potentially regional) units of higher rank. Relationships between vegetational microlandscapes and the geobotanical regions were established using the differentiation of potential vegetation. While not unambiguous, microlandscapes correspond to a very low level in the regional landscape hierarchy and are distinguished through the division of sub-districts. Microlandscapes defined irrespectively of geobotanical division (on more detailed material, but encompassing smaller areas) make it possible to draw more precise courses for boundaries of sub-districts, while the description of their spatial structure enriches the characteristics of the geobotanical regions.

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LINKS BETWEEN VEGETATION AND MORPHODYNAMICS OF HIGH-MOUNTAIN SLOPES IN THE TATRA MOUNTAINS

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Abstract: This study examines the propositions that: 1. in high-mountain areas, the differentiation of vegetation units at the landscape (supra-ecosystem) scale is closely linked to variations in the geomorphology of slopes and valley bottoms across various morphodynamic units; 2. morphodynamic units constitute the natural boundaries of the vegetation-related landscape units; 3. different types of geomorphological unit at the landscape scale are characterized by the vegetation types growing on them. These propositions were tested by comparing overlays of digital maps of vegetation and geomorphology. A characteristic combination of plant communities was determined for each of the five types of morphodynamic unit identified.

Key words: geomorphology, morphodynamic units, vegetation, landscape units, vegetation-relief links, Tatra Mountains, Poland.

INTRODUCTION

The diversity of mountain vegetation depends upon an entire complex of factors, including, first and foremost, climate and bedrock geology. The dependent relationships have been the subject of numerous studies that have emphasised zonality, differences between calcareous and non-calcareous substrates, and the influence of snow (Mirek and Piękoś-Mirkowa 1992 a,b; Piękoś-Mirkowa and Mirek 1996; Kozłowska and Rączkowska 2006). The resulting differentiation is apparent on vegetation maps at different scales, ranging from small-scale maps showing climatic and vegetation belts to detailed-scale maps like that of high-mountain vegetation in part of the Tatra Mountains (Figure 2.1)[1]. This map

[1] The map (Figure 2.1) is to be found under the band on the inside back cover.

reflects the influence of multiple factors and portrays the diversity of habitats. However, the primary factor conditioning all others is the relief of the mountain massif itself, namely the pattern of ridges, slopes and valleys, and the dynamics of the geomorphological processes that take place there. The relief forms the structural and geometric basis for any kind of diversification on the Earth's surface, including the geoecological one (Barsch 1990). It is relief that determines the differentiation of habitats and vegetation in mountains into units of supra-ecosystem rank (i.e. landscape units).

Slopes can be differentiated into a number of component units (Hreško 1994, 1997), such as gullies, cones and rockwalls. Experience to date shows that it is not possible to demonstrate a close relationship between such narrowly defined units of relief and vegetational units, since the differentiation of vegetation is the result of many and varied factors, not only linked with slope morphology. This ensures that boundaries of units determined on the basis of just a single abiotic criterion (relief) coincide poorly with those of vegetational units. For this reason, the results of such comparisons have often been vague and imprecise (Kozłowska *et al.* 1999; Rączkowska and Kozłowska 1994).

A similar problem was also encountered by Balcerkiewicz and Wojterska (1985), who assigned the plant associations in the Dolina Pięciu Stawów Polskich in the Tatra Mts. (The Valley of Five Polish Tarns) to narrowly defined categories of meso-forms of relief and obtained a highly complex picture of the dependence of vegetation upon geomorphological units. It was only when the number of relief units was reduced through combination into units of higher rank, and landscape vegetation units of the so-called sigma-associations were considered (Beguin and Hegg 1975, 1976; Géhu 1976; Balcerkiewicz and Wojterska 1978), that it became possible to determine the types of vegetation complexes characteristic of geomorphological units defined sufficiently broadly for landscape-scale vegetational types to be fully developed.

Taking into account the results of previous studies, the following propositions were investigated in this study:

- that the differentiation of vegetation in high-mountain areas among units of supra-ecosystem (landscape) rank is closely linked to variations in the geomorphology of slopes and valley bottoms across various morphodynamic units;
- that morphodynamic units provide the natural boundaries for vegetation landscape units;
- that different types of morphodynamic unit are characterized by particular types of vegetation growing on them.

The purpose of the present paper is to establish the relationships between the high-mountain vegetation and the landforms and geomorphological processes modelling the slopes of the Tatra Mountains, and to test the proposition that these relationships are only fully manifested at the meso-scale (i.e. within relief units of appropriately large area).

STUDY AREA AND METHODS

The study encompassed the area in the Polish Tatras above the treeline as shown on Figure 2.2. This area has alpine relief, with steep slopes rising up to 2301m a.s.l., above glacial cirques and troughs filled with glacial drift deposits (Klimaszewski 1988). Granites and metamorphic rocks dominate in bedrock geology, but calcareous and quartzite outcrops occur as well (Mapa geologiczna Tatr Polskich 1979). The following maps at a scale 1:10,000 were prepared: a vegetation map developed from field mapping, and a map of morphodynamic units compiled from existing geomorphological information, aerial photography, a topographical map at 1:10,000 scale and knowledge of the terrain. The maps were prepared in digital form.

The method of preparation of the vegetation map was described by Kozłowska and Plit (2002). The foundations for the construction of the legend were laid by the

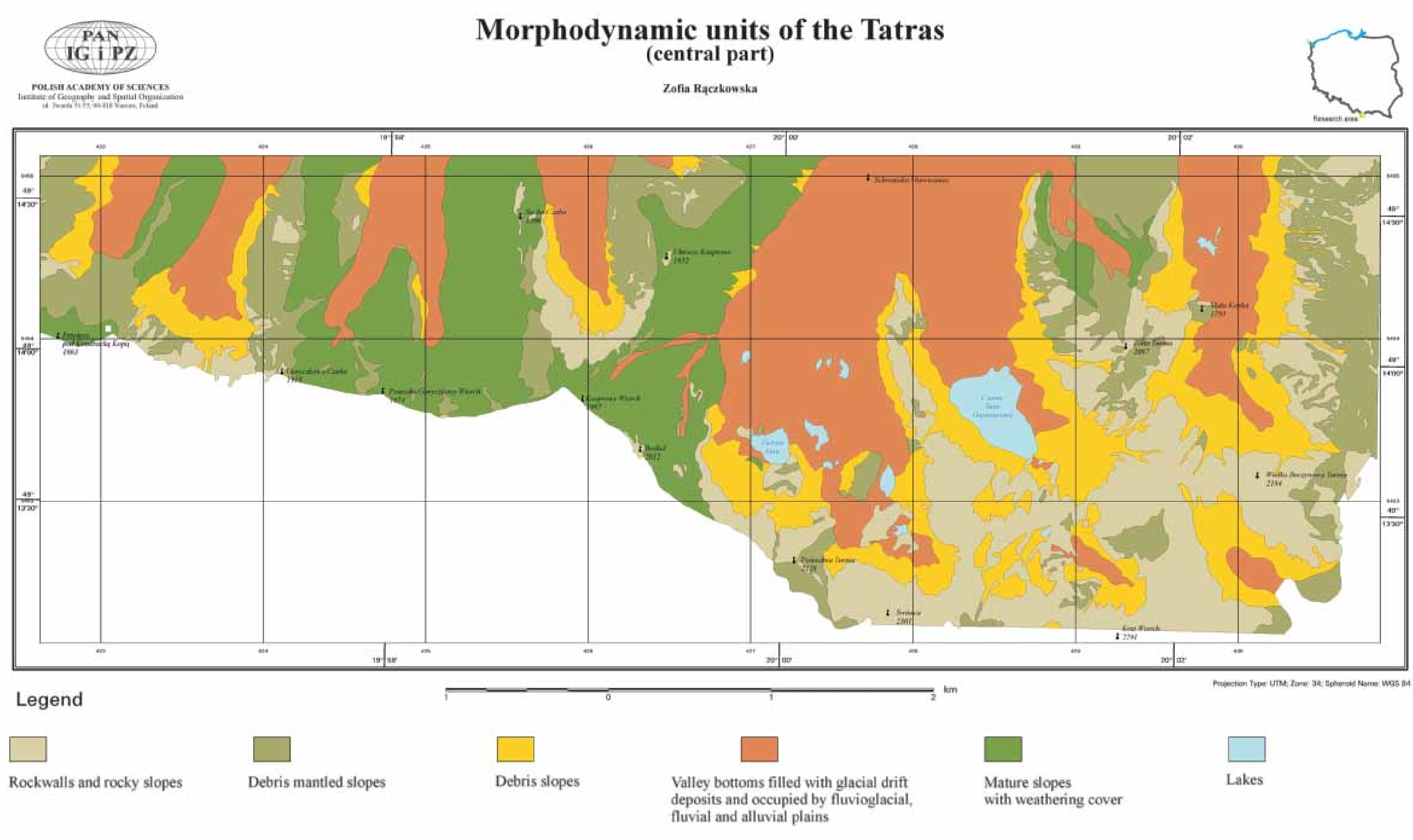

Figure 2.2. Morphodynamic units of the Tatras

Source: elaborated by Z.Rączkowska (2006) work of Balcerkiewicz (1984) for the aforementioned Dolina Pięciu Stawów Polskich in the Tatra Mountains, including the types of plant communities distinguished by him in line with the Braun-Blanquet's phytosociological approach. These types were modified and adapted to the larger area encompassed by the map presented here.

The geomorphological map of the area initially had seven legend units, distinguished using morphological, morphometric, genetic and morphodynamic criteria, but these were later reduced to five. Smaller relief forms existing within their boundaries were treated as attributes of a given unit (for example, debris-flow levées in the 'mature' slope unit).

The strength of the links between vegetation and relief was analyzed by overlaying the digital vector layers of vegetation and geomorphology (using ArcGIS software-overlay procedure) and calculating the index of strength of these linkages (Richling 1992). The basis of this index is the ratio of the area occupied by spatial units having given properties and the theoretically maximal area over which a given relationship may occur. The indicator of the strength (W) of an interrelationship is expressed by the formula:

$$W = P_{vg}/P_g, \text{ when } P_g < P_v,$$
$$W = P_{vg}/P_v, \text{ when } P_v < P_g,$$

where:

P_{vg} is the area of the units, in which both features v and g appear together, as corresponding to the area with the vegetation category v and geomorphology category g;

P_v is the total area of spatial units with feature v of the vegetation;

P_g is the total area of spatial units with feature g of geomorphology.

The values of the index range between 0 and 1. The maximum value of 1 occurs when the boundaries of two analyzed categories coincide fully. The value of the index decreases to 0 when the components considered do not coincide at all. High values for the index correspond to persistent and stable associations, which play a leading role in the structure of the environment. The values obtained were grouped into five classes (after Bezkowska 1986):

I: W = 0.0–0.2—very weak linkages
II: W = 0.21–0.4—weak linkages
III: W = 0.41–0.6—moderate linkages
IV: W = 0.61–0.8—strong linkages
V: W = 0.81–1.0—very strong linkages.

In the subsequent analysis, the linkages belonging to class I were neglected as incidental. The values of moderate to very strong linkages (classes III to V) were used in the assessment of plant communities as indicators of the morphodynamic types of relief.

THE VEGETATION MAP

The legend of the vegetation map of the study area (Figure 2.1) comprises 41 units (listed in Table 1).

The particular patches on the map are rarely uniform in typological terms, usually constituting various types of the complexes distinguished by Seibert (1974). In the majority of cases these are domination complexes, as demonstrated by Balcerkiewicz and Wojterska (1978) in the aforementioned Dolina Pięciu Stawów Polskich. This is especially true of the zonal communities, with the large areas (e.g. of upper montane spruce forest, dwarf mountain pine scrub, post-grazing communities or alpine swards) featuring small-area fragments of other communities. The label of the dominating community is used for entire areas, despite these actually being inhomogeneous as regards vegetation. In other cases, zonation complexes are typical of the numerous gullies existing in the mountain areas, where vegetation changes in a belt-like manner from the edge of the gully towards its axis. This was demonstrated in micro-scale studies (Kozłowska and Rączkowska 2006).

Mosaic complexes are also very frequent, particularly on slopes with varied micro-relief, on narrow rock shelves, or in places in which various dynamic stages of vegetation coexist within a small space, as for instance on the talus cones and during the regeneration of vegetation after grazing. Such mosaic

Table 1. The legend units of the vegetation map

Group of plant communities	No. of unit	Plant community, spatial complex of plant communities
Initial cryptogamic plant communities	1	Initial cryptogamic plant communities
Epilitic lichen communities (*Rhizocarpetalia*)	2	*Rhizocarpetalia*
Scree vegetation (*Androsacetalia alpinae*)	3	*Androsacetalia alpinae*
Snow-bed vegetation (*Salicetea herbaceae*)	4	*Luzuletum alpino-pilosae*
	5	*Salicetum herbaceae, Polytrichetum sexangularis*
	6	*Salicetum herbaceaea* in a complex with *Empetro-Vaccinietum*
Alpine swards on siliceous rocks (*Oreochloo distichae-Juncetum trifidi*)	7	*O. d.-J. t.* subnivale form in a complex with *Oreochloetum distichae subnivale*
	8	*O. d.-J. t. typicum*
	9	*O. d.-J. t. cetrarietosum*
	10	*O. d.-J. t. typicum* in a complex with *O. d.-J. t. cetrarietosum*
	11	*O. d.-J. t. sphagnetosum*
	12	*O. d.-J. t. salicetosum herbaceae*
	13	*O. d.-J. t. salicetosum retusae*
	14	Scree form with *Juncus trifidus*
	15	*O. d.-J. t. caricetosum sempervirentis*
	16	*O. d.-J. t.* subalpine form
	17	*Oreochloo distichae-Juncetum trifidi* in a complex with *Salicetea herbaceae*
	18	*Oreochloo distichae-Juncetum trifidi* in a complex with *Calamagrostietum villosae*
	19	*Oreochloo distichae-Juncetum trifidi* in a complex with *Festuco versicoloris-Agrostietum*
Alpine swards on calcareous rocks (*Elyno-Seslerietea*)	20	*Seslerion tatrae*
Fens, transition mires and peat-bogs	21	*Caricetum fuscae subalpinum*
	22	*Sphagno-Nardetum*, *Polytricho-Nardetum*
	23	*Sphagno-Nardetum, Polytricho-Nardetum* in a complex with *Caltha laeta*-community
Tall-herb and tall-grass vegetation (*Betulo-Adenostyletea*)	24	*Calamagrostietum villosae tatricum*
	25	*Calamagrostietum villosae tatricum* in a complex with *Luzuletum alpino-pilosae* - pioneer form
	26	*Calamagrostietum villosae tatricum* in a complex with wet post-grazing grasslands

	27	*Calamagrostietum villosae tatricum* in a complex with *Pinetum mugo* and subalpine post-grazing grasslands
	28	*Adenostylion*
Semi-natural vegetation after grazing	29	*Festuca picta* community in a complex with *Luzuletum alpino-pilosae*
	30	*Festuca picta* community and wet forms of *Hieracio alpini-Nardetum*
	31	*Deschampsia flexuosa* community, and *Hieracio alpini-Nardetum*, *Agrostis rupestris* community
	32	Semi-natural vegetation after grazing in a complex with *Rumicetum alpini, Rumici obtusifoliae-Urticetum*
Subalpine dwarf scrub communities (*Loiseleurio-Vaccinion*)	33	*Empetro-Vaccinietum*
	34	*Empetro-Vaccinietum* in a complex with *Pinetum mugo carpaticum*
	35	*Vaccinium myrtillus* community in a complex with *Pinetum mugo carpaticum*
	36	*Vaccinium myrtilus* community in a complex with *Betulo-Adenostyletea*
Deciduous shrub communities of clearings (*Epilobietea angustifolii*)	37	*Chamaenerion angustifolium-Salix silesiaca* community, *Rubus idaeus* community
Dwarf pine shrubs (*Pinetum mugo carpaticum*)	38	*Pinetum mugo carpaticum silicicolum*
	39	*Pinetum mugo carpaticum silicicolum* in a complex with *Rhizocarpetalia*
	49	*Pinetum mugo carpaticum calcicolum*
Upper-montane spruce forest (*Plagiothecio-Piceetum*)	41	*Plagiothecio-Piceetum*

Source: Kozłowska 2006

complexes are characteristic of the high-mountain vegetation and are even distinguished at the very detailed scale of 1:1,000 (Kozłowska 1999).

THE MAP OF MORPHODYNAMIC UNITS

Five categories of surface were distinguished (Figure 2.2):

ROCKWALLS AND ROCKY SLOPES are completely devoid of a weathering mantle, although the accumulation of small quantities of debris is possible on small shelves within the rocky slopes. Their inclination is always greater than 62–64^{o}, while the rockwalls are vertical or even overhanging. They are cut through by rock gullies of diverse magnitude (Kotarba *et al.*1988). The processes responsible for their contemporary development are weathering (mainly mechanical), rockfall, corrasion, erosion and transport by snow avalanches, as well as debris flows (Kotarba 2002). The intensity of the processes is low. The rate of retreat of the rock walls varies between a few millimetres to more than ten millimetres per annum.

SLOPES WITH DEBRIS MANTLE or blockfield covers have resulted from the degradation of rocky slopes owing to weathering in the periglacial climate, and so they most often exist above the walls of glacial cirques. They are characterized by a convex, non-smoothed longitudinal profile and gradients between 38–62°. There are often small rock walls on these slopes, with a height of several to a dozen metres, as well as blockfields which occupy the ridges (e.g. Pośrednia Turnia) or fragments of cirque slopes weakly transformed by glaciers (e.g. Goryczkowy pod Zakosy). The thickness of the weathering mantle is limited, and varies between several tens of centimetres and two metres. These slopes are shaped by piping, sliding, cryogenic processes, nivation, deflation and aeolian accumulation, erosion and transport by snow avalanche and debris flows (Kotarba 2002).

DEBRIS SLOPES comprise overlapping systems of talus slopes and cones, together with debris cones formed by debris flows and snow avalanches, situated at the foot of the rockwalls and slopes of the glacial cirques. The average thickness of the talus slopes in the High Tatras has been estimated at 15 metres (Lukniš, 1968). These slopes are differentiated by their inclination and degree of stabilization through vegetation, as well as the sorting of the debris building them up. The angle of the talus slopes is approximately 30°, while the debris cones are less steep, at 20–30°. The manner and rate of their development depend upon the morphological and climatic conditions on the rockwalls above. The debris cones are currently modified over their entire surfaces by snow avalanches and by the linear tracks of debris flows. On the talus slopes the material is accumulated over the entire surface, albeit at differing intensities. Their highest parts are most active (Kotarba *et al.*1983). Today, debris slopes are shaped by a range of processes, including (in order of frequency of occurrence) rockfalls and the accumulation of talus, debris flows, debris creeping, deposition of dirty snow avalanche, piping and nivation (Kotarba 2002). These slopes are among the most intensively transformed ones.

BOTTOMS OF VALLEYS filled with glacial drift material and occupied by spreads of fluvial, fluvioglacial and alluvial accumulation deposits are stabilized by vegetation, although fragments of moraines built of large blocks and boulders are completely devoid of vegetation. This morphodynamic unit is highly differentiated morphologically and morphogenetically. Within the the glacial drift deposits covering the valley bottoms, there are distinct moraine ridges with short, steep slopes and relatively shallow undrained depressions of various magnitudes, without fine material or filled with flat spreads of fluvial and fluvioglacial deposits. Alluvial plains appear between the slopes and the lateral moraine ridges. Slopewash and avalanche accumulation are the main processes acting on this unit (Kotarba 2002).

'MATURE' SLOPES are those with a smoothed longitudinal profile and uniform inclination of about 30°. Their relief is little diversified. They are covered with a layer of weathered debris, comprising coarse debris with a mixture of fine material. In the soil, 40 to 60% is gravel and very coarse sand (Degórski 1999). These slopes are overgrown with a compact vegetation cover. On the slope and/or their segments situated at higher altitudes cryogenic processes (gelifluction and frost creep) dominate. On the slopes and/or their segments situated at lower altitudes these are replaced by soil creeping and sliding. The other processes modelling them are nivation, piping, debris-and-mud flows, slopewash and linear erosion, avalanche erosion and transport, deflation and wind accumulation (Rączkowska 2002; Kotarba 2002).

The morphodynamic units outlined above comprise a hierarchy of smaller-scale forms (Brundsen 1996). Thus, for example, 'mature' slopes may contain erosion or nival niches. The individual units also differ in their contemporary process dynamics and even within individual units there are variations in the the types of process and their rates of activity. The micro-structure and differences in dynamics may be responsible for the internal diversification of vegetation growing on a defined type of relief unit.

GEOBOTANICAL CHARACTERISTICS OF THE MORPHODYNAMIC UNITS

Overlaying of the two maps and comparison of the distributions of their respective units allows identification of the characteristic and dominating plant communities supported by the different types of morphodynamic unit (Table 2). It also allows spatial relationships to be determined between the types of morphodynamic unit and the vegetation (Table 3).

Characterization of the morphodynamic units using the percentage of vegetation type present (Table 2) shows that only a few communities exceed 5% of a unit's area, while the very same kinds of communities often dominate in various relief units.

- On the rockwalls and rocky slopes, the largest areas are occupied by fragmentarily developed alpine swards, for both the lime-free habitats (10) and the mylonites (19). A relatively large share is also taken by the dwarf mountain pine scrub (38). The remaining types of plant communities occupy areas less than 5% of the overall area of this morphodynamic type.
- On the debris-mantled slopes, the highest proportion is of dwarf mountain pine scrub (38) and epilithic lichen communities (2). There is a significant (5–10%) proportion of alpine swards: the sub-association *typicum* (8), the form with *Juncus trifidus* (14), as well as the complexes of rock shelf swards (10) and the dwarf scrub communities, especially combined with tall herbs (36).
- The debris slopes have the largest areas covered with communities of epilithic lichens (2) and dwarf mountain pine scrub (38), like the debris-covered slopes. The pioneering communities, like those of cryptogamic plants (1) and vascular plants on taluses and humid gravel (3), and the avalanche meadows (24), also account for significant proportions of the communities on these slopes.
- The bottoms of valleys filled with glacial drift deposits and occupied by spreads of fluvial, fluvioglacial and alluvial deposits are largely covered by dwarf mountain pine shrub (38), upper montane spruce forest (41) and epilithic lichen communities (2). Bilberry scrub (35) also accounts for significant areal cover.
- 'Mature' slopes with weathering covers are characterised by a high proportion of the dwarf mountain pine scrub (38) and a considerable proportion of upper montane spruce forest (41), bilberry scrub (35) and crowberry scrub (33), as well as subalpine sward forms (16) and the typical sub-association of the alpine swards (10).

Examination of the strength of linkages between the plant communities and morphodynamic units reveals different patterns(Table 3). Values of linkage strength above 0.4 (classes III, IV and V) indicate communities moderately to strongly connected with a given relief type, while lower values (class II) show that such linkages are poorly developed.

The highest parts of rockwalls are characterized by plant communities that are very specific, especially in terms of their structure. They are poorly developed by their very nature (subnival swards) or developed only in fragments, and this is the case both when they are complexes of communities of epilithic lichens with various swards belonging either to the dry (*cetarietosum*) or typical (*typicum*) sub-associations with fragments of snowbed communities and scree debris communities, or low tufts of dwarf mountain pine scrub. This type of morphodynamic unit features high values for the index of strength of the interrelationships, corresponding to strong and very strong linkages.

The debris slopes under the rockwalls are habitats for pioneering plant communities, which appear on fine debris (few cm in diameter), as well as the snow-bed areas in the niches under the walls and the avalanche

Table 2. Occurence of vegetation units in the morphodynamic units (in % of area).

Vegetation units No.	Morphodynamic types 1	2	3	4	5
1	1.9	0.7	**5.7**	0.2	0.3
2	3.4	**14.3**	**21.7**	**11.1**	1.9
3	1.3	0.7	**5.1**	0.1	0.2
4	1.7	1.8	4.1	0.7	1.8
5	0.2	0.0	1.1	0.5	0.0
6	0.1	0.1	1.0	0.6	0.0
7	3.0	0.1	0.0	0.0	0.0
8	1.6	**8.4**	3.3	0.6	**5.5**
9	0.2	0.9	0.3	0.3	1.7
10	**41.1**	**6.3**	4.4	0.0	2.9
11	0.1	0.2	0.0	0.0	2.6
12	0.4	1.4	0.2	0.1	0.4
13	0.3	0.7	2.0	0.0	0.0
14	4.4	**8.6**	4.3	0.5	1.7
15	0.5	2.9	0.2	0.0	2.5
16	0.4	2.3	1.7	1.1	**8.3**
17	1.5	0.3	3.0	0.4	1.9
18	1.6	1.0	2.2	0.3	0.2
19	**19.7**	1.2	2.7	0.1	0.0
20	0.3	0.4	0.2	0.1	1.4
21	0.0	0.0	0.0	0.1	0.0
22	0.0	0.0	0.0	0.7	0.0
23	0.0	0.0	0.0	0.3	0.0
24	1.1	2.3	**7.9**	1.4	1.6
25	0.3	0.1	0.8	0.0	0.0
26	0.1	0.2	2.4	0.3	0.0
27	0.3	1.7	1.3	0.4	0.1
28	0.0	0.0	0.1	1.3	0.4
29	0.2	0.0	0.6	0.4	0.3
30	0.1	0.4	0.0	3.6	3.1
31	0.1	0.1	0.1	1.2	1.0
32	0.0	0.0	0.0	0.3	0.0
33	1.0	2.6	2.5	1.9	**6.4**
34	0.4	2.2	0.4	0.0	0.8
35	0.5	2.2	3.4	**5.6**	**7.7**
36	0.5	**5.1**	1.9	4.7	3.4
37	0.1	0.1	0.7	0.3	0.2
38	**8.6**	**28.5**	**13.9**	**48.4**	**35.2**
39	2.9	0.6	0.6	0.0	0.2
40	0.0	0.0	0.0	0.1	0.9
41	0.0	1.4	0.2	**12.4**	**5.4**

Values exceeding 5% are in bold .

Table 3. Links between vegetation communities and morphodynamic types (index of strength of interrelationship according to value classes).

Vegetation units No.	Morphodynamic types 1	2	3	4	5
7	**V**				
10	**IV**				
19	**V**				
39	**IV**				
12		**III**			
14	II	**III**			
27		**III**	II		
34		**III**			II
15		**III**			**III**
3			**IV**		
26			**IV**		
24			**III**		
1	II		**IV**		
25	II		**IV**		
13		II	**IV**		
5			**III**	II	
6			**III**	**III**	
21				**V**	
22				**V**	
23				**V**	
28				**V**	
32				**V**	
29			II	**III**	
36		II		**III**	
30				**IV**	II
31				**IV**	II
35				**III**	II
38				**III**	II
41				**IV**	II
11					**V**
16					**III**
20					**IV**
40					**V**
33				II	**III**
9		II			**III**
17	II		II		II
2		II	II	II	
18	II		II		
8		II			II
37			II	II	
4			II		

Source: calculations by the authors

meadows (particularly in their pioneering, weakly-compact forms), and in well-drained places—alpine swards with *Salix retusa*.

The slopes with debris mantles and blockfields are of limited specificity where their floristic characteristics are concerned. There are no strong linkages, only moderate ones. The reason perhaps lies in the limited thickness of the debris cover, as well as the good drainage of the shallowly situated rocks, something which determines the quality of habitats so strongly that altitude-related differentiation does not play a major role in this case. The effect is azonality in both alpine and subalpine zones (and lower). The degree of ground cover by vegetation may be different, depending upon the length of the period since colonization. The debris slopes in the ridge-adjacent locations are covered by alpine swards with *Salix herbacea*. At lower altitudes there are scree forms (with *Juncus trifidus*) of the alpine sward. At lower levels still, more heavily vegetated slopes are covered by post-grazing grassland communities (grazing was carried out not only on the slopes best suited to this purpose), as well as the crowberry scrub in mosaics with dwarf mountain pine and avalanche meadows.

The 'mature' slopes with weathering covers are associated with a large range of plant communities. These are highly compact and form uniform surfaces, frequently of significant dimensions, mainly comprising various alpine swards, ranging from the dry lichen swards to the humid peat-moss swards, as well as the subalpine anthropogenic forms. The latter group includes all the communities on carbonate rocks, as well as large areas of crowberry scrub.

The specific feature of the valleys floors filled with glacial drift and occupied by the spreads of fluvial, fluvioglacial and alluvial deposits is the presence of vegetation related to water flows and humid environments: tall herbs and avalanche meadows, humid post-grazing swards and peatbogs, as well as snowbeds. Similarly, the communities of the subalpine belt and the upper montane belt are also linked with this type of morphodynamic unit: the post-grazing grassland communities, dwarf scrubs, dwarf mountain pine shrubs and the upper montane spruce forest.

Not all of the vegetation types have clear linkages with specific morphodynamic units. A number are only weakly linked (class II linkages), nonetheless, with more than one type of morphodynamic unit. In addition, different morphodynamic units may be associated with similar plant communities. This might be exemplified by a number of plant communities which overgrow the valley bottoms filled with glacial drift deposits, and the 'mature' slopes with weathering covers, with particular focus on the areas of glacial accumulation.

CONCLUSIONS

This study has demonstrated clear links between plant communities and the type of morphodynamic surface on which they grow. The majority of plant communities have their main occurrences in a definite morphodynamic type (i.e. they are associated with a definite type of habitat) and the different types of morphodynamic surface are associated with characteristic sets or combinations of plant communities. In geobotany, characteristic combinations of species are used in describing plant associations, while characteristic combinations of communities are used in the description of landscape-rank units called sigma-associations. The approach applied in the present study is close to the level of sigma-associations, because characterization is provided on the basis of plant communities, and not species. The measures of association are provided by an index of the strength of interlinkage between vegetation types and relief, and not by the areal proportions of plant communities in the higher-rank (landscape) units alone. Areal proportions, as such, constitute a rather imprecise indicator, emphasising the dominating plant communities. These are the zonal ones—the dwarf mountain pine shrub, the upper montane spruce forest, the alpine swards (especially the typical sub-association) but also the extensive post-grazing (grassland and scrub) communities, as well as azonal communities of epilithic lichens. They constitute the main components for individual morphodynamic types.

Application of the index of strength of interlinkage avoided the problem of dominating vegetation communities, which reduces the clarity of specificity of particular habitats. Consequently each of the identified types of morphodynamic unit has its own combination of plant associations strongly linked with it These associations reflect the character of the slope, especially its dynamics or degree of stability.

Only some plant communities exist on one type of slope only. These are the associations linked with a definite type of habitat, such as those that are very dynamic or the those strongly influenced by water. Even those associations which display linkages with several, most often two, types of relief, have strong linkages with just one type of morphodynamic type of surface. The patterns of interrelations between vegetation and relief are more distinct for the large morphodynamic units than for more narrowly defined units of relief, thereby attesting to the role of the large units of relief in the development of vegetation patterns of supra-ecosystem (landscape) rank. Namely large morphodynamic units can be accepted as a basis for delimitation of vegetational landscape units.

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VEGETATION MAPPING IN NORWAY AND A SCENARIO FOR VEGETATION CHANGES IN A MOUNTAIN DISTRICT

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Abstract: This article presents vegetation mapping in Norway, with special emphasis on the main operational survey mapping system used by the Norwegian Institute of Land Inventory. A vegetation map prepared with this system is used to predict regrowth of forest following the abandonment of land use in a mountainous area of south-eastern Norway. Logging, outfield fodder collection and domestic grazing connected to summer dairy farming have been markedly reduced in the last few decades. Possible effects of changed climate on the upper potential forest-limits are also predicted. The results make it clear that a large area in the sub-alpine summer dairy farm landscape is exposed to regrowth after abandonment of land use. Forest advance often attributed to climate change is also shown to be the product of regrowth due to reduced land use. A preliminary effort is made to separate the effects of present regrowth from future climate change, as a means of understanding the processes underpinning landscape changes.

Key words: vegetation mapping, regrowth and climate scenarios, mountainous areas, land-use changes, summer dairy farming, Norway, forest-limit

INTRODUCTION

VEGETATION MAPPING

A vegetation map represents a spatially simplified map with a classification of vegetation into predefined types. Vegetation mapping, based on field-work and the interpretation of aerial photography, captures the extent of structural vegetation types at a landscape level (Wyatt 2000). The vegetation types represent more or less stable entities based on physiognomy, plant species composition or indicator species, or a combination of the three. The vegetation types can be structured by all ecological processes through time and space, but some systems exclude the effects of human impact. A detailed mapping system will access detailed ecological interpretation (Coker 2000). The vegetation types defined vary from country to country, but also among different scientific schools within countries. In Norway, more than 10% (>30 000 km^2) of the country has been mapped via a survey vegetation mapping system. This has 45 vegetation types, though thanks to additional information in the form of symbols, the number of detectable vegetation types is considerably higher (Balle 2000; Rekdal and Larsson 2005; Bryn *et al.* 2006).

AIM

This preliminary study has three aims. Firstly, we are seeking to present vegetation mapping in Norway, with special emphasis on the most common survey vegetation mapping system in use, i.e. that developed by the Norwegian Institute of Land Inventory (NIJOS), albeit on the basis of other systems. Secondly, we have assessed the utility of the aforementioned system in a temporal perspective. Thirdly, we have studied the effects of potential regrowth following the cessation of land use, and/or climate change, on the vegetation at landscape level, making a preliminary attempt to separate the effects of these two processes. The third goal is to be explored further in the coming years.

THE HISTORY OF VEGETATION MAPPING IN NORWAY

The vegetation mapping of Norway started in the early 1920s, though plant-geography maps and forest-type maps were made earlier (Blytt 1876; Resvoll-Holmsen 1920; Ve 1930). Professor Rolf Nordhagen created a phytosociological system for vegetation types in sub-alpine and alpine regions that was based on different Nordic and European phytosociological work (Fries 1913; Braun-Blanquet 1928; Nordhagen 1936 and 1943). The first vegetation map from Norway based on units defined by phytosociology was published in 1937, and had a map scale of 1:10 000 (Mork and Heiberg 1937). The latter authors based their separation of phytosociological units on the work by Du Rietz (1930). In the years up to the late 1960s, very few vegetation maps were compiled, though there was an increase in scientific studies of the different plant communities (e.g. Dahl 1956; Gjærevoll 1956; Kielland-Lund 1962).

After 1968, (when the International Biological Programme came into its operational phase), the vegetation mapping of Norway gained new momentum (Marker 1969, Marker 1973, Hesjedal 1973, Moen and Moen 1975, Balle 2000). Several institutes and universities developed their own systems for mapping vegetation. These parallel systems were in many ways similar, if differing as regards the distinctive ecological features of the region in which they were developed. Above all, vegetation was grouped into series; the mire-, meadow- and heath-series, and subsequent vegetation types (e.g. Moen and Jensen 1979).

There was an upsurge in vegetation mapping in the second part of the 1970s and early 1980s, mainly in the context of environmental impact analysis related to the development of hydro-electrical power plants. Post-1974, NIJOS had begun developing a less-detailed mapping system whereby information could be detected and plotted using air photos in the field (Hesjedal 1973; Larsson 1974; Hesjedal 1975; Solheim 1978). NIJOS started mapping a number of watersheds under temporary protection in 1977, producing yet further accelerated development of the mapping system and related methods, adapted to a scale of 1:50 000. NIJOS was made responsible for the development of an operational field mapping system in Norway in the 1980s (NOU 1983), and, since then each vegetation type has been explored more systematically, such that characteristics are better understood and more details have been added (Rekdal and Larsson 2005).

In 1987, a group from different institutes presented a national system for the detailed vegetation mapping of Norway, and revealed a great need for further scientific study (Fremstad and Elven 1987). The intention was for the system to be updated as new knowledge became available. However, as the recommended studies were disregarded by scientific institutes in the following years, a less-scientific development of vegetation mapping systems took place. A strong emphasis on vegetation ecology shifted to sampling methods, gradient analysis and subsequent biostatistics (e.g. Økland 1990). A revised version of the system was nevertheless completed in 1997 (Fremstad 1997). In 2001, detailed vegetation types were evaluated and classified according to their environmental vulnerability (Fremstad and Moen 2001). The detailed system is now mostly used in large-scale scientific projects, except in forestry, where a derived system of vegetation types for the description of forest stands is applied (Larsson and Søgnen 2003).

VEGETATION MAPPING SYSTEMS IN NORWAY

Today there are two nationwide vegetation mapping systems in Norway. One is for detailed mapping at scales between 1:5 000 and 1:20 000 (Fremstad 1997), the other is a survey map system used for scales between 1:20 000 and 1:50 000 (Rekdal and Larsson 2005). Units from the detailed system can be aggregated to units in the survey map system. None of these systems for vegetation mapping is directly in accordance with the Central European phytosociological system for the classification of vegetation (e.g. Dierschke 1994). Originally, both mapping systems were developed on the basis of phytosociological works, at least for types that were well defined (Hesjedal 1975; Moen and Moen 1975; Fremstad and Elven 1987). Today, they are more related to ecological gradients in snow cover, soil types, moisture, exposure to wind, nutrient availability, cultural influences, regional and local climate, etc. Both systems are therefore adapted to the development of vegetation ecology and gradient analysis of the Nordic region and the need for an operational field mapping system (e.g. Økland 1990). However, some vegetation mapping systems partly developed in Norway are typical phytosociological mapping systems (Vevle 1987; Kielland-Lund 1994).

The philosophy behind choosing operational systems only partly related to phytosociology has both natural and traditional explanations. Firstly, several deglaciations in the Quaternary period have given small species pools of plants in the Nordic countries (e.g. Dahl 1998). This reduces the possibilities of finding good character- and lead-species necessary for a separation between different associations in phytosociology. The great variety of natural types in Norway, stretching from lowland nemoral oak forests to low-arctic palsa-bogs, and from maritime damp heath to continental dry meadows, intensifies the problem with few characteristic species (Moen 1999). This is the reason behind the 'Nordic school' of phytosociology, leaning less on character- and lead-species and more on dominant species. Secondly, the Central European phytosociological school has to a great extent relied on information found through character- and lead-species of vascular plants (Dierschke 1994; Ellenberg *et al.* 2001). For a good separation of e.g. fens in the Nordic countries, it has been necessary to involve cryptogams better, especially mosses (Moen 1990; Rydin *et al.* 1999). Thirdly, the assumption of a truly hierarchical system built on character- and lead-species is not supported by many scientists in Norway. The higher levels of phytosociology, e.g. classes and orders, have been especially hard to identify in Norway (Fremstad 1997).

The detailed mapping system is built on three hierarchical levels called groups, types and subtypes. There are 24 main groups of vegetation that operate at the level of one or more classes in the phytosociological system. There are 137 vegetation types that represent associations or higher levels. The types are divided into 379 subtypes that operate at the lower levels of either associations or sub-associations. The subtypes represent main regional (climatic) variants or subtypes caused by other ecological gradients (Fremstad 1997). The identification of types and subtypes is mainly based on characteristic species, but the detailed system is clearly a compromise between different scientific schools. Some units are still not well documented, especially some regional subtypes and units in the cultural landscape. The mapping is field-intensive and time-consuming. The detailed system functions well during field work, and average progress per person with black and white air photos is 0.5–1 km^2 per day (Rekdal and Bryn 2003). From the end of the 1970s on, the Nordic countries worked out a common detailed vegetation classification system (Påhlsson and Påhlsson 1984). This work was later updated, and represents an excellent introduction to Nordic vegetation types (Påhlsson 1994).

The NIJOS survey mapping system is adapted to far less-intensive fieldwork. Average progress per person with black and white air photos is 3–5 km^2 per day (Rekdal and Larsson 2005). The identification of units is mainly based on physiognomy, as it appears from dominant species or species groups, secondly by characteristic species. The classification system is primarily based on mapping of actual vegetation. The system has 12 main vegetation groups (Table 1), with 45 vegetation types and 9 subordinate land cover types. The 45 vegetation types mainly operate at the level of classes in the phytosociological system. In both systems there is a great deal of additional information attached to the vegetation types by the use of symbols. Ad-

Table 1. Vegetation types used by NIJOS in the survey mapping system.
Area in decares (1000 m^2) and percent from the vegetation map of Venabygdsfjellet.

Vegetation group	Signature and vegetation type	Area (1000m^2)	%
1 Snow bed vegetation	1a Moss snow—bed	—	—
	1b Sedge and grass snow—bed	196	0.1
	1c Stone polygon land	—	—
2 Alpine heath communities	2a Mid—alpine heath	—	—
	2b Dry grass heath	634	0.4
	2c Lichen heath	18,200	11.5
	2d Mountain avens heath	179	0.1
	2e Dwarf shrub heath	34,798	22.1
	2f Alpine calluna heath	49	0.0
	2g Alpine damp heath	—	—
3 Alpine meadow communities	3a Low herb meadow	388	0.2
	3b Tall forb meadow	2,311	1.5
4 Deciduous forest	4a Lichen— and heather birch forest	2,773	1.8
	4b Blueberry birch forest	36,543	23.2
	4c Meadow birch forest	3,801	2.4
	4d Birch forest on lime soils	—	—
	4e Alder forest	395	0.3
	4f Flood—plain shrubs	—	—
	4g Pasture land forest	415	0.3
5 Termophilic deciduous forest	5a Oak forest	—	—
	5b Beech forest	—	—
	5c Broad—leaved deciduous forest	—	—
6 Pine forest	6a Lichen— and heather pine forest	1,202	0.8
	6b Blueberry pine forest	580	0.4
	6c Meadow pine forest	16	0.0
	6d Pine forest on lime soils	—	—
7 Spruce forest	7a Lichen— and heather spruce forest	2358	1.5
	7b Blueberry spruce forest	20,623	13.1

	7c Meadow spruce forest	4,926	3.1
8 Peatland forest	8a Damp forest	—	—
	8b Bog forest	—	—
	8c Poor swamp forest	230	0.1
	8d Rich swamp forest	664	0.4
9 Wetlands	9a Bog	7,307	4.6
	9b Deer-grass fen	39	0.0
	9c Fen	9,185	5.8
	9d Mud-bottom fens and bogs	947	0.6
	9e Sedge marsh	247	0.2
10 Non-forested land below the forest-limit	10a Coastal heath	—	—
	10b Calluna heath	—	—
	10c Damp heath	—	—
	10d Shrubs	—	—
	10e Moist meadows	—	—
	10f Dunes and gravel beaches	—	—
	10g Alluvial sand and gravel planes	—	—
11 Farm land	11a Cultivated land	4,935	3.1
	11b Pastures	1,760	1.1
12 Non-productive areas	12a Barren land	—	—
	12b Boulder field	1,355	0.9
	12c Exposed bedrock	448	0.3
	12d Built-up areas	44	0.0
	12e Scattered housing	118	0.1
	12f Artificial impediment	147	0.1
	12g Glacier	—	—
Sum area		157,813	100.0
Water		3,618	

Cells in the table without information represent vegetation types absent from Venabygdsfjellet.
The list of main vegetation types is complete. More information of the vegetation types is presented in Larsson and Rekdal (1997).

ditional information is adapted to ecological extremes, potential vegetation and specific regional variation, or else serves in fulfilling the goal of local customers. Examples of such information are lichen cover, grass cover, calcareous demanding subtypes and cover of bare ground (Table 2). The survey system used by NIJOS has many similarities with that used in mapping mountain vegetation in Sweden and Iceland (Ihse and Wastenson 1975; Steindórsson 1980; Guðbergsson 1980; Andersson *et al.* 1985).

In addition to the two systems described here, a number of adjacent specific thematic mapping systems have focused on some selected vegetation-, bio- or habitat-types (e.g. Haugseth *et al.* 1996; DN 1999; Norderhaug *et al.* 1999; Baumann *et al.* 2001; Sickel *et al.*

Table 2. Additional information figures attached to vegetation types.

◊	50–75% rocks and boulders	*	Norway spruce
⋀⋀	50–75% bare ground	+	Scots pine
~	Unproductive areas (12a, b, c) with 10–25% cover of vegetation	o)	Deciduous forest, mainly mountain birch
v	25–50% cover of lichens	o	Grey alder
x	More than 50% cover of lichens	$	Salix sp. in forest layer
ᑕ	25–50% cover of Salix sp.	]	25–50% cover of trees
s	More than 50% cover of Salix sp.	⊥	Regrowth
j	More than 50% cover of Juniperus communis	I	Clear-cut areas or young forest up to 2.5 m
n	More than 75% cover of Nardus stricta	II	Young forest from 2–5m to 6–7m
g	More than 50% cover of grass	k	Lime-demanding subtypes

All percentages of plants are actual cover. Tree species information is used in two situations: a) when more than 25% of a forest figure is another tree species than defined through the main vegetation type, b) when a tree species covers more than 5% in non-forested vegetation types.

The list of additional information is not complete. Only the most commonly used information is listed. A complete list and more information are presented in Rekdal and Larsson (2005).

2003; Lieng *et al.* 2006). Some of the natural types, i.e. units of environmentally vulnerable areas, can be extracted from vegetation types in line with the NIJOS system (DN 1999). Recently, a model for deriving natural types from vegetation types has been developed and tested over an area of 200 km^2 (Bryn *et al.* 2006).

The major part of the vegetation mapping done in Norway over the last 15 years has been carried out by NIJOS on scales between 1:20 000 and 1:50 000 (Fremstad 1997). NIJOS is aiming at a nationwide vegetation map series, but the priorities regarding areas are based partly on private assignments. More than 10% of the country has been mapped so far, and all mapping projects for Norway are listed in Balle (2000) (Figure 3.1).

REGROWTH AND CLIMATE SCENARIO

Expected future climate change causes concern for the natural environment and its development (Framstad *et al.* 2006). Special attention has been paid to the mountainous region at northern latitudes, in which serious effects of changed climate are expected. Most future climate scenarios for the Nordic region anticipate a warmer summer climate, giving raised forest-limits and a reduced area for species evolved in and adapted to mountainous environments (Benestad 2001; Strand 2002; Engen-Skaugen 2004; Gautestad *et al.* 2005). Since the cold period of the Little Ice Age during the 18th century, average summer temperature has generally been rising, although with major variation. The last period of significant forest level rise in Norway occurred in the period between 1930 and 1950. According to Aas (1969), the average rise in the climatic birch forest-limit in south-eastern Norway in these years was 40 meters. Since the 1990s, average summer temperature has risen again in south-eastern Norway, and the climatic forest-limit is expected to rise dramatically in the coming years, if the expected temperature rise takes place (Strand 2002; Larsson 2004; Framstad *et al.* 2006).

Alongside the climatic shifts is a decrease in human encroachment into the mountainous regions of Norway during the 20th century (Almås *et al.* 2004). The abandonment of felling and mowing, and the reduction

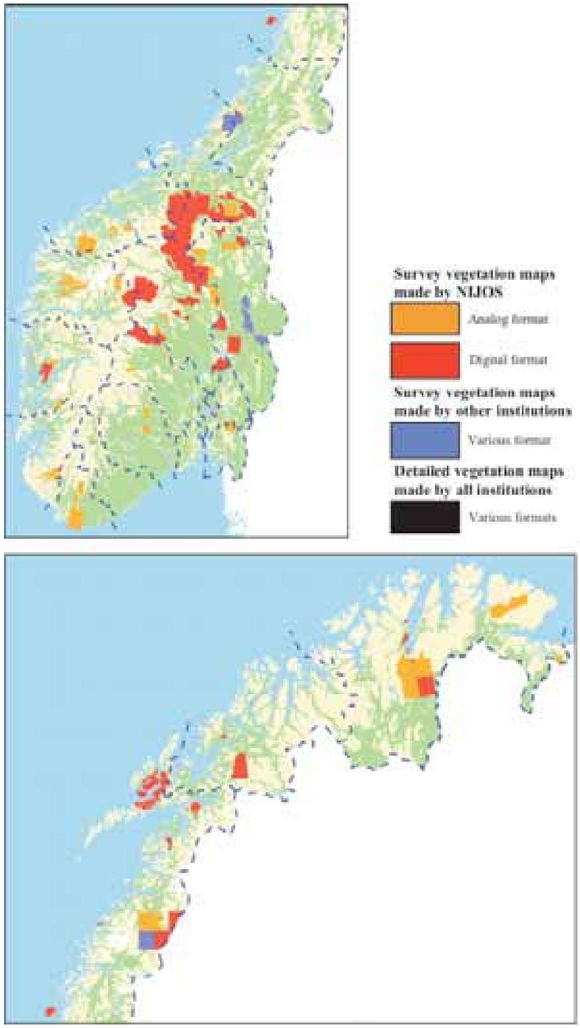

Figure 3.1. Present status of vegetation mapping in Norway by January 2005

Source: author's own elaboration

in grazing connected with the more than 1500-year old tradition of summer dairy farming, has resulted in regrowth of forest across Norway. Mountain birch (*Betula pubescens* Ehrh. ssp. *czerepanovii* (Orlova) Hämet-Ahti), Norway spruce (*Picea abies* (L.) Karsten) and Scots pine (*Pinus sylvestris* L) are expanding in most sub-alpine areas of the country (Aas and Faarlund 1995; Hofgaard 1997; Austrheim and Eriksson 2001; Bryn and Daugstad 2001; Lundh 2001; Wehberg *et al.* 2005). The specific extent and progress of this regrowth is in contrast less well known, and often mistaken as an effect of climate change (Framstad *et al.* 2006).

A large proportion of the endangered species and vegetation types in Norway are in the open and disturbed sub- and low-alpine summer dairy farm landscape (DN 1998; Bryn and Daugstad 2001; Fremstad and Moen 2001). These species and vegetation types are presently threatened by extensive regrowth all over Norway. Thus far, climate change has been considered one of the greatest threats to biological diversity in Norway (Framstad *et al*. 2006). The threat of regrowth has apparently been underestimated by many scientists. It is therefore necessary to focus more on the possibilities of separating the effects of forest advance between regrowth following abandonment of land use and climate change, as a means of better understanding the effects the two processes impose on nature.

MATERIALS AND METHODS

THE STUDY AREA: NATURE

The investigated area comprises a broad valley-mountain profile situated in Ringebu municipality, Oppland County, southern Norway (61°40’ N and 10°05’ E, Figure 3.2). A total area of 160 km^2 was mapped, the lowest part being at 330 m a.s.l. and the highest point 1356 m a.s.l. Most of the mapping area is on poor sedimentary rocks, mainly feldspar-yielding sandstones (Siedlicka *et al.* 1987). Two narrow strips of easily weathered chalk-yielding sandstone and dolomite cut through the area, together with a band of phylite. In the north-east of the mapping area, easily-weathered chalk-yielding rocks appear scattered around.

Bio-climatically, the mapping area is in a transition zone between a continental and an oceanic climate (Moen 1999). The annual mean temperature is -0.3°C (at 940m a.s.l.), the coldest month is January with an average of -9.7°C and the warmest July with 10.4°C. Average precipitation is moderate, 660 mm a year in the period 1961–1990. Winter precipitation is low, but the period from June to October consistently exceeds 70 mm per month on average. The climatic gradient from the valley bottom to the mountains reflects a typical change from mid-boreal to mid-alpine vegetation zones. The boreal zones of southeast Norway are dominated by Norway spruce, scattered with patches of mountain birch and Scots pine. In the upper parts of the north-boreal zone, mountain birch dominates, and this part is usually called the sub-alpine birch belt. At the bottom of Fryadalen, a small nature reserve for elm (*Ulmus glabra* Hudson) represents the lower parts of the mid-boreal zone. Around the farms in Venabygd (500–700 m a.s.l.), there are variants of meadow forest with birch and grey alder (*Alnus incana* (L.) Moench), both secondary succession regrowth forests. In the same region, and at up to 900 m a.s.l. (but more distant from farms), blueberry spruce forest dominates, with patches of li-

Figure 3.2. Location of the study area (circle) in Oppland County, southern Norway

Source: author’s own elaboration

chen- and heather pine forest on dry ground. Forest stands of spruce are found at up to 980 m a.s.l., whereas mountain birch forest stands extend to 1060 m a.s.l. Low-alpine vegetation exists down to 780 m a.s.l., but the main low-alpine zone stretches from around 1000 m a.s.l. up to 1200 m a.s.l. The low-alpine zone is dominated by dwarf shrubby heaths, lichen heaths, bogs and fens. The dwarf shrub heath is typical leeside vegetation, formed by dwarf birch (*Betula nana* L.), crowberry (*Empetrum nigrum* ssp. *hermaphroditum* (Hagerup) Bøcher), blueberry (*Vaccinium myrtillus* L.) and other heaths, with interspersed wavy hair-grass (*Deschampsia flexuosa* (L.) Trin.), chickweed wintergreen (*Trientalis europaea* L.) and goldenrod (*Solidago virgaurea* L.). The lichen heath dominates on wind-exposed sites, with less snow cover during winter time. Lichen heaths are formed by light lichens mainly from the genus *Cladonia* and *Cetraria*, but often with trailing individuals of e.g. crowberry. The dominant vegetation types are fractioned by mountain avens heath on chalk-yielding sandstone and dolomite. This vegetation type is species-rich and formed by mountain avens (*Dryas octopetala* L.). Bands of tall-forb meadows exist, where nutrient-enriched water affords conditions for such demanding species as wolf's-bane (*Aconitum septentrionale* Koelle), tufted hair-grass (*Deschampsia cespitosa* (L.) Beauv.) and other species. Snow beds formed by mat-grass (*Nardus stricta* L.) and different mosses exist in the upper part of the low-alpine zone. Higher up, the mid-alpine zone is dominated by dry grass heaths formed by three-leaved rush (*Juncus trifidus* L.), and boulder fields often covered with crustose lichens.

THE STUDY AREA: CULTURE

Venabygd is a traditional village of the upper mountain valleys in Southeast Norway, with traditional agriculture based on husbandry. Farmers' incomes still depend to a relatively great degree on outfield resources, e.g. logging, hunting and outfield grazing. However, historically this dependency is at a low-level these days (Almås *et al.* 2004). According to tax registrations from the early 17th century up to today, all resources have been valuable. Several legal disputes and court settlements dealt with outfield grazing, outfield scything, fishing, logging, the collection of lichens and other types of outfield fodder. This indicates intensive use of all outfield resources, as well as the fact that the society needed to control resources, and divide them among its inhabitants.

Venabygd was probably settled during the Late Stone Age, from 4000 B.C. onwards. By the end of the Viking Age, the 8–9 oldest farms had been settled and cultivated (Hovdhaugen 1988). Venabygd and the surrounding mountainous region were probably abandoned after the great bubonic plague in 1349 A.D., but resettled 150–200 years after. Summer dairy farming was re-established early in the 16th century. The resettlement depended on local conditions, however, the most productive areas being resettled first. Throughout the 16th and 17th century, settlements spread to new areas, pushed by a rapidly increasing population. A growing population also ensured that many farms were divided. In the same period, a development with cotter farms took place. Cotter farms spread out in the outfields and cultivated new land. As of 1723 A.D. there were 9 cotter farms in Venabygd, but the number peaked in the 1860s with 70–80 cotter farms (Hovdhaugen 1988). In the period 1851–1930, at least 3765 people emigrated from Ringebu municipality to North America, but many also migrated to other parts of Norway. By 1942 Ringebu municipality had 443 summer dairy farms, around 45 within the study area. As of 1974 there were 5 summer dairy farms within the study area, and today only 1 remains active.

According to Hovdhaugen (1988), the major recent change in Venabygd appeared from the early 1950s. In 1949 there were 16 tractors in Ringebu municipality, but by 1959 the number had increased to 169. Agriculture had been revolutionized by the tractor and electrical power. Outfield scything ended and the decline in summer dairy farming accelerated. The population of Venabygd decreased from the 1950s on, from 537 in 1949 to below 300 in 2001. In 2001, there were 121 persons in work living inside the study area, but only around 30% of these were in agriculture or forestry (Statistisk Sentralbyrå 2003). Around 40% were working in the services sector. Nevertheless, as of 2003 there were still some 8100 sheep and 200 cows grazing outfield, partly within the mapping area, during the summer (NIJOS 2006).

Forest-limit

The upper forest-limit is defined as the highest limit of forest patches with trees above 2.5 m tall. In most cases this will be the same as the empirical forest-limit, defined by the presence of continuous forest. Both species-limits and tree-limits are normally found at considerably higher altitudes than the forest-limit (Kullmann 1990). The upper forest-limit is predominantly defined by two fundamental ecological processes: climate and different human activities. The forest-limit may also be structured by the topography (e.g. via the *massenerhebungseffect*, top-effect and snow-avalanches), edaphic conditions or biotic interactions (e.g. caterpillar pest outbreaks). Körner (1999) lists five interrelated mechanisms behind the formation of tree and forest-limits (e.g. the growth limitation hypothesis and the disturbance hypothesis). The response time of forest-limits to climate change varies between regions, but birch generally has a shorter response time than spruce and pine (Aas and Faarlund 2000).

Vegetation mapping

The methodology behind this experiment was the multistep procedure, depicted in the conceptual model (Figure 3.3). The starting point was vegetation mapping in the field, in line with the survey mapping system of NIJOS (Rekdal and Larsson 2005). The vegetation map was combined with altitude through an overlay with a digital elevation model (DEM) of the area. The new table behind the map split vegetation-type figures into separate figures for each altitudinal level (at 20-meter contour intervals). The table was exported to a suitable program and reorganized, and new sets of vegetation data were built up on the basis of prescribed rules. The table was then joined back to the original vegetation map, and vegetation-change maps produced.

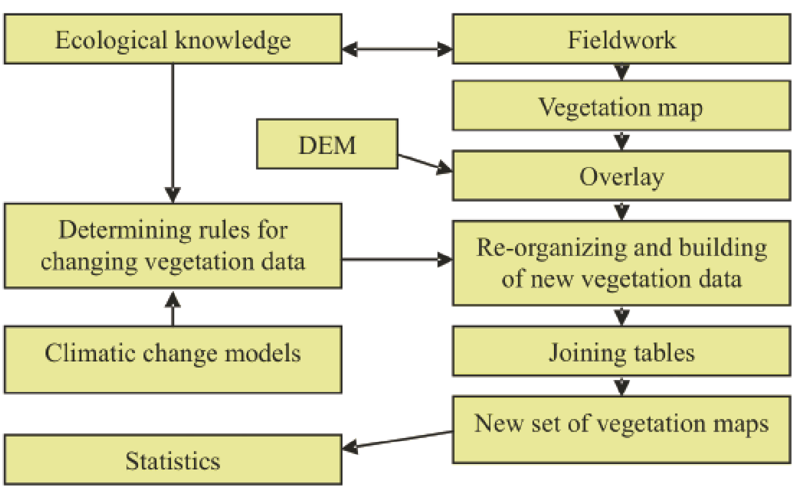

Figure 3.3. Conceptual model of material and methods. DEM—digital elevation model

Source: author's own elaboration

Table 3. Explanation and examples of different transformations in the two derived map types.

Regrowth of forest below present upper potential climatic forest-limit for mountain birch (1060 m a.s.l.)	Examples from below coniferous forest limit (≤ 980 m a.s.l.)	Examples from above coniferous forest-limit (>980 m a.s.l.)
Vegetation types already in phase of regrowth	2e* ⇒ 7b	2e& ⇒ 4b
Rich vegetation types	3b ⇒ 7c	3a ⇒ 4c ,
Intermediate vegetation types	2e ⇒ 7b	2e ⇒ 4b
Poor and dry vegetation types (up to 1040m a.s.l.)	2c ⇒ 6b , 2cv ⇒ 6a	2c ⇒ 4a , 2cv ⇒ 4a,
Phasing out of birch below coniferous forest-limit (980m a.s.l.)	4a ⇒ 6a , 4b ⇒ 7b , 4g ⇒ 7c , 4e ⇒ 7c	
Regrowth of pasture land or cultivated land	11a ⇒ 7c, 11b⊥ ⇒ 7c	11a ⇒ 4c, 11b ⇒ 4c
Climatic change giving new forest below raised upper potential climatic forest-limit for mountain birch (1100 m a.s.l.)	**Examples from below coniferous forest limit (≤1020 m a.s.l.)**	**Examples from above coniferous forest-limit (>1020 m a.s.l.)**
Vegetation types with observed trees	2e& ⇒ 7b	2c& ⇒ 4a
Rich vegetation types	3a ⇒ 7c	3b ⇒ 4c
Intermediate vegetation types	2ex ⇒ 6b , 2ev ⇒ 7b	1b ⇒ 4b
Poor and dry vegetation types (up to 1080m a.s.l.)	2cx ⇒ 6a , 2f ⇒ 6a	2cx ⇒ 4a , 2f ⇒ 4a
Phasing out of birch below coniferous forest-limit (1020 m a.s.l.)	4a ⇒ 6a , 4c ⇒ 7c	

Vegetation types were outlined on black and white air photos at a scale of 1:40 000, using lens stereoscopes in the field. Each person covered approximately 3 km^2 per day, and the minimum figure size was 10 decares. The vegetation mapping units and additional information are listed in Tables 1 and 2. Mosaic figures with two vegetation types within one polygon were allowed if the vegetation changed continuously between the two types. The second vegetation type in a mosaic figure had to cover more than 25% of the figure, and no mosaic figures were smaller than approximately 50 decares (though exceptions were made for important vegetation types). The vegetation figures were then digitised and the map corrected for possible errors. Five derived map themes were produced; grazing for sheep, cattle and reindeer, biological diversity and vulnerability to trampling. Methods and results were further described in a report (Bryn and Rekdal 2002). In this report each vegetation type was described in more detail, i.e. with information on ecology, physiognomy, dominant species, distribution, relationships with other vegetation types, mapping instructions and additional information.

REGROWTH AFTER REDUCED LAND USE

A regrowth map of the study area was produced on the basis of potential vegetation map principles (Ricotta *et al.* 2002). The basis for reorganizing the vegetation map from 2001 was ecological knowledge, literature studies, field experience and the actual vegetation map. Important background information is the history of human utilization of outfield resources, briefly presented in the introduction and described in more detail by Bryn and Murvold (2003). The present-day upper potential climatic forest-limit of the different forest types in the region was found in remote areas, less influenced by human

Table 4. Area statistic of changed vegetation types.

	Present situation		Re-growth				Climate change			
Sign	Area	% cover	Area	% cover	% change	Area change	Area	% cover	% change	Area change
1b	196	0.1	154	0.1	-21.4	-42	132	0.1	-14.3	-22
2c	19,492	12.4	12,863	8.2	-34.0	-6,629	8,164	5.2	-36.5	-4,699
2e	33,016	20.9	11,362	7.2	**-65.6**	-21,654	5,913	3.7	-48.0	-5,449
2f	49	0.0	0	0.0	**-100.0**	-49	0	0.0	0.0	0.0
2	52,557	33.3	24,225	15.4	**-53.9**	-28,332	14,077	8.9	-41.9	-10,148
3a	455	0.3	443	0.3	-2.6	-12	266	0.2	-40.0	-177
3b	2,144	1.4	664	0.4	**-69.0**	-1,480	63	0.0	**-90.5**	-601
3	2,599	1.7	1,107	0.7	**-57.4**	-1,492	329	0.2	**-70.3**	-778
4a	2,606	1.7	5,264	3.3	**102.0**	2,658	6,606	4.2	25.5	1,342
4b	36,934	23.4	14,327	9.1	**-61.2**	-22,607	10,460	6.6	-27.0	-3,867
4c	4,192	2.7	701	0.4	**-83.3**	-3,491	1,054	0.7	**50.4**	353
4e	395	0.3	0	0.0	**-100.0**	-395	0	0.0	0.0	0
4g	389	0.2	0	0.0	**-100.0**	-389	0	0.0	0.0	0
4	44,516	28.2	20,292	12.9	**-54.4**	-24,224	18,120	11.5	-10.7	-2,172
6a	1,252	0.8	3,012	1.9	**140.6**	1,760	6226	3.9	**106.7**	3,214
6b	607	0.4	3,756	2.4	**518.8**	3,149	5,646	3.6	**50.3**	1,890
6	1,859	1.2	6,768	4.3	**264.1**	4,909	11,872	7.5	**75.4**	5,104
7a	2,406	1.5	4,665	3.0	**93.9**	2,259	4,809	3.0	3.1	144
7b	20,976	13.3	62,089	39.3	**196.0**	41,113	69,536	44.1	12.0	7,447
7c	4,392	2.8	12,837	8.1	**192.3**	8,445	13,260	8.4	3.3	423
7	27,774	17.6	79,591	50.4	**186.6**	51,817	87,605	55.5	10.1	8,014
11a	4,935	3.1	2,973	1.9	-39.8	-1,962	2,973	1.9	0.0	0
11b	1,710	1.1	661	0.4	**-61.3**	-1,049	661	0.4	0.0	0
11	6,645	4.2	3,634	2.3	-45.3	-3,011	3,634	2.3	0.0	0

Areas are measured in decares and represent the actual area for each vegetation type in each map type. Sign. = vegetation type signature (see Table 1 for explanation). The column Area means the area of each vegetation type in Venabygdsfjellet. The column % cover is the cover of the specific vegetation type as a % of the total mapping area. The % change column is the areal change from one phase to the next. Percentage changes by more than 50% in either direction are in bold face. Different vegetation types have been grouped together following Table 1.

encroachment (Resvoll-Holmsen 1918; Aas 1969). These limits defined the present-day potential forest-limit in the model. The model was aided by prescribed rules that decided whether a vegetation figure was changed or not, and eventually what vegetation type it should be changed to. The changed figures express the vegetation types after completed regrowth, i.e. potential vegetation. An example may clarify the method. Figures with dwarf shrub heath (2e) below the upper potential coniferous forest-limit were anticipated to have been deforested by human encroachment. The model then transformed this figure to its potential vegetation type, the blueberry spruce forest (7b). Each 20 m altitudinal contour level of each vegetation figure, in combination with all additional information, was run through the model and subsequently given a new vegetation signature or left as it was.

CLIMATE CHANGE

A climate-change map was produced on the basis of the same principles as the regrowth map described above. However, the starting point for the modelled climate-change map, was the regrowth map described above, giving a map containing both regrowth and climate-change transformations. The climate was expected to change in a manner increasing the altitude of the forest-limit by 40 vertical meters (Table 3). Productive mountain vegetation types below the potential climatic forest-limits were converted to productive forest types, intermediate mountain types to intermediate forest types and so forth. Mountain birch forest below the raised coniferous forest-limit was changed to either spruce (on rich or intermediate ground) or pine forest (poor ground).

RESULTS

The present-day upper potential climatic forest-limit for mountain birch was found to be 1060 m a.s.l., whereas the upper limit for coniferous forest was 980 m a.s.l. (Table 3). Deforested vegetation types below the present-day potential climatic forest-limit were converted to different forest types. Between 980 and 1060 m a.s.l. they were converted to birch forest types. Below that altitude, they were directly converted to coniferous forest types with Norway spruce on rich and intermediate ground, Scots pine on poor types. Furthermore, productive deforested vegetation types were converted to productive forest types, intermediate deforested types to intermediate forest types and so forth. Regrowth of low-productivity deforested types, mainly lichen heaths (2c, 2cv, 2cx), was set 20 meters below the potential upper climatic forest-limit of the other types, according to Aas (1964). In other parts of Norway, this altitudinal difference might be considerably larger. Peatland forest (group 8), mires (group 9) and non-productive areas (group 12) were not changed either by regrowth or climate change. All farm land (group 11) above 800 m a.s.l. was assumed to be abandoned and exposed to regrowth.

In the course of mapping at Venabygdsfjellet, we did not find any significant differences in the upper climatic forest-limits when localities of a southerly exposure were compared with those facing north. Exposure was not therefore introduced into the models of either regrowth or climate change. We did, however, find that the upper forest-limits were lower on poor and dry localities.

The results are presented in two ways: as statistics (Tables 1, 4 and Figure 3.4) and as a map series showing the physical distribution of different vegetation types (Figures 3.5 to 3.7). Three vegetation maps are presented. The first map shows the actual vegetation from 2001 (Figure 3.5) and the areal statistics are given in Table 1. This is the starting point map for the two derived and modelled maps. The second one shows the vegetation pattern after regrowth has been modelled, a process driven by abandonment of land use (Figure 3.6). The third map show the combined effect of modelled regrowth and modelled future climatically-raised forest-limits (Figure 3.7).

By comparing the areal statistics (Table 4) between the three vegetation maps, the effects of regrowth after cessation of land use and future climate change can be analyzed. Regrowth after abandonment of land use reduced the non-forested mountain vegetation types (groups 1, 2 and 3) by approximately 30 km^2. This means that about 19% of the total study area was forested by regrowth alone. The main mountain vegetation type altered by forest regrowth was dwarf shrub heath (2e) and lichen heaths (2c), reduced by about

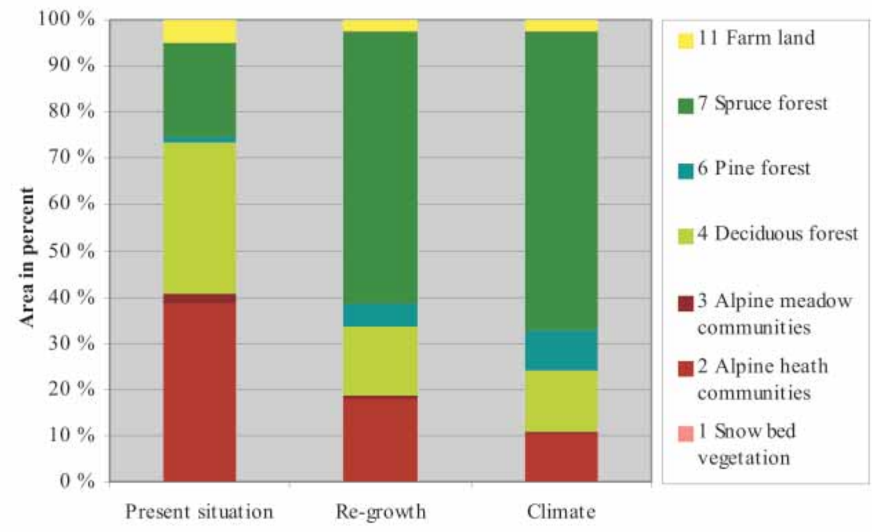

Figure 3.4. Area development of the changed vegetation groups in percent of total changed area
Source: author's own elaboration

21.6 km^2 and 6.6 km^2 respectively. Regrowth also reduced the extent of deciduous forests, mainly birch forest (group 4). The birch forest vegetation types were reduced by about 24 km^2, indicating the present distribution of pioneer succession forest and previous regrowth. The vegetation type that benefited from both regrowth and climate change was of coniferous forest types, mainly spruce forest, but on poor and dry ground also pine forest. Blueberry spruce forest (7b) increased by approximately 41 km^2 by regrowth alone, and by another 7.4 km^2 through climate change alone. Altogether, climate change alone reduced the non-forested mountain vegetation types (groups 1, 2 and 3) by approximately 11 km^2. This means that about 7% of the total area was forested by climate alone. This is only one third of the area forested by regrowth alone. Most of these areas were forested with spruce and pine forest.

DISCUSSION

PATTERNS OF REGROWTH

Large areas below the upper potential climatic forest-limit have been deforested by such historical outfield activities as logging, domestic grazing and scything. These activities have been greatly reduced across Norway since the 1950s (Almås *et al.* 2004). In the reported study area almost 20% of the landscape was still deforested as of 2001. The landscape is now dominated by regrowth of mountain birch, Norway spruce and to some extent Scots pine and grey alder. The regrowth after agricultural activities ceased is a process that will take place whether there is climate change or not, though climatic change can alter the speed and direction of regrowth. However, as long as the temperature is stable or rising and other factors do not restrict forest growth, the regrowth will continue as more and more summer dairy farms are abandoned and outfield grazing and logging are reduced. However, regrowth and climate change are concurrent, and a temperature rise will probably speed up the regrowth rate (Karlsson *et al.* 2005).

It is likely that neither regrowth nor climate change will follow a linear growth pattern. Vegetation changes will depend on altitude, site productivity, biotic interactions, germination conditions, domestic and wild animal grazing and so forth. Our experience

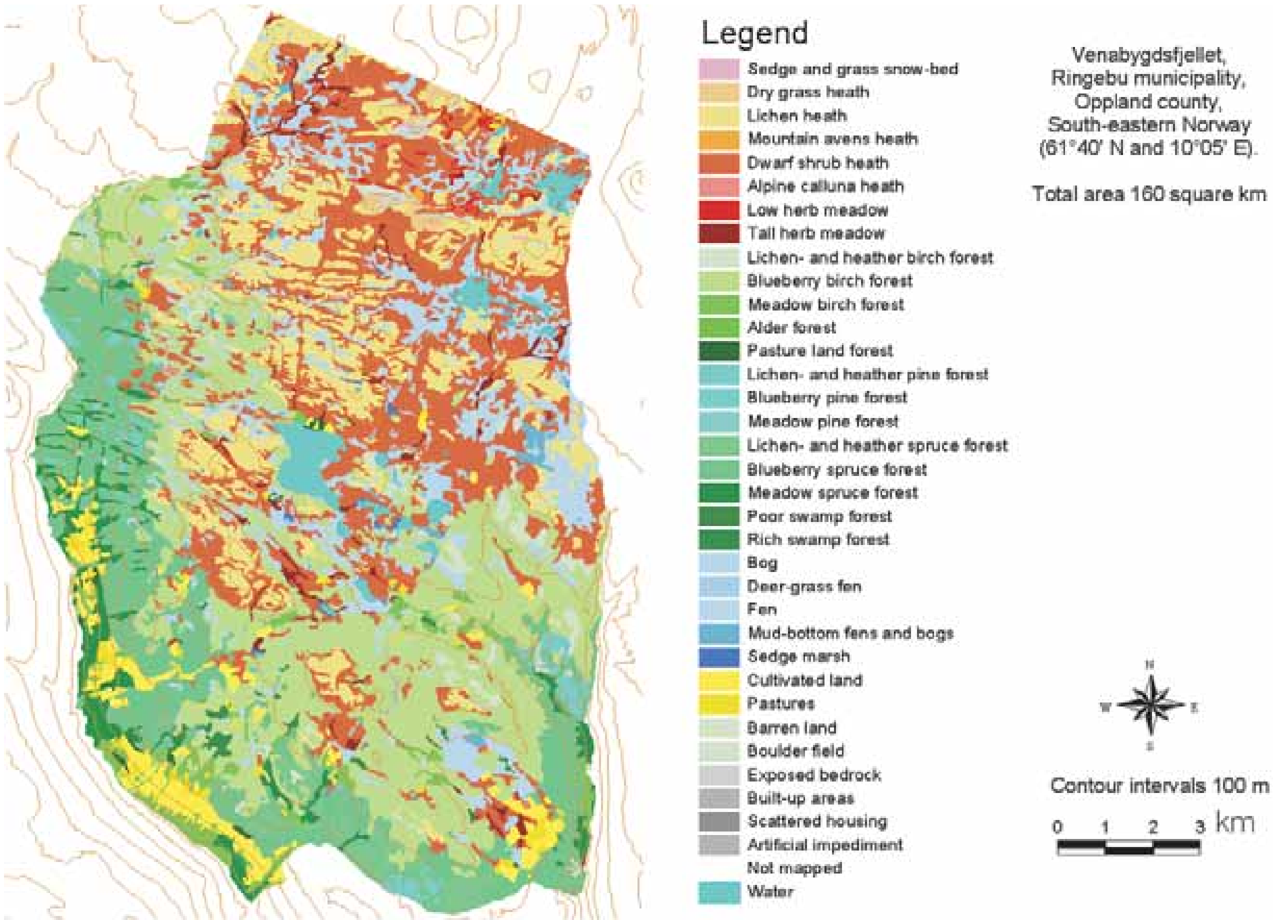

Figure 3.5. Present situation at Venabygdsfjellet, Oppland county (total area 160km2)

Source A.Bryn (2004)

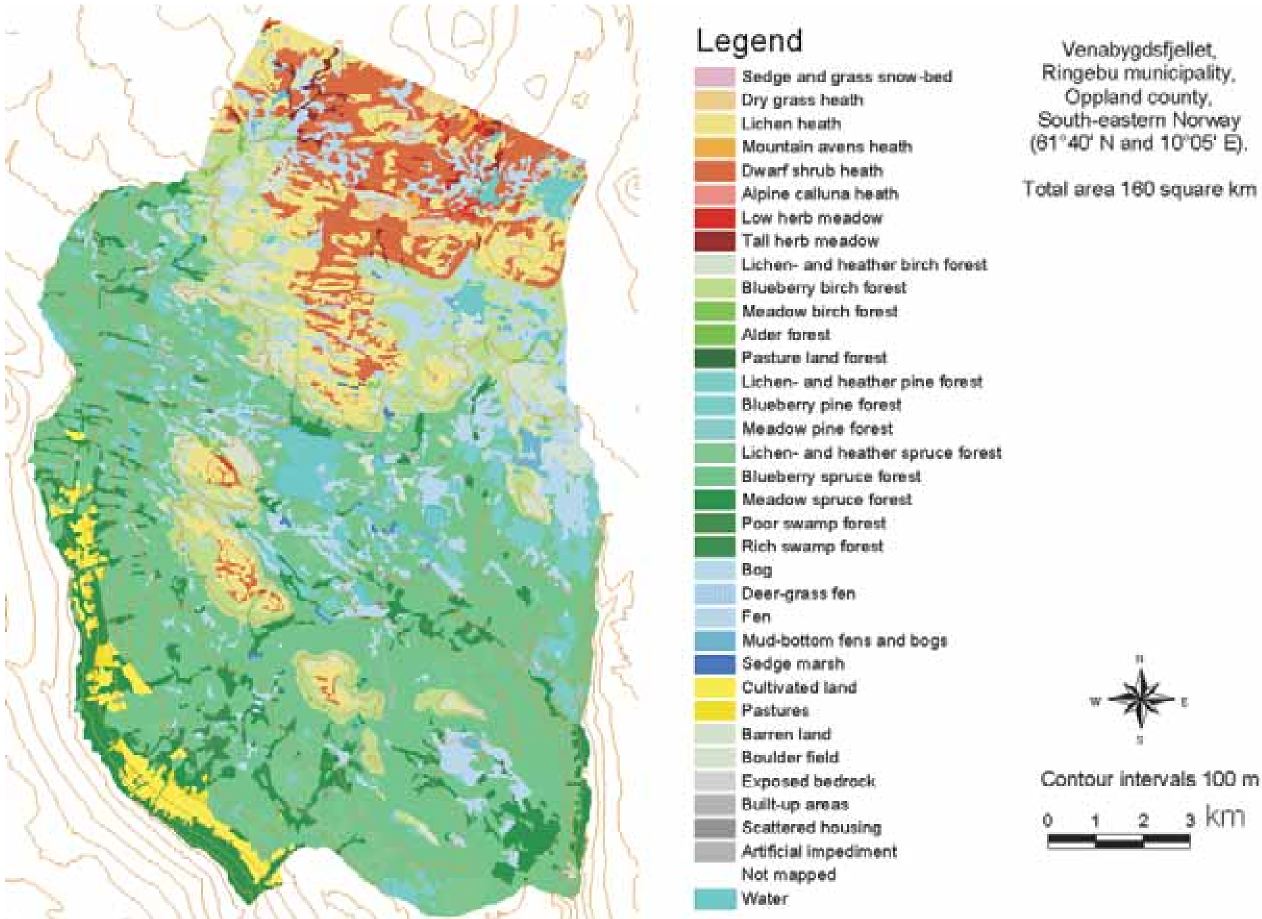

Figure 3.6. Venabygdsfjellet after re-growth

Source A.Bryn (2004)

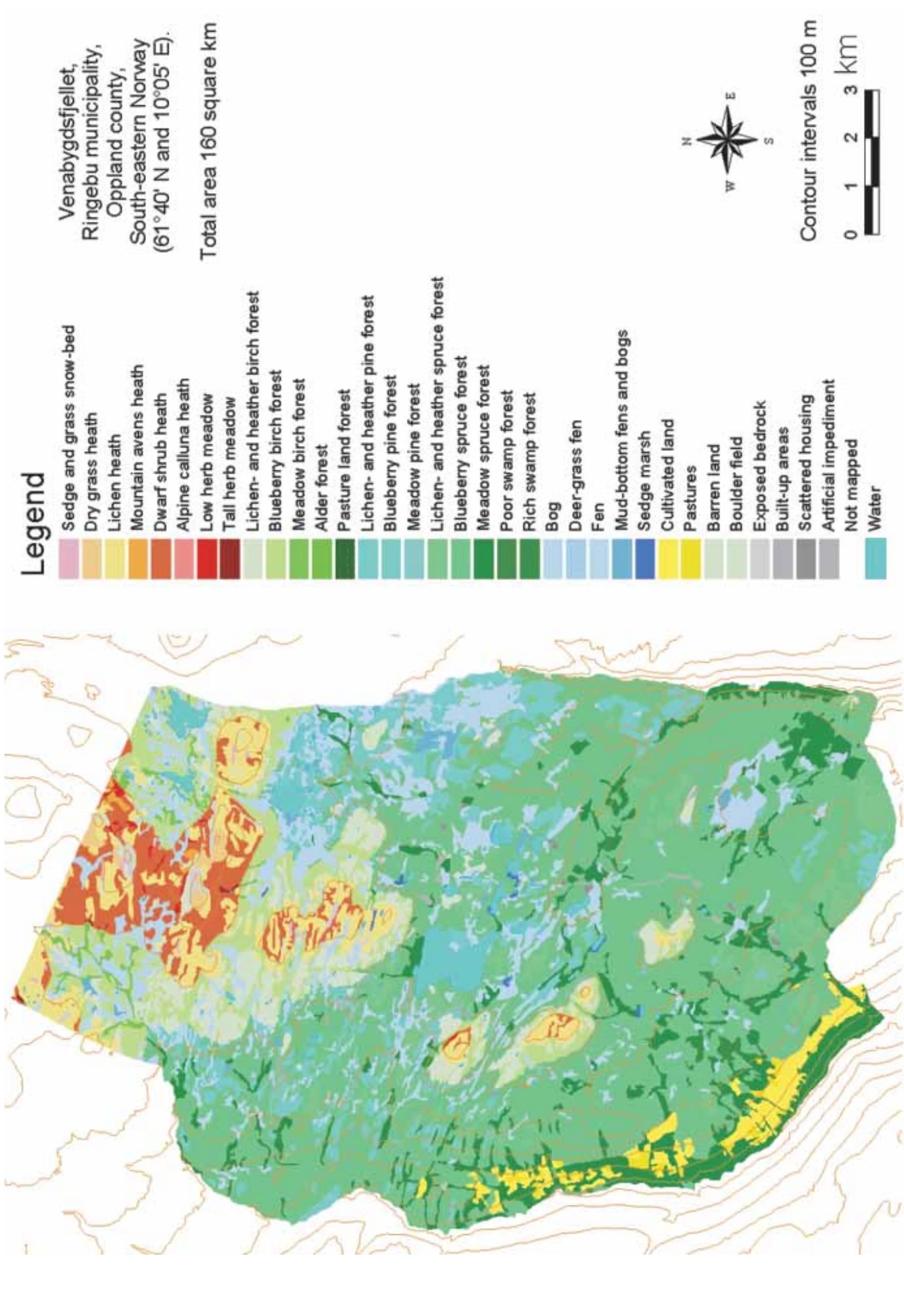

Figure 3.7. Venabygdsfjellet after climate change

Source: A.Bryn (2004)

is that a vegetation-change sequence will approximate the following pattern: first, areas already exposed to regrowth will be among the first to be changed fully. Such areas can be forested within a very few decades (Bryn *et al.* 2001). Second, highly-productive and intermediate vegetation types will change, and these changes may also come within a few decades. Third, low-productivity and wind-exposed vegetation types will change. Such changes are slow, and dependent on soil development, topography, wind protection and snow cover. Particularly exposed localities may need more than a century to reach what can be defined as forest. Lastly, the outphasing of birch below the upper coniferous forest-limit may take many decades. However, logging of birch for cottage fuelwood, and domestic browsing of birch seem likely to speed up the phasing-out of birch by spruce.

The presence of large areas of primary successional mountain birch forest far down in the potential coniferous forest zone indicate that larger areas were deforested earlier than the 2001 situation (Figure 3.5). The existence of this birch forest and smaller patches of grey alder forest suggest that the regrowth started many decades ago, probably late in the 1920s. The roads built to the summer dairy farms in this period caused a shift in the production site of cheese. Cheese production was very firewood intensive, but was, from that period on, moved from the summer farm landscape down to the farm landscape at lower altitudes. This reduced the need for firewood in the summer dairy-farm landscape. Also, the regrowth probably speeded up after the outfield scything ended in the 1950s, going progressively onward as outfield domestic grazing was moved further into the mountains and summer dairy farms were abandoned.

UNCHANGED VEGETATION TYPES

Many vegetation types and other area types have not been changed by either regrowth or climate change. The possible future transformation of these types, e.g. peatland forest (group 8) and mires (group 9), depends largely on unpredictable changes in precipitation, but also on unknown past regrowth (Benestad 2001; Iversen *et al.* 2003). However, scything on fens (9c) and domestic grazing in swamp forests (8c and 8d) has been widespread in these areas, and they were amongst the first to be left alone for regrowth (Bryn and Daugstad 2001; Øyen and Moen 2001). The last scything on fens in these areas ended in the early 1950s, but the tradition had started to decline as early as in the 1920s (Almås *et al.* 2004). During the last 25 years, most domestic animals have been brought to mountainous areas to the north of the mapped locations, in which potential swamp forest is absent. Both peatland forest and mires are therefore believed to be in a late-succession phase already, and are therefore left unchanged by future regrowth or climate change.

SIMPLIFICATION OF THE CLIMATE MODEL

The example of climate change presented here confines its considerations to temperature rise into consideration. Changes in precipitation, snow, wind, etc. are more uncertain than the predictions of a warmer climate (Benestad 2001; Iversen *et al.* 2003). Also, the future temperature rise could be greater, or else unknown climatic, biotic or edaphic feedback mechanisms could alter future forest growth. At these latitudes, in a transitional climate (Moen 1999), the approximate temperature change per 100 vertical meters is of 0.7°C. The expected temperature change giving a 40 m rise in the forest-limit is therefore of 0.28°C. This is a conservative estimate (Benestad 2001). Since a rise in the upper forest-limit mostly depends on climate change in the growing season, it seems to be a fair estimate. The total average yearly temperature rise might be considerably greater, but the future temperature changes at these latitudes are expected to become greater during the winter season than in the summer (Førland and Nordeng 1999; Hanssen-Bauer *et al.* 2001; Iversen *et al.* 2003). According to the Norwegian RegClim model downscaled from the Max-Planck Institute global climate model (Benestad 2001), the yearly average temperature in the area will rise with 0.6°C until the year 2060 (location

Dombås and Røros). If around half of this change can be achieved in the short mountainous growing season, then a rise of 0.28°C seems a fair estimate of the change over the next 50–60 years. The present upper climatic forest-limit of Norway was found to be best correlated with the three warmest summer months (Dahl 1983; Aas and Faarlund 1988). Precipitation at these altitudes is not a limiting growth factor for forests (Aas and Faarlund 1988).

EFFECTS ON BIOLOGICAL DIVERSITY

Both regrowth after abandoned traditional land use and forest expansion caused by climate change are known to have profound effects on biological diversity (Bryn and Daugstad 2001; Framstad *et al.* 2006). The results exemplify the large-scale effect regrowth in the summer farm landscapes has on biotope diversity expressed in terms of vegetation types. Regrowth is at present a great risk for sub-alpine and alpine vegetation types, cultural landscape vegetation types, mountain species and species adapted to cultural landscapes in Norway (DN 1998, Norderhaug *et al.* 1999; Fremstad and Moen 2001). At a vegetation map level, it seems more realistic to evaluate the threat to vegetation types as opposed to species, though we have some information on the relationship between different vegetation types and threatened species (Lid and Lid 1994; DN 1998; DN 1999; Fremstad and Moen 2001). Both Pasture land forest (4g) and Pastures (11b) are valuable types of area for endangered species related to the cultural landscape of Norway (DN 1999). Pasture land forest (4g) and vegetation types close to this grazed by domestic animals, disappear completely from an area through regrowth (Bryn *et al.* 2001). Mountain vegetation types valuable for the winter grazing of wild reindeer (2c and partly 2e) are heavily reduced by regrowth. Mountain vegetation types below the upper climatic forest-limit, related to cultural encroachment around the summer dairy farms of southern Norway, are especially species-rich and valuable in a national context (Austrheim 1998; Norderhaug *et al.* 1999; Bryn *et al.* 2001; Vandvik 2002; Øien 2002; Potthoff 2005). According to the regrowth scenario given here (Figure 3.6), the next 50–60 years will see large, open, species rich, seminatural sub-alpine mountain vegetation change to forest, due to regrowth after land use is abandoned. Whether the mountain areas will be further threatened by a forest expansion due to climate change is uncertain. If the expected temperature rise takes place, we can expect less mountain vegetation in the study area in the future.

HOW REPRESENTATIVE IS THE AREA?

There is no doubt that large areas of the Nordic mountainous region have been deforested by human encroachment through history (Aas and Faarlund 1995; Hofgaard 1997; Moen 1999; Austrheim and Erikson 2001; Bryn and Daugstad 2001; Lundh 2001; Dalen 2004; Wehberg *et al.* 2005). The mapped area of Venabygdsfjellet is an example of an inland valley-mountain profile, situated within Puschmann's (2005) landscape regions 11, 14 and 15 in southern Norway; the valley and mountain villages, the mountain forest and the low-alpine mountains. These regions share the same geographical and historical characteristics as the mapped area and cover approximately 70 770 km^2 of a total of 320 000 km^2 in Norway. The specific area changes will obviously differ between study sites, but the overall trend for changes caused by regrowth and climate change will probably remain.

FURTHER STUDIES

The shortcomings of this preliminary study will be pursued in terms of five aspects. First a vegetation map prior to 2001 needs to be interpreted from old aerial photos and new fieldwork. Such a map will shed light on the past vegetation pattern, the regrowth ahead of 2001 and the regrowth speed of birch, spruce, pine and alder forests (Skånes 1996). It will also provide information on difficult vegetation types, e.g. peatland forest and mires. Second, the annual forest growth rates of the last decades need to be measured. This will indicate whether a recent temperature rise has resulted in changed growth rates or not. Third, the effects of exposure on the forest-limit in the study area have so far probably been suppressed by the effects of human encroachment. The future effects of this need to be modelled to obtain even more realistic numbers of the potential forest area at higher altitudes. Fourth, the potential vegetation types below 800 m a.s.l. need to be interpreted. These intensively-used farm areas have been changed more permanently than the extensively-used sub-alpine summer dairy farm landscape. The reconstruction of potential vegetation in such areas will have to lean more on manual aerial photo interpretation and fieldwork than derivations from simple models (Tüxen 1956; Ricotta *et al.* 2002; Carranza *et al.* 2003). Fifth, the climatic scenario used should be more area-specific, i.e. locally downscaled for the study area.

CONCLUSION

Vegetation mapping in Norway has been presented briefly, and an example of application with the most used mapping system has been given. Vegetation maps were used as a basis for two future scenarios driven by two concurrent processes; forest regrowth following abandonment of land use, and forest expansion following future climate change. The finding of large potential areas for forest regrowth correct thoughts regarding vast areas exposed to expanding forest due to present climate change. The large present forest expansion in the mountainous areas of southeast Norway is a response to a historically low level of human utilization. This process will continue as human outfield encroachment is still decreasing. In addition, large areas at higher altitudes can be forested in the future, if the expected climate scenarios of the IPCC are realized. Up to now only small areas above the recent upper climatic forest-limits have been forested, indicating only a preliminary effect of climate change. It is important to make an effort to separate the effects of present regrowth from those of future climate change, as a means of explaining and understanding the processes underpinning landscape changes.

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FORECASTING OF STATES OF ECOSYSTEMS IN PROTECTED AREAS ON THE BASIS OF A COMPREHENSIVE DIGITAL VEGETATION MAP (AS EXEMPLIFIED BY POLAND'S BORY TUCHOLSKIE NATIONAL PARK)

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Abstract: This paper presents: (1) a method by which to forecast future states of ecosystems on the basis of deterministic models of development pathways, (2) necessary data to achieve this, and (3) an application of the above method to Poland's Bory Tucholskie National Park. The three required datasets to predict vegetational states were a complex digital map of potential[1] and actual vegetation, scenarios concerning future anthropogenic impacts on vegetation and habitats, and general models of vegetation development. The chosen study area is shown to feature processes of vegetation transformation, such as degeneration, regeneration, restitution, succession, slow evolution from type to type, stabilization and fluctuation. The three scenarios applied entailed: (1) the development of plant communities in conditions of a stable habitat and persistent human impact; (2) fully spontaneous[2] development of vegetation in unchanged habitats and free of human impact; (3) full achievement of a conservation plan's recommendations. The results of modelling future states of vegetation show that regeneration and evolution will prevail as a result of the first and second scenarios, resulting in noticeable changes in spatial and typological diversity of vegetation, whilst regeneration and stabilization will be dominant processes according to the third scenario.

Key words: potential vegetation, actual vegetation, dynamic circles of substitute communities, forecast, vegetation dynamics, National Park, Poland.

INTRODUCTION

Currently binding legal regulations and requirements as regards the rational and sustainable use of natural resources, make necessary the detailed identification of the state of ecosystems, recognized most frequently on the basis of characteristics of vegetation. One of the elements to such identification of ecosystems is (alongside historical analysis and the assessment of current state) the

[1] 'Potential vegetation' is a theoretical construct denoting the vegetation types that would most likely develop in the absence of human disturbance. This construct is used as an indicator of site, and is conventionally referred to as 'habitat types' (Tüxen 1956; Moravec 1998).

[2] The term 'spontaneous development' is here subject to wider interpretation than 'natural development,' meaning that a plant community develops without direct human influence on the species composition (but possible in the presence of an indirect influence, e.g. on habitats). Spontaneous vegetation characterizes all natural communities and in part also anthropogenic ones (e.g. meadows).

forecast of future states of vegetation, under both conditions of spontaneous development, and the influence of various additional external factors. This issue is particularly important in the case of protected areas, for which so-called 'protection and management plans' are elaborated, as well as for forest management which requires that stands be managed to anticipate climatic changes (cf. eg.: Habitat Directive 1992; Wear *et al.* 1996; Parks Canada 1997; Nature Protection Act 2004; Molinari *et al.* 2005). In recent years, numerous models have been developed to determine future states of vegetation cover. In line with the suggestions of Rupp *et al.* (2001), these can be categorized as:

(a) models of development pathways, referring to definite types of land cover, and not to individual patches, with a division into (a1) the stochastic ones, making use of the Markov chain concept, and (a2) the deterministic ones based on constant succession interdependences;

(b) models of patch dynamics, based on the determination of changes occurring during successional development within individual patches with respect to one or several selected parameters, with division into (b1) the empirical models making use of data from long-term observations on permanent plots; and (b2) the biogeochemical ones simulating changes in photosynthesising surfaces;

(c) individual models, simulating the growth, multiplication and mortality of individual trees or other plants, with a distinction made between (c1) statistical models that make use of interrelationships determined on the basis of empirical data, and (c2) gap regeneration models that account for the environmental factor complex in the causal perspective.

In analyses carried out at survey scales (e.g. country or continent) it is the stochastic models that are used most often, although their utility in the modelling of the dynamics of forest communities may recently have been shown to be limited (Korotkov *et al.* 2001). While on the very detailed scales (e.g. forest patch), the individual and empirical models of patch dynamics are superior, on the intermediate scales (especially in regions with well-understood dynamic interdependences between communities and precisely determined differentiation of human impact), the deterministic models of development pathways are most useful, being at the same time relatively simple in implementation (Rupp *et al.*2001). It was the latter kind of approach that was applied in the study reported here.

This paper concerns the area of the 'Bory Tucholskie' National Park (hereinafter PNBT)[3] (Figure 4.1). It was elaborated from work within the framework of the Park's protection plan (Matuszkiewicz and Solon 2002; Matuszkiewicz *et al.* 2002). Its purpose is to present the forecasting procedure, the necessary initial materials, as well as the assumptions and results, with the aim of modelling feasible directions to potential transformations of vegetation in the Park.

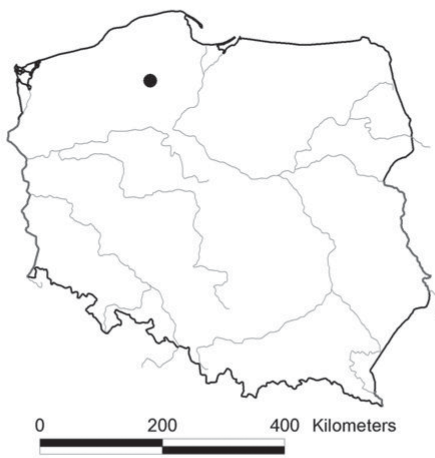


Figure 4.1. Location of study area.

[3] The 'Bory Tucholskie' National Park (PNTB) was created on 14 May, 1996 by virtue of a Regulation of the Council of Ministers of Poland. It covers 4, 613.05 ha, and boasts relief formed during the last Baltic Glaciation, most notably outwash plains as the dominant feature. Forest covers 79.5% of the Park's area, surface waters 11.5%. The Park's large areas of pine forest and oligotropic lakes may be considered the most valuable of its natural features.

MATERIALS AND PREREQUISITES FOR THE FORECASTING METHOD

BASES AND SCOPE OF FORECAST

The forecast of future states of and directions to the development of plant communities, extending in general outline some 20–50 years into the future in the PNTB, is based on the three following sets of data and the interrelationship between them:

- data on the present state contained in a detailed, comprehensive vegetation map entailing: 1) a description (via field mapping and direct habitat data) of the aforementioned potential natural vegetation; 2) a detailed description of the actual vegetation, its degree of deformation and current dynamic processes;
- assumptions concerning future human impact on vegetation and habitats (in particular on the level of groundwater with respect to humid habitats);
- generally known developmental trends for plant communities, based on relationships between phytocoenons forming dynamic circles of substitute communities.

CHARACTERISTICS OF THE COMPREHENSIVE VEGETATION MAP

The fundamental output from the cataloguing of vegetation in the National Park is the comprehensive vegetation map in digital form, elaborated as part of the framework of the PNBT protection plan. The basis for this map was a map of forest distinctions, whose phytosociological field interpretation yielded the spatial outlines to the basic units (polygons) of the digital map. The particular polygons were characterized with respect to a number of features concerning vegetation, and partly also habitat, as well as theproposed forms of protection of the given area. The elaborated vegetation map is referred to as 'comprehensive' in view of the inclusion within it of a number of different characteristics. In the database, each polygon is assigned:

- characteristics automatically generated by the GIS software (ArcView 3.2.), concerning areas and perimeters of the polygons in the measurement units adopted,
- order characteristics (numbers given during field charting or others),
- subject characteristics of the spatial variability to the phenomena investigated.

The subject characteristics, most important to the map, can be classified as: primary (parameters being introduced through direct entering into the database, e.g. through field charting), secondary (parameters being acquired through analysis of the primary-characteristic data introduced into the map earlier). The subject characteristics can be divided into basic (concerning vegetation directly), and complementary (concerning other elements, e.g. soil conditions).

The content of the database for the comprehensive vegetation map of PNBT is shown in Table 1. The basic primary characteristics obtained through the field charting encompass:

- actual vegetation currently growing in a given place, defined in terms of typological or descriptive units,
- potential natural vegetation, and current dynamics of vegetation,
- the degree to which vegetation is deformed from the state considered natural.

SCENARIOS FOR THE PROTECTION AND SHAPING ECOSYSTEMS IN THE PNBT

The forecast was elaborated in respect of three selected scenarios:

- Scenario 1 assuming the development of plant communities in conditions of more or less stable habitats (such as the current ones) and of persistent human impact, albeit with the exclusion of the kind of drastic impact not allowed by National Park status, e.g. felling of stands over large areas. The developmental trends already visible (e.g. degeneration or regeneration of plant communities, already-developing successional processes, transformations of forest stands subject to management) are assumed to continue.
- Scenario 2 assuming fully spontaneous development of vegetation under unchanged habitat conditions (i.e. the same as now) and a cessation of human impact on

Table 1. Contents of the attribute table (database) for the comprehensive vegetation map.

Number	Code in database	Type of characteristic	Subject of derived map	Description of characteristics	Number of units in legend
1	AREA	Automatically generated		Patch (polygon) area (sq. m)	—
2	PERIMETER	automatically generated		Patch (polygon) perimeter (m)	—
3	ROS	Order	running numbers of polygons	Field number of a polygon distinguished	(1320 numbers)
4	POTEN	Basic, primary	Potential natural vegetation	Determination of potential natural vegetation (based on field mapping)	12
5	RZECZ	Basic, primary	Actual vegetation - base map	Determinaton of actual vegetation (based on field mapping) - simplified for easy analysis of whole area	50
6	LASY	Basic, primary	Actual vegetation - forest communities	Determinaton of actual vegetation (based on field mapping) - very detailed for forest areas	37
7	NIELESNE	Basic, primary	Actual vegetation, non-forest communities	Determinaton of actual vegetation (based on field mapping) - very detailed for non-forest areas	52
8	ODKSZ	Basic, primary	Degree of deformation of vegetation	Determinaton of degree of deformation of vegetation (based on field mapping)	7
9	DYNAM	Basic, primary	Current dynamic processes	Determinaton of current dynamic processes (based on field mapping)	9
10	NATURA2	Basic, secondary	NATURA 2000 communities	Distribution of vegetation types registered as NATURA2000 habitats (based on comparison and interpretation of actual vegetation and Habitat Directive list)	3
11	ROZP2	Basic, secondary	Protected plant communities	Distribution of vegetation types protected by law (based on comparison and interpretation of actual vegetation and the Regulation of the Ministry of Environment)	3
12	TORFY	Complementary, primary	Peat distribution	Distribution of peat soils (based on field analyses conducted by the other team)	2
13	OCHR_P	Complementary, primary	Directions of protection and management of vegetation	Management proposals derived from PNBT Protection Plan	17
14	PROG1	Basic, secondary	Forecast number 1	Real vegetation forecast according to scenario 1	53
15	PROG2	Basic, secondary	Forecast number 2	Real vegetation forecast according to scenario 2	53
16	PROG3	Basic, secondary	Forecast number 3	Rreal vegetation forecast according to scenario 3	53

vegetation. In this variant, the free development of succession is assumed to take place in areas currently in use by man and occupied by substitute communities (like the overgrowing of meadows or moors), being more or less conditioned by the current-state spontaneous processes of regeneration of forest stands, and transformations consisting in the adaptation of current vegetation to present habitat conditions, i.e. the process by which actual vegetation will approach potential natural vegetation. For various reasons this forecast has only a theoretical sense, since its full realisation would not be possible, particularly because forest succession under high-voltage lines cannot be allowed and because forest service facilities (like houses) will have to be abandoned.

• Scenario 3 assuming complete and successful implementation of recommendations contained in the protection plan, including the reconstruction of the water economy. This variant anticipates that both the natural processes of succession and the regeneration of plant communities will take a course conforming to the intentions of the plan's authors. It is assumed that activities aimed at maintaining the dynamically unstable communities, changing the structure of forest stands and change of composition of stands, even leading to the restitution of some communities (e.g. oak-beech forests), will be successful. The forecast elaborated in accordance with this variant is, by its very nature, optimistic since it does not admit the possibility of conditions worsening due to the implementation of protection recommendations.

THE STAGES TO THE FORECASTING PROCESS

As mentioned in the introduction, the forecasting of future states of vegetation employs the model of the so-called 'development pathways' of a deterministic character, on the basis of predefined development capacities and successional interrelationship of plant communities. The initial stage of the work encompassed the listing of all types of plant communities observed in the field, in the form of circles of substitute communities.[4] When constructing these circles account was taken of: age-related development forms, deformations from the typical forms and the observed on-going dynamic processes (or ones interpreted on the basis of historical data, soil data and species composition). Feasible development pathways for each type of community were determined on this basis.

The forecasting procedure concerned each vegetation patch and comprised several steps corresponding to individual transformations and performed on the attribute databases for a set of mapes: the comprehensive vegetation map, and three maps presenting the spatial distribution of the expected directions to human impact and changes in soil moisture elaborated in line with the assumptions of the three scenarios. The consecutive steps are shown in Table 2.

The first step corresponded to the syntaxonomic identification of the patch, as enriched with information concerning protective status or use (Figure 4.2). On this

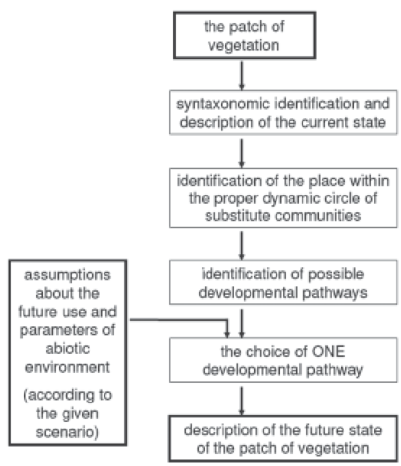


Figure 4.2. General scheme of the forecasting procedure

[4] The term circle of substitute communities (sensu Schwickerath 1954) means the set of communities including the final stable (i.e. climax) natural plant association, all the successional stages leading up to it, and all the semi-natural, segetal and ruderal communities present in the habitat of a given potential community.

Table 2. Steps to the forecasting procedure

Step number	Preceding step(s)	Problem	Source of information	Goal to achieve	Description	Succesive step
1	—	Determination of potential natural vegetation for a patch	POTENC' field in attribute table of comprehensive digital vegetation map	Choice of dynamic circle of substitute communities	There are special tables, one for each type of potential vegetation, in which the first column has a list of all actually occurring communities. All possible future vegetation types are listed in the first row. Each cell at the intersection describes prerequisites and conditions under which the actually occurring community may be replaced by the possible future vegetation type.	2
2	1	Phytosociological determination of a patch as well as determination of degree of deformation of vegetation	'RZECZ' field in attribute table of comprehensive digital vegetation map	Choice of possible development pathways for given type of vegetation	After the choice of the appropriate table (step 1), the right row (describing given actual vegetation) is chosen.	5
3	—	Choice of scenario of future management and protection scheme	Map or text description of proposed management	Determination of scope of methods and activities planned to achieve goals of management	Scenario can be very detailed (a list of all 'whats and whens' for all vegetation patches), more general (preferences for vegetation types) or very general (with zonation for different protection forms, eg. strict protection, partial or active protection, landscape protection). For a given patch one form of management is to be selected from the scenario adopted.	4
4	3	Model of future vegetation processes for given patch	Detailed description of management (a list of activities)	Determination of only one pathway of future development (one dominating process) for given patch of vegetation	There is an auxiliary table, in which included are informations about processes taking place in vegetation due to different form of management. Suitable data, necessary for modelling the future vegetation processes, are chosen from this table.	5
5	2, 4	Determination of future effects for given process	Table mentioned in step 1 and type of process determined in step 4	Model of future phyto-sociological position of vegetation of given patch	From the row of the table chosen in step 2 identified is a cell (on the basis of the information on the dominating process determined in step 4). The name of forecasted vegetation type is read from the first row (the header of the column in which the selected cell is placed).	6
6	5	Input of new data on prognostic map	'ID' field in attribute table of comprehensive digital vegetation map	Elaboration of complete prognostic vegetation map	Name of forecasted vegetation type is put into cell on the intersection of the proper ID number row and the column 'PROG#' of the attribute table of the comprehensive digital vegetation map.	—

basis, the given phytocoenosis was assigned to a concrete location within the dynamic scheme of substitute communities. The next step saw feasible developmental pathways determined, in connection with both the processes resulting from the dynamics of the vegetation alone, and those imposed by habitat-related or land-use changes. For the majority of types of community, the pathways were presented in terms of degeneration, regeneration, restitution supported by human activity, primary or secondary succession, stabilization and fluctuation, as well as slow evolution, associated with change in the potential community.

The subsequent step involves selection of one developmental route based around assumptions (resulting from a particular scenario) as regards the future use and envisaged parameters of the abiotic environment. The detailed analysis of the selected direction to development of a phytocoenosis in a given place provided the basis for the future type of community (syntaxon) and dynamic phase thereof to be determined.

INPUT DATA TO FORECAST FUTURE STATES: CHARACTERIZATION AND ASSESSMENT OF THE PRESENT VEGETATION STATE

POTENTIAL NATURAL VEGETATION

Starting from the aforementioned concept of potential natural vegetation, and drawing on the methods for the elaboration of vegetation maps of this kind (Faliński 1971; Matuszkiewicz, W. 1966; Matuszkiewicz, J. M. 1981; Matuszkiewicz and Kozłowska 1981) it was possible to identify this attribute in the cases of all the map's spatial units. The classification assumed was founded on the system of forest associations after Matuszkiewicz (2001). The respective list is given in Table 3, while the distribution across the PNBT is shown in Figure 4.3. The list provided makes it clear that the area investigated is dominated by habitats corresponding to one association—the suboceanic pine forest *Leucobryo-Pinetum*. The habitats of all other associations only occupy a little over 1/10 of the Park's area. This is quite a special situation resulting from the location on an extensive outwash plain.

Table 3. The spatial share of different types of potential natural vegetation in the area of PNBT

Potential natural vegetation	Area (ha)	% of total area of PNBT	% of terrestrial area of PNBT
Cladonio-Pinetum	21.72	0.47	0.53
Leucobryo-Pinetum	3627.21	79.01	89.26
Molinio-Pinetum	27.34	0.60	0.67
Vaccinio uliginosi-Pinetum	28.85	0.63	0.71
Vaccinio uliginosi-Betuletum pubescentis	9.60	0.21	0.24
Betulo-Quercetum roboris	139.96	3.05	3.44
Fago-Quercetum petraeae	82.53	1.80	2.03
Stellario-Carpinetum	39.77	0.87	0.98
Fraxino-Alnetum (Circaeo-Alnetum)	2.91	0.06	0.07
Ribeso nigri-Alnetum	83.56	1.82	2.06
Sphagno squarrosi-Alnetum	0.41	0.01	0.01
surface water	527.21	11.48	—

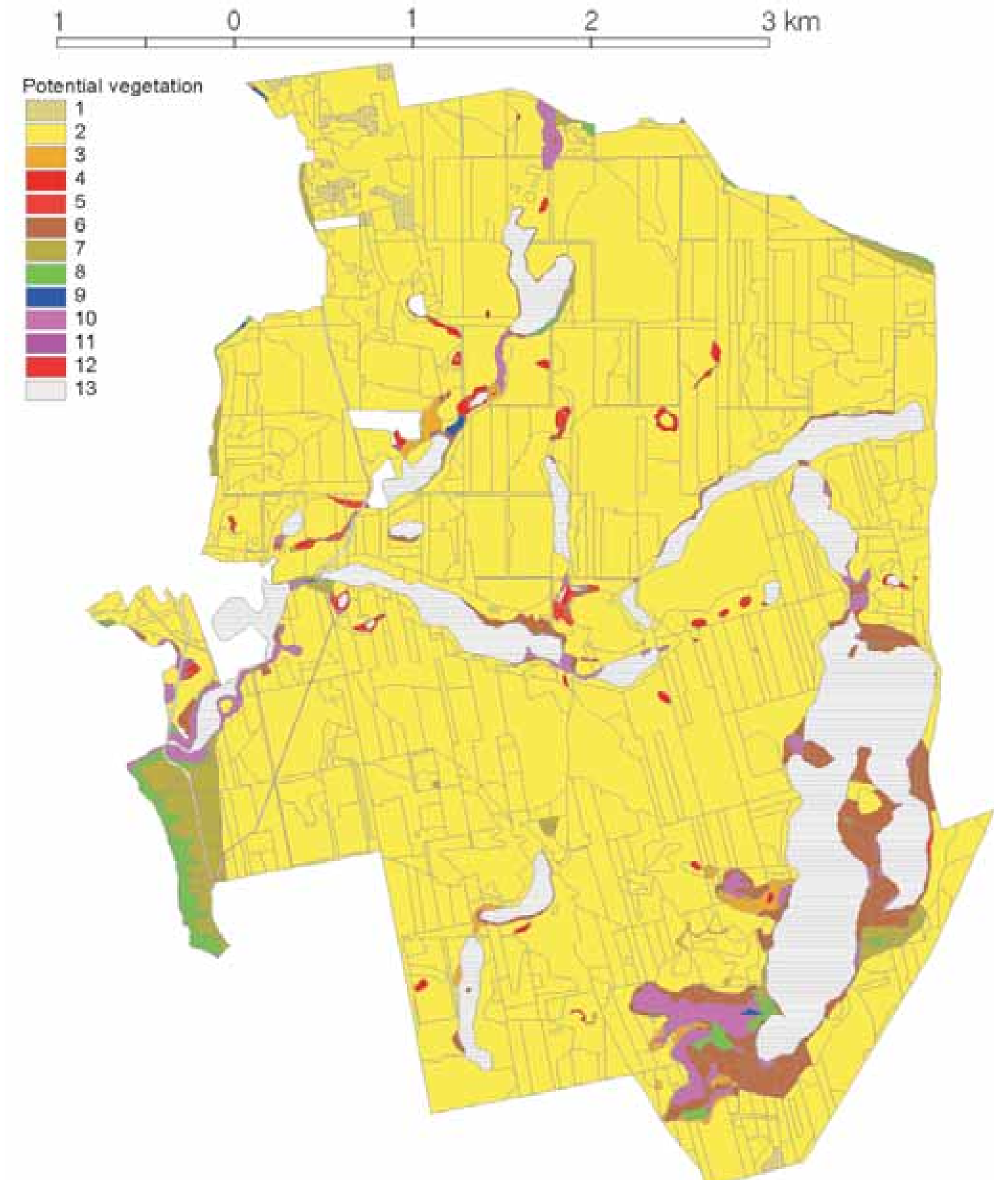


Figure 4.3. Potential natural vegetation of the PNBT: 1—Dry lichen-rich pine forest (*Cladonio-Pinetum*); 2—Fresh subatlantic pine forest (*Leucobryo-Pinetum*); 3—Moist pine forest (*Molinio-Pinetum*); 4—Swampy pine forest (*Vaccinio uliginosi-Pinetum*); 5—Swampy birch wood (*Vaccinio uliginosi-Betuletum pubescentis*); 6—Acidophilous oak-birch wood (*Betulo-Quercetum roboris*); 7—Acidophilous oak-beech wood (*Fago-Quercetum petraeae*); 8—Subatlantic oak-hornbeam forest (*Stellario-Carpinetum*); 9—Deciduous floodplain forest (*Fraxino-Alnetum*=*Circaeo-Alnetum*); 10—Alder swamp (*Ribeso nigri-Alnetum*); 11—Peatmoss-rich alder swamp (*Sphagno squarrosi-Alnetum*); 12—High moor (*Sphagnetum magellanici*); 13—surface water

Table 4. Number of units and occurrence of selected types of actual vegetation

Groups of typological units identified on map of actual vegetation	Number of units according to scheme of classification		Area (ha)	% of total area of PNBT	Number of polygons (patches)
Chosen units and sub-units	Simplified scheme	Detailed scheme			
Forest communities	13	35	3,908.68	85.18	1,099
Dry and fresh pine forests	2	8	2,841.62	61.62	520
Cladonio-Pinetum	1	1	930.58	20.28	79
Leucobryo-Pinetum	1	7	1,911.04	41.64	441
Leucobryo-Pinetum, typical variant		1	1,064.60	23.20	219
Leucobryo-Pinetum, Cladonia variant		1	598.50	13.04	108
Wet coniferous forest and marshy coniferous forest and scrub with bog villery	4	4	49.50	1.08	74
Molinio-Pinetum	1	1	17.89	0.39	18
Vaccinio uliginosi-Pinetum	1	2	21.74	0.47	41
Betuletum pubescentis	1	1	9.55	0.21	14
Acidophilous beech-oak forests or birch-oak forests	2	4	59.08	1.29	66
Betulo-Quercetum	1	3	48.52	1.06	57
Fago-Quercetum	1	1	10.57	0.23	9
Fresh or moist deciduous forests	2	2	7.40	0.16	19
Stellario-Carpinetum	1	1	6.79	0.15	14
Fraxino-Alnetum (Circaeo-Alnetum)	1	1	0.61	0.01	5
Alder swamps	2	6	22.24	0.48	60
Ribeso nigri-Alnetum	1	5	22.05	0.48	59
Ribeso nigri-Alnetum, variant with *Carex*		1	8.69	0.19	21
Forest communities not-classified syntaxonomically	1	11	928.85	20.24	360
Scots pine stands, less than 10 years old, on *Dicrano-Pinion* habitats		1	175.74	3.83	64
Scots pine stands, 10-15 years old, on Dicrano-Pinion habitats		1	400.83	8.73	128
Scots pine stands, 15-30 years old, on Dicrano-Pinion habitats		1	232.65	5.07	61
Non-forest communities	38	52	155.55	3.39	196
Different meadow communities	12	15	71.40	1.56	77
Calthion	1	2	18.11	0.39	19
Arrhenatherion	1	2	13.95	0.30	17
Heathlands and grasslands	5	6	46.94	1.02	29
Callunetum	1	1	9.09	0.20	6
Sedge rush communities and water vegetation	5	10	7.46	0.16	25
High-moor and transitory peat bogs	3	5	3.90	0.08	11
Ruderal and segetal communities	6	5	3.97	0.09	10
Other plant communities	7	11	21.88	0.48	44
Lakes (not analysed)	1	1	524.74	11.43	25
TOTAL	52	88	4,588.96	100.00	1,320

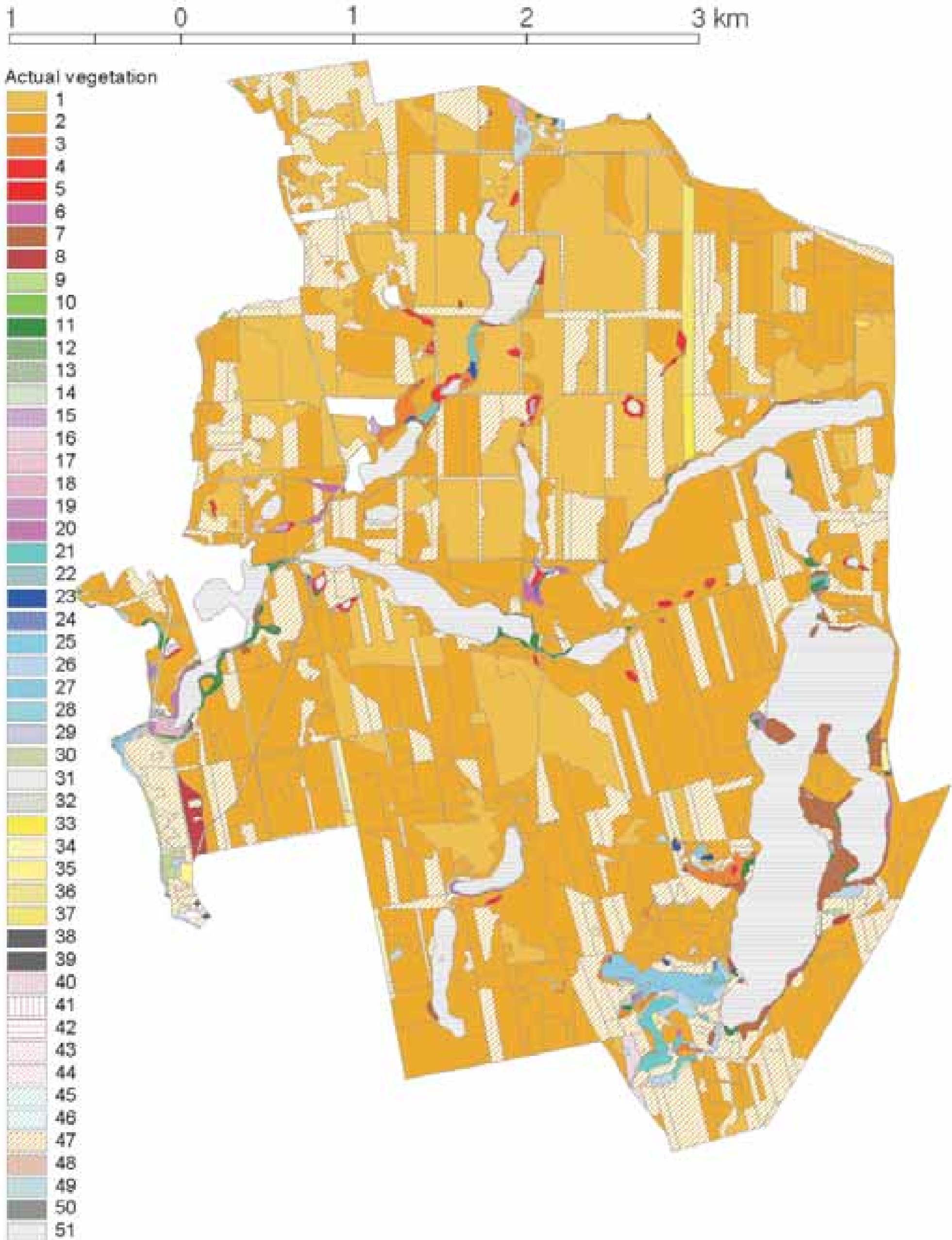


Figure 4.4. Actual vegetation of the PNBT; 1—*Cladonio-Pinetum*; 2—*Leucobryo-Pinetum*; 3—*Molinio-Pinetum*; 4—*Vaccinio uliginosi-Pinetum;* 5—*V.u.-Pin. + Sphagnion magellanici;* 6—*Vaccinio uliginosi-Betuletum pubescentis;* 7—*Betulo-Quercetum roboris;* 8—*Fago-Quercetum petraeae;* 9—*Stellario-Carpinetum;* 10—*Fraxino-Alnetum;* 11—*Ribeso nigri-Alnetum;* 12—*Sphagno squarrosi-Alnetum;* 13—*Salicetum pentandro-cinereae;* 14—*Pruno-Rubion fruticosi;* 15—*Sphagnion magellanici;* 16—*Scheuchzerietalia palustris;* 17—*Scheuchzerietalia palustris + Salicetum pentandro-cinereae;*

ACTUAL VEGETATION AND ITS DEGREE OF DEFORMATION

In field-mapping the vegetation, the primary task was to identify actual vegetation on particular fragments of terrain. The phytosociological classification of plant communities (Matuszkiewicz W. 1981, 2001) was used as the general reference here, in some cases being augmented by descriptive units from beyond this classification system. The latter was, in particular, true of young pine stands, numerous in the area investigated, in which plant communities have not developed properly and cannot thus be defined in syntaxonomic terms. The results of an identification of actual vegetation were entered into the database of the numerical map in a simplified or more detailed way. In the former case, 52 units were distinguished, and in the latter 88. The detailed classification was carried out separately for forest vegetation and non-forest vegetation, these being the subject of separate records in the database for the numerical vegetation map (Table 1). The actual vegetation of the PNBT is dominated by forest communities and especially by pine forests (Table 4). The most common plant community is the association of the subatlantic fresh pine forest (*Leucobryo-Pinetum*), divided up into some variants, and occupying more than 2/5 of the area altogether. Considerable areas (20% of the total) are also occupied by the dry lichen-rich pine forest (*Cladonio-Pinetum*), as well as communities of pine stands of various ages, undefined in syntaxonomic terms, these kinds of formations each taking 1/5 of the area. In addition to the communities mentioned, only the association of acidophilous birch-oak wood (*Betulo-Quercetum*) has an areal share exceeding 1% of the PNBT. All the remaining communities take smaller shares. If we subtract the various forms of pine forest and stands, as well as lakes, than not much more than 1/20 of the area is left for other types of plant communities. An outline of the spatial differentiation of actual vegetation is presented in Figure 4.4.

A further element of the field identification of the state of vegetation was the assessment of the degree of deformation of particular patches, as part of the primary basic characterization. This assessment assumed that the state described by the type of forest community (association), corresponding to the potential natural vegetation, is the most natural state that a community can attain and conversely, that changes in the community yielding a floristic composition and structure different from those of the community 'type' signify a deformation of the community. A seven-degree assessment scale was used, in which 0 meant lack of deformation, i.e. a fully natural state, and 6 complete deformation, i.e. a community that is outside the definite phytosociological class. The proportions of the areas occupied by the patches of vegetation classified in the categories proposed are shown in Figure 4.5, and their extent over the area of the PNBT—in Figure 4.6. Communities relatively little deformed (assessment classes 0 to 2) are

18—*Caricion nigrae;* 19—*Phragmition;* 20—*Magnocaricion;* 21—*Calthion palustris;* 22—*Calthion x Caricion nigrae;* 23—*Molinion caeruleae;* 24—*Molinion + Salicetum pentandro-cinereae;* 25—*Scirpetum sylvaticae;* 26—*Arrhenatherion elatioris;* 27—*Arrhenatherion + Calthion;* 28—*Arrhenatherion + Cynosurion;* 29—*Arrhenatherion + Plantaginetalia majoris;* 30—*Arrhenatherion x Sedo-Scleranthetea;* 31—*Nardetalia;* 32—*Nardetalia x Arrhenatheretalia;* 33—*Pohlio-Callunion;* 34—*Pohlio-Callunion + Corynephorion;* 35—*Vicio-Potentillion;* 36—*Corynephorion canescentis;* 37—*Corynephorion + Pohlio-Callunion;* 38—*Artemisietea vulgaris;* 39—*Artemiseitea + Plantaginetalia majoris;* 40—*Senecioni sylvatici-Epilobietum angustifolii;* 41—*Polygono-Chenopodietalia;* 42—*Centauretalia cyani;* 43—*Plantaginetalia;* 44—*Stellarietea mediae;* 45—*Potamion;* 46—*Nymphaeion;* 47—*Indefinite forest communities;* 48—*Indefinite shrubs communities;* 49—*Indefinite herbaceous communities;* 50—*No vegetation;* 51—*Surface water (not analyzed)* shown to occupy a similar area as the communities completely deformed (class 6)—1/4 of the area each. These two opposing groups display a tendency to concentrate separately from each other in space.

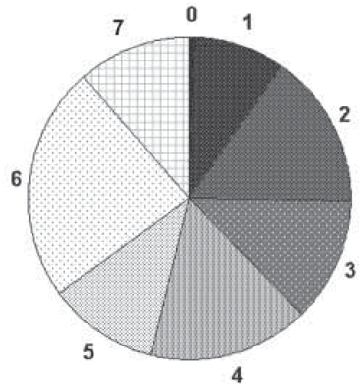


Figure 4.5. Area shares of communities featuring various degrees of deformation in the PNBT 0—no deformation; 1—minimal; 2—small; 3—average; 4—big; 5—very big; 6—total; 7—other areas.

DYNAMIC CIRCLES OF SUBSTITUTE COMMUNITIES: THE CURRENTLY APPEARING AND POTENTIAL DIRECTIONS TO CHANGES IN PLANT COMMUNITIES (DEVELOPMENT PATHWAYS)

General characteristics of the dynamic circles of substitute communities

Among the eleven types of potential vegetation, one (*Betuletum pubescentis*) revealed no substitute communities, only different degeneration and regeneration phases of the terminal community. A similar situation is expected in the future. For the remaining potential communities (*Betulo-Quercetum*, *Fraxino-Alnetum*, *Cladonio-Pinetum*, *Fago-Quercetum*, *Leucobryo-Pinetum*, *Molinio-Pinetum*, *Ribeso-Alnetum*, *Sphagno-Alnetum*, *Stellario-Carpinetum*, *Vaccinio uliginosi-Pinetum*) there are between two (for the dry lichen-rich pine forest) and eleven (for *Ribeso-Alnetum* and *Stellario-Carpinetum*) differently defined types of community forming the dynamic circles of substitute communities (Figure 4.7 a–j). Given the specific character of the National Park it is assumed that the defined interrelations between the vegetation types are of a permanent nature, that is no new factor shall appear to cause the development of completely different types of substitute community.

Main pathways to the transformations of plant communities are now and will remain in the future the resultant of several processes, namely degeneration, regeneration, anthropogenic restitution, primary or secondary succession, slow evolution linked with the change of the potential community, as well as stabilization and fluctuation (Figure 4.8).

Processes of degeneration of communities, understood as changes in the composition and structure of communities, passing from more natural forms (closer to the type of the given community) towards transformed ones, were predicted in cases in which these processes have already been observed and there are no bases for anticipating their reversal. This is mainly true of communities which are in general natural, but with habitat undergoing changes disadvantageous to the given community (most often a lowering of the water table) or with introduced tree species (e.g. spruce or pine) exerting a long-term destructive influence on it. It is expected that there will be degeneration of:

- raised bogs and transitional peat lands (usually due to observed lowering of the water table),
- swampy pine forest (e.g. owing to a lowering of the water table or the destruction of stands),
- swampy birch woods (e.g. owing to a lowering of the water table or the destruction of stands),
- oak-birch woods (usually owing to the introduction of conifers),
- oak-hornbeam forest (also usually owing to the introduction of conifers),
- deciduous floodplain forest,
- alder swamp (owing to the lowering of the water table or a deformation of stand composition).

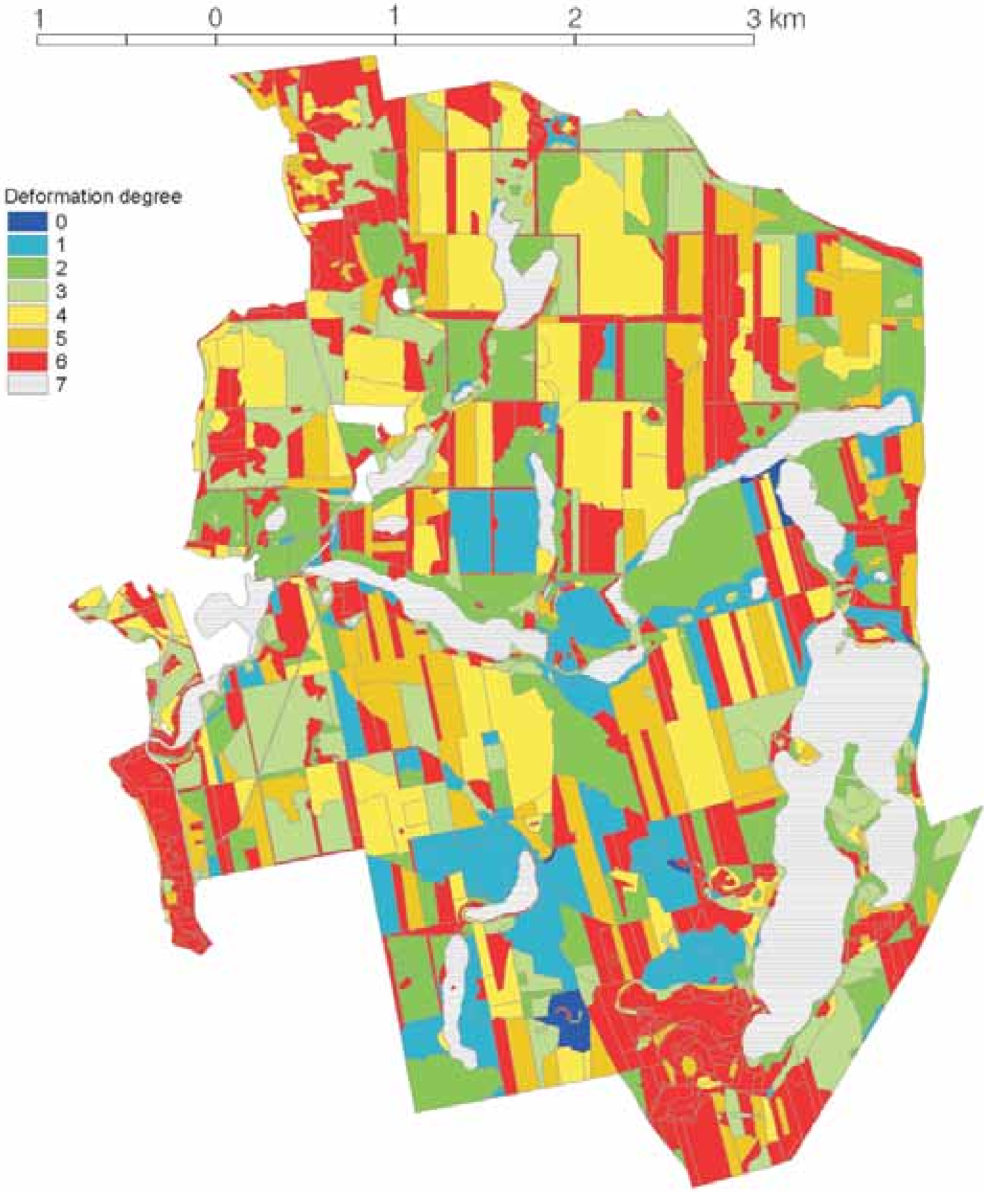
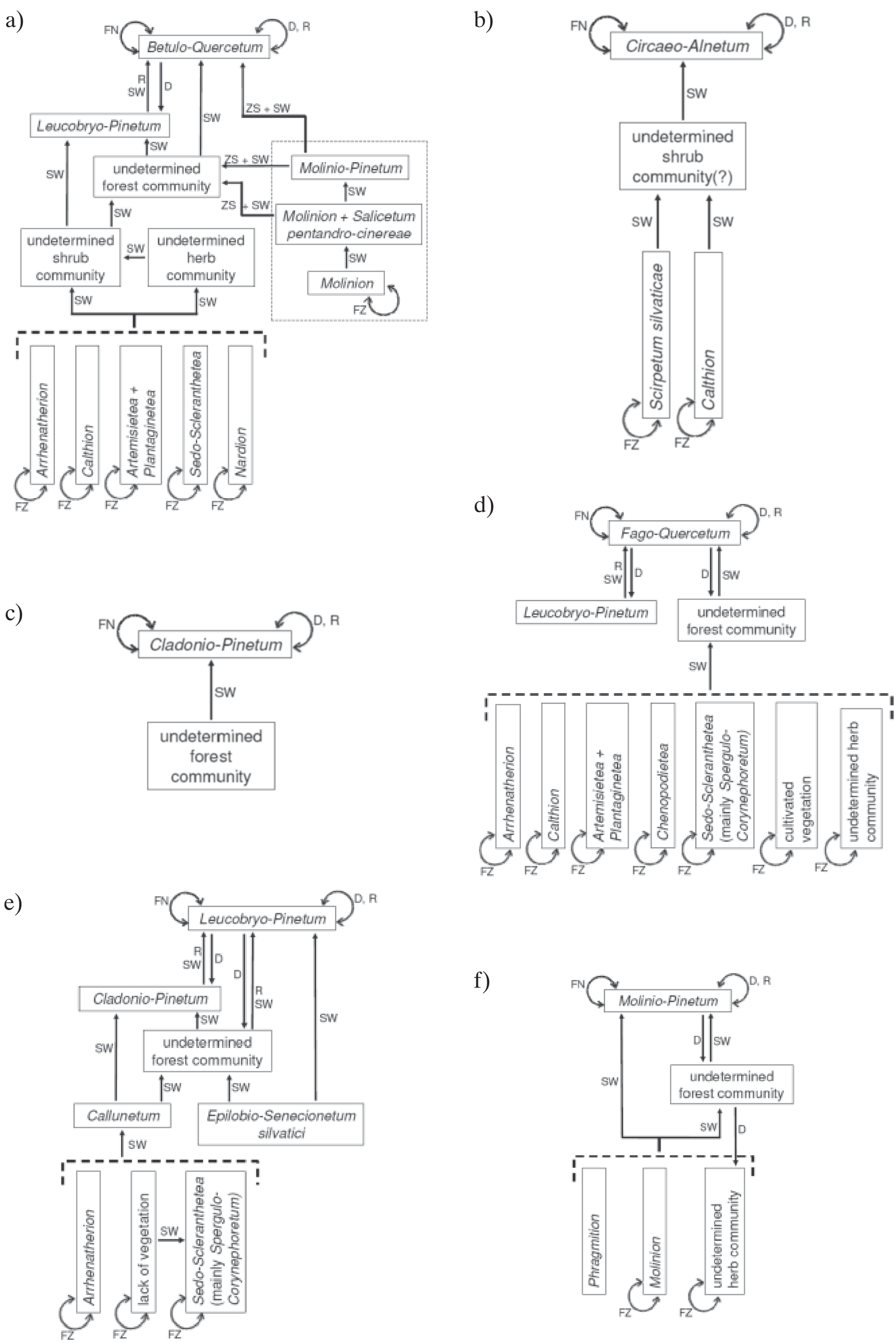


Figure 4.6. Deformation degree of actual vegetation of the PNBT.; 0—no deformation; 1—minimal; 2—small; 3—average; 4—big; 5—very big; 6—total; 7—other areas


a)
FN
D, R
Betulo-Quercetum
R
SW
D
SW
ZS + SW
Leucobryo-Pinetum
SW
SW
undetermined forest community
ZS + SW
Molinio-Pinetum
SW
ZS + SW
Molinion + Salicetum pentandro-cinereae
SW
undetermined shrub community
SW
undetermined herb community
SW
Molinion
FZ
SW
SW
Arrhenatherion
Calthion
Artemisietea + Plantaginetea
Sedo-Scleranthetea
Nardion
FZ
b)
FN
D, R
Circaeo-Alnetum
SW
undetermined shrub community(?)
SW
SW
Scirpetum silvaticae
Calthion
FZ
c)
FN
D, R
Cladonio-Pinetum
SW
undetermined forest community
d)
FN
D, R
Fago-Quercetum
R
SW
D
D
SW
Leucobryo-Pinetum
undetermined forest community
SW
Arrhenatherion
Calthion
Artemisietea + Plantaginetea
Chenopodietea
Sedo-Scleranthetea (mainly Spergulo-Corynephoretum)
cultivated vegetation
undetermined herb community
FZ
e)
FN
D, R
Leucobryo-Pinetum
R
SW
D
D
R
SW
SW
Cladonio-Pinetum
SW
SW
undetermined forest community
SW
SW
Callunetum
Epilobio-Senecionetum silvatici
SW
Arrhenatherion
lack of vegetation
SW
Sedo-Scleranthetea (mainly Spergulo-Corynephoretum)
FZ
f)
FN
D, R
Molinio-Pinetum
D
SW
SW
undetermined forest community
SW
D
Phragmition
Molinion
undetermined herb community
FZ

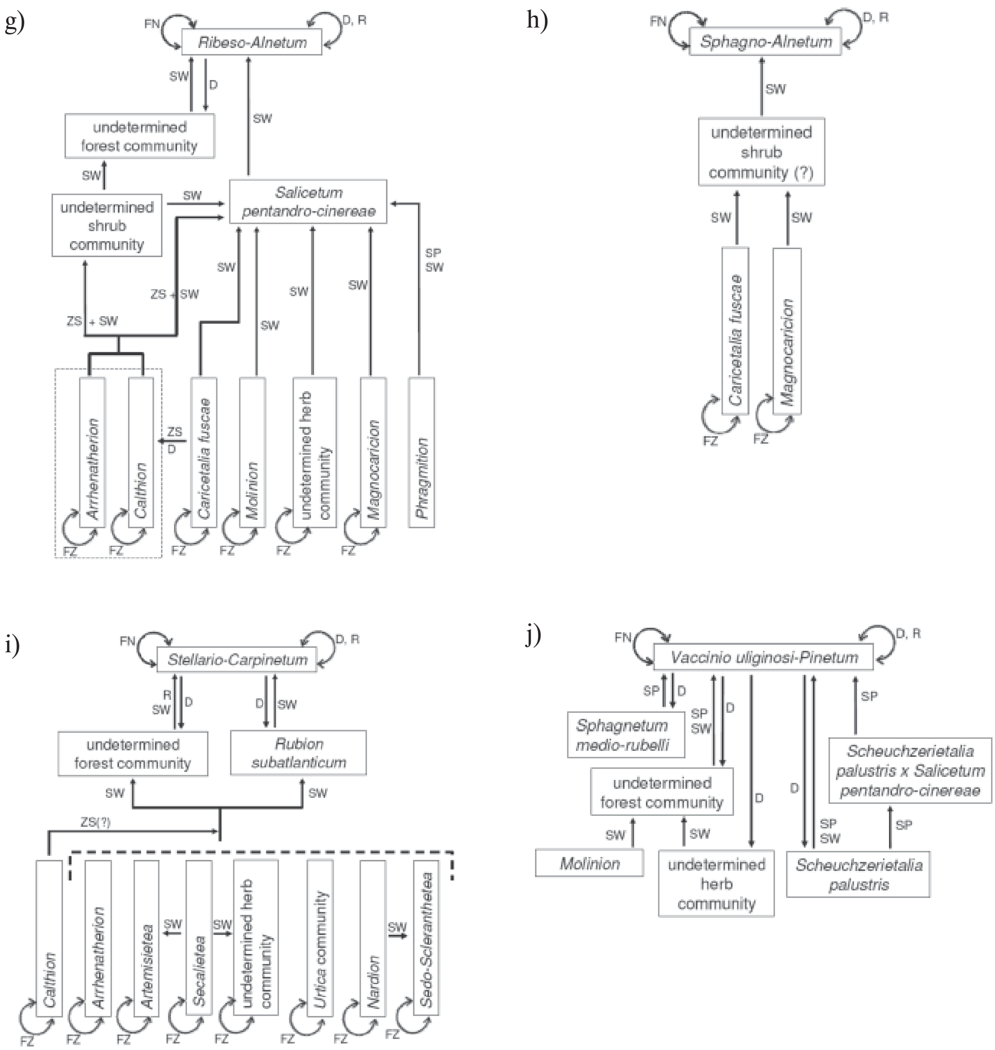


Figure 4.7 a–j. Dynamic circles of substitute communities identified on the area of the PNBT. Explanation of symbols: D—degeneration; FN—natural fluctuation; FZ—anthropogenically conditioned fluctuation; R—regeneration and restitution; SP—primary succession; SW—secondary succession; ZS—change of abiotic conditions

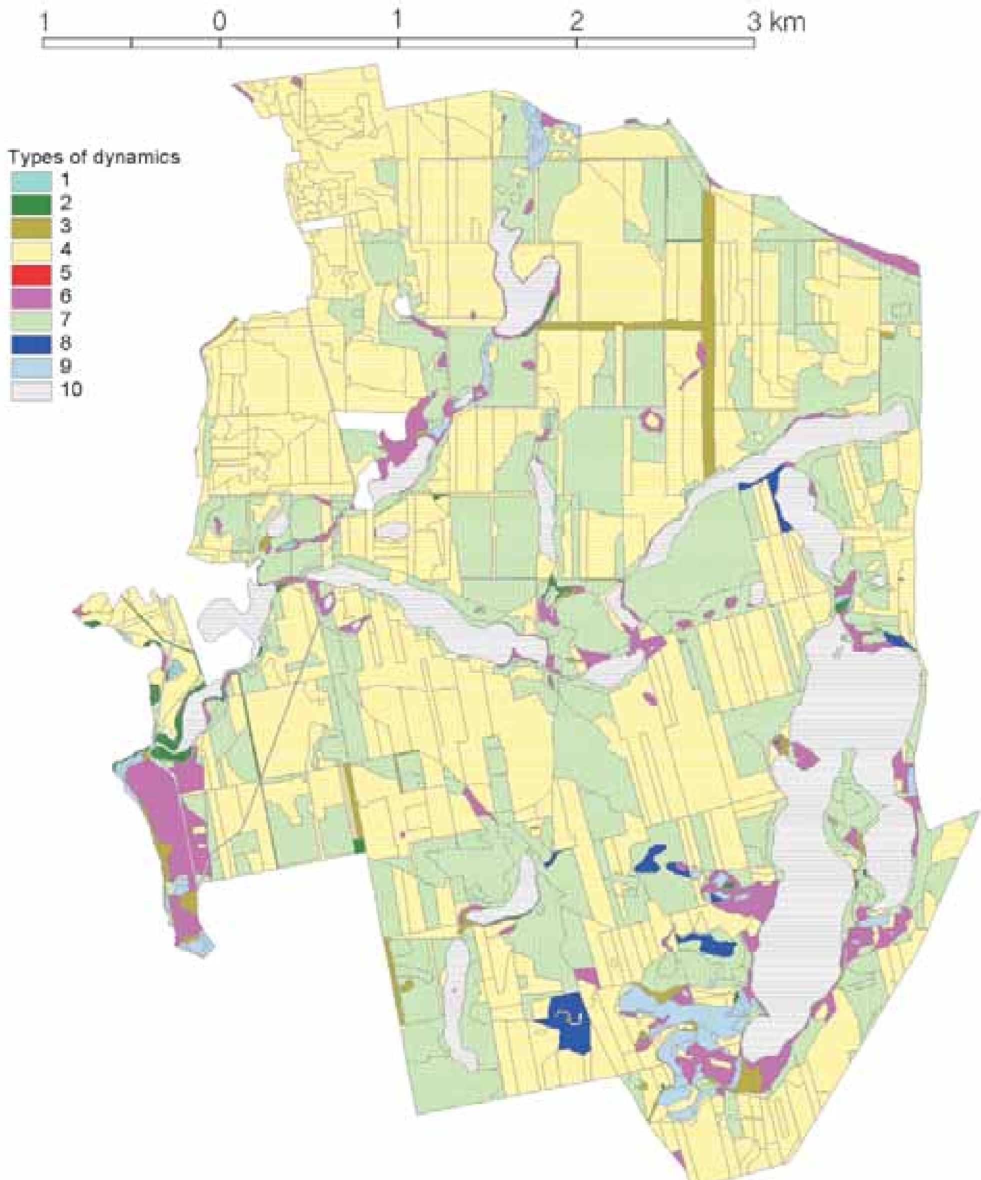


Figure 4.8. Types and direction of dynamics of vegetation in the PNBT.;
1—Primary succesion; 2—Spontaneous secondary succession; 3—Conditional secondary succession;
4—Anthropogenically directed secondary succession; 5—Substitute secondary succession;
6—Degeneration; 7—Regeneration; 8—Natural fluctuation; 9—Anthropogenically forced fluctuation;
10—Lakes and water courses

Processes of regeneration of communities were understood as changes in composition and structure as communities pass from a deformed to a more natural state (closer to the type). These processes can take place naturally or with human assistance. It may emerge that changes in habitat are necessary if they are to proceed (above all changes in water management). Regeneration is observed now and expected in the future in the case of dry lichen-rich pine forest, fresh pine forest, humid pine forest, swampy pine forest, swampy birch woods, oak-birch forest, oak-hornbeam forest, deciduous floodplain forest, and alder swamp.

Processes of restitution (re-establishment) of communities, were understood as the creation, with human assistance (via stand reconstruction) of the communities natural to the region, but destroyed some time ago at a given site, and only capable of very slow natural regeneration. In this context, activities envisaged in the protection plan assume re-establishment of oak-beech forest through planting of both species.

Processes of succession were understood as mostly spontaneous changes entailing replacement at the same location of communities belonging to different associations (or even classes of associations), with the consecutive replacement stages representing communities of increasing complexity of structure. The successional sequences envisaged across the Park are:

- succession from different grass communities through the stage of self-sown pine towards fresh pine forest,
- succession from sandy grasslands through *Calluna* heathlands towards pine forest,
- a weakly defined succession from moist grasslands leading towards humid pine forest,
- succession from meadow-ruderal communities, via undefined scrub, towards acidophilous mixed forest,
- succession from meadow-grassland communities, via scrub, towards the initial forms of the acidophilous forest,
- succession from ruderal communities, via various kinds of scrub, towards the initial forms of oak-hornbeam forest,
- succession from a meadow community, via scrub, towards the initial forms of oak-hornbeam forest,
- succession from a humid meadow community, via willow scrub, towards deciduous floodplain forest,
- succession from sedge communities, via willow scrub, towards alder swamp,
- succession in the communities of shallow waters, leading from typically aquatic communities of plants with floating leaves towards swamp.

Processes of slow evolution of communities from type to type were understood as transformations of a forest community, even with a small degree of deformation, belonging to one association, into a community of another association. This takes place where an association is conditioned by past situations and is ill-adapted to the habitat. Processes of this kind were identified for:

- the evolution of dry lichen-rich pine forest towards fresh pine forest—a process observed both within the PNBT and the entire area of the Bory Tucholskie forests (as well as in other regions), and being regarded as a slow process of regeneration of pine forests after strong former pressure resulting from grazing (especially shepherding), and the raking of litter,
- evolution of fresh pine forest towards oak-birch woods,
- evolution of pine forest with moor grass towards oak-birch woods,
- evolution of pine forest towards a poorly defined mixed forest.

Processes of stabilization of currently-existing communities and fluctuation were understood as the persistence in an approximately unchanged state of currently-existing natural or anthropogenic plant communities. Stabilization may concern natural, persistent communities left to themselves, or, in contrast, communities closely dependent upon defined human activities, when it is assumed that these will persist as unchanged or modified through the forecast period.

Stabilization is expected for number of patches of: fresh pine forest, humid pine forest, boggy pine forest, oak-birch woods, alder swamp, forest communities which cannot be classified syntaxonomically , raised bogs and transitional peatlands, *Calluna* heathlands, sandy grasslands, various communities of meadow type, ruderal communities, segetal (field) communities.

An additional group, most probably linked with the processes of succession and regeneration, embraces transformations weakly defined with respect to their character and effects, resulting mainly from changes in the age structure of forest stands. This category, above all, includes unavoidable spontaneous or anthropogenic transformations of young forest cultures, which over 20 years have little chance of reaching the age allowing for full regeneration of the natural association corresponding to the habitat. Development routes distinguished within this category are:

- transformation of Scots pine stands into stages of regeneration of fresh pine forest, currently encompassing older pine stands which may, under advantageous circumstances be transformed into the stages of regeneration of Leucobryo-Pinetum in about 20 years (even though these would not yet be communities with natural properties),
- transformation of undefined communities into stages of regeneration of the fresh pine forest, currently concerning forests of different stand composition, undefined in phytosociological terms, which in the perspective of 20 years may pass to phases of regeneration of Leucobryo-Pinetum,
- transformation of the undefined communities into stages in the regeneration of humid pine forest, currently concerning forests of different stand composition, undefined in phytosociological terms, which in the perspective of 20 years may pass to phases in the regeneration of Molinio-Pinetum,
- age transformations in currently young Scots pine stands that will remain communities undefined in phytosociological terms during the next 20 years,
- transformations in forests undefined in phytosociological terms whose directions are not known yet.

ELEMENTS OF THE NATIONAL PARK PROTECTION PLAN NECESSARY FOR THE ELABORATION OF A FORECAST

The forecast of the future state of vegetation was performed in line with the aforementioned three scenarios. The third scenario requires knowledge of both general and detailed prerequisites of the protection plan, within the scope required for the determination of the state of the vegetation. For the purposes of forecasting in line with the third scenario a division of the Park into three basic zones was adopted, one to be subdivided further with respect to the scope and form of human intervention. Protection forms and activities oriented at vegetation, resulting from the prerequisites of the plan, are provided in Table 5. The extent of the zones are shown on Figure 4.9. As can be seen, the primary forms of managing vegetation would be to allow for spontaneous development on approximately 1/3 of the area, and for changes of the already existing stand compositions, envisaged on about half of the PNBT area. On only 3.4% of the area does the plan envisage maintenance of current vegetation in a dynamically-unstable state diverging from that defined by the potential natural vegetation, and in 3.9% of the area the introduction of new elements to the tree stands, for the purposes of reconstruction and restoration.

FORECASTING VEGETATION CHANGES IN THE PNBT IN LINE WITH THREE SCENARIOS

The results of a forecast of the future state of the vegetation according to the three scenarios are presented on Figures 4.10, 4.11 and 4.12. A comparison of the spatial extends of the forecasted states of the vegetation is provided in Table 6. Several conclusions can be formulated on the basis of this table.

The processes of the degeneration of communities are forecast exclusively within the framework of scenarios 1 and 2. They

Table 5. Spatial differentiation of protection and management of vegetation (according to the protection plan of PNTB)

Forms of protection and management / Influence on vegetation	Number of polygons (patches)	Area (ha)	% of total area of PNBT
A. Strict protection			
Spontaneous development	94	284.4	6.20
B. Partial (active) protection			
B.1. No management			
Spontaneous development	407	940.0	20.48
B.2. Preservation			
preservation - dry lichen-rich pine forests	3	57.7	1.26
preservation - grasslands and heathlands	12	39.5	0.86
preservation - meadows	20	15.0	0.33
preservation and exploitation—meadows	25	45.1	0.98
B.3. Change of state			
Spontaneous development with small modifications	99	483.3	10.53
modifications of stand structure	419	2,011.2	43.83
introduction of *Quercus robur*	84	72.0	1.57
introduction of *Quercus petraea* and *Fagus sylvatica*	60	77.3	1.68
introduction of different deciduous tree species	41	22.7	0.50
introduction of *Acer platanoides, Acer pseudoplatanus* and *Tilia sp.*	1	2.8	0.06
introduction of *Fraxinus excelsior*	3	0.7	0.02
introduction of *Alnus sp.* and *Fraxinus excelsior*	5	2.5	0.05
introduction of *Pinus sylvestris*	4	2.2	0.05
C. Landscape protection			
built-up and economically used areas	18	7.8	0.17
Lakes (not analyzed)	25	524.7	11.43

are not envisaged in scenario 3, by definition. Their share should not be great, for the area over which they are forecast to occur amounts to about 1.5% of terrestrial habitats in the PNBT. Degeneration processes are mainly forecasted with respect to boggy pine forests, boggy birch woods, oak-birch woods and alder swamps. The patches of communities which may undergo degeneration are dispersed across the entire area of the Park, and they do not form large complexes. According to each scenario the processes of

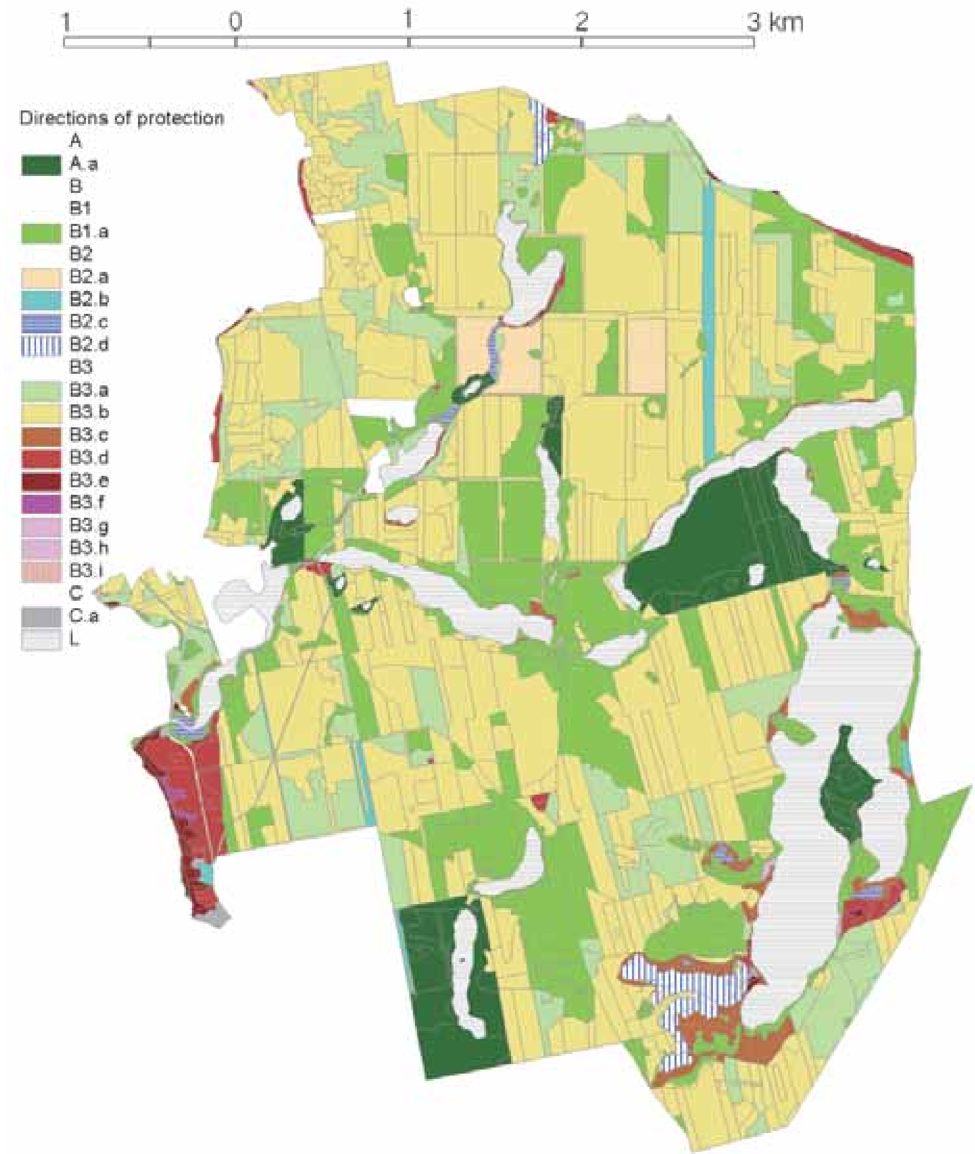


Figure 4.9. Directions of protection and management of vegetation in the PNBT.; A—Strict protection; A.a—Spontaneous development; B—Partial (active) protection; B1—No management; B1.a—Spontaneous development; B2—Preservation; B2.a—preservation—dry lichen-rich pine forests; B2.b—preservation—grasslands and heathlands; B2.c—preservation—meadows; B2.d—preservation and exploitation—meadows; B3— Change of state; B3.a—spontaneous development with small modifications; B3.b—modifications of treestands structure; B3.c—planting of Quercus robur; B3.d—planting of Quercus petraea and Fagus sylvatica; B3.e—planting of different deciduous tree species"; B3.f—planting of Acer platanoides, Acer pseudoplatanus and Tilia sp. ; B3.g—planting of Fraxinus excelsior; B3.h—planting of Alnus glutinosa and Fraxinus excelsior; B3.i—planting of Pinus sylvestris; C—Landscape protection; C.a—built-up and economically used areas; L—Lakes

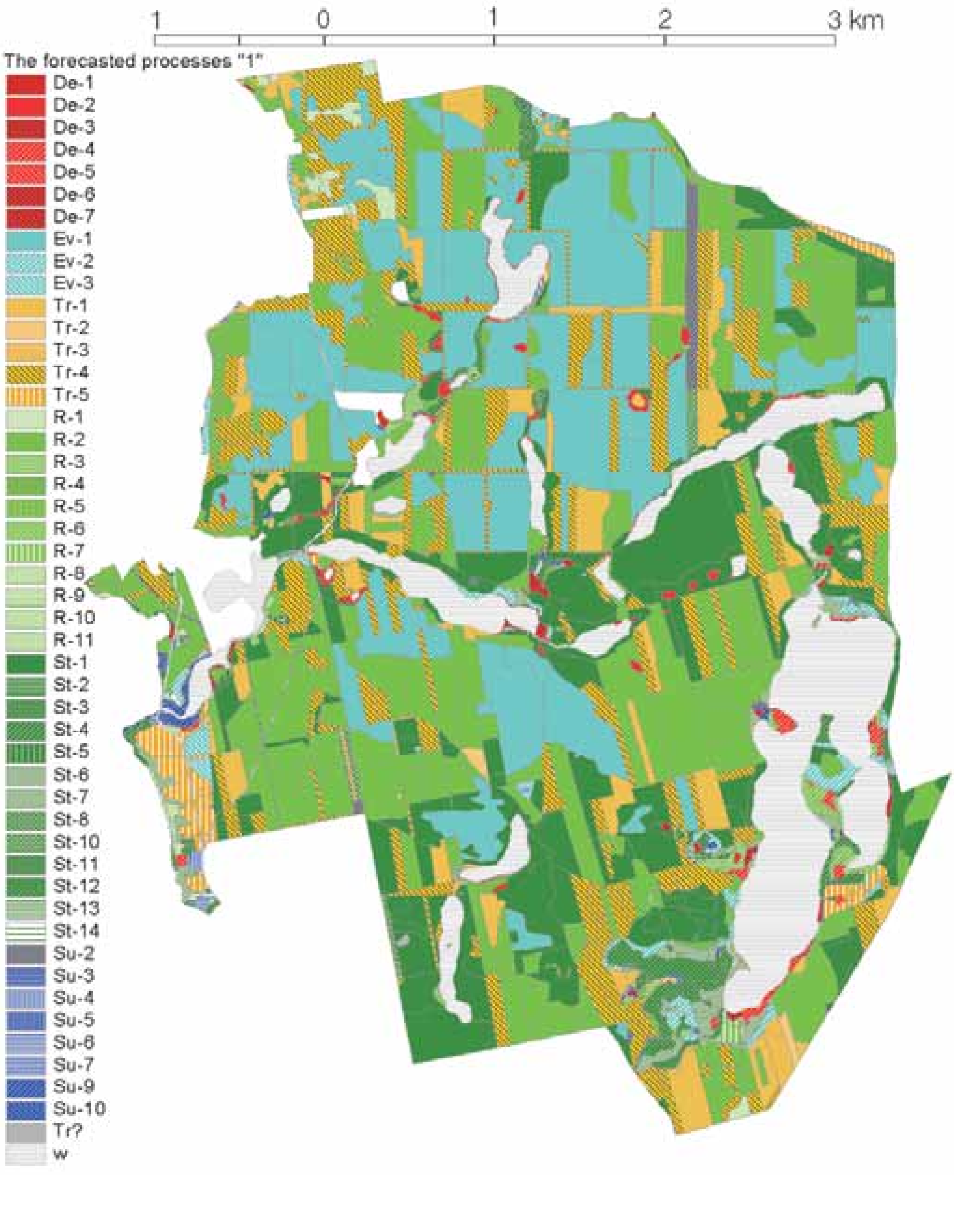


Figure 4.10. The forecasted processes of real vegetation according to scenario 1

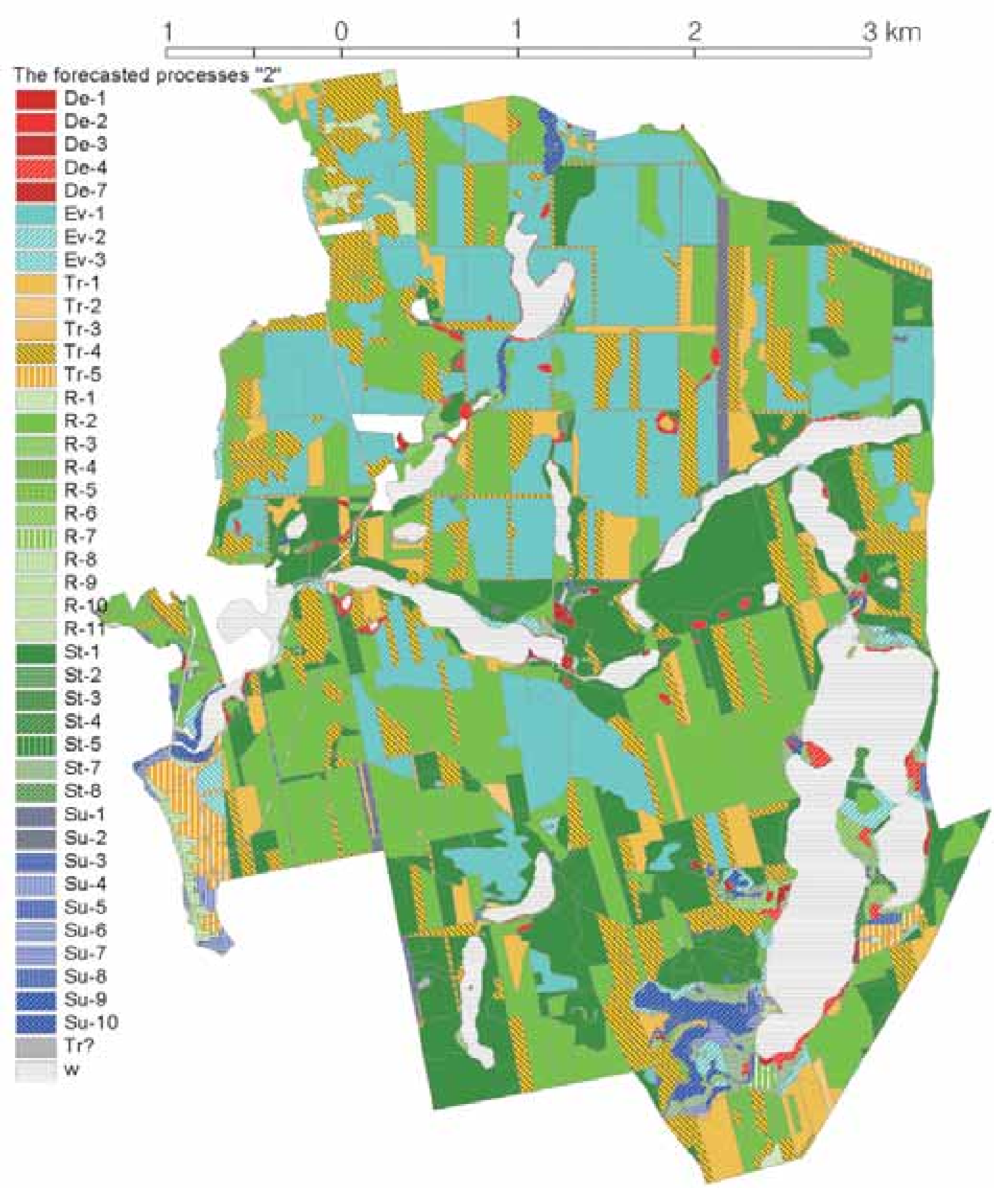


Figure 4.11. The forecasted processes of real vegetation according to scenario 2

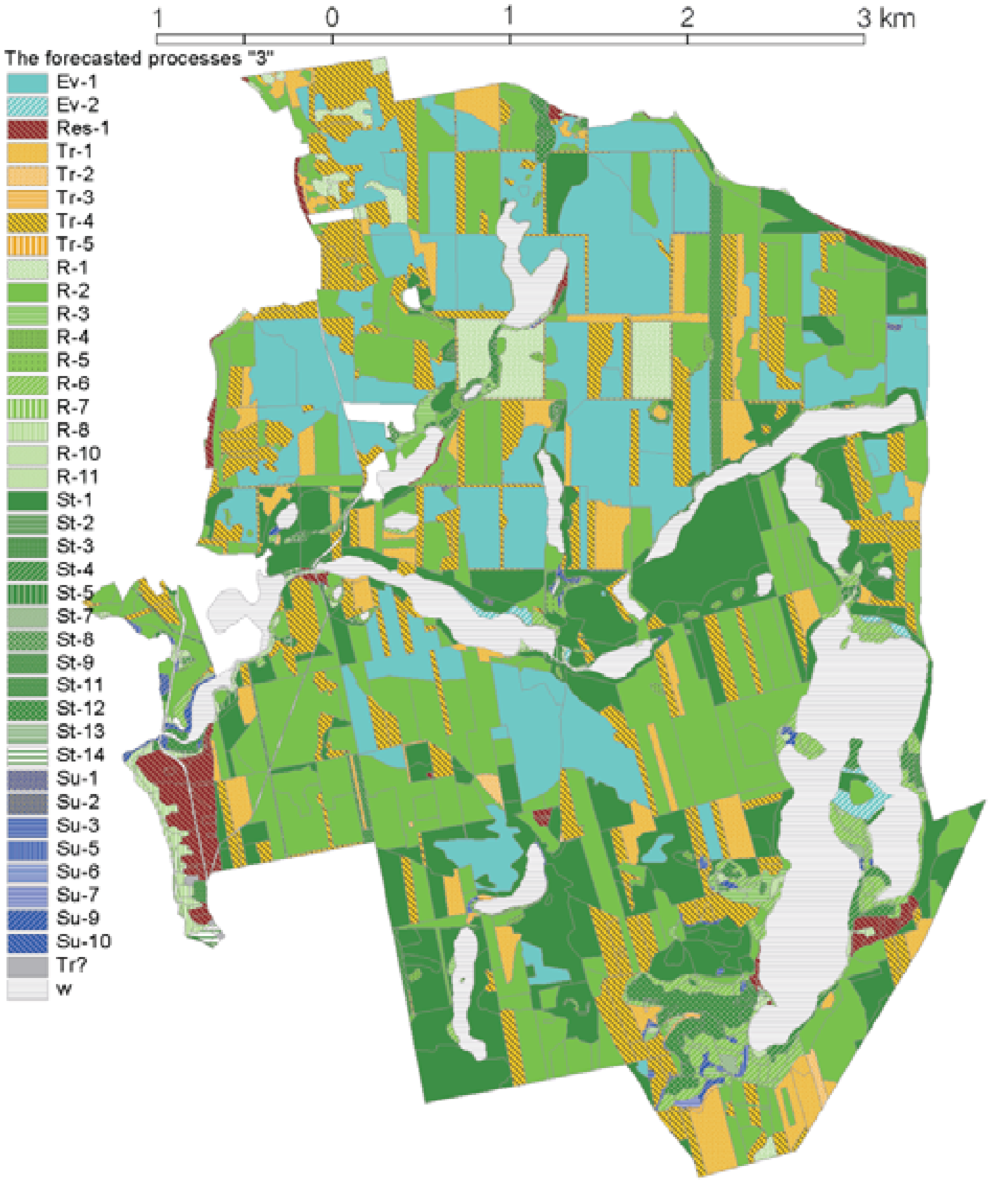


Figure 4.12. The forecasted processes of real vegetation according to scenario 3

Table 6. Directions of vegetation changes according to three scenarios

Processes	Scenario 1			Scenario 2			Scenario 3		
Plant communities	Number of polygons (patches)	Area (ha)	% of total area of PNBT	Number of polygons (patches)	Area (ha)	% of total area of PNBT	Number of polygons (patches)	Area (ha)	% of total area of PNBT
Processes of degeneration	124	63.00	1.37	113	60.03	1.31	0	0.00	0.00
swampy pine forest (Vaccinio uliginosi-Pinetum)	31	17.15	0.37	31	17.15	0.37			
swampy birch woods (Betuletum pubescentis)	12	8.11	0.18	12	8.11	0.18			
oak-birch woods (Betulo-Quercetum)	30	20.63	0.45	30	20.63	0.45			
oak-hornbeam forests (Stellario-Carpinetum)	8	2.60	0.06						
deciduous floodplain forests (Fraxino-Alnetum)	3	0.36	0.01						
alder swamps (Ribeso nigri-Alnetum)	35	12.39	0.27	35	12.39	0.27			
raised bogs and transitional peatlands (Oxycocco-Sphagnetea)	5	1.75	0.04	5	1.75	0.04			
Processes of regeneration	331	1,172.75	25.56	360	1,188.20	25.89	543	1,382.86	30.13
dry lichen-rich pine forests (Cladonio-Pinetum)	12	21.72	0.47	12	21.72	0.47	15	79.45	1.73
fresh pine forests (Leucobryo-Pinetum)	223	1,089.31	23.74	223	1,089.31	23.74	231	1,114.23	24.28
moist pine forests (Molinio-Pinetum)	15	16.13	0.35	15	16.13	0.35	16	16.86	0.37
swampy pine forests (Vaccinio uliginosi-Pinetum)	7	1.36	0.03	9	2.13	0.05	39	18.04	0.39
swampy birch woods (Betuletum pubescentis)	4	1.78	0.04	4	1.78	0.04	15	9.66	0.21
oak-birch woods (Betulo-Quercetum)	22	19.29	0.42	22	19.29	0.42	118	97.74	2.13
oak-birch woods (Betulo-Quercetum), very slow	10	6.84	0.15	10	6.84	0.15	1	0.22	0.00
oak-hornbeam forests (Stellario-Carpinetum)	7	4.56	0.10	15	7.16	0.16	46	26.54	0.58
oak-hornbeam forests (Stellario-Carpinetum), very slow	5	3.10	0.07	21	14.83	0.32			
deciduous floodplain forests (Fraxino-Alnetum)	3	0.44	0.01	6	0.80	0.02	6	0.80	0.02
alder swamps (Ribeso nigri-Alnetum)	23	8.22	0.18	23	8.22	0.18	56	19.34	0.42

Restitution									
oak-beech forests (Fago-Quercetum)							60	77.28	1.68
Processes of secondary succession	75	48.24	1.05	170	142.74	3.11	72	25.72	0.56
fast succession: heathlands (Callunetum) → fresh pine forest (Leucobryo-Pinetum)				10	16.85	0.37	4	1.76	0.04
succession: sandy grasslands (Spergulo-Corynephoretum) → heathlands (Callunetum) → fresh pine forest (Leucobryo-Pinetum)	13	25.15	0.55	13	25.15	0.55	6	2.06	0.04
fast succession: not-classified syntaxonomically community with Molinia → moist pine forest (Molinio-Pinetum)	11	2.72	0.06	15	4.77	0.10	15	4.77	0.10
succession: different meadows and grasslands → not-classified syntaxonomically thickets → initial stages of oak-birch forest (Betulo-Quercetum)	7	1.65	0.04	23	9.95	0.22	7	2.87	0.06
succession: different moderately nitrophilous segetal and ruderal communities as well as fragments of meadows and grasslands → bramble thicket (Rubion subatlanticum) → initial stages of mixed oak-beech forest (Fago-Quercetum)	4	2.61	0.06	16	6.90	0.15			
succession: meadows (Arrhenatherion) → different thickets → initial stages of oak-hornbeam forest (Stellario-Carpinetum)	1	0.45	0.01	17	13.02	0.28	2	1.66	0.04
succession: ruderal communities (Arthemisietea and others) → bramble thicket (Rubion subatlanticum) → initial stages of oak-hornbeam forest (Stellario-Carpinetum)	7	2.85	0.06	11	4.91	0.11	1	0.22	0.00
fast succession: moist meadows (Calthion) → willow thicket (Salicetum pentandro-cinereae) → floodplain forest (Fraxino-Alnetum)				2	2.11	0.05	0	0.00	0.00
fast succession: moist meadow (Calthion, Molinion) → sedge rushes (Magnocaricion, Phragmition) → willow thicket (Salicetum pentandro-cinereae) → alder swamp (Ribeso nigri-Alnetum)	32	12.80	0.28	63	59.08	1.29	37	12.38	0.27
Processes of primary succession									
succession: water vegetation (Nymphaeion, Potamion) → sedge rushes (Phragmition, Magnocaricion) → willow thicket (Salicetum pentandro-cinereae) → alder swamp (Ribeso nigri-Alnetum)	2	0.33	0.007	2	0.33	0.01	2	0.33	0.01

Table 6 *cont.*

Processes	Scenario 1			Scenario 2			Scenario 3		
Plant communities	Number of polygons (patches)	Area (ha)	% of total area of PNBT	Number of polygons (patches)	Area (ha)	% of total area of PNBT	Number of polygons (patches)	Area (ha)	% of total area of PNBT
Evolution	115	974.23	21.23	115	974.23	21.23	74	872.35	19.01
dry lichen rich pine forest (Cladonio-Pinetum) towards fresh pine forest (Leucobryo-Pinetum)	71	916.20	19.97	71	916.20	19.97	68	858.47	18.71
fresh pine forest (Leucobryo-Pinetum) towards oak-birch wood (Betulo-Quercetum)	28	37.95	0.83	28	37.95	0.83	6	13.89	0.30
fresh pine forest (Leucobryo-Pinetum) towards mixed oak-beech wood (Fago-Quercetum)	16	20.08	0.44	16	20.08	0.44			
Stabilization	352	928.11	20.22	243	822.52	17.92	292	907.33	19.77
of natural community of fresh pine forest (Leucobryo-Pinetum)	176	765.39	16.68	176	765.39	16.68	176	765.39	16.68
of natural community of moist pine forest (Molinio-Pinetum)	2	0.85	0.02	2	0.85	0.02	2	0.85	0.02
of natural community of swampy pine forest (Vaccinio uliginosi-Pinetum)	8	4.28	0.09	8	4.28	0.09	13	7.08	0.15
of natural community of oak-birch wood (Betulo-Quercetum)	6	8.99	0.20	6	8.99	0.20	9	15.91	0.35
of natural community of alder swamp (Ribeso nigri-Alnetum)	9	4.86	0.11	9	4.86	0.11	11	6.12	0.13
of anthropogenic, not-classified syntaxonomically, forest communities	16	11.73	0.26						
of anthropogenic, not-classified syntaxonomically, forest communities (possible is slow regeneration towards oak-birch woods (Betulo-Quercetum))	37	36.31	0.79	37	36.31	0.79	3	3.32	0.07
of natural communities of high-moor and transitory peat bogs	5	1.85	0.04	5	1.85	0.04	8	3.04	0.07
of semi-natural communities of sandy grasslands (Sedo-Scleranthetea)	9	3.69	0.08				8	25.04	0.55
of semi-natural communities of heathlands (Callunetum)							6	15.10	0.33

of semi-natural communities of heathlands (Callunetum); possible is slow overgrowing by Scots pine	9	16.68	0.36						
of moderately anthropogenic different meadow and meadow-like communities (Arrhenatherion, Calthion, Nardetum, Caricetalia fuscae, Magnocaricion)	69	71.97	1.57				48	61.92	1.35
of anthropogenic ruderal communities (Artemisietea and others)	4	1.00	0.02				4	1.02	0.02
of anthropogenic segetal communities (Chenopodietea and others)	2	0.53	0.01				4	2.53	0.06
Transformations of forest monocultures	291	875.39	19.08	291	875.39	19.08	247	796.51	17.36
pine monocultures towards regeneration stages of fresh pine forest (Leucobryo-Pinetum)	55	235.97	5.14	55	235.97	5.14	54	231.60	5.05
young pine monocultures towards older age classes without signs of regeneration	186	572.84	12.48	186	572.84	12.48	181	553.58	12.06
indefinite forest communities, mainly spruce-dominated, towards regeneration stages of fresh pine forest (Leucobryo-Pinetum)	6	7.46	0.16	6	7.46	0.16	6	7.46	0.16
indefinite forest communities, mainly spruce- or pine-dominated monocultures, towards regeneration stages of moist pine forest (Molinio-Pinetum)	5	3.71	0.08	5	3.71	0.08	5	3.71	0.08
different indefinite or degenerated forest communities, mainly pine-dominated monocultures, on the habitat of Fago-Quercetum	39	55.40	1.21	39	55.40	1.21	1	0.15	0.00
Surface water (not analysed)	25	524.74	11.43	25	524.74	11.43	25	524.74	11.43
Transformations, whose directions can hardly be forecasted	5	2.19	0.05	1	0.77	0.02	5	1.85	0.04

regeneration will be realized over the largest areas. This applies particularly to forecast 3, on the basis of which regeneration will take place over 1/3 of the Park area. In all the forecasted scenarios a clear majority of regeneration cases concern fresh pine forests (*Leucobryo-Pinetum*). A significant share of the regeneration processes are also predicted for the oak-birch woods (*Betulo-Quercetum*), especially in forecast 3, and also for communities covering small areas, like boggy pine forest, alder swamp, oak-hornbeam forest, humid pine forest, boggy birch woods and deciduous floodplain woods (here again in forecast 3 especially). Regeneration of some patches of the dry lichen-rich pine forest is also predicted, as supported by some special activities in the case of forecast 3. The forecast conforming to scenario 3 envisages the re-establishment (over 20 years to the initial stage only) of beech-oak forests (*Fago-Quercetum*), owing to the planned reconstruction of the stands. This will concern an area of more than 77 hectares.

Succession processes are likely to be ongoing over a relatively limited part of the PNBT, the greatest area being predicted under scenario 2. In forecasts 1 and 3, the largest areas relate to succession within two sequences, one leading from sandy grasslands, via *Calluna* heathlands, to fresh pine forests, and a second leading from swamp via willow scrub, to alder swamp. In Forecast 2, some role will be played by successional sequences leading from various open communities (meadows, grasslands, ruderal communities), via scrub, towards young acidophilous oak or oak-hornbeam forests.

The processes of evolution of communities from type to type will have major significance for the vegetation of the PNBT, particularly in its northern part, as a consequence of the transformation of numerous patches of dry lichen-rich pine forests (*Cladonio-Pinetum*) into fresh pine forests (*Leucobryo-Pinetum*). This can altogether take place over 1/5—1/4 of the land habitats of the PNBT. In this respect, the forecasts under scenarios 1 and 2 are analogous, meaning that this process is considered to occur spontaneously. Under forecast 3, a somewhat more limited spatial reach of this process is predicted, since the prerequisites of the protection plan envisage active maintenance of the dry lichen-rich pine forests.

Stabilization of communities will take place over a large part of the PNBT; all the forecasts predicting that this will apply to the same patches of the spatially-dominating community of fresh pine forest (*Leucobryo-Pinetum*). Stabilization will also encompass (in a similar manner in all forecasts) some patches of the less-common forest communities. On the other hand, the forecasts differ very significantly with respect to stabilization of the non-forest communities. Forecast 2 virtually excludes stabilization of the non-forest communities, except for raised bog and transitional peatland. In the two remaining forecasts, there is a significant stabilization of numerous meadow patches, and of the much less numerous patches of grasslands and *Calluna* heathlands.

Resulting from the growth and ageing of stands, the processes taking place in Scots pine plantations will have major significance. Above all, this will result in the transformation of many pine stands currently undefined phytosociologically into phases of the regeneration of the fresh pine forest association (*Leucobryo-Pinetum*). The occurrence of such processes is predicted over more than 1/5 of the territory of the Park, virtually independently of the scenario. These processes will take place both under conditions of forest management and spontaneously, although appropriately selected activities should be assumed to accelerate this advantageous process.

FINAL REMARKS

Though relatively simple, the method applied is appropriate in the forecasting of future states of vegetation, especially in protected areas, where numerous impacts that have serious negative consequences for the state of vegetation cover are eliminated. The fundamental assumption of this approach is the invariability of the dynamic interrelations between types of community, the constancy of habitat requirements of particular species, as well as the permanency of biocoenotic interrelations between species. Such assumptions certainly hold good for relatively short periods of time (of the order of 20 years). However, over a longer time perspective such assumptions may no longer be valid, because of unpredictable changes in local flora, and slow transformations of the characteristic combinations of species for different syntaxonomic units. Processes of this nature were observed in different regions and within different forest types (Faliński 1986; Jakubowska-Gabara 1993; Piotrowska 1997).

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THE MAP OF POTENTIAL NATURAL VEGETATION AS A SOURCE OF KNOWLEDGE ON THE HOLOCENE HISTORY OF THE VISTULA RIVER VALLEY

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Abstract: This paper concerns the relationships between potential natural vegetation and geomorphological forms. The study area covers a fragment of the Vistula river valley for which units of potential vegetation were identified and a digital vegetation map constructed. Correlations between the potential natural vegetation and geomorphological forms were analyzed, and general conclusions drawn in regard to the geomorphology of the valley (beyond the range of the detailed map). Some changes to the general map have also been proposed and a hypothesis on the presence of an 'island' of Pleistocene deposits within the Holocene valley advanced.

Key words: potential natural vegetation, Holocene valley of the Vistula, terraces, Pleistocene deposits.

INTRODUCTION

The concept of potential natural vegetation (Tüxen 1956) is understood to denote the hypothetical state of vegetation that would arise through natural succession and regeneration processes, should current man-made impacts and other external disturbances stop, and should the natural trends for plant associations be fully realized, leading ultimately to a stable end community. The concept allows for a synthetic description of vegetational diversity (more precisely, its habitats), and is particularly useful in cartographic presentations (e.g. Faliński 1971, 1990; Matuszkiewicz J. M. 1981, 1993; Matuszkiewicz J. M. and Kozłowska 1981; Matuszkiewicz J. M.; Matuszkiewicz W. 1994; Matuszkiewicz W. 1966; Wojterski et al. 1974).[1] The units of potential natural vegetation are defined on the basis of phytosociological characteristics of a hypothetical final community (being natural forest communities in the case of the study area).[2] Plant associations are most often used as the basic taxonomic units, although units of lower rank are also used as necessary.

The specificity and spatial distribution of habitats of various natural communities result from the joint action of various elements of the natural environment, in particular surface

[1] A survey map based on this concept was elaborated for the entire territory of Poland (Matuszkiewicz W. *et al.* 1995)

[2] These units are listed in Matuszkiewicz, J. M. (2001) and Matuszkiewicz, W. (2001).

and underground waters, geological bedding and relief forms, as well as soils. It is a consequence of their actions that the spatial system composed of units of potential natural vegetation emerges. These units can then be mapped. The identification of potential natural vegetation allows for reasoning (if of limited scope) as regards the differentiation of individual elements of the natural environment.

The present paper attempts to verify whether the information contained on the map of potential natural vegetation allows conclusions to be drawn as regards the past development of the Vistula river valley. The study is based on a comparison of geobotanical and geomorphological maps encompassing the segment of the Vistula valley between the mouth of its tributary the Bzura and the town of Płock, i.e .at distances between km 587 and 632 of the source (Figure 5.1).

MATERIALS AND METHODS

A fragment of the vegetation map of the Vistula valley (Figure 5.2) by Matuszkiewicz, J. M. *et al*. (1998) constitutes the basis for the analysis. The map was constructed by means of geobotanical field mapping (on the basis of a topographical map at 1: 25,000) and use of aerial photography. During the fieldwork, the units of actual vegetation were distinguished as having uniform phytosociological characteristics, as detailed as allowed by the scale of the map. The legend of this map describes the types of actual vegetation treated as taxonomic units of various levels: associations and lower or higher hierarchical units. In cases where a high degree of spatial complexity precludes the creation of homogeneous units, complex or composite units were distinguished. Thus the basic spatial divisions were established and then assigned to the polygons of a numerical map. Each polygon was identified in the field in terms of its actual vegetation, dynamics and structural transformation of vegetation, and potential natural vegetation. It was assumed that a patch is homogeneous in terms of potential natural vegetation, even if the actual vegetation had a complex character. In this manner the characteristics of the potential natural vegetation constituted an independent element in the database of the numerical map that could be analyzed separately.

The basic numerical vegetation map served as a basis for the map of potential natural vegetation assuming a thematic limitation to characteristics of the potential natural vegetation only, and a joining ('dissolving' of the boundaries) of neighbouring polygons having identical characteristics in a given domain. This task was carried out using ArcView software. The selected segment of the valley (of about 450km^2) was covered by a map composed of 1009 polygons.

The geomorphological diversification of the study area was presented on two digital maps:

- a general geomorphological map for the entire study area at 1:500,000 and smaller scales (Figures 5.3 and 5.4), as based on survey maps by Starkel (1980, 2001) and Starkel and Wiśniewski (1990), and
- a detailed (but simplified) geomorphological map of the western part of the area at approximately 1:100,000 (Figure 5.5), based on the work of Florek *et al.* (1987). These maps were spatially concordant with the vegetation map based on the topographical map (at 1: 25,000).

The method applied in this study entailed the overlaying of vegetation and geomorphological maps, the search for pattern similarities of vegetation units and geomorphological forms, and the subsequent analysis of these in line with the following steps:

- if there is a similarity between the potential natural vegetation and the geomorphology of the river valley, (i.e. between Figure 5.2 and Figures 5.3 and 5.4), and
- if this similarity is then confirmed for the details over a part of the study area (Figures 5.2 and 5.5),
- then we assume that the differences between the vegetation (Figure 5.2) and the general geomorphological maps (Figures 5.3 and 5.4) over that part of the area which is not covered by the detailed geomorphological map (Figure 5.5), may be used as an

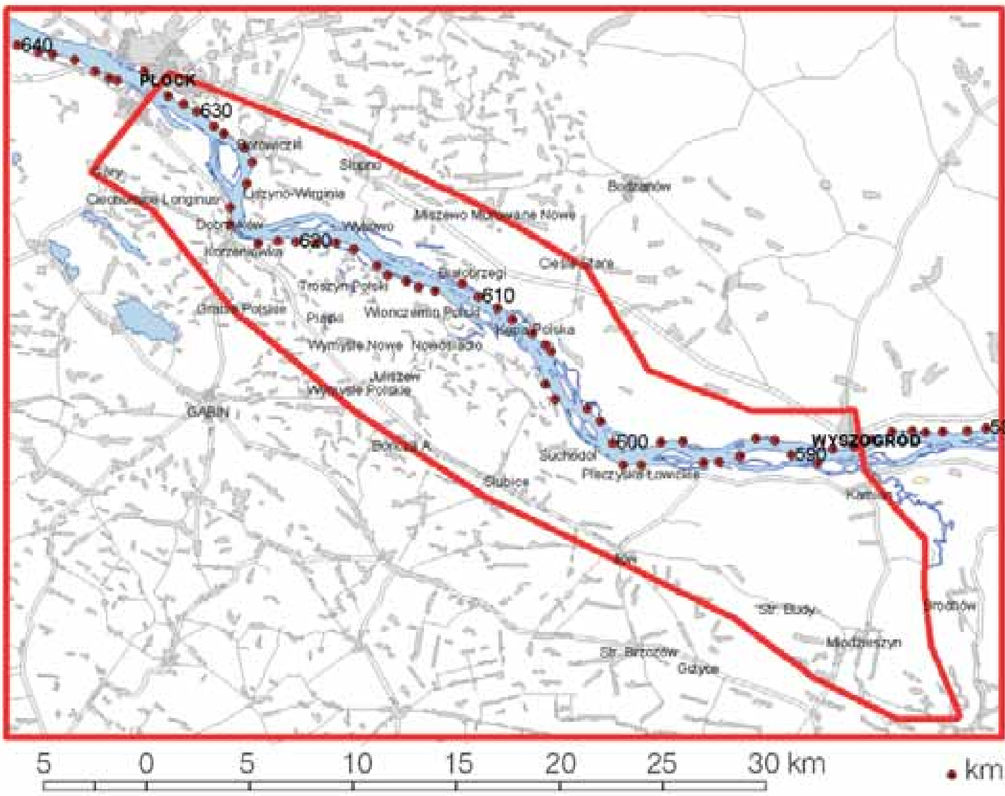

Figure 5.1. Study area.
Km—kilometers of the river course

indication by which to modify the general geomorphological map (Figures 5.3 and 5.4) with a view to the proposed, corrected general geomorphological map being obtained in two variants (Figures 5.6 and 5.7).

Finally, the results are set against other data for the valley, and especially datings of the sediments (Figures 5.6 and 5.7).

DIFFERENTIATION OF POTENTIAL NATURAL VEGETATION OF THE VISTULA VALLEY IN THE STUDY AREA

The map of the potential natural vegetation (Figure 5.2) allowed for the habitats of nine plan communities to be identified within the study area, their limits being treated as the limits of the basic types of potential natural vegetation. Lower-level units (sub-associations or habitat forms) could be distinguished in some of these. 14 cartographic units were identified in total.

THE COMMUNITY OF TYPICAL ALDER (Blackcurrant) SWAMP (*Ribeso nigri-Alnetum*) encompasses swampy woods with alder (*Alnus glutinosa*), including in their composition a group of bog and rush species. The habitats of the blackcurrant/alder swamp comprise depressions of the terrain, or valleys with limited flows of water, persistently flooded and with a shallow water table, filled with a

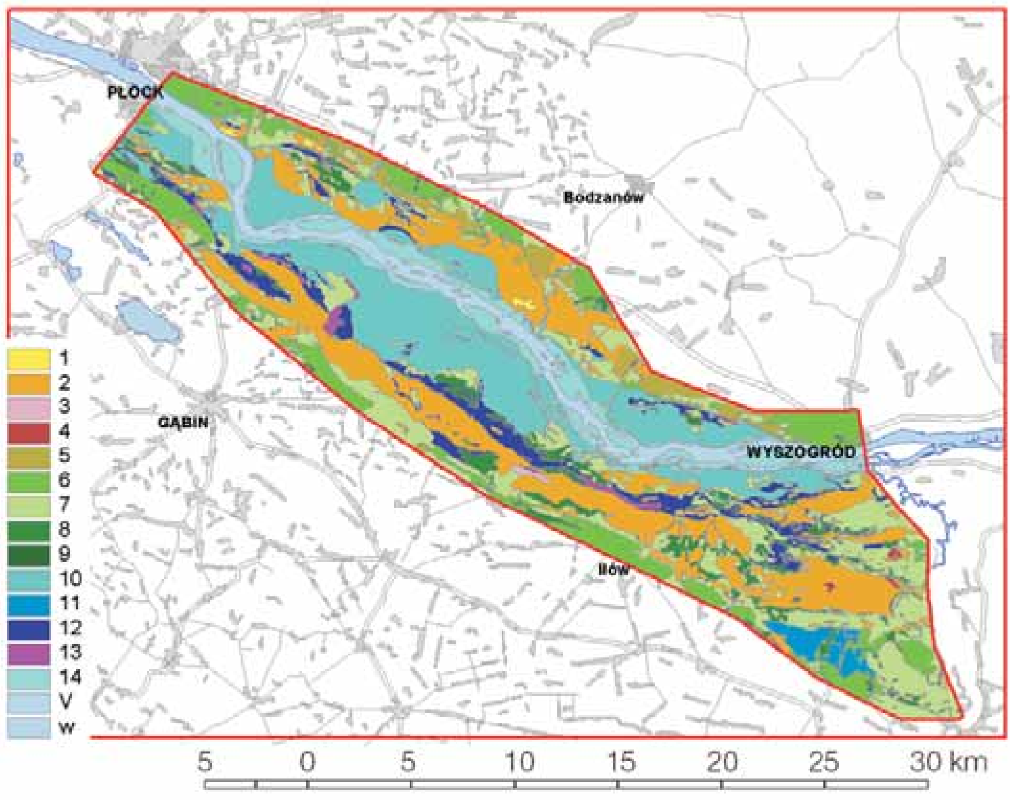

Figure 5.2. Map of potential natural vegetation.; 1—*Peucedano-Pinetum*; 2—*Querco-Pinetum typicum*; 3—*Querco-Pinetum molinietosum*; 4—*Serratulo-Pinetum*; 5—*Potentillo-Quercetum*; 6—*Tilio-Carpinetum*—typical variant; 7—*Tilio-Carpinetum*—poor variant; 8—*Tilio-Carpinetum*—moist variant; 9—*Tilio-Carpinetum*—rich variant; 10—*Ficario-Ulmetum typicum*; 11—*Ficario-Ulmetum chrysosplenietosum*; 12—*Fraxino-Alnetum*; 13—*Ribeso nigri-Alnetum*; 14—*Salici-Populetum*; V—Vistula; w—water

lowmoor peat type. This community is quite common in the lowlands. It is encountered in the Vistula valley mainly on the glacial accumulation terraces, less frequently within the confines of the Holocene terrace. The habitats of alder woods are often limited nowadays by land reclamation schemes involving drainage, which entails their evolution towards the ash-alder floodplain forest habitat. This type of habitat occupies less than 1% of total study area, with patches concentrating mainly along the boundary of the glacial and Holocene terraces on the left bank of the valley.

THE COMMUNITY OF WILLOW-POPLAR FLOODPLAIN WOODS (*Salici-Populetum*) is composed of willow species (white and brittle willow) or of white and black poplar. In this study, the riverside willow-poplar floodplain woods have been treated (in line with a former classification) as the one single association *Salici-Populetum*.[3]

[3] It is also possible to treat this community as two independent associations: *Salicetum albo-fragilis* – encompassing willow floodplain woods, and *Populetum albae* – encompassing poplar floodplain woods, whose locations in the valley are somewhat different (Matuszkiewicz J. M. 2001).

These communities appear on sandy river fen soils close to the watercourse, i.e. in the transformed valley, very often in the area between the flood banks, and especially on islands in the river, or rarely beyond the walls.This type of habitat occupies more than 7% of the study area, thus ranking it among the most important potential vegetation communities.

THE COMMUNITY OF ASH-ALDER FLOODPLAIN WOODS (*Fraxino-Alnetum* = *Circaeo-Alnetum*) occupy humid, moderately marshy habitats in the area's depressions, especially frequently in the valleys of small watercourses. The substratum is constituted by river alluvium or marshy fen-type peat soils. This association is generally very common in the lowlands. In the lower Vistula valley these habitats appear most often within the slopes of the present valley terrace and in the somewhat boggy depressions on the glacial terraces, as well as in the valleys of the small tributaries. This type of habitat covers more than 6% of the study area.

THE COMMUNITY OF TYPICAL ASH-ELM FLOODPLAIN WOODS (*Ficario-Ulmetum typicum*) are unambiguously linked with the fine-grained (loamy) river alluvium, deposited on the relatively more elevated parts of the present river terrace. These habitats dominate on present river terraces, mainly at a certain distance from the river, i.e. within the transformed valley beyond the flood banks, while between the banks they are encountered over rather small areas where the bank has encroached onto higher terraces covered with loamy fens. This type of habitat occupies almost 18% of the study area, thus ranking third among the defined units of potential natural vegetation.

THE COMMUNITY OF ELM-SAXIFRAGE FLOODPLAIN WOODS (*Ficario-Ulmetum chrysosplenietosum*) appear close to small river courses in conditions of a very fertile, fine-grained substratum and high humidity resulting from the water flow, but without any tendency towards stagnation. 'Black soils' usually form in such locations. This community occurs in the valleys of the small watercourses entering the valley of the Vistula from the clayey uplands or, more frequently, in the flat depressions within the so-called 'Iłowo horizon'.[4] Although this habitat does not occur frequently, it can occupy small, but locally extensive areas.

THE COMMUNITY OF DRY GROUND OAK-LIME-HORNBEAM FOREST (*Tilio-Carpinetum*) are multi-species deciduous forests in which oaks, hornbeams and small-leaved limes occur most frequently. These forests are represented in the study area by the subcontinental association *Tilio-Carpinetum*. This extends over a broad spectrum of habitats from fresh to moderately humid and from moderately to very fertile. In line with this significant degree of differentiation, four lower-level units have been distinguished: i.e. typical, poor, humid and very fertile. The oak-lime-hornbeam forests are an essential component of potential lowland vegetation, covering 36% of the study area.

Typical oak-lime-hornbeam forest develops on the fresh habitats associated with a substratum of clays and richer sands of various origins. These habitats are very common in the uplands touching upon the valley of the Vistula, and also including its slopes. They are less frequent in the valley itself, but still appear in many places, especially on the parts of the glacial river terraces composed of richer formations, so that they occupy more than 11% of the total study area.

Poor oak-lime-hornbeam forest appears on the poorer, fresh clayey, sandy-clayey and clay-gravel habitats with different origins of the substratum. Such habitats are frequent on the morainic uplands neighbouring the valley, as well as within the confines of the valley on some habitats linked with flood (mainly diluvial) terraces of the valley. The habitat of this type encompasses more than 19% of the study area, which puts it second among the distinguished types of potential natural vegetation.

Humid oak-lime-hornbeam forest occurs on the sandy-clayey or clayey areas with a shallow water table (moderately humid

[4] It is a remnant of the old Warsaw ice-marginal lake.

Table 1. Units of potential natural vegetation on the study area.

Units	Area (km²)	Share (%)	Number of distinguished patches	Mean area ofdistinguished patches (km²)
Willow-poplar floodplain woods (*Salici-Populetum*)	33.14	7.36	87	0.38
Typical ash-elm floodplain woods (*Ficario-Ulmetum typicum*)	81.05	17.99	32	2.53
Elm-saxiphrage floodplain woods (*Ficario-Ulmetum chrysosplenietosum*)	6.26	1.39	8	0.78
Ash-alder floodplain woods (*Fraxino-Alnetum*)	28.68	6.37	115	0.25
Typical alder (black currant) swamp (*Ribeso nigri-Alnetum*)	4.47	0.99	76	0.06
Floodplain and alder woods in total	**153.60**	**34.10**	**318**	**0.48**
Dry ground oak-hornbeam subcontinental forests (*Tilio-Carpinetum*) – typical form	50.86	11.29	106	0.48
Dry ground oak-hornbeam subcontinental forests (*Tilio-Carpinetum*) – poor form	87.04	19.32	248	0.35
Dry ground oak-hornbeam subcontinental forests (*Tilio-Carpinetum*) – humid form	24.73	5.49	167	0.15
Dry ground oak-hornbeam subcontinental forests (*Tilio-Carpinetum*) – highly fertile form	0.21	0.05	7	0.03
Oak-hornbeam dry ground forests in total	**162.83**	**36.15**	**528**	**0.31**
Sparse oak woods (*Potentillo albae-Quercetum*)	11.85	2.63	26	0.46
Subcontinental pine forest (*Peucedano-Pinetum*)	0.91	0.20	4	0.23
Central-European fresh oak-pine forest (*Querco-Pinetum typicum*)	91.39	20.29	101	0.90
Central-European humid oak-pine forest (*Querco-Pinetum molinietosum*)	0.77	0.17	9	0.09
Continental mixed pine forest (*Serratulo-Pinetum*)	0.60	0.13	4	0.15
Pine and mixed pine forests in total	**93.68**	**20.80**	**118**	**0.79**
Vistula river course	27.71	6.15	1	27.71
Other water bodies	0.74	0.16	18	0.04
Grand totals	**450.42**	**100.00**	**1009**	**0.45**

Source: author's own elaboration

habitats), on which soils develop with a domination of the gleying and browning processes. This kind of habitat is quite frequent on the glacial river terraces of the Vistula valley, while being much less so on the uplands and the Holocene terraces. These habitats occupy almost 5.5% of the stydy area.

Very fertile oak-lime-hornbeam forest communities are quite rare, and occur on the most fertile, moderately humid loamy and clayey habitats which occupy a marginal share of the study area.

THE COMMUNITY OF SPARSE OAK WOODS (*Potentilo albae-Quercetum*) are composed mainly of the common oak, along with many light-loving species. This community has a partly manmade character and displays dynamic linkages with the oak-lime-hornbeam forest. However, it is traditionally treated as a type of potential natural vegetation. The community occurs on the sandy-gravel, moderately fertile and well-drained habitats, encountered in central Poland mainly on the morainic uplands or valley edges. It may be encountered on the elevated parts of the glacial terraces of the Vistula. This type of habitat occupies 2.6% of the study area and is concentrated on the slopes of uplands on the right bank of the valley.

THE COMMUNITY OF CONTINENTAL MIXED PINE FOREST (*Serratulo-Pinetum*) is distinguished by the presence of light-loving species of continental range. This community generally occurs in the sandy-gravel, mesotrophic fresh habitats of areas with a continental climate. It is rare in the Vistula valley, and covers relatively small areas, mainly within the confines of the glacial river terraces. This type of habitat was observed on the study area in four very small patches only.

THE COMMUNITY OF CENTRAL-POLISH OAK-PINE FOREST (*Querco-Pinetum*) is the most common type of mixed/pine forest in central Poland. It develops in a number of habitat types, of which the most important are: fresh mixed/pine forest (mainly the sub-association *Q.-P. typicum*) and the humid mixed/pine forest (represented by *Q.-P. molinietosum*).

CENTRAL-POLISH FRESH MIXED/PINE FOREST (*Querco-Pinetum typicum)* appears on the fresh sandy habitats of river sands on the glacial accumulation terraces. It also appears on fragments of outwash plains or sandy, denuded uplands adjacent to the valley. This type of habitat occupies more than 20% of the study area, thus ranking first among the units of potential natural vegetation.

HUMID MIXED/PINE FOREST (*Querco-Pinetum molinietosum*) occurs within the glacial terraces, with a sandy, moderately poor substratum and shallow groundwater table, though not frequently and covering less than 0.2% of the study area.

THE COMMUNITY OF SUBCONTINENTAL FRESH PINE FOREST (*Peucedano-Pinetum*) occurs on trophically poor dry or fresh sands, mostly of aquatic origin (e.g. the diluvial river sands), or aquatic-glacial (outwashes), or derived from dunes. It is common in areas in which a continental climate dominates. It is also quite frequent on the diluvial terraces of the Vistula, upstream and downstream of the study area, and on the outwash plains neighbouring the valley. However, over the study area as a whole, this type of habitat accounts for only 0.2%.

GEOMORPHOLOGICAL SHAPING OF THE STUDY AREA

The general diversification of geomorphological forms of the study area (Starkel 2001) is presented in Figures 5.3 and 5.4. The typology of the geomorphological forms encompasses:

- the Holocene floodplain elevated to 5m above the level of the Vistula,
- the glacial terraces adjacent to the Holocene terrace over the entire length of the segment on the left side, and over a significant part of the segment on the right side, elevated to 5–12m (rarely higher) above the river level,
- the 'Iłowo horizon'(streaching along the left-bank),
- upper part of the studied section, covered with glacio-limnic deposits and elevated at 82–85m a.s.l. on average (Wiśniewski 1987), thus corresponding to elevations of 17–32m above the level of the contemporary Vistula,
- the outwash horizon, stretching as a narrow belt on the right-hand bank, elevated up to 32–40 m above the level of Vistula,
- the 'Ciechomice horizon', glacial with pot-hole forms on the left, downstream part of the segment and elevated at 20–40m above the river level,
- the morainic uplands on both sides of the valley, elevated form 25 to 60m above the level of Vistula.

A more detailed geomorphological study by Florek *et al.* (1987) (see simplified results

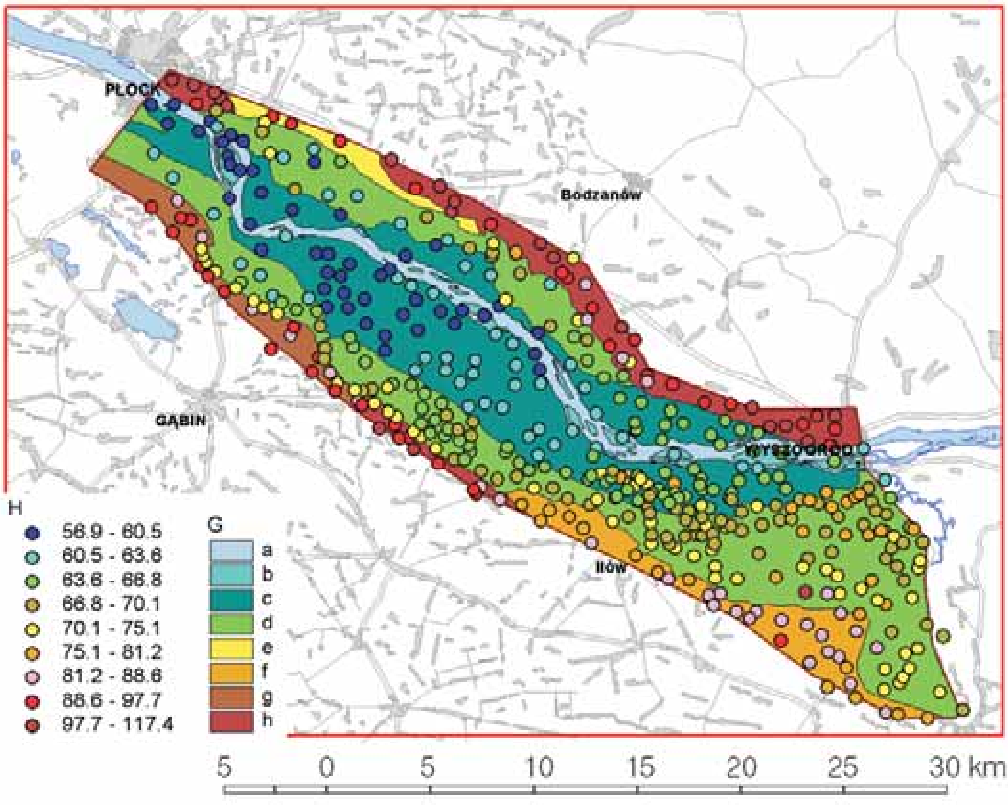

Figure 5.3. Geomorphological survey map and the altitudes a.s.l.; H – Height abowe seelevel [m]; G—Geomorphology; a—river course; b—islands in river course; c—Holocene floodplain; d—Pleistocene depositional terraces; e—sandr; f—Ilow level; g—Ciechomice level; h—morainic plateau

on Figure 5.5), allows for classification of the Holocene floodplain into the four terraces (from the oldest to the youngest), TH1 to TH4. The oldest is built of deposits dating from the Preboreal period up to the beginning of the Subboreal period, and is characterized by the remnants of large palaeo-channels with meanders. TH2 is bedded with sediments from the SubAtlantic period, TH3 and TH4 with contemporary deposits (Starkel 2001). Construction of the flood banks limited the deposition of sediments significantly, these now being deposited only in the part of the floodplain closest to the river channel (TH4).

Three levels are distinguished within the glacial terraces, i.e. TP0, TP1 and TP2 (from the oldest to the youngest). TP0 is really developed only on the right-bank, downstream part of the segment. TP1 stretches over a significant area with numerous dunes, while the TP2 horizon has numerous depressions filled with peat.

CONNECTIONS BETWEEN POTENTIAL VEGETATION AND RELIEF FORMS

The Vistula valley between the mouth of its tributary the Bzura and the town of Płock

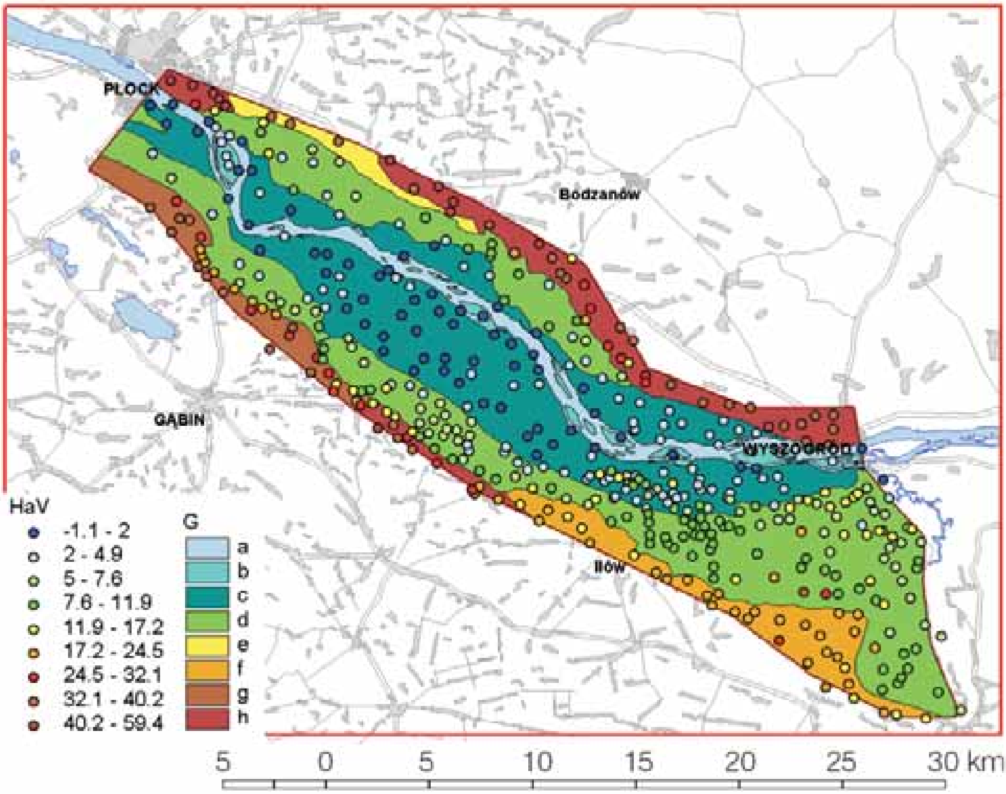

Figure 5.4. Geomorphological survey map and the altitudes above the river level.; HaV—Height abowe Vistula level [m]; G—Geomorphology; a—river course; b—islands in river course; c—Holocene floodplain; d—Pleistocene depositional terraces; e—sandr; f—Ilow level; g—Ciechomice level; h—morainic plateau

is much narrower than the one directly upstream, and narrows yet further downstream. Its last segment near Płock was encompassed by the reach of the Vistulian Glaciation (Starkel 2001).

HOLOCENE TERRACES

The Holocene floodplain terrace, narrowed at the beginning by the cone of the Bzura river(1.3–1.5km wide) broadens to 5.5 or even 7km, then narrows again and splits into branches at the end of the section of the Vistula considered. The Holocene floodplain terrace is elevated up to 5m above the average level of the river.The difference between the upper and lower parts of the section should also be noted (Figure 5.4). The upper part of the floodplain is elevated by 2–5m above the average level of the river, the lower by less than 2m. The geological structure of the Holocene floodplain is very complex (Starkel 2001). Within its boundaries, 3 (or 4) terraces are distinguished, these partly overlaying the formations deposited earlier. Within the highest terrace (TH1), shaped from the Preboreal to the beginning of the Subboreal periods, the remnants of numerous braided palaeo-channels are

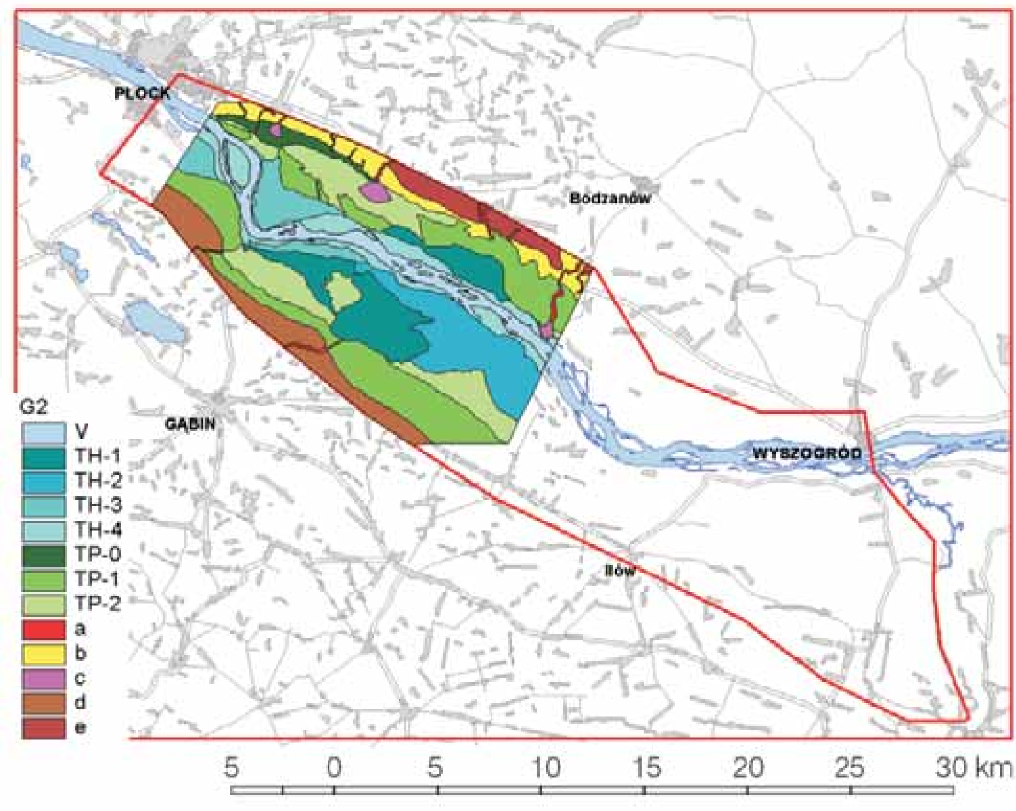

Figure 5.5. Detailed geomorphological map (on the basis of Florek et al., 1987).; G2—Geomorphology; V—river course; TH—Holocene depositional terraces; TP—Pleistocene depositional terraces; a—side valley; b—sandr ; c—alluvial cone; d—Ciechomice leavel; e—morainic plateau

visible, and of palaeo-meanders with deposits dated at about 8,500 years BP at one study point, at about 6,300 years BP at two points, at ca 5,300 years BP at one point, at ca 4,700 BP at one point, and at around 3,800 BP at anther point. The lower (TH2) terrace, shaped in the SubAtlantic period, bears the traces of gullies and braiding. The deposits in one of them are dated at about 1,000 BP (Florek *et al.* 1987, after Starkel 2001). The lowest terraces (TH3 and TH4) are formed by modern swellings, the deposition of sandy alluvia, and lateral migration of the channel. These processes are influenced by the construction of the flood banks and of the Włocławek Reservoir (some 40 years ago), which resulted in the differentiation of terrace TH3 (beyond banks) from TH4 (within them).

The complex origins and geological structure of the floodplain along this stretch bring about a significant diversification of the potential natural vegetation. It is on the lowest levels in the vicinity of the contemporary river channel, and especially on the islands in the braided river course, that the habitats of the willow-poplar floodplain woods (*Salici-Populetum*) are distributed, their reach being partly limited by the floodbanks. However, in many places these habitats are also recognized beyond the walls,on parts of the lower terraces cut away by the banks, and sequences of recently-abandoned channels.

The largest share of the river section considered here is taken by the habitats of ash-elm floodplain woodland (*Ficario-Ulmetum*). These occupy higher parts of the Holocene floodplain (mainly terrace TH2), covered with flood clays (Florek *et al.* 1987, after Starkel 2001). These habitats were also identified in the smaller palaeochannels, where they are largely filled with ooze brought in by high waters. They do not appear in conditions of intensive watering, nor on organic substratum. These habitats are mostly situated beyond the flood banks, only in a few cases being found between them.

A great part of the floodplain analyzed here is covered by ash-alder woods (*Fraxino-Alnetum*) and, to a much lesser degree, by blackcurrant-alder swamps (*Ribeso nigri-Alnetum*). These stretch along the left edge of the Holocene valley along virtually the entire length of the river section. These habitats occupy a particularly large area in the great palaeo-meander facing km 614–616 of the river course. They are also found in the two complexes near to the right bank. The basic factors conditioning the appearance of these habitats are the organic filling of palaeo-channels of various age and a significant watering caused mainly by waters seeping in from the higher terraces, and especially from the areas of the uplands surrounding the valley. The lower and more watered peat areas are habitat for the black currant-alder swamps, while the higher, more drained (often antropogenically-drained) ones (as well as the palaeo-channels partly filled with ooze), are habitat for ash-alder floodplain woods, much more common in the valley than the alder swamps. The areas of fen are significantly transformed nowadays by the digging of peat.

The Holocene floodplain section of the valley has small areas of fresh poor and humid oak-lime-hornbeam forest. These are places distanced from the river course, more elevated, with sandy soils. It is hard to indicate the factors accounting for the separation of these habitats from the surrounding ash-elm floodplain wood habitat. A certain amount of influence could have been exerted by human activity (i.e. a raising of ground level for construction purposes).

The habitats of the mixed pine forests identified on the available geomorphological maps as belonging to the Holocene floodplain (Wiśniewski 1987; Starkel 1980; Błaszkiewicz and Kordowski 1998), are fully separated out. In one location they form a large complex on the left bank, but appear in smallish patches elsewhere in the study area. They occupy areas elevated even up to 15 m above river level (Figure 5.4). This means that flooding probably cannot occur in these locations, since the difference between the average river level and the maximum level observed amounts to approximately 4.5 m (Glazik 1998). There are no other so-elevated areas within the Holocene terrace. These and lower elevations are characteristic of the glacial terraces. A question then arises as to whether the geomorphological identification of the terrace dating is correct. Perhaps a particular set of conditions resulted in the appearance of habitats of mixed/pine forest within the Holocene terrace. This question is returned to further on.

PLEISTOCENE (GLACIAL) TERRACES

These stretch beyond the contemporary valley along the entire left bank section considered and on the right bank starting with km 601 along the river course. Florek *et al.* (1987) have distinguished three Pleistocene terraces (from the highest: TP0, TP1,TP2 respectively). The age of the organic formations of these terraces exceeds even 14,000 years at two study points, attaining almost 12,000 years at one point, amounting to between 10,000 and 11,000 years at another two points and approximating 10,000 at one point (Florek *et al.* 1987; Starkel 2001). The elevation of these terraces above the average level of the Vistula most often varies from 5 to 12 m (to 20 m in some parts).

On the Pleistocene terraces, especially terrace TP1, the habitats of fresh mixed/ pine forests dominate. They are often adjacent to poorer forms of oak-lime-hornbeam forests, both fresh and humid, as well as ash-alder floodplain woods (in particular on terrace TP2). Of lesser importance are the habitats of sub-continental pine forest, humid mixed/pine forest, and alder swamp. In general, this is a typical combination for a poor sandy substratum. It is largely a continuation of the fully-developed substratum situated in the upstream section of the Vistula valley; its classical form being the Kampinos Forest.

Within the Pleistocene terraces one rarely encounters the habitats of ash-elm floodplain woods (*Ficario-Ulmetum*), typical for the Holocene terraces. The appearance of these habitats is always related to the deposits of fine-grained sediments which could be brought in by the smaller lateral tributaries. Thus, these habitats usually amalgamate within the older terraces with the alluvial fans (e.g. the fans of the right-bank tributaries of the Vistula. This is an interesting observation, since it has been held until now that the habitats of ash-elm floodplain woods in their typical form (*Ficario-Ulmetum typicum*) are related uniquely to the Holocene terraces of the river (Matuszkiewicz J. M. 2001).

AREAS OUTSIDE THE VALLEY

Beyond the Pleistocene terraces, on the left bank of the valley in the upstream part of the studied section, there is the aforementioned 'Iłowo horizon'. This area is dominated by oak-lime-hornbeam forests, mainly of a fertile nature, and the specific form of the ash-elm floodplain woods (*Ficario-Ulmetum chrysosplenietosum*). In the lower part of the Vistula segment, still on the left bank, the Pleistocene terrace is adjacent to the esker and kame forms on the clay-gravel bedding referred to as the 'Ciechomice horizon' (90–92 m a.s.l., i.e. some 25–30m above the river level, after Starkel 2001). These areas are occupied by oak-lime-hornbeam forests.

On the right bank (in particular in the downstream part of the segment considered), at the foot of the uplands, an outwash horizon stretches out in the form of a narrow belt of roughly 95–98m a.s.l., (i.e.30–40m above the level of the Vistula waters). This horizon is occupied by the habitats of poor oak-lime-hornbeam forests and sparse oak woods (the latter in particular forming a sequence readily visible on the map of potential vegetation). These habitats seem to be related in this location to the gravel bedding and southern exposure of the valley slope. This again is an interesting observation, since the habitats of sparse oak woods in central Poland have been found on morainic elevations, and not on outwash. It is also worth noting that the areas of sparse oak woods identified in the neighbourhood of the Vistula valley correlate with the very old settlement areas dated from the 11th century, and recognized in detail upstrem of the town of Płock (Matuszkiewicz J. M. 1998). It was stated some ten years ago (Jakubowska-Garbara 1993) that sparse oak woods have in part a manmade character and appeared due to grazing in forests. Their presence in this particular place may thus also have been conditioned historically and anthropogenically.

The upland areas bordering the Vistula valley to the north and south form habitats of poor and fertile oak-lime-hornbeam forests to only a limited degree. The habitats of mixed/pine forest or sparse oak woods appear over much smaller areas. These combinations are commonly encountered in central Poland on the morainic uplands.

THE MOST IMPORTANT CONNECTIONS BETWEEN POTENTIAL VEGETATION AND GEOMORPHOLOGICAL FORMS

In summarising observations on the relationships between the potential vegetation and the geomorphological forms along the studied section of the Vistula valley, we can conclude that:

• First, there is a high level of co-occurence of given types of potential natural vegetation and given relief forms, these relationships reflecting:

—the close spatial correlation between the presence of willow-poplar floodplain woods (*Salici- Populetum*) and the youngest parts of the Holocene terraces,

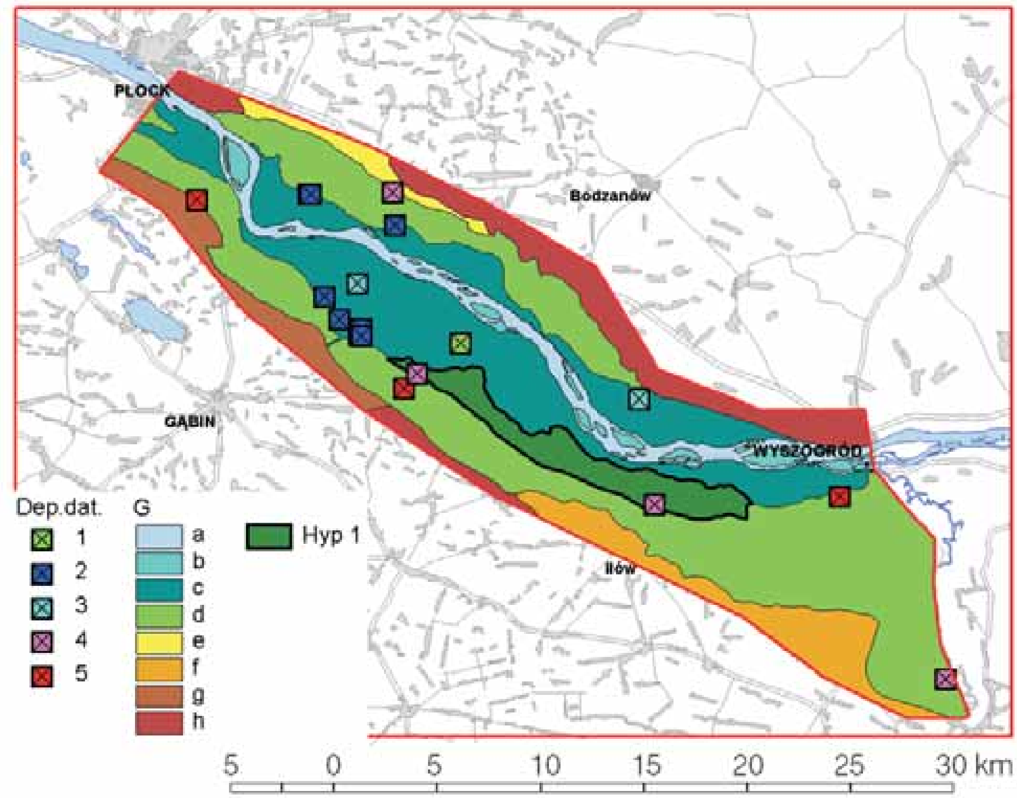

Figure 5.6. Geomorphological survey map—proposal of modifications, variant I.; Dep.dat.—Depositing dating; 1—historic period (100–1000 BP); 2—neoholocen (1000–5500 BP); 3—mesoholocen (5500–8400 BP); 4—eoholocen (8400–11500 BP); 5—pleistocen (>11500 BP); G—Geomorphology; a—river course; b—islands in river course; c—Holocene floodplain; d—Pleistocene depositional terraces; e—sandr; f—Ilow level; g—Ciechomice level; h—morainic plateau; Hyp 1—Hypothesis 1: Pleistocene terrace?

—the occurrence of ash-elm floodplain wood habitats in their typical form (*Ficario-Ulmetum typicum*) on the older and higher parts of the Holocene terraces, and, in particular cases, on the contemporary alluvial cones within the glacial terraces,

—the appearance of boggy ash-alder wood habitats (*Fraxino-Alnetum*) and alder swamps (*Ribeso nigri-Alnetum*) in the peatland parts of the Holocene (and especially Pleistocene) terraces, the coverage of the higher parts of the Pleistocene terraces by habitats of mixed/pine forest (*Querco-Pinetum*), or, more rarely, pine forests (*Peucedano-Pinetum*),

—the appearance of the oak-lime-hornbeam forest (*Tilio-Carpinetum*) habitats, most especially the humid ones, on the lower, but not boggy parts of the Pleistocene terraces.

• Second, there is a clear inconsistency between the spatial distribution of habitats of potential natural vegetation and the extent of the landforms as shown on the geomorphological survey map in

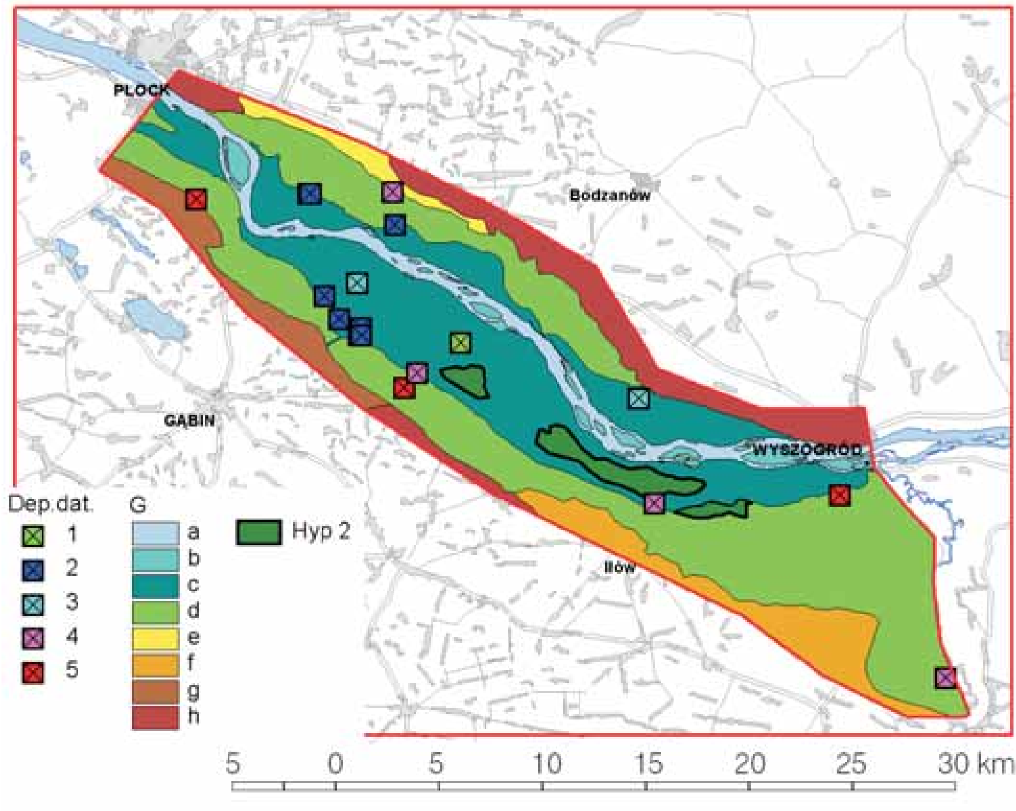

Figure 5.7. Geomorphological survey map—proposal of modifications, variant II.; Dep.dat.—Depositing dating; 1—historic period (100–1000 BP); 2—neoholocen (1000–5500 BP); 3—mesoholocen (5500–8400 BP); 4—eoholocen (8400–11500 BP); 5—pleistocen (>11500 BP); G – Geomorphology; a—river course; b—islands in river course; c—Holocene floodplain; d—Pleistocene depositional terraces; e—sandr; f—Ilow level; g—Ciechomice level; h—morainic plateau; Hyp 2 – Hypothesis 2: Pleistocene terrace?

the upstream part of the section of valley considered. This inconsistency appears in line with the presence of extensive patches of mixed/pine and oak-lime-hornbeam forest in an area being part of the Holocene terrace on the aforementioned map. An area of a particularly distinct inconsistency is indicated on Figure 5.4. Taking into account the linkages established on the studied valley segment, (which also find confirmation in other regions), it may be hypothesized that these areas of inconsistency are the fragments of the Pleistocene (not the Holocene) terrace. This hypothesis is also supported by the setting of the sequences of glacial terraces, in which the fragment of the area in question constitutes the western extreme of a sequence stretching between the northern dune belt in the Kampinos Forest via the dune terraces in the vicinity of Kamion (where fossil soils date from 12,235 years BP) and the organic horizons in the channel sands (dated to about 14,590 years BP) (Manikowska 1982, 1985, 1991, after Starkel 2001).

CONCLUSIONS FROM THE ANALYSIS OF POTENTIAL NATURAL VEGETATION REGARDING THE HISTORY OF THE VISTULA VALLEY

In the light of the analysis of the spatial distribution of habitats of potential natural vegetation we may suggest a few observaions regarding the past development of the Vistula valley along the segment investigated. If we admit (on the basis of the contemporary identification of habitats), that the Pleistocene terrace is in fact wider than that presented on the geomorphological survey map, and encompasses the previously refered to fragment of the valley, then this map ought to be modified as shown in Figures 5.6 or 5.7. However, there would seem to be two possible variants. According to the first (Figure 5.6), the boundaries between the Pleistocene and Holocene terraces would be moved towards the Vistula course, meaning that the Holocene valley is distinctly narrower than held previously. It might have been caused by the rapid cutting in of the Vistula channel after deglaciation, over the stretch downstream of the mouth of the Bzura river, as noted by Starkel (2001). Such a shift would encompass a belt some 18km long and up to 1.5km wide. Another possibility has also to be considered: given the known dating (ca 8,450 BP) of the organic deposits in the boggy sequence with ash-alder floodplain wood and alder swamp habitats stretching to the south of the elevated fragment of the area considered with oak-lime-hornbeam and mixed/pine forest habitats, we could envisage there having been a large island of Pleistocene terrace in the middle of the early Holocene (Eo-Holocene) valley (Figure 5.7). According to this variant, the southern branch of the valley would have functioned for a short time, only in one of the phases of more intensive flooding (indicated by Starkel 2001).

Finally, having been formulated by a non-geomorphologist the above remarks certainly require thorough verification by specialists. If they have been forwarded here, this is because the hypothetical existence of a relatively large former island in the Vistula has appeared noteworthy to the author.

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LAND-USE CHANGE IN DIFFERENT NATURAL HABITATS OF THE VISTULA RIVER VALLEY DURING THE 19TH AND 20TH CENTURIES

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Abstract: This paper concerns the extent and causes of spatial and temporal land-use changes ongoing in different habitats of the Vistula River valley in central Poland. The study area extends along that valley between the city of Warsaw and Włocławek, while the study period spans about 150 years. The analysis was based on digital topographical maps from the 19th and 20th centuries, as well as a potential vegetation map. The history of land-use change was shown to be different in each habitat in the study area, while the character of land-use and direction of changes that did arise were mostly determined by habitat conditions.

Key words: map of potential vegetation, historical land-use changes, habitat diversity, digital map analysis, Vistula River valley.

INTRODUCTION

Various hydroclimatic factors (rainfall, flooding) and human activities such as adaptation to navigation and rafting, flood protection, the use of water supplies as well as settlements and agriculture have been studied to determine the nature of the intensive environmental changes observable in river valleys (Werritty and Leys 2001; Uribelarrea *et al.* 2003). These natural and anthropogenic factors have influence on the river-bed as well as on the close vicinity of the river (floodplains) and higher terraces in the valley. All parts of the valley are closely connected and any interruption to one of them influence others (Żelazo and Popek 2002). One of the most difficult challenges is that of separating the effect of human activities on change in the valley from change which would occur without human interference and which are connected with habitat conditions, particularly in the interactions between the channel and floodplain (Marston *et al.* 1995).

Over the last three centuries, anthropogenic changes introduced in valleys have progressively increased the percentage of disturbed area (Decamps *et al.* 1988; Marston *et al.* 1995). The pace of the modifications has been various in different European valleys. In industrialized valleys such as that of the Rhine River it has been much more rapid then in, say, the Garonne River valley—in which human impact has been more progressive through the ages (Decamps et al. 1988). However, in the majority of European river valleys, there was a great intensification of anthropogenic processes in the 19th century, as a result of the development of steam shipping and a growing demand for water and arable land, and consequent significant changes in flow conditions, hydro-engineering and land-use (Deiller *et al.* 2001; Decamps *et al.* 1988; Uribelarrea *et al.* 2003). The same situation was observed in the Vistula River valley (*Wisła Środkowa*… 1986).

A large river valley's great diversity of environmental conditions and attendant habitat diversity open up many possibilities for valley management. In line with its nature, each habitat is transformed differently, in relation to the intensity, types and causes of change (Decamps *et al.* 1988). Historic and present-day valley transformations are depicted on archival and contemporary topographical maps (Marston *et al.* 1995; Bielecka and Ciołkosz 2002; Hohensinner *et al.* 2004). A comparison of these materials with a vegetation map permits the reconstruction of changes in land-use in specific habitats and allows for the observation of their diversity, as well as an indication of the links between habitat conditions and changes introduced by man. The use of computers has eliminated the majority of the problems and limitations that historical maps present (deformation, lack of coordinates, various scales, etc.) (Uribelarrea *et al.* 2003).

Changes in land-use in the Vistula River valley and their connection with habitat diversity are the subject of this paper. They were identified along the stretch of river between Warsaw and Włocławek, with special attention paid to the Kampinos forest complex—the national park since 1959. The study spans the period of about 150 years (1830–1985) during which the original maps were made. The analysis compared digital topographical maps from four time periods in the 19th and 20th centuries with the potential vegetation map.

The aim of the paper is to:

- indicate the temporal and spatial range of changes, as well as the character of and trends for land-use in different habitats of the Vistula River valley comparing historical maps and a map of vegetation,
- indicate important factors in the transformations which have occurred.

MATERIALS AND METHODS

The analysis of land-use changes in connection with habitat diversity was based on digital maps. The maps were compiled from cartographic material from the 19th and 20th centuries[1] and the potential vegetation map which was made after the topographical base-map from the 1970s (at 1:25 000 scale). Vegetation units previously marked on the base-map were identified during fieldwork done in the 1990s by geobotanists from the Institute of Geography and Spatial Organization (Polish Academy of Sciences). Digital maps were prepared with ArcView 3.0 software for digitalization and rectification of the source material, and then for analysis of the vector maps created. The four historical maps were classified with respect to the four types of land-use (area occupied in Table 1). Their transformations were investigated in connection with the 15 types of potential vegetation depicted on the vegetation map. The historical maps and the map of vegeta-

Table 1. Land-use changes in the study area in %

	Area			
Land-use type	1830	1889	1930	1985
Forest and scrub	41.9	27.8	23.5	33.7
Grasslands	8.9	14.0	16.8	12.0
Vistula waters	9.6	7.8	8.4	9.0
Other (arable land, fallow or built-up areas)	39.6	50.4	51.3	45.2

Source: survey 1990s

[1] Maps used in the analysis were: *Topograficzna Karta Królestwa Polskiego* of 1839 at 1:126 000 (called the Kwatermistrzostwo map), a Russian map of 1889 at 1:84 000 (called *Dwuwiorstówka*), *Mapa Taktyczna* elaborated by WIG (Wojskowy Instytut Geograficzny i.e. Military Institute of Geography) in the years 1920–1930 at 1:100 000 scale and topographical maps elaborated by GUGiK (Główny Urząd Geodezji i Kartografii—i.e. Central Office of Geodesy and Cartography) in 1985 at 1:100 000.

tion were overlaid and intersected, to obtain the area of land-use in those 15 habitat types in each time period (obtained values are presented in Tables 2 and 3). The statistical software applications PAST and Excel were used to determine the results. They were augmented by data from other sources (not cartographic), which permitted elucidation of the reasons for these modifications.

The study area was divided into two parts in line with diversity as regards dominant land-use type. These were Kampinos—a large forest complex with specific natural habitats and landscapes and an extensive protected area in the form of a National Park, and the area outside the Park in which agricultural use dominates.

NATURAL CHRACTERISTICS OF THE STUDY AREA

The study encompasses an area of about 1428 km^2 in the Vistula River valley, between the city of Warsaw and the town of Włocławek (Figure 6.1). The edge of the postglacial plateau constitutes the borders of the valley. This is characterized by the presence of many erosional forms like ravines and dry denudation valleys, as well as of accumulation forms (alluvial cones and deluvial covers).

The riverbed is the lowest part of the valley plain. In the study area, it is mostly unregulated and braided. There are many sandbars in the middle of the course and next to the banks. In this part of the valley the average riverbed width is of about 0.35 km, with the exception of the stretch between Płock and Włocławek—where a dam reservoir has a width exceeding 2 km. A system of floodplain and upper terraces is contiguous with the riverbed. The floodplain dates from the Holocene. It is a few meters in relative height, and built of contemporary alluvial deposits (sands and silts) which allow alluvial soil to form (Starkel 2001). Together with river islands, these are places characterized by willow-poplar alluvial forest (*Salici-Populetum*). Frequent flooding in these habitats leads to the accumulation of river-bed deposits and formation of alluvial soils, but also causes destruction of banks and vegetation which is restored after withdrawal of the waters. In the higher parts of floodplain terraces, where flooding is only occasional, alluvial soils are formed on fine sands. These places are suited to riparian ash-elm forests (*Ficario-Ulmetum*). Beyond the immediate vicinity of the

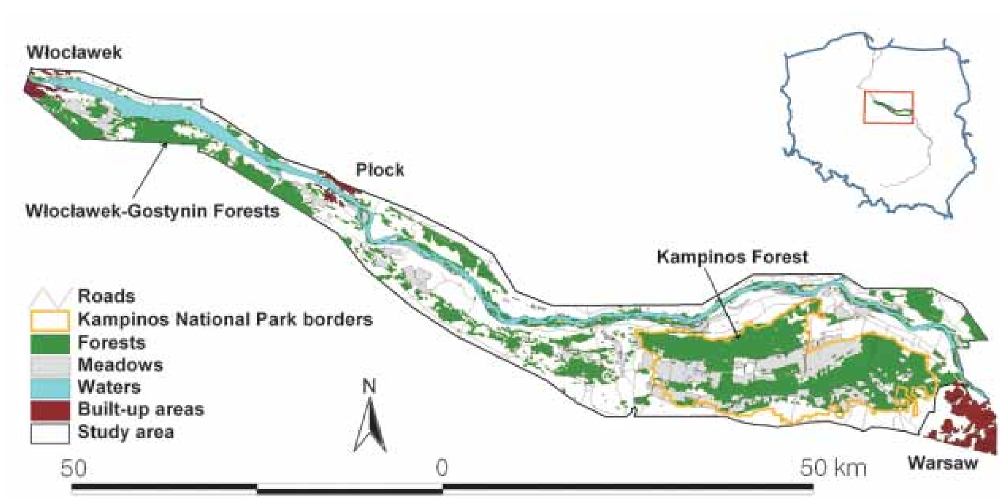

Figure 6.1. The study area

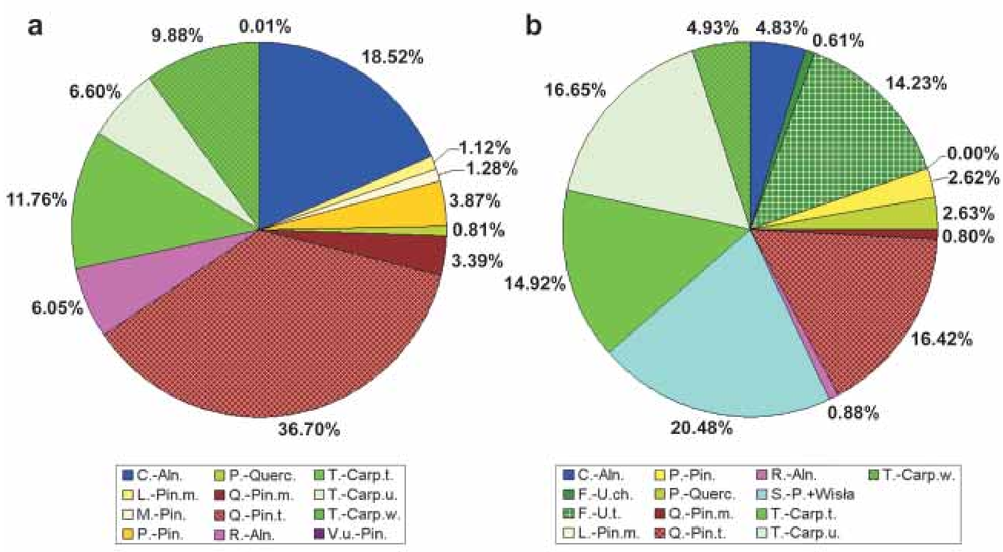

Figure 6.2. Habitat proportions in Kampinos Forest (a) and outside Kampinos Forest (b). C.-Aln.—Circaeo-Alnetum, F.-U.ch.—Ficario-Ulmetum chrysosp., F.-U.t.—Ficario-Ulmetum typical, L.-Pin.m.—Leucobryo-Pinetum var. with Molinia, M.-Pin.—Molinio-Pinetum, P.-Pin.—Peucedano-Pinetum, P.-Querc.—Potentillo albae-Quercetum, Q.-Pin.m.—Querco roboris-Pinetum molinietosum., Q.-Pin.t.—Querco roboris-Pinetum typicum, R.-Aln.—Ribeso nigri-Alnetum, S.-P.—Salici-Populetum, T.-Carp.t.—Tilio-Carpinetum typical, T.-Carp.u.—Tilio-Carpinetum mesotrophic, T.-Carp.w.—Tilio-Carpinetum eutrophic, V.u.-Pin.—Vaccinio uliginosi-Pinetum

river, there is a different form of this association, characteristic of wet and fertile soils or black earths (*Ficario-Ulmetum chrysosplenietosum*). Over the greater part of the studied stretch, the floodplain terrace is observed only on the left side of the river; on the right side it is present in the river-bends. In fragments of ox-bows (often observed in this terrace) and in erosional channels, hydrogenic soils (with a high groundwater table but without flooding) were formed – black soils, silty soils, peat or half-bog soils. These habitats, as well as small river and stream valleys and the margins of peat areas, are characteristic of alder-ash forests (*Circaeo-Alnetum*). In the late 1960s, the floodplain terrace between Płock and Włocławek was transformed into a dam reservoir (its total area being 70 km^2).

The next, higher and older, terrace dates from the Pleistocene and is built of sands and gravels of fluvio-glacial accumulation, as well as of fluvial sands and alluvial soils, in some places covered with aeolian sands. In the upper part of this terrace, there are several large dunes and other deflation forms. On the left side of the river, dune fields form the area of the largest forest complexes: the Kampinos and Włocławek-Gostynin forests. On sandy ground, poor podzolic soils characteristic of pine forests were formed: soils with the deep-laying groundwater of fresh pine forests (*Peucedano- or Leucobryo-Pinetum*), or the higher water table characteristic of moist pine forests (*Molinio-Pinetum*). Podzolic and rusty soils on clayey sands are associated with mixed oak-pine forest (*Serratulo-Pinetum, Querco roboris-Pinetum*). Lime-oak-hornbeam forest (*Tilio-Carpinetum*) dominates on rich brown soil and rust-brown soil built of clayey sands or boulder clay. Among the dunes, the terrace depressions support many swamps and wet areas. In these places, on peat with a high water table, there are habitats characteristic of alder forest (*Ribeso nigri-Alnetum, Sphagno-Alnetum*), and in their oligotrophic parts, of swampy pine forest (*Vaccinio uliginosi-Pinetum*) (Matuszkiewicz 2001). Figure 6.2 shows the spatial proportions of these habitats.

LAND-USE CHANGES

In the first half of the 19th century, forests and agricultural land dominated the Vistula River valley between the cities of Warsaw and Włocławek; the former mainly in the Kampinos area, but outside it, the study area had a rather agricultural character (Table 1 and Figures 6.3 a, b). Between 1815 and 1918 the study area belonged to the so-called Kingdom of Poland, whose economy was dependent on Russian occupation policy. Russia designated only very limited expenditure to the development of the Kingdom. However, financial limits did not entirely stop economic development and changes connected with it. Between 1830 and 1889 the area of forest and scrub decreased by 14%. Above all, this concerned the Kampinos area.

Deforestation was associated with an increase in population, the development of settlements, urban and suburban expansion into forest sites, as well as the laying out of new roads and railways. These processes intensified in the second half of the 19th century after the granting of freehold to peasants (1864). This was followed by the division of estates and settlement of ground for sale. The new owners used their land in different ways. Forest felling and the sale of the wood useable in many industries offered the possibility of fast enrichment. A large part of the deforested land was used arably or as grassland. The introduction of new crop systems and agricultural machinery intensified farming. Between 1830 and 1930, the area of arable land increased by over 11% and that of grasslands by about 8%. In the Kampinos area, the majority of forests were changed into meadows (Figure 6.3 a). This decrease in the forest area was also brought on by a change in habitat conditions caused by drainage, first introduced at the beginning of the 19th century (Romanowska 1934). During World Wars I and II, additional cutting was done by German Occupants (Zielony 2004). In 1930, forest and scrub covered only about one fourth of the study area. But the deforestation rate was slowed through the creation of protected forests and the implementation of tax breaks for the afforestation of fallow land (*Forest Protection Act 1898*, cited after Degórska 1999).

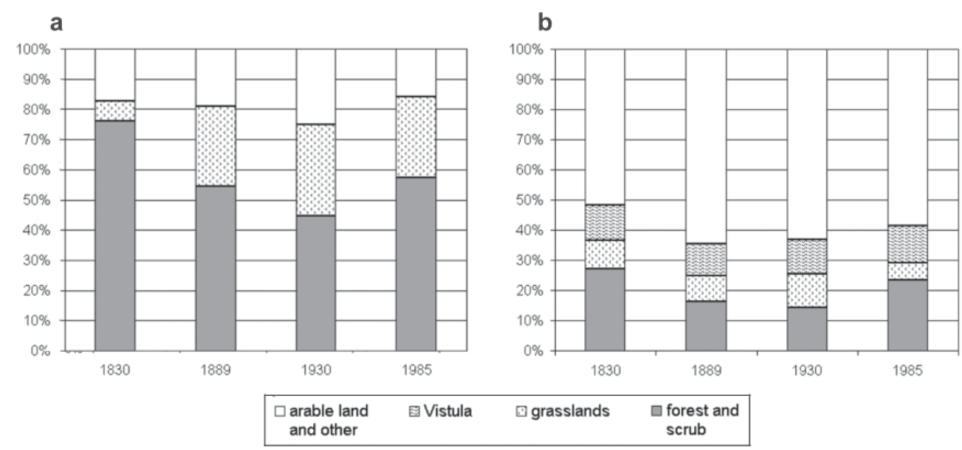

Figure 6.3. Land-use changes a) in Kampinos Forest b) outside Kampinos Forest

In the second half of the 20th century, there was a significant increase in the area of forests (to a level about 10% higher than in 1930). Wartime destruction, depopulation, a change of economic system and industrial development all resulted in great population movements. Inhabitants of the countryside moved into towns, extending the settlement of the outskirts close to roads and railways. As a result, the rural population decreased and the area of agricultural land shrank. Agriculture became concentrated on more fertile land. Areas of poor soil, sand or fallows were afforested (Rokicki 1971). By 1985 the extent of arable and fallow land in the study area had decreased by 6%, the area of grasslands by about 5%. Implementation of land reform (1945) resulted in the nationalization of the greater part of the Polish forests; the rest was surveyed during clear-cutting and planting. The increase in forest area was also a consequence of the implementation of forest protection laws (Plit 1996). In 1959, the Kampinos National Park was established, and in 1979 the Włocławek-Gostynin Landscape Park, both within the study area.

Close to the Vistula, land-use changes were encouraged by navigation and river-channel regulation. In the last 150 years, changes to the area of river-bed in the whole study area were marginal, not exceeding 2% in scale (Table 1), partly for economic and historical reasons, and partly because of the changes in forms of transportation.[2] The area between dikes was not used intensively. Land-use there was limited to grazing, industrial cultivation (e.g. willow plantations) and meadows, with the exception of the part of the floodplain changed into a dam reservoir (*Wisła Środkowa*… 1986).

[2] Under the Russian occupation (up to 1918), regulation works were not very intensive because of limited funds. They were mainly introduced where the risk of bank erosion or embankment destruction was great, or to protect water devices, e.g. water intakes. Flood protection demanded embankments that intersected the floodplain, tree-cutting and the clearing of the river-bed of bars and outwashes. This also made shipping easier and facilitated water and ice run-off *(Regulacja Wisły…* 1930). After the recovery of independence by Poland in 1918, more intensive work was done in the name of systematic river regulation along this stretch. However, limited funds again slowed works down. The economic crisis of the 1930s, and the outbreak of the Second World War stopped realization of the plan. After the War, work was restarted, but limited to the protection of banks and embankments and small dam construction, because navigation was becoming less popular and other forms of transport were developing rapidly.

CHANGES IN HABITATS

After analysis of land-use changes in different habitats (Tables 2 and 3) it is possible to indicate a few groups of plant communities in which changes were similar in character.

The division into groups was based on dendrograms (Figure 6.4) for each part of the study area (data derived from Tables 2 and 3—% area in four time periods), made with the help of the PAST statistical application. The Euclidian distance measurement was taken as a similarity index with Ward's method for joining clusters. The results are reported in Table 4.

In 1830, in both parts of the study area the majority of the pine forest habitats were afforested (Figures 6.5a,b). In following years (and up to 1930), deforestation diminished the area of forest and scrub by a few to a few dozen percent. In both parts, the deforested area was mainly transformed into arable land. In the second half of the 20th century, reforestation of these habitats resulted in an increase in the wooded area to its level in 1830 or even more.

However, there were exceptions to this trend. In the Kampinos area, in moist pine-forest (*Molinio-Pinetum, Leucobryo-Pinetum var. Molinia*) and swampy-pine-forest habitats (*Vaccinio uliginosi-Pinetum*) forests covered nearly 100% of the area in 1830 (Figure 6.6a). In the 19th and 20th centuries, land-use changes were minimal and mainly affected lands close to settlements. On the other hand, the greatest decrease (up to 1930) in forest area was noted in the thermophilous pine-oak forest habitat (*Potentillo albae-Quercetum*) (Figure 6.6b). These deforested areas were mainly transformed into arable land, and despite a general increase in forest area in the second half of the 20th century, this has not changed very much.

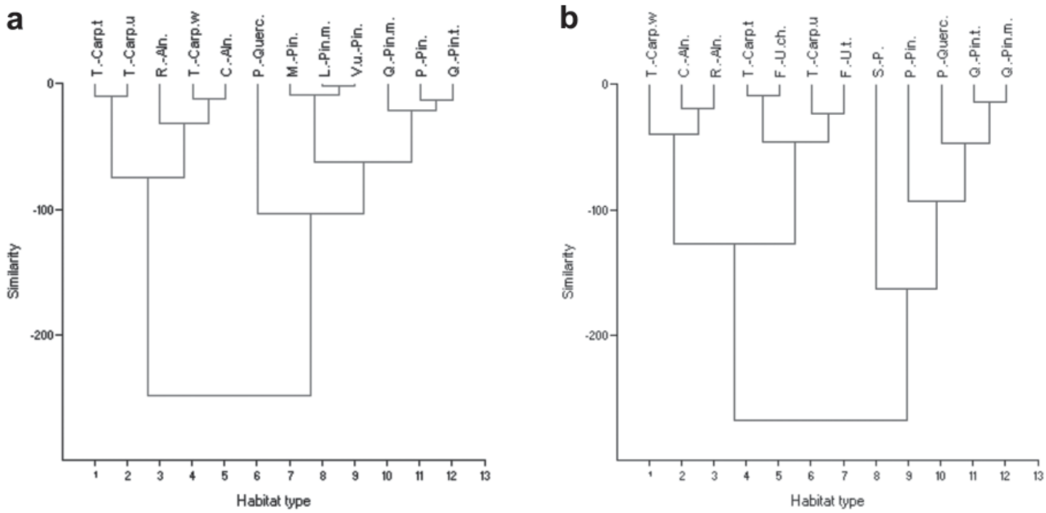

Figure 6.4. Habitat similarity in terms of land-use changes 1830–1985; a) in Kampinos Forest, b) outside Kampinos Forest. Vertical axis: statistical distance between compared units; horizontal axis: units grouped by Ward's method

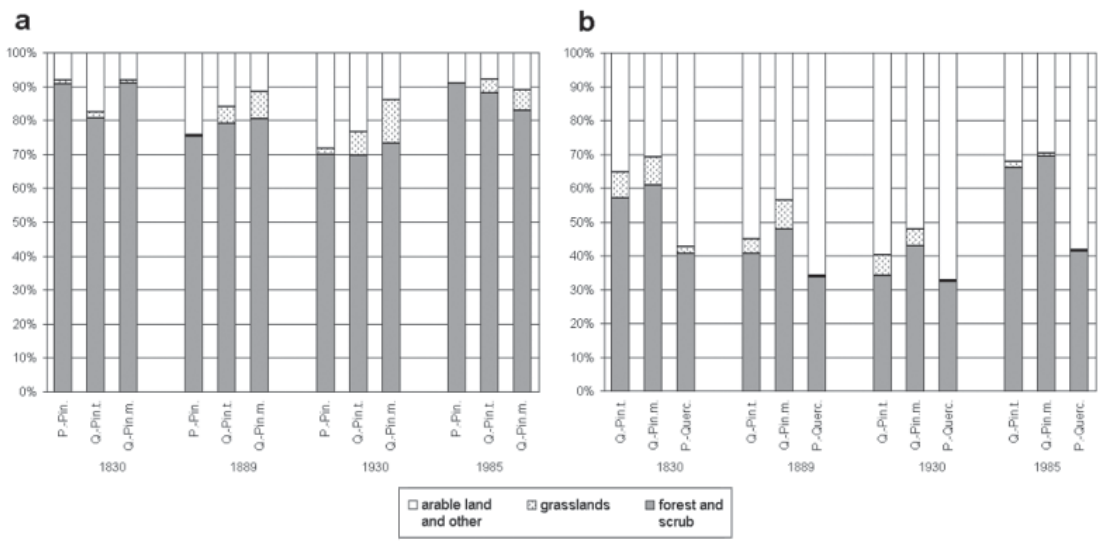

Figure 6.5. Land-use a) in Kampinos Forest—*Querco-Pinetum* and *Peucedano-Pinetum* habitats; b) outside Kampinos Forest—*Querco-Pinetum* and *Potentillo albae-Quercetum* habitat

Table 2. Land-use changes in habitats outside the Kampinos forest

Habitat type	Area [sq km]	Area [%]	Area [%]											
			1830			1889			1930			1985		
			Forest and scrub	Grasslands	Other (river waters)	Forest and scrub	Grasslands	Other (river waters)	Forest and scrub	Grasslands	Other (river waters)	Forest and scrub	Grasslands	Other (river waters)
P.-Pin.	25.4773	2.51	48.86	8.43	42.71	77.70	1.55	20.75	76.36	1.39	22.25	98.80	0.05	1.15
L.-Pin.m.	0.0100	0.00	100.00	0.00	0.00	100.00	0.00	0.00	100.00	0.00	0.00	100.00	0.00	0.00
Q.-Pin.t.	164.1236	16.20	57.11	7.62	35.26	40.75	4.19	55.06	34.09	6.23	59.67	66.18	1.65	32.18
Q.-Pin.m.	8.1825	0.81	60.96	8.21	30.83	47.89	8.59	43.51	42.91	5.04	52.05	69.45	0.83	29.72
P.-Querc.	31.2037	3.08	40.63	2.16	57.20	33.76	0.43	65.81	32.30	0.53	67.17	41.33	0.50	58.17
T.-Carp.t.	160.9353	15.88	13.84	2.10	84.06	4.22	1.38	94.40	2.55	1.66	95.79	4.93	1.17	93.89
T.-Carp.u.	160.1591	15.81	31.27	8.48	60.25	11.91	6.13	81.96	8.88	8.72	82.40	15.51	2.96	81.54
T.-Carp.w.	58.9765	5.82	33.32	24.21	42.47	6.64	34.54	58.82	3.83	34.27	61.90	10.54	17.81	71.65
F.-U.t.	140.4795	13.87	12.33	18.71	68.95	5.17	14.85	79.99	5.91	17.93	76.16	1.91	13.57	84.53
F.-U.ch.	6.0276	0.59	21.41	0.00	78.59	1.11	0.00	98.89	1.39	3.24	95.37	1.72	0.00	98.28
C.-Aln.	47.1608	4.65	43.31	18.26	38.43	8.64	34.17	57.19	5.68	45.46	48.86	29.01	15.96	55.03
R.-Aln.	8.8139	0.87	34.94	14.86	50.19	13.54	26.74	59.72	10..21	49.15	40.64	44.41	12.54	43.05
S.-P.+ River waters	201.6001	19.90	7.85	7.15	27.21 (57.79)	10.80	3.98	32.35 (52.87)	11.86	5.96	24.72 (57.45)	12.39	5.39	20.36 (61.86)
TOTAL	1013.1499	100.00	27.02	9.66	63.32	16.31	8.68	75.01	14.36	10.98	74.67	23.37	5.79	70.85

C.-Aln.—Circaeo-Alnetum. F.-U.ch.—Ficario-Ulmetum chrysosplenietosum. F.-U.t.—Ficario-Ulmetum typicum. L.-Pin.m.—Leucobryo-Pinetum var. with Molinia. P.-Pin.—Peucedano-Pinetum. P.-Querc.—Potentillo albae-Quercetum. Q.-Pin.m.—Querco roboris-Pinetum molinietosum. Q.-Pin.t.—Querco roboris-Pinetum typicum. R.-Aln.—Ribeso nigri-Alnetum. S.-P.—Salici-Populetum. T.-Carp.t.—Tilio-Carpinetum typical. T.-Carp.u.—Tilio-Carpinetum mesotrophic. T.-Carp.w.—Tilio-Carpinetum eutrophic

Source: survey 1990s

Table 3. Land-use changes in habitats in the Kampinos forest

Habitat type	Area [sq km]	Area [%]	Area [%]											
			1830			1889			1930			1985		
			Forests and scrub	Grasslands	Other	Forests and scrub	Grasslands	Other	Forests and scrubs	Grasslands	Other	Forests and scrub	Grasslands	Other
P.-Pin.	16.20	3.91	90.88	1.12	7.99	75.40	0.29	24.31	69.92	1.81	28.27	90.94	0.19	8.87
L.-Pin.m.	4.66	1.12	99.94	0.00	0.06	98.55	0.00	1.45	98.87	0.00	1.13	98.83	0.04	1.13
M.-Pin.	5.42	1.31	97.27	0.48	2.25	95.92	3.14	0.94	94.34	5.35	0.30	94.78	2.45	2.77
V.u.-Pin.	0.05	0.01	100.00	0.00	0.00	100.00	0.00	0.00	98.83	0.00	1.17	100.00	0.00	0.00
Q.-Pin.t.	151.81	36.59	80.83	1.68	17.49	79.16	4.83	16.01	69.68	7.08	23.24	88.10	4.04	7.86
Q.-Pin.m.	14.620	3.52	91.01	0.84	8.15	80.53	8.05	11.42	73.35	12.68	13.96	82.95	6.03	11.01
P.-Querc.	3.35	0.81	87.15	1.62	11.23	50.86	1.39	47.75	47.01	0.36	52.64	62.94	0.22	36.85
T.-Carp.t.	47.26	11.39	61.76	6.40	31.84	27.75	36.16	36.09	19.80	38.50	41.70	27.04	36.80	36.16
T.-Carp.u.	28.87	6.96	55.57	12.03	32.40	25.61	30.85	43.54	16.09	36.57	47.33	30.35	33.22	36.44
T.-Carp.w.	42.36	10.21	76.30	9.32	14.38	30.66	50.51	18.83	21.78	55.58	22.64	31.64	48.95	19.41
C.-Aln.	75.91	18.29	73.50	14.70	11.80	33.70	53.82	12.48	18.11	62.75	19.14	25.64	58.31	16.05
R.-Aln.	24.40	5.88	78.10	9.02	12.89	47.92	48.94	3.14	35.27	51.36	13.38	46.98	45.92	7.10
TOTAL	413.91	100.00	76.17	6.44	17.39	54.59	26.26	19.15	44.53	30.28	25.19	57.45	26.60	15.95

C.-Aln.—Circaeo-Alnetum. L.-Pin.m.—Leucobryo-Pinetum var. with Molinia. M.-Pin.—Molinio-Pinetum. P.-Pin.—Peucedano-Pinetum. P.-Querc.—Potentillo albae-Quercetum. Q.-Pin.m.—Querco roboris-Pinetum molinietosum. Q.-Pin.t.—Querco roboris-Pinetum typicum. R.-Aln.—Ribeso nigri-Alnetum. T.-Carp.t.—Tilio-Carpinetum typical. T.-Carp.u.—Tilio-Carpinetum mesotrophic. T.-Carp.w.—Tilio-Carpinetum eutrophic. V.u.-Pin.—Vaccinio uliginosi-Pinetum

Source: Survey 1990s

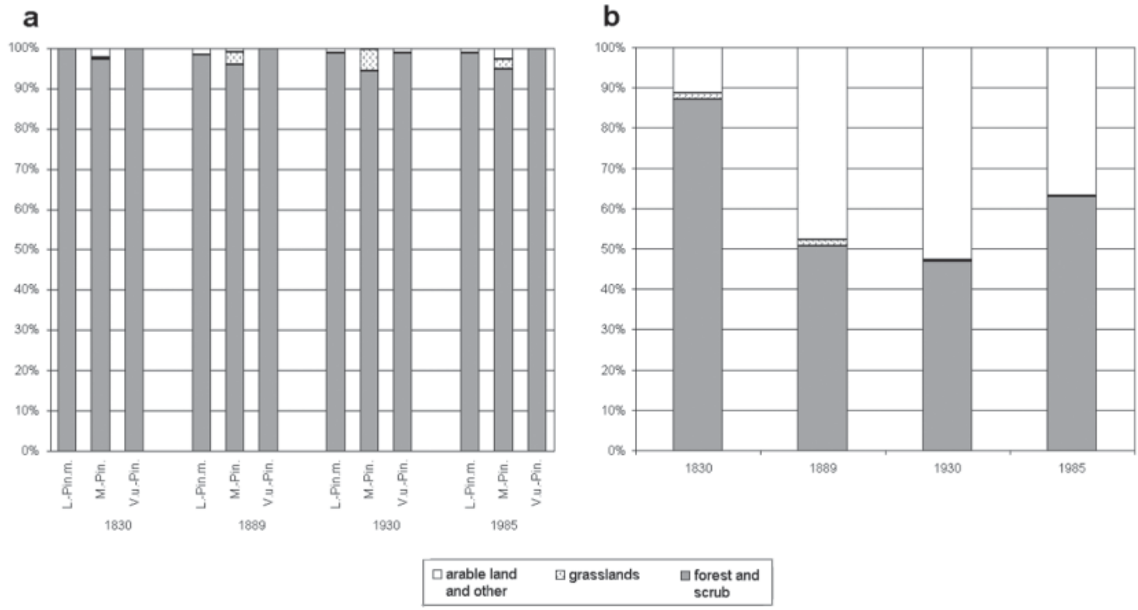

Figure 6.6. Kampinos Forest: land-use a) in *Molinio-Pinetum*, *Leucobryo-Pinetum molinietosum* and *Vaccinio uliginosi-Pinetum* habitats b) in *Potentillo albae-Quercetum* habitat

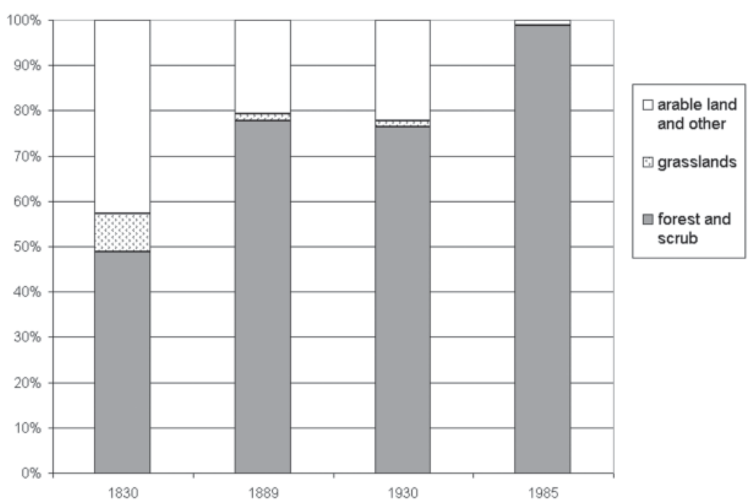

Figure 6.7. Land-use outside Kampinos Forest in *Peucedano-Pinetum* habitats

Away from Kampinos, land-use changes in fresh pine forest habitats (*Peucedano-Pinetum*) also proceeded in a manner different from general management trends in the study area (Figure 6.7). A first considerable increase in woodland area was observed in the 19th century, and then in the latter half of the 20th century. By 1985, forests covered over 98% of the habitat (in 1830 only 48%). During the whole study period, the area of forest and scrub in pine forest habitats was significantly greater than the mean forest cover in the study area. But the area of meadows was below average.

Outside Kampinos, the majority of habitats from the next group: lime-oak-hornbeam forest—(*Tilio-Carpinetum*) and riparian ash-elm forest (*Ficario-Ulmetum*), were used in agriculture. This type of land-use dominated over the study period (Figure 6.8).

Unlike the area outside Kampinos, the habitats of typical and mesotrophic lime-oak-hornbeam forests in the Kampinos area were mainly covered by forest and scrub in 1830 (Figure 6.9). But in the second half of the 19th century, there was a huge decrease in the woodlands of these habitats. In following years, the extent of forest and scrub shrank still further. The majority of deforested land was transformed into meadows. However, in the second half of the 20th century, a rise in the cover of forest and scrub was noted (7% in typical lime-oak-hornbeam forest and about 14% in the mesotrophic lime-oak-hornbeam forest habitat).

In the second half of the 19th century and at the beginning of the 20th century, a marked decrease in the area of forest and scrub was observed in the habitats clustered in the next group: alder carr (*Ribeso nigri-Alnetum*), alder-ash forest (*Circaeo-Alnetum*) and eutrophic lime-oak-hornbeam forest (*Tilio-Carpinetum*). In both parts of the study area, forests were mainly replaced by meadows. The contribution of meadows to these habitats was several times above average in the area (the highest value in any of the habitat types). The area of meadows grew until the 1930s, and this was not halted until the second half of the 20th century. The greater part of the meadows were afforested, most with alder carr, least with eutrophic lime-oak-hornbeam forests. It can be noted that afforestation activity was greater in wetter habitat (Figures 6.10 a, b).

Land-use changes were different and less intensive in willow-poplar alluvial forest habitat (*Salici-Populetum*) (Figure 6.11). Over time, the area of forest and scrub increased, but by only a rather small amount (ca 4.5% between 1830 and 1985). Unlike other habitats, the land in question was rarely used for agriculture. The strongest pressure was put on it in the second half of the 19th century. At that time, the area of the river-bed was greatly reduced and meadows and arable land covered most ground. However, at the beginning of the 20th century, the area of agricultural land decreased, and this continued into the latter half of the 20th century. At the same time, the area of river-bed increased as a consequence of the construction of the Włocławek reservoir.

SUMMARY AND CONCLUSIONS

General trends to land-use changes were the same in both parts of the study area. The most intensive and greatest changes occurred between 1830 and 1889. There was a significant decrease in the area of forest and scrub in that period. Deforested land was transformed into arable land and meadows. Deforestation continued into the first part of the 20th century, but at a slower pace. It was in that period grassland cover peaked, whereas in the second half of the 20th century, the area of forest and shrub increased. Away from the Kampinos area, forests returned to their 1830 level; in the Kampinos area, the extent of forests was about 1/4 smaller than at the beginning of the study period.

Apart from the changes, constant characteristics were noted in both parts. The Kampinos area was continuously dominated by forest; while outside it the greatest area was under arable land. In Kampinos, deforested areas were mainly transformed into meadows, while elsewhere, this terrain was changed into arable land.

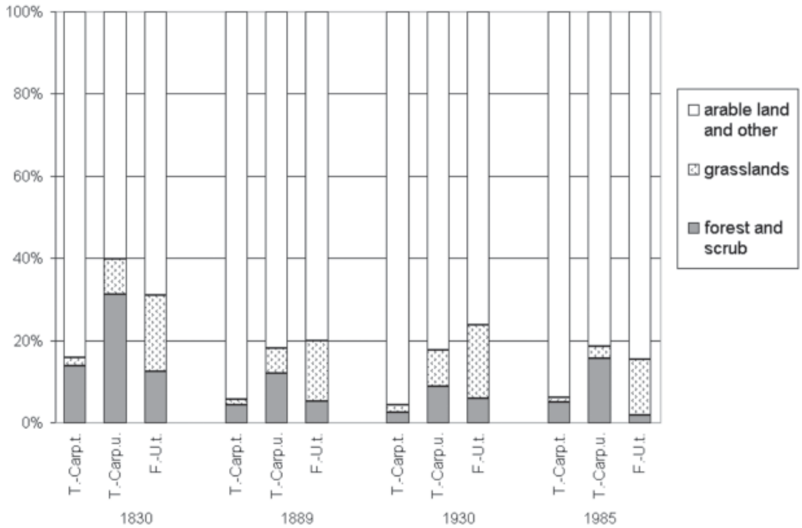

Figure 6.8. Land-use outside Kampinos Forest in *Tilio-Carpinetum* and *Ficario-Ulmetum* habitats

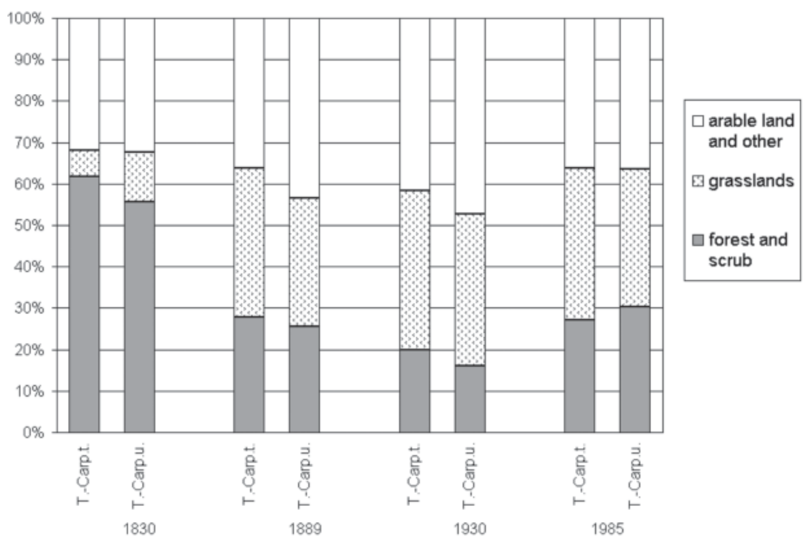

Figure 6.9. Kampinos Forest: land-use in *Tilio-Carpinetum* habitats (typical and mesotrophic)

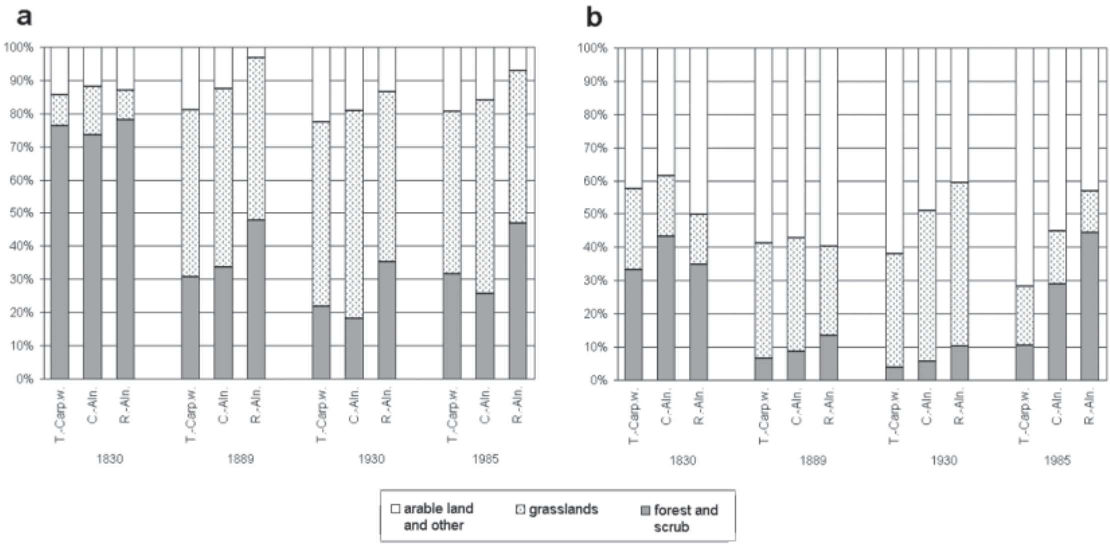

Figure 6.10. Land-use in *Circaeo-Alnetum*, *Ribeso nigri-Alnetum* and eutrophic *Tilio-Carpinetum* habitats; a) in Kampinos Forest, b) outside Kampinos Forest

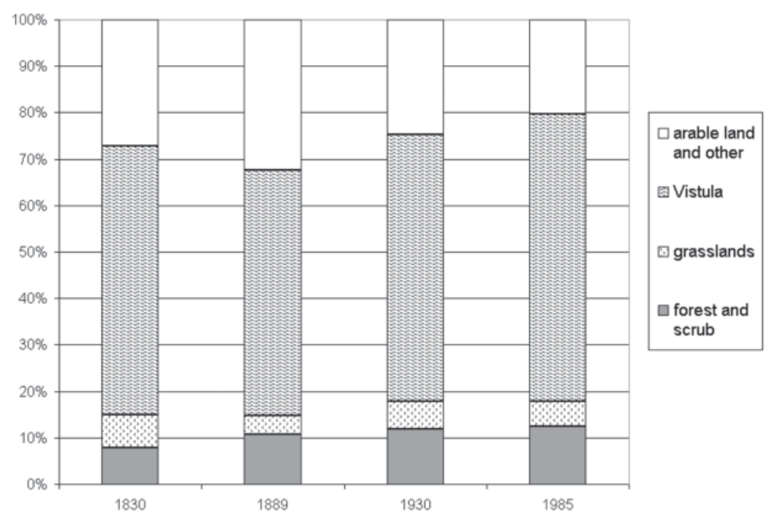

Figure 6.11. Land-use outside Kampinos Forest: *Salici-Populetum* habitat and Vistula waters

Table 4. Groups of habitats distinguished in each part of the study area on the base of dendrograms

Kampinos	outside Kampinos
—fresh pine forest (Peucedano-Pinetum) and mixed oak-pine forest (Querco roboris-Pinetum)	—fresh pine forest (Peucedano-Pinetum)
—moist pine forest (Molinio-Pinetum) and pine swamp forest (Vaccinio uliginosi-Pinetum)	—mixed oak-pine forest (Querco roboris-Pinetum) and thermophilous pine-oak forest (Potentillo albae-Quercetum)
—thermophilous pine-oak forest (Potentillo albae-Quercetum)	—lime-oak-hornbeam forest – typical and mesotrophic (Tilio-Carpinetum) and riparian ash-elm forest (Ficario-Ulmetum)
—lime-oak-hornbeam forest – typical and mesotrophic (Tilio-Carpinetum)	—alder-ash forest (Circaeo-Alnetum), alder carr (Ribeso nigri-Alnetum) and eutrophic lime-oak-hornbeam forest
—alder-ash forest (Circaeo-Alnetum), alder carr (Ribeso nigri-Alnetum) and eutrophic lime-oak-hornbeam forest	—willow-poplar alluvial forest (Salici-Populetum)

Source: dendrograms (Figures 6.5 ab)

Forests were mainly in pine forest habitats. In moist and fresh pine forest habitats, forestry uses dominated during the whole study period. In mixed oak-pine forest habitats, the domination of forests was maintained within the Kampinos area. Away from Kampinos, extensive areas of this habitat were deforested and changed into agricultural land (Figures 6.12 and 6.13).

Forests were less closely associated with the habitats of oak-lime-hornbeam forest, hardwood alluvial forest and alder carr. Around Kampinos, forests covered the majority of the area at the beginning of the study period, but further deforestation reduced their extent. Deforested land was transformed into grassland or arable land (mainly in mesotrophic oak-lime-hornbeam forest habitat). Away from Kampinos, agricultural use dominated in these habitats as early as in 1830, and was maintained during the whole study period, although their forest cover increased in the second half of the 20th century.

It was also the time that reforestation commenced in all habitats of the Kampinos area, more in pine forest and mesotrophic oak-lime-hornbeam habitats than in alder carr or alder-ash forest habitats (dominated by meadows). Afforestation in pine forest habitats resulted in an increase in the woodland area back up to the level of 1830. Away from Kampinos, afforestation generally affected smaller areas. The process was the most intensive in pine forest habitats. By 1985, the area of forest in these habitats was a few percentage points greater than in 1830. Apart from in pine forest habitats, intensive afforestation was also observed in alder carr and alder-ash forest. The increase in the woodland area in lime-oak-hornbeam forest habitats was smaller. Riparian ash-elm forest habitats were not reforested.

In the Kampinos area, the greatest changes were introduced in moist habitats of alder carr, alder-ash forest and eutrophic lime-oak-hornbeam forest, mainly in the 19th century. Beyond, the marked variability of these habitats was also noted in the 20th century.

The smallest changes in the Kampinos area were observed in moist and swampy pine forest habitats (minimal changes), as well as in the mixed pine-oak forest habitat. Elsewhere, the most limited transformations emerged in deforested and agricultural habitats of riparian ash-elm forest, typical oak- lime-hornbeam forest and the not-easily-accessible willow-poplar alluvial forest. The variability

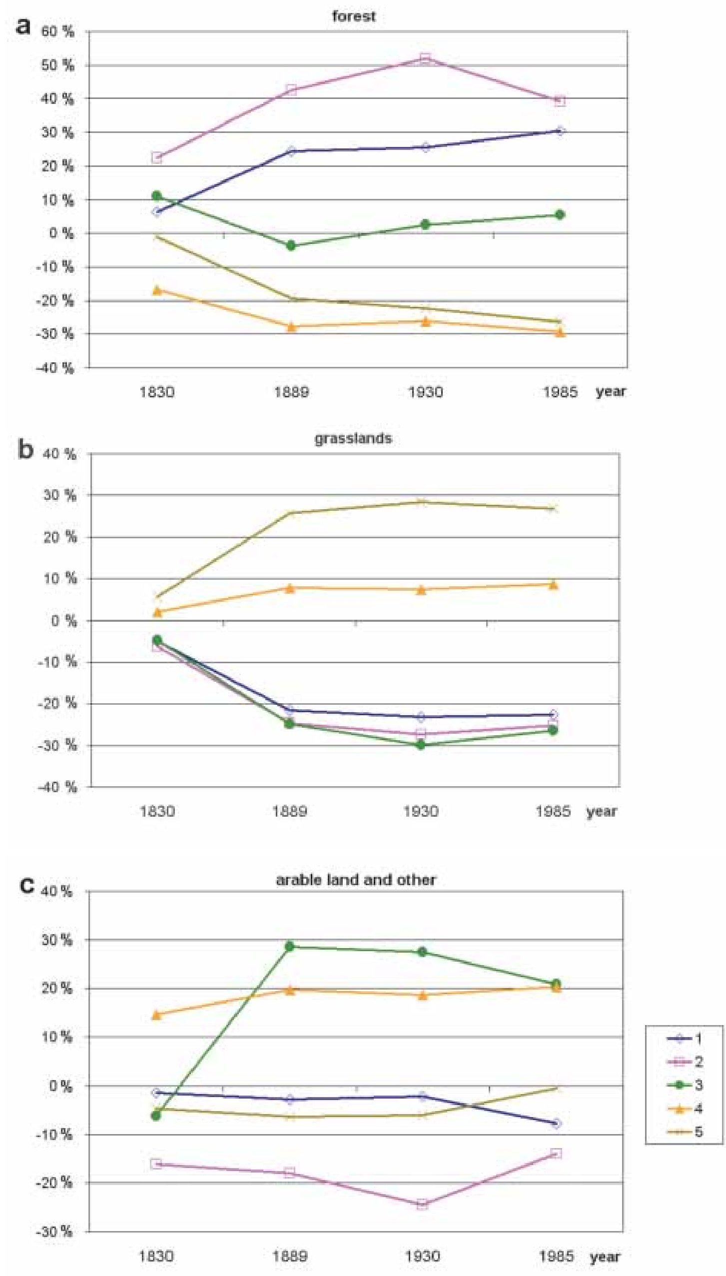

Figure 6.12. Land-use changes in different habitat groups estimated as a difference between an area of land-use type in a habitat group (%) and an area of that land-use type in the whole area of the Kampinos Forest (%). 1—fresh pine forest and mixed oak-pine forest, 2—moist pine forest and pine swamp forest, 3—thermophilus pine-oak forest, 4—lime-oak-hornbeam forest—typical and mesotrophic, 5—alder-ash forest, alder carr and eutrophic lime-oak-hornbeam forest

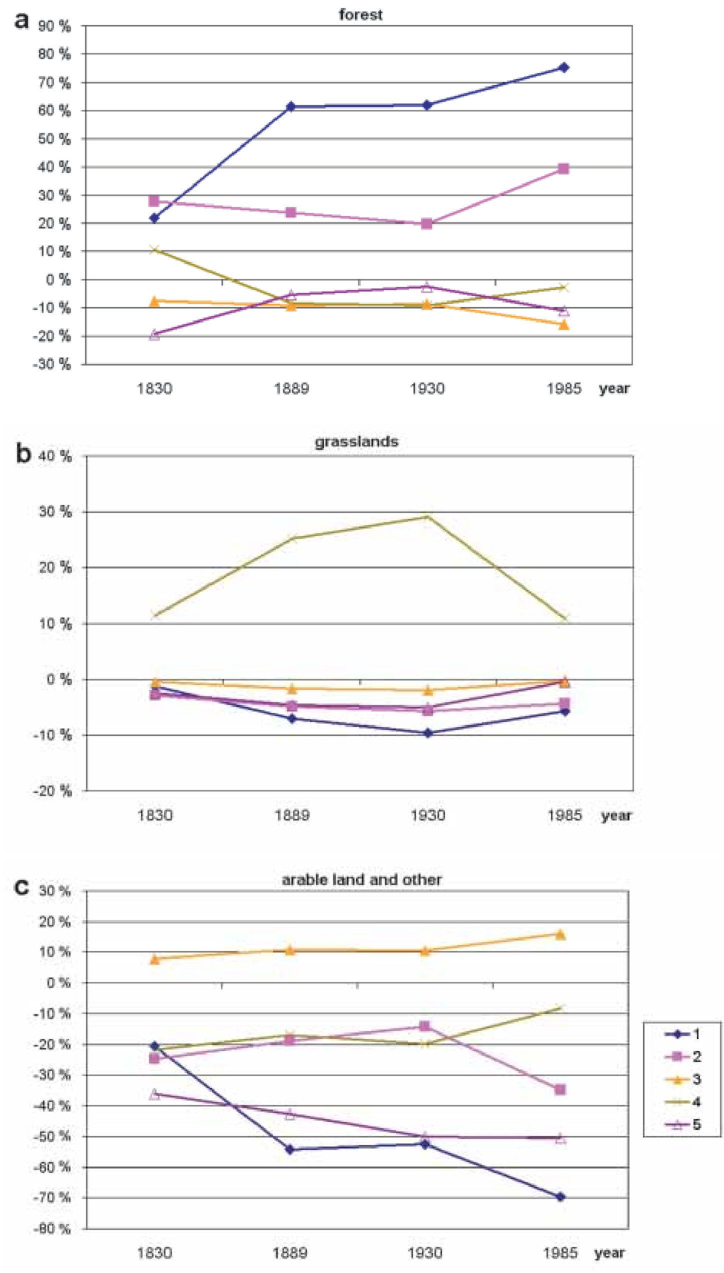

Figure 6.13 Land-use changes in different habitat groups estimated as a difference between an area of land-use type in a habitat group (%) and an area of that land-use type in the whole area outside the Kampinos Forest (%). 1—fresh pine forest, 2—thermophilus pine-oak forest and mixed oak-pine forest, 3—lime-oak-hornbeam forest—typical and mesotrophic and hardwood alluvial forest, 4—alder-ash forest, alder carr and eutrophic lime-oak-hornbeam forest, 5—willow-poplar alluvial forest

in pine forest habitats was greater than in Kampinos. They were further deforested.

At the beginning of the study period, agriculture was concentrated on the best, most-fertile and easily accessible habitats (oak-lime-hornbeam forest, and riparian ash-elm forest). Forests covered both good and less-fertile habitats (alder carr, alder-ash forest and pine forest). As time went on, meadows and arable land appeared in less-favourable habitats. However, in the latter part of the 20th century, the extent of agricultural land become limited once more to more fertile areas. Fallow land and less-fertile habitats were afforested.

To conclude:

1. Despite similar general management trends in the study area, the history of land-use changes proved to be different in each habitat, in relation to both the spatial and temporal extent of changes and their nature.

2. The character of and trends to land-use changes in the valley were mostly determined by habitat conditions. In areas with similar conditions, the course of changes was much the same.

3. The influence of habitat conditions is noticeable in the asynchronicity of land-use changes in different habitats. The most fertile and easily-accessible habitats were transformed first (human pressure on these was the strongest), then changes in less-fertile habitats were made, if at lesser intensity, with the natural character being retained more often.

4. Differences in land-use changes in the same habitat type in the two identified parts of the study area reflected the different kinds of land management being pursued: the domination of forest-uses in the Kampinos area, and the domination of agriculture elsewhere in the region.

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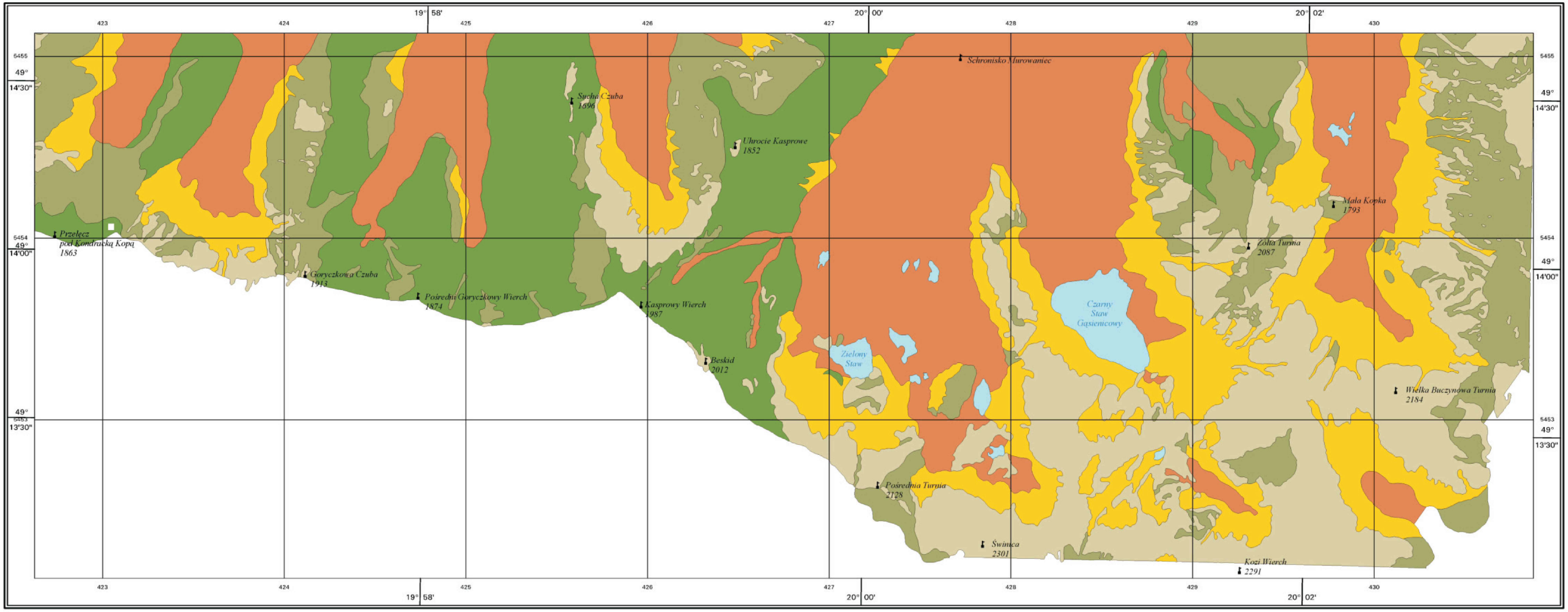
Morphodynamic units of the Tatras
(central part)

Zofia Rączkowska



1 0 1 2 km

Projection Type: UTM; Zone: 34; Spheroid Name: WGS 84

Legend

- Rockwalls and rocky slopes
- Debris mantled slopes
- Debris slopes
- Valley bottoms filled with glacial drift deposits and occupied by fluvioglacial, fluvial and alluvial plains
- Mature slopes with weathering cover
- Lakes

Figure 2.2. Morphodynamic units of the Tatras
Source: elaborated by Z.Rączkowska (2006)