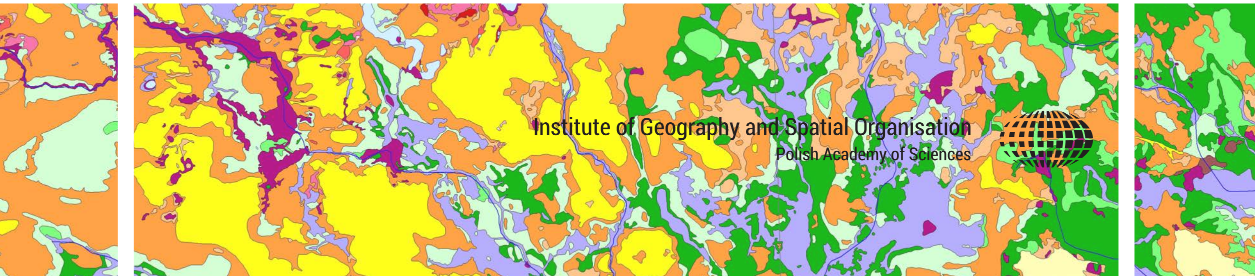
FOREST COVER CHANGES AND LANDSCAPE SUSTAINABILITY – A RETROSPECTIVE STUDY IN CULTURAL BORDERLAND

Edited by
Jan Marek Matuszkiewicz



Institute of Geography and Spatial Organisation
Polish Academy of Sciences

INSTITUTE OF GEOGRAPHY AND SPATIAL ORGANIZATION
POLISH ACADEMY OF SCIENCES

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na pograniczu mazursko-kurpiowskim w aspekcie rozwoju
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TABLE OF CONTENTS

Introduction – Research assumptions (*Marek Degórski*) **9**
References.. 11

1. Physical-geographical characteristics of the borderland of Masuria and Kurpie (*Jacek Wolski*) **12**
1.1. Administrative location.. 12
1.2. The geographical location 12
1.3. Relief with elements of geology 14
1.4. Soil cover 21
1.5. Surface waters 24
1.6. Selected elements of climate... 27
1.7. Nature conservation forms 30
1.7.1. Nature conservation forms in the light of the Nature Conservation Act 30
1.7.2. Other initiatives to nature conservation.. 35
1.8. The most important features differentiating the northern and southern parts of the area 36
References.. 37

2. Prussian, Russian and Polish cartography of the borderland of Masuria and Kurpie (*Jacek Wolski*) **42**
2.1. Introduction 42
2.2. Assessment of utility of the source materials.. 43
2.3. Selection and classification of the source materials.................................... 44
2.4. Characterisation of the basic source materials.. 45
2.4.1. The Prussian and German cartography.. 45
2.4.2. Polish and Russian cartography from before 1918 64
2.4.3. Polish cartography after the year 1918 68
2.4.4. Polish cartography after the year 1945 71
References.. 77

3. Elaboration of the cartographic materials for the purposes of analysis of changes in forest cover (*Jacek Wolski*) **80**
3.1. Need for digital maps 80
3.2. The scheme of developing the model of forest cover changes 81
3.2.1. Scanning.. 81
3.2.2. Selecting the way to represent the environment.................................. 81
3.2.3. Calibration and registering of the raster images 81
3.2.4. Selection of objects... 84
3.2.5. Designing the database... 85
3.2.6. Vectorisation and normalisation of data 86
3.2.7. Graphical and cognitive generalisation 87
3.2.8. Developing the map of the sequence of changes in forest cover............ 87

3.3. Summary 87
References 88

4. Potential natural vegetation – the basis for habitat characterisation and its relation to geological substratum and regional variation (*Jan Marek Matuszkiewicz, Jerzy Solon, Anna Kozłowska, Anna Kowalska*) 89
4.1. Map of potential natural vegetation – methodological prerequisites and field works 89
4.2. The list and characteristics of potential natural vegetation types 89
4.3. Relationships between potential natural vegetation and geological substratum 93
4.3.1. Variation of geological substratum types in the study area 95
4.3.2. The potential natural vegetation units associated with the substratum types 96
4.3.3. Relationship between the potential natural vegetation and the geological substratum – analysis of indicators 96
4.4. Geobotanical division based on the potential natural vegetation 104
4.4.1. The study area in the existing geobotanical division 104
4.4.2. Suggestions of changes in the geobotanical division 107
References 113

5. Deforestation and afforestation processes of the Masuria-Kurpie borderland (*Jan Marek Matuszkiewicz, Anna Kowalska*) 115
5.1. Changes in forest cover within last 200 years 115
5.2. Sequences of "forest – non-forest" states 124
5.3. Identification of the ancient forests reach 129
References 132

6. Changes in forest cover regarding historical regions and habitat types (*Jan Marek Matuszkiewicz, Anna Kowalska*) 135
6.1. Changes in forest cover within habitats 135
6.1.1. Changes in forest cover within different habitats of Masuria 135
6.1.2. Changes in the forest cover within different habitats in Kurpie 140
6.1.3. The differences of the forest cover changes in the regions 144
6.2. The sequences "forest – non-forest" in main habitat types 146
6.2.1. The sequences of changes in the habitats of Masuria 147
6.2.2. The sequences of changes in the habitats of Kurpie 151
6.2.3. The differences between regions regarding the frequencies of sequences of "forest – non-forest" in the most important habitats 156
6.2.4. Frequency of habitat types on areas with definite sequences of "forest – non-forest" states 159
6.2.5. The relationships between habitat types and sequences of "forest – non-forest" states 167
6.3. The share of "ancient forests" according to habitat types in the regions 169
6.4. Evaluation of changes in the forest cover in habitats using the "sustainable landscape" criteria 171
6.4.1. "Sustainable landscape" – what does it mean? 171

6.4.2. Changes in the share of forest cover in habitats and in the regions according to criteria of sustainable landscape ... 175
References ... 177

7. Directions of historical landscape changes – fragmentation and consolidation of forests in the years 1800-2000 within the Masuria-Kurpie borderland (*Jerzy Solon*) ... 178
7.1. Types of forest area changes ... 178
7.2. General characterisation of changes ... 183
7.3. Landscape consequences of forest fragmentation and consolidation processes ... 193
7.3.1. District of Parciaki ... 194
7.3.2. District of Myszyniec ... 199
7.3.3. District of Jedwabno ... 204
7.3.4. District of Wielbark ... 210
7.3.5. District of Szczytno ... 215
7.3.6. District of Spychowo ... 220
7.4. The similarities and the differences as to the course of processes on the areas considered ... 225
7.5. The persistence and the changes in the districts ... 236
7.6. Habitat-related interdependencies of the processes of forest fragmentation and consolidation ... 238
7.7. Summary and conclusions ... 242
References ... 245

8. The history of human impact on forests of the Masuria-Kurpie borderland (*Joanna Plit, Ryszard Wojciech Pawlicki*) ... 246
8.1. An outline of climate changes from the early Middle Ages until today ... 246
8.2. The history of settling and development of the southern part of East Prussia 247
8.2.1. Changes in population density ... 247
8.2.2. Agriculture ... 253
8.2.3. Forest economy ... 257
8.3. The history of settling and development of Northern Masovia – Green Kurpie ... 259
8.3.1. Population changes ... 259
8.3.2. Agriculture ... 266
8.3.3. Forest management (including beekeeping, amber and peat exploitation) ... 270
8.4. Political boundary between Prussia and Masovia – its course, persistence and perception in the landscape ... 274
8.5. Type of villages ... 275
8.6. Land improvement works ... 276
8.7. Summary ... 278
References ... 279

9. Pressure from wild ungulates upon the forests of the Masuria-Kurpie borderland (*Jan Marek Matuszkiewicz, Jerzy Solon, Bożenna Grabińska*) ... 283
9.1. Scope of the research ... 283

9.2. Temporal and spatial differentiation of the magnitudes of ungulate populations in the years 1994-2010 ... 285
9.3. The pressure from the ungulates on forest biocoenoses ... 292
9.4. Similarity of the areas in terms of pressure from the game animals ... 298
9.5. The influence of the habitat diversity of the forests and spatial structure of landscape on the pressure exerted by the game animals ... 299
9.5.1. Introduction ... 299
9.5.2. Associations between the composition and configuration of landscape and the pressure from the game animals ... 301
9.6. The states of the populations of ungulates within the borderland of Masuria and Kurpie after the World War II in retrospection ... 309
9.7. Estimated changes of pressure from the ungulates during the 60 years considered ... 322
References ... 324

10. Hunting exploitation of the ungulates, now and in the past – a factor impacting ecosystem services (*Jan Marek Matuszkiewicz, Bożenna Grabińska*) ... 326
10.1. Introduction ... 326
10.2. Bag number of the ungulates in the study area in the years 1993-2008 ... 326
10.2.1. Bag number of red deer ... 328
10.2.2. Bag number of roe deer ... 329
10.2.3. Bag number of wild boar ... 330
10.2.4. An attempt of estimating monetary value of the hunted game ... 331
10.3. Retrospective analysis of the historical changes in the bag number of ungulates during the last 400 years in East Prussia ... 333
10.4. Summary of considerations on historical changes in the numbers and bag numbers of the ungulates ... 337
References ... 338

11. The concept and model of Sustainable Forest Distribution – SuFoD (*Andrzej Affek*) ... 339
11.1. Research problem and the concept of sustainable development ... 339
11.2. The concept of Sustainable Forest Distribution (SuFoD concept) ... 340
11.3. Research questions ... 342
11.4. The model of Sustainable Forest Distribution (SuFoD model) – operationalisation of the SuFoD concept ... 342
11.5. Assumptions of the model construction ... 343
11.6. Source data and processing ... 345
11.7. Results ... 347
11.8. Discussion and conclusions ... 352
11.8.1. Masuria ... 352
11.8.2. Kurpie ... 352
11.8.3. Limitations of inference ... 353
11.9. Summary ... 353
References ... 354

12. Forest ecosystems and rural communities – components and indicators of sustainable development (*Jan Marek Matuszkiewicz, Jerzy Solon, Anna Kowalska*) 356
12.1. Sustainable development – definitions and principles 356
12.2. Components of sustainable development and their indicators 357
12.2.1. The analysed elements of sustainable development 357
12.2.2. Characteristics of the indicators used 359
12.3. Indicators of "environment" change 359
12.3.1. Forest cover in the regions 359
12.3.2. Selective deforestation of habitats – indicator of excessive habitat exploitation 361
12.3.3. Degree of landscape sustainability in regard to the spatial structure of forest cover 365
12.3.4. Assessment of changes in the population density and the pressure of big wild animals 366
12.4. Indicators of changes in "society" component 368
12.4.1. Population density in the studied area 368
12.4.2. Density of rural settlements 370
12.4.3. Density of livestock animals and their pressure on the environment 371
12.4.4. Comparing the pressure of two ungulate groups – wild and livestock animals 378
12.5. Variability of the studied indicators 379
References 380

13. Assessment of historical changes in landscape sustainability based on selected indirect indicators (*Jan Marek Matuszkiewicz, Jerzy Solon, Anna Kowalska*) 381
13.1. Approaches to sustainable development evaluation 381
13.2. Theoretical assumptions of the sustainable development analysis 382
13.3. Procedures and identification of partial indicators 383
13.4. Synthetic indicators of historical changes 384
13.5. Final remarks 388
References 389

14. Social-ecological analysis – in search of the best criteria for sustainable development (*Jan Marek Matuszkiewicz, Anna Kowalska*) 391
14.1. Assessment of selected indicators 391
14.2. Relations between historical changes in the regions and concepts of sustainable development 395
References 395

INTRODUCTION – RESEARCH ASSUMPTIONS

Marek Degórski

The geographical environment links together two fundamental categories of space, i.e. the natural and the anthropogenic. The system of the natural environment is shaped under the influence of energy from the Earth's interior (an endogenous factor), as well as from the Sun (an exogenous factor), though today it is also influenced by human activity. In the geographical environment, the human being is an active creator and shaper of reality, on the one hand existing in natural space (which is put to use and transformed to meet people's needs), and on the other bringing into the geographical environment megasystem the creations of activity both intellectual and material. Many of the attendant activities leave more or less permanent traces (so-called "footprints") in the environment; and – in the context of analyses of changes ongoing in the structure and functioning of the environmental system – these prove interesting research topics for many different scientific disciplines, including geography.

Almost 40 years ago now, one of the representatives of the so-called behavioural geography – Peirce Lewis (1979) – sought to describe directions to the study of the environment (understood as the landscape) by proposing a set of relevant axioms. His claim was that elements of the cultural landscape do not have much sense unless studied in their geographical context. He further drew attention to the fact that most cultural landscapes are linked closely with the physical environment, with the consequence that interpretation of the former is dependent on familiarity with the physical landscape.

These statements make it very clear that it is not only among physical geographers (Degórski, 2004; Wojtanowicz, 1998), but also among social and economic geographers (Chojnicki, 1999; Domański, 2004; Isard, 1969) that the idea of the megasystem of the geographical environment has become fixed, with this being characterised by close interdependence between its natural and socio-economic parts, where shaping of the landscape is concerned (Degórski, 2009, 2012). Conceptualised in this way, the megasystem comes to look holistic, and also meets criteria for systems theory.

The geographical environment can therefore be defined as a megasystem composed of the aforementioned natural and anthropogenic systems, with the former encompassing biotic and abiotic elements of geographical space, while the latter comprises its socio-economic elements, including even the spiritual and intellectual potential of human beings (Degórski, 2004). The two systems continue to interact, to the extent that changes ongoing in one system must by definition give rise to changes in the other. The natural environment resembles the socio-economic one in being characterised by reference to defined elements, and attributes thereof, with both subject to continuous change. The aforesaid megasystem is thus a dynamic configuration that nevertheless remains in some kind of equilibrium, both within the different systems and within the whole megasystem. Capacities to self-regulate are also implicit here, the consequence being the emergence of dissipative structures. Nevertheless, disturbance in the functioning of one of the system is associated with changes in the attributes of the other.

In recent years, the matter of the transformation of the landscape under human influence – in a historical perspective whose time horizon extends over several hundred years – has become a subject for research carried out on the national (Poland-wide) scale (Maruszczak, 1988), but also at the levels of different regions including the Lublin region (Maruszczak, 1974), Masovia (Plit, 1996), Kujawy (Degórska, 2015) and the Przemyśl Foothills (Affek, 2016).

A research topic taken up very commonly in the historical concept as regards transformations of the landscape entails changes in the role played by forests in land-use structure in different geographical regions, with the directions and sizes of changes being elaborated by reference to analysis of available historical and contemporary cartographic materials, as well as – more and more often – on the basis of aerial photographs or satellite images. Such analyses have not confined their considerations to the dynamics of change, given that they have also taken in historical factors involved in their conditioning. And it is the demographic, economic and cultural conditioning that have proved especially important to this kind of work. It is after all these that go a long way to determining the direction and transformations a given region's environment are characterised by; with there being a certain perpetuation of landscape dominants and artifacts in future capable of being treated as indicators that allow for identification of the impact of different ethnic groups in the landscape (Affek, 2016; Degórska, 1996, 2015).

The issues concerning landscape transformations in Poland's Masuria (Mazury) and Kurpie regions that are presented here serve as a perfect example of work on changes ongoing over two hundred years in the geographical environment of two regions separated by a state border up to the end of World War II. This reflects a history whereby the Masuria region was partitioned off into German-controlled East Prussia, while the Kurpie region came within the so-called Congress Kingdom of Poland under the Russian Partitioners. It may thus be anticipated that differences in properties of the landscape arising out of the different natures of young- and old-postglacial areas have been overlain very strongly by economic differences, different ways of cultivating the land, and even the traditions and cultures of the people inhabiting the given geographical region.

The scope of the work described here has thus extended to take in both environmental aspects, and socio-economic transformations of the landscape in the borderland area between Kurpie and Masuria. In considering the development of the landscape in the study area, analysis draws attention to the role of conditioning that relates to morphology and lithology, soils, vegetation, forest management, settlement and tradition. It has furthermore sought to assess ongoing changes in the landscape from the point of view of sustainable-development principles. The studies here thus constitute an original attempt to look at a landscape retrospectively, as regards the balancing of three fundamental groups of (social, economic and natural) processes to which landscape has been subject, during the history of its development.

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1. PHYSICAL-GEOGRAPHICAL CHARACTERISTICS OF THE BORDERLAND OF MASURIA AND KURPIE

Jacek Wolski

Characterisation of the study area, preceded by the description of its administrative and geographical location, comprises selected issues associated with relief, geological bedding, soil cover, surface waters, climate, and nature conservation forms. The biggest portion of the characterisation is devoted to the geomorphological and lithological questions in the dynamic perspective. It is exactly the contemporary relief and its morphogenesis that determine to the highest extent the structural and functional differentiation of the entire considered landscapes and ecosystems, being, at the same time, decisive for its separate features in distinction with respect to the neighbouring regions.

1.1. Administrative location

The study area encompasses the surface of 2843.7 km^2, stretching between 53°06′00″N and 53°40′12″N, and between 20°31′48″E and 21°41′24″E. According to the administrative division of the country, the area is situated within the borderland of the provinces of Warmia-Masuria (approximately 54% of the area) and Masovia (approximately 46% of the area), and it encompasses six administrative units of a lower level – counties – of, respectively Szczytno, Olsztyn and Nidzica, and of Ostrołęka, Przasnysz and Maków Mazowiecki (Fig. 1.1).

Now, conform to the organisational-territorial division of The State Forests National Forest Holding, the area is subordinated to the Regional Directorate of State Forests in Olsztyn, and includes in entirety or in a major part, six forest districts: Jedwabno, Szczytno, Wielbark, Spychowo, Myszyniec, and Parciaki. It should be noted at this point that in a couple of places the course of the outer boundaries of the study area and the territorial reach of the organisational units of the state forests differ a bit between each other, this fact finding its most visible expression in the inclusion in the study area of the fragments of the forest precinct of Korpele (district of Korpele), and exclusion of the virtually whole precinct of Sławki (district of Parciaki).

1.2. The geographical location

From the point of view of the regionalisation related to physical geography (Kondracki, 1981; Solon et al., 2018) the study area is located at the interface of two regional units of the highest rank in the division of Europe: the areas of Western and Eastern Europe. One can speak of a broad transitory zone, whose course is determined, in particular, by the differences in the relief (heterogeneous mosaic landscape in the west and the vast plains

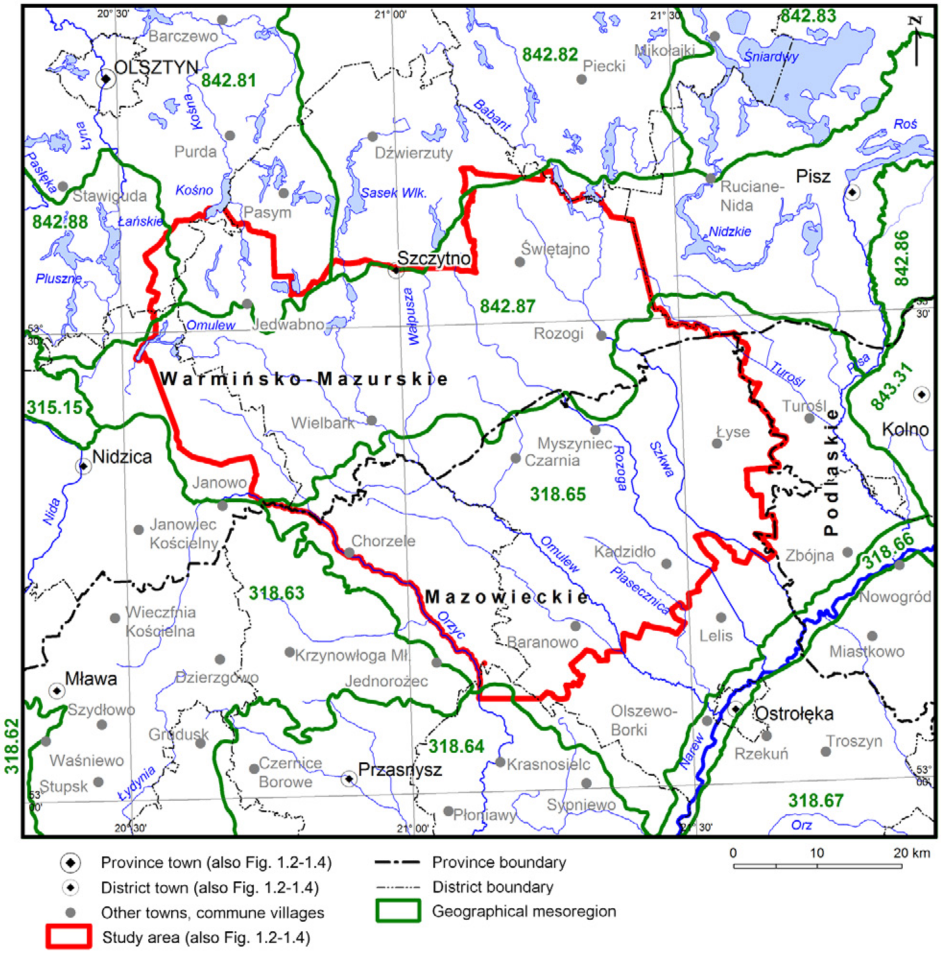

Fig. 1.1. Location of study area against a background of mesoregions and administrative division of Poland

Source: own elaboration; borders of mesoregions according to Solon et al. (2018).

Mesoregions (digital codes)
315.15 – Garb Lubawski (Lubawa Hummock)
318.62 – Równina Raciąska (Raciąż Plain)
318.63 – Wzniesienia Mławskie (Mława Hills)
318.64 – Wysoczyzna Ciechanowska (Ciechanów Heights)
318.65 – Równina Kurpiowska (Kurpie Plain)
318.66 – Dolina Dolnej Narwi (Lower Narew River Valley)
318.67 – Międzyrzecze Łomżyńskie (Łomża Interfluve)
842.81 – Pojezierze Olsztyńskie (Olsztyn Lakeland)
842.82 – Pojezierze Mrągowskie (Mrągowo Lakeland)
842.83 – Kraina Wielkich Jezior Mazurskich (Great Masurian Lakes)
842.86 – Pojezierze Ełckie (Ełk Lakeland)
842.87 – Równina Mazurska (Masurian Plain)
842.88 – Równina Olsztynka (Olsztynek Plain)
843.31 – Wysoczyzna Kolneńska (Kolno Heights)

featuring low hypsometric diversity in the East) and the dominating atmospheric circulation (oceanic vs. continental influences), as well as the specificity of the bio-geographical continuum (distinct climatic and vegetation vertical zonation in the mountains of the western part of the continent compared to the geographical zonal setting in the East), see Richling (2005).

In the study practice, regarding smaller areas, of primary importance, though, there are the differences between the regional units of lower levels (usually the mesoregions), within which one might assume relatively important territorial compactness and internal cohesion. Thus, for the here considered fragment of the large structural units of Europe the detailed regional division has the following outline (Fig. 1.1):

- area of Western Europe, sub-area Beyond-Alps Europe (3), province of Central European Lowland (31), sub-province of Central Poland Lowlands (318), macroregion Northern Masovian Lowland (318.6), mesoregion Kurpie Plain (318.65);
- area of Eastern Europe, sub-area East European Plain (8), province of the Eastern Baltic-Belarusian Lowland (84), sub-province of Eastern Baltic Lake Districts (842), macroregion Masurian Lakeland (842.8), mesoregions of Olsztyn Lakeland (842.81), Mrągowo Lakeland (842.82) and Masurian Plain (842.87).

1.3. Relief with elements of geology

According to the geomorphological regionalisation of Poland (Gilewska, 1999), the entire study area belongs to the Central European Plain province and to the following units of the lower level:

- sub-province of Southern Baltic Lake Districts (A II), macroregion Masurian Lakeland (A II.c), mesoregions: Olsztyn Lakeland (A II.c1), Mrągowo Lakeland (A II.c2), and Masurian Plain (A II.c8);
- sub-province of the Central Polish Lowlands (A V), macroregion Northern Masovian Lowland (A V.e), mesoregion of Kurpie Plain (A V.e7).

The above units of the regional division match well the belt-wise pattern of the relief of Poland (see Gilewska & Klimek, 1997; *Przeglądowa mapa…*, 1980), while the study area can be classified in two main morphogenetic zones: the early glacial lakeless plains (and uplands), called formerly the Land of Great Valleys (Dylikowa, 1973) and the late glacial lake uplands, neighbouring to the north with the lake ridge (Gilewska, 1999). In the typology of the natural landscapes of Poland (Richling & Dąbrowski, 1995) these distinctions correspond to the fluvioglacial plains and the undulating areas, cut across with the wide accumulation bottoms of the valleys, having the character of floodplains, as well as the post-glacial wavy and locally hilly landscapes.

Then, on a more local level one can distinguish:

- the early post-glacial landscapes: outwash plains with weakly marked eolian forms or vast areas with developing dunes, of upland islands evened out with the peri-glacial processes, and of wide valleys featuring high groundwater levels (Kuźnicki et al., 1978);
- the late post-glacial landscapes: of clayey-sandy hills and mounds, undulating plains of sandy formations or gravels, as well as flat sandy plains (Gotkiewicz & Smolucha, 1996; Piaścik et al., 1996).

The origins of the surface relief forms are directly associated with the course of the relief-forming processes during the last glaciation phases: the accumulating and disturbing activity of the ice sheet in the glaciation stages, as well as the accumulating and eroding activity of the pro-glacial waters in the warmer periods, along with the influences of the peri-glacial character. The changes, taking place in the Holocene (in the pre-historical times) were essentially the continuation of the processes, initiated in the Late Vistulian Glaciation. Nowadays, almost whole study area is constituted by the vast outwash surface with altitude differences not exceeding 130 m – between approximately 100 m a.s.l. in the valley of Rozoga in the south-east and not quite 230 m a.s.l. in the north-west (Złote Góry – 228.6 m a.s.l.). The area is often referred to as the Masuria-Kurpie outwash. How did it arise, though, and can it be treated as a homogeneous area? In order to be able to answer these questions, one should take a look at the morphogenesis[1] of the more broadly conceived borderland of the early and late glacial zones in this part of Poland.

Let us note, first, that the relief of the study area depends also indirectly upon the palaeo-morphology of the Precambrian crystalline foundation. It was influenced by the tectonic movements – both those from before the Pleistocene, and the ones linked with the later changing pressures (glacial isostasy) during the glaciation stages and between them. These disturbances of the gravitational equilibrium displayed particular intensity in the confines of the gradient troughs at the boundaries of structures of the deep bedding (see Morawski, 2011). In practice, the direction of the course of geological boundaries of the crystalline foundation, along with the accompanying discontinuities and tectonic breaks, determined to a large extent the later pattern of a part of sub-glacial gullies, as well as the maximum and recession limits of the ice sheet during the consecutive stages and phases of the last glaciation.

Not without consequence for the image of the contemporary relief was also the later activity of the older glaciations, which brought about a remodelling of the ceiling of the sub-Quaternary surface, along with the "blanket" of the glacio lacustrine deposits, covering it in many places[2]. Ice sheet, namely, in the course of the glacial erosion of various kinds (ploughing, tearing, wearing), during the successive transgressions, evened out the elevations of the Tertiary formations (like, e.g., the mounds in the vicinity of Szczytno – see Słowański, 1971) and deepened the existing depressions (like, e.g., the low in the neighbourhood of Chorzele and Opaleniec – see Bałuk, 1979). For this reason the moraine material frequently contains inserts and xenoliths – fragments of rocks removed from the geologically much older bedding. These formations, though, have been covered in their entirety with the Pleistocene sediments.

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[1] Morphogenesis of the area considered is in an obvious way associated with the Pleistocene stratigraphy, which, however, gave rise to numerous controversies (Ber et al., 2007; Mojski, 2005, pp. 40-45; Racki & Narkiewicz, 2006). The classification and the stratigraphic scheme of the particular glaciation episodes, applied in this chapter, are in general terms conform to the *Instruction of the elaboration and publication of the Detailed geological map of Poland on the scale of 1:50 000* (Instrukcja…, 1996).

[2] During the Pliocene the entire Masovian Plain – as a part of the great central depression – was a lake-rich area, its reach gradually shrinking in the lower Pleistocene.

The older Pleistocene glaciations, including the middle-Polish glaciation of Odra, according to the classification of Lindner (1992), did not leave apparent traces on the surface of the Earth. Only locally, in uncovered places, like at the high edges along the river channels, the sediments are visible that can be correlated with the early glaciation episodes. Lack of forms being the consequence of areal or frontal deglaciation, taking place during the recession of the ice sheet, is associated both with the maximum limits, which are distant from the study area, and with the activity of the erosion and accumulation processes, taking place during the successive transgressions.

The oldest elements of the contemporary terrain relief are being correlated by a significant proportion of scholars only with the Wkra and Mława stages of the middle-Polish glaciation of Warta[3]. They are, first of all, associated with the morphogenesis of the glacial uplands (in particular – those of Kolno and Ciechanów) and the pronounced elevations (of Mława and the Lubawa Mound), as well as the lower, separating erosion-accumulation plains (Kurpie Plain). The Warta stage retrograded very slowly, which led to the appearance of vast surfaces of stagnating and dead ice. Numerous forms took shape, especially within the Kurpie Plain and to the south of it, these forms having undergone during the later glaciation of Vistula only a superficial retouch. The sands, gravels and boulders of the Warta stage, side by side with pronounced hills near to Mława and to the south of Łomża (Lindner, 1992), form, in particular, accumulation frontal moraine hillocks and the insularly preserved fragments of the denudation plains in the northern part of the Kurpie Plain.

The warming period, that is – the Eemian Interglacial, which separated the middle-Polish glaciations away from the northern-Polish ones, took quite a mild course within the study area. The relatively weak denudation has not wiped out the glacial relief forms nor did it remove the moraine covers, while erosion in the river valleys was much less intensive than during the great interglacial.

At around 115,000 years BP the Vistulian, northern-Polish glaciation, entered the arena of the Pleistocene transformations of landscape. In the period of the Early Vistulian (the Toruń stage) the Scandinavian ice sheet did not play a bigger role in the north-eastern Poland. There are, on the other hand, controversies as to the maximum limit of the subsequent stage – that of Świecie. Some scholars maintain that the ice sheet reached during this stage almost the line of river Narew and it is exactly with the activity of this glacier that the sediments of the frontal moraines in the southern part of the Kurpie Plain correlate (Lisicki & Nizicka, 2010). Others are of the opinion that this ice sheet could have at most reached the line of the maximum limit of the main stage (Ber, 2000; Mojski, 2005), or that it even did not exceed the limit of the Pomeranian phase (Morawski, 2010).

In general terms, scholars are in agreement as to the fact that on the area in question the primary relief-forming role was played only by the Masurian lobe (one of the large-scale patches of the Scandinavian ice sheet). Its activity in the successive phases of the main stage of the essential Vistulian Glaciation was, however, strongly spatially differentiated, and had, in addition, an asynchronous character (see Fig. 1.2). This is why the division

[3] The stratigraphic position of these glacial episodes is subject to discussion (Lindner, 2005). So, for instance, Mojski (2005) proposes to replace the horizon of the middle-Polish glaciations by the Odra glaciation, to reduce the Warta glaciation to the rank of the recession stage of the strictly conceived Odra glaciation, and to treat the stages of Wkra and Mława as phases.

of the main stage, identified previously with the entire Baltic Glaciation, into the Leszno, Poznań and Pomeranian phases, was debated already during the elaboration of the first *Detailed geological map of Poland 1:50 000* (Słowański, 1971), and then in the consecutive years, even by its promoters (Kondracki, 1981).

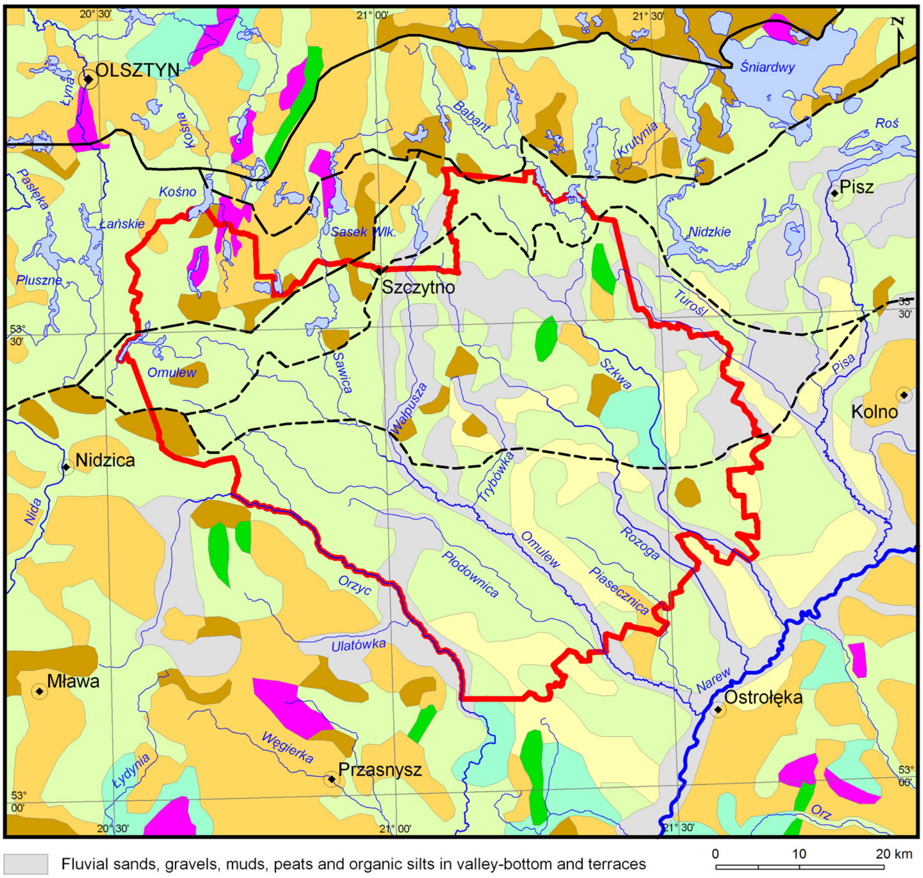
In the Leszno phase the cover of the ice sheet had quite limited thickness, and, owing to fast deglaciation, the sole trace of its presence is the thin, singular layer of boulder clay (Lindner, 1992). Besides, accumulation of the fluvioglacial sediments was not facilitated by the good conditions for the outflow of the meltwaters, while the not too pronounced marginal forms were to a large extent washed away and covered by the younger material during the later phases of the glaciation (Białousz, 1978; Lindner, 1992; Piaścik, 1996). In effect, the water-and-glacier sediments of this phase do not get uncovered on the surface, while the marginal forms are visible within the confines of the outwash in only few places and that solely as singular islands or moraines of dead ice. Distinct sequences of frontal moraines have been preserved only as far as in the northern part of the Kolno Heights (Lisicki & Nizicka, 2010).

All this sums up to the fact that the maximum limit of the Vistulian Glaciation in the north-eastern Poland is still a subject of debate. It was held previously that the so-called LGM (Last Glacial Maximum) line defined the boundary between the Kurpie and the Masurian Plains (Kuźnicki et al., 1978; Słowański, 1971). It is now admitted that this line had its course somewhat more to the south (Kozłowska & Kozłowski, 1998; Fig. 1.2). The most recent studies, in addition, indicate the presence of numerous maximum limits from various glacial episodes, whose rank is hard to determine (Gałązka et al., 2006).

During the subsequent period, that is – during the Poznań phase – the ice sheet covered only the northern part of the study area. Conform to what was held previously (see Kondracki, 1981) the line of maximum limit of this phase defined approximately the northern boundary of the Masurian Plain and, at the same time, of the sandy outwash plain, in the vicinity of Napiwoda most probably exceeding the LGM of the Leszno phase (see Wysota & Molewski, 2007). To the north of the frontal marginal forms of the Poznań phase, built primarily of the sands and thick gravels (in some places with a high number of rock boulders), the recession moraines as well as glacier accumulation forms were preserved, associated with dead ice. The material, washed out of the glacier front, covered these sediments, giving rise to higher horizons of the fluvioglacial forms of the Masuria-Kurpie outwash plain (Białousz, 1978; Piaścik, 1996).

Newer studies showed, though, and thus also confirmed some of the earlier suppositions (Mańkowska & Słowański, 1980; Słowański, 1971), that on the area here considered there does not exist sufficient evidence to document the lithostratigraphic independence of the Poznań phase. This may mean that the moraine hills and mounds, which have been correlated until now with the Poznań phase, are, in reality, the remnants of the successive stabilisation recession phases during the Leszno phase (Morawski, 2010). In this vein, some of the geologists distinguish locally only the Poznań-Leszno phase (Lindner, 1992), or refer to the entire main stage as to the Leszno-Pomeranian stage or the upper stage, thereby avoiding the reference to the stratigraphic divisions of a lower rank (see, e.g., Ber, 2000).

The very last glacial episode in history was the Pomeranian phase of the Vistulian Glaciation. The great Masurian lobe got divided then into two lobes: the Warmian one (previously called the lobe of Łyna river) in the West, and the proper Masurian one in the east, separated by the inter-lobe zone stretching from Biskupiec through Pasym to Omulew lake (Morawski, 2010). The maximum ice sheet limit is marked by the distinct frontal moraine ridges (Piaścik, 1996; Fig. 1.2). The successive stages of ice sheet recession



Fluvial sands, gravels, muds, peats and organic silts in valley-bottom and terraces
Eolian sands, locally in dunes
Ice-dam clays, silts and sands
Sandr sands and gravels
Kame sands and silts
Esker sands, silts and gravels
Frontal moraine gravels, sands, boulders and tills
Tills, weathered tills, glacial sands and gravels
Maximum ice sheet limit of the Pomeranian Phase of the Vistulian Glaciation
Maximum ice sheet limit of the Poznań Phase of the Vistulian Glaciation (two interpretations)
Maximum ice sheet limit of the whole Vistulian Glaciation (LGM) - Leszno Phase (two interpretations)

Fig. 1.2. Simplified, uncovered geological map with maximum limits of ice sheet during following phases of main stage of Vistulian Glaciation. Holocene formations, classified as the undivided Quaternary and the coming from times of the Vistula and Warta Glaciations

Source: own elaboration based on *Geological Map of Poland 1:500 000,* sheets: 1NW, 2NE (*Mapa geologiczna...,* 2006), changed and simplified; also *Detailed Geological Map of Poland 1:50 000* (*Szczegółowa mapa...*), Lisicki & Nizicka (2010).

are well visible in the field, both within the Olsztyn Lakeland, where the hills of the frontal moraines of the accumulation character form concentric arches exceeding the altitudes of 200 m a.s.l., and within the Mrągowo Lakeland, which is characterised by the grid-like pattern of relief: the consecutive chains of the moraine hills, oriented along the parallels, reaching the altitudes of 221 m a.s.l., are cut across perpendicularly by the meridionally oriented glacial lake gullies, accompanied by the walls of eskers and kames.

The period of glacial covers left in the landscape numerous forms of glacial relief. The group of marginal forms can be considered to include the chains of moraine hills in the north and the rudimentary mounds dating from the period of the Leszno phase and older glacial episodes, sticking out from beneath the fluvioglacial sediments in the central and southern parts of the study area. These forms are first of all represented by the frontal moraines and the hilly moraine (Kondracki, 1998). There are only few, but quite vast, visible on the surface of the Earth, remnants of the dead ice moraines (to the South of Omulew lake). More important groupings of the mounds and kame walls, whose fluvioglacial origins have been giving rise again in the recent years to debate (Jaksa, 2003), were identified only in the north-eastern part of the study area and in the northern part of the forest district of Spychowo (to the north-west of Świętajno lake). Other forms of crack accumulation can be found first of all within the forest district of Spychowo (Kozłowska & Kozłowski, 1998).

Yet, the specific character of the landscape here considered is determined primarily by the extramarginal forms, having arisen due to the fluvioglacial activity of the glacier. The deposits, transported by the meltwaters brought in effect formation within the forefront of the subsequent marginal zones of the great outwash plain. While, however, in western Poland individual horizons of fluvioglacial sands and gravels are quite well correlated with the concrete periods of deglaciation, on the study area such distinction – both vertical and horizontal – is often impossible or at least debatable. This is the consequence of the fact that the limits of the consecutive phases had courses situated close one to another, while the channels of outflow of the meltwaters were common. So, partial washing away of the older material and deposition of the younger would take place in the same places. The similarity of the sediments is also associated with the long transport distances, having exerted, as well, an influence on the thickness of these deposits – decreasing in the southern direction, from 15-20 m in the northern part of the Kurpie Plain down to 5-6 m at the confluence of Pisa and Narew rivers (Kuźnicki et al., 1978).

The outwash plain is also accompanied by the valleys, having characteristic course from the north-west to the south-east. Their morphogenesis is linked with the routes of the ancient outflow of the proglacial waters. Intensive transport and accumulation of sediments in the early warming periods, in connection with the continuous presence of the permafrost, playing the role of the persistent erosion basis, effectively hampered the advance of the in-depth erosion. The activity of the meltwaters was directed, therefore, uniquely to the sides. The lateral erosion was, however, specific, since it had not only mechanical, but also thermal character – water, constituting the medium of a positive temperature, acted upon the frozen ground and the ground ice, thereby degrading the permafrost (Migoń, 2006). The melt-down rivers, forming strongly branching network of streams, wandered across the valley bottoms, which resulted, with time, in the development of the very wide, shallow valleys with strongly boggy bottoms.

Another characteristic form on the study area is constituted by the sub-glacial gullies and all kinds of melt-out depressions. The former ones often make up radial systems of many kilometres of dimension, the course of these systems revealing the direction of movement of the main lobe or the smaller glacier tongues. The origins of the melt-out depressions, highly differentiated as to their magnitudes, depths, shapes and nature of draining (more so with respect to the surface waters), is associated with the blocks of dead ice, pressed down into the bedding, these blocks having been left by the ice sheet due to the disintegration of the strongly fissured ice cap during the areal deglaciation – both in the course of the long-lasting recession phases and during the short-lived oscillations (Piaścik, 1996). Smaller drainless depressions may also constitute the remnants of the fluvioglacial ice covers (Kozłowska & Kozłowski, 1999).

During the final period of the Vistulian Glaciation, characterised by intermittent periods of warming and cooling, the presence of the ice sheet was not registered any more on the study area. The Late Vistulian, even though having constituted only a short episode on the geological time scale (having lasted approximately 4000 years), played a very important role in the development of the post-glacial relief and of the new forms, being a kind of introductory stage for the approaching Holocene. During the warmer periods the process started of intensive melting of dead ice blocks, and thereby – of appearance of great multiplicity of lakes. During Alleröd and Bölling the permafrost either disappeared or at least its depth significantly decreased, and, at the same time, the thickness of the active layer of the soil increased. This resulted in the intensive in-depth erosion, leading to the changes in the deployment of the river valleys – from the single-channel-multiple-stream ones (braided river) towards the winding ones with large meanders, meaning single-channel-single-stream ones (Kondracki, 1998).

Activity of the wind played also a very important relief forming role on the study area. This activity affected sands accumulated in river valleys and on the outwash areas. Within the Kurpie Plain both the vast fields of eolian sands, and the inland dunes in the form of compact or dispersed clusters as well as single walls, are treated as the undivided Quaternary. In the subsequent phases of Dryas intensive eolian activity was induced by the cool and dry climate, presence of winds with relatively stable directions, and domination of low and sparse tundra vegetation (oldest Dryas), park-like tundra with birch (older Dryas) and park-like tundra with birch and steppe elements (younger Dryas). The dune-forming processes slowed down during Alleröd and Bölling, when a distinct warming took place of climate, which became also more humid, and woody vegetation developed (Dylikowa, 1973; Kozłowska & Kozłowski, 1998; Kuźnicki et al., 1978).

With the beginning of the Holocene, dated at 10,250 years BP, end came to the period of Pleistocene glaciations, this period lasting for approximately one million years. As mentioned earlier already, the majority of the processes, initiated in the Later Vistulian, were continued just in the Holocene (Błaszkiewicz, 2010; Rotnicki & Starkel, 1999). Complete disappearance of the permafrost, intensive development of the vegetation, as well as limited accumulation of the material in the outwash valleys led again to the development of in-depth erosion and changes in the deployment of the river channels. The subsequent gully reservoirs would get connected with short gorges and would thus become a part of the river network, which, with time, would incorporate also lakes having melt-out or damming origin. In this manner characteristic, poly-genetic river-and-lake systems developed. At the same time, though, numerous small, shallow reservoirs frequently with no outlet, characteristic for the Masurian Plain, started to overgrow and to undergo the eutrophication processes[4]. This was caused by the intensive increase of the role of biogenic factor – the increase of the volume and the annual production of the biogenic mass, as well as the rate and volume of the biological circulation of the elements in nature (Ostaszewska, 2005). Additionally, both in the drainless depressions and in the valleys of small creeks, sandy and peaty loams accumulated, as well as humus sands (Kozłowska & Kozłowski, 1998). The process of disappearance might have encompassed even up to 70% of the then existing post-glacial lakes (Kalinowska, 1961).

Soil cover underwent transformation, as well, especially the organic horizons. There was, namely, an acceleration of the process of creation of humus, and, at the same time, a change took place of the way humus accumulated in the soil – the place of the cryogenic accumulation, having taken place until then in the entire layer of the permafrost, was taken by the biogenic type – within the surface layer (Ostaszewska, 2005). Besides, intensive development of peat bogs started. On the Kurpie Plain this phenomenon was not only limited to the depressions of the terrain, but was taking place, as well, in the wide bottoms of the valleys and along the elevated areas between the valleys. Development of peat bogs within the flat area of the Masuria-Kurpie outwash is dated for the pre-boreal and boreal periods, while in the river valleys – for the Atlantic and sub-Atlantic periods (Listkowska, 1999ab). The peat bogs, which exist there nowadays, dominated by low peats (mainly overgrown with trees, swards, and mosses in the ceiling), are sometimes very vast (like, e.g. the belt accompanying the middle and the upper parts of the Orzyc river valley) and thick. A part of these entities is subject to commercial extraction carried out with surface slicing, while other ones were given conservation (like, e.g., the nature reserves of Karaska and Serafin).

During the Holocene the dune-forming processes were continued, as well, but both their course (secondary wind action on the late-Vistulian eolian sands) and the causal factor (anthropogenic pressure, particularly forest felling), had already quite a different character.

1.4. Soil cover

Soil cover of the study area and the neighbouring areas[5] is characterised by a distinctly zonal appearance of the autogenous soils, which remains in a strong genetic connection with the distribution and type of the Pleistocene fluvioglacial and boulder sediments,

[4] The gradual disappearance of lakes within the Masurian Lakeland takes place also currently, with an important contribution from human activity. This is statistically reflected in the more frequent and more intensive decrease of water volume (lakes getting shallower) than regarding the area of the water bodies. Interestingly, this process takes place in the lake bowls of various genetic types, including also the deep gully reservoirs (Choiński, 2007).

[5] The soil characteristics were based on nomenclature, genetic and hierachic divisions of 4th edition of *Systematyka gleb Polski* (PTG, 1989). The author is aware that the 1989 soil classification has already an archival status, but such an approach guaranteed unambiguous identification of taxons on the soil maps and other studies dating back 1970-1990s, which were used in the work.

as well as local diversification of the meso- and micro-forms of surface relief. Appearance of semi-hydrogenic, hydrogenic and inflow forms is, on the other hand, conditioned, first of all, by the differentiation of the hydrological aspect.

In general terms, the soils of the early-glacial areas are characterised by low content of calcium carbonate, and, due to intensive frost-induced weathering – by high shares of the dust and loam fractions in the ceiling horizons of the sediments, especially those built of the river-and-glacier and outwash sands (Kondracki, 1981). Then, the soils of the late-glacial areas, having developed usually on the river-and-glacier and boulder sands, and on moraine clays, are characterised by deeper dewatering of the mineral and mineral-organic colloidal bodies and stronger denaturation of the humus substances, this being facilitated by the higher amplitudes of air temperature in north-eastern Poland (Wicik, 2005).

The area considered is dominated by the autogenous, zonal podsolic-earth soils, which constitute a background for the mosaic of the remaining, interzonal taxonomic units (see Fig. 1.3). They are primarily developed from the material of granularity of the loose and weakly clayey sands – the fluvioglacial outwash sands (the sorted out sands of the so-called distant transport), or the extremely poor and eolically remodelled quartz dune sands. Within the Kurpie Plain and in the southern part of the Masurian Plain, that is – on the area of the so-called farther external outwash, podsolic soils appear (locally forming complexes with rusty soils and gley-podsolic soils of various sub-types in land depressions). In places occupied by the dune sands of eolian origin, azonal soils are encountered – mineral non-carbonate ones, weakly developed from the loose rocks (mainly the subtype of the podsolised soils). In the northern and north-western parts of the study area, within the so-called closer external outwash (Białousz, 1978), rusty soils start to dominate. A belt of these formations, preferring in the bedding the outwash sands of the close transport and other sandy forms, weakly sorted and little washed, reaches deeper into the Olsztyn and Mrągowo Lakelands, constituting in practice a transitory zone between the podsolic soils in the south and proper brown soils in the north. This situation is evidenced by the appearance in the complexes with the rusty soils of the accompanying formations (podsolic and brown soils) and presence of sub-types with both distinct traces of the processes leading to brown soils (the brown-rusty soils) and of podsolisation (the podsolic-rusty soils, called also crypto-podsolic). Local domination of the particular soil-forming processes is determined by the character and fertility of the habitat and by the persistence of the forest communities.

Against the here described background of the podsolic-earth soils, the single bigger patches stand out of the complexes of proper brown soils, as well as rusty and fallow soils (including the precipitation-gley ones, appearing in the circumstances of the periodic stagnation of precipitation waters in the surface horizons, having developed, in particular, on the dust and dusty sediments of the local marginal waters). These complexes appear especially to the south of Spychowo and in the northern part of the forest district of Szczytno. The proper brown soils and the rusty soils occupy also the north-western fringes of the study area, mainly in the forest district of Jedwabno, having developed there from the boulder clays and shallow dusty formations, characteristic for the landscape of undulating clayey-sandy plains, as well as gravel-and-sand hills and mounds. In numerous locations,

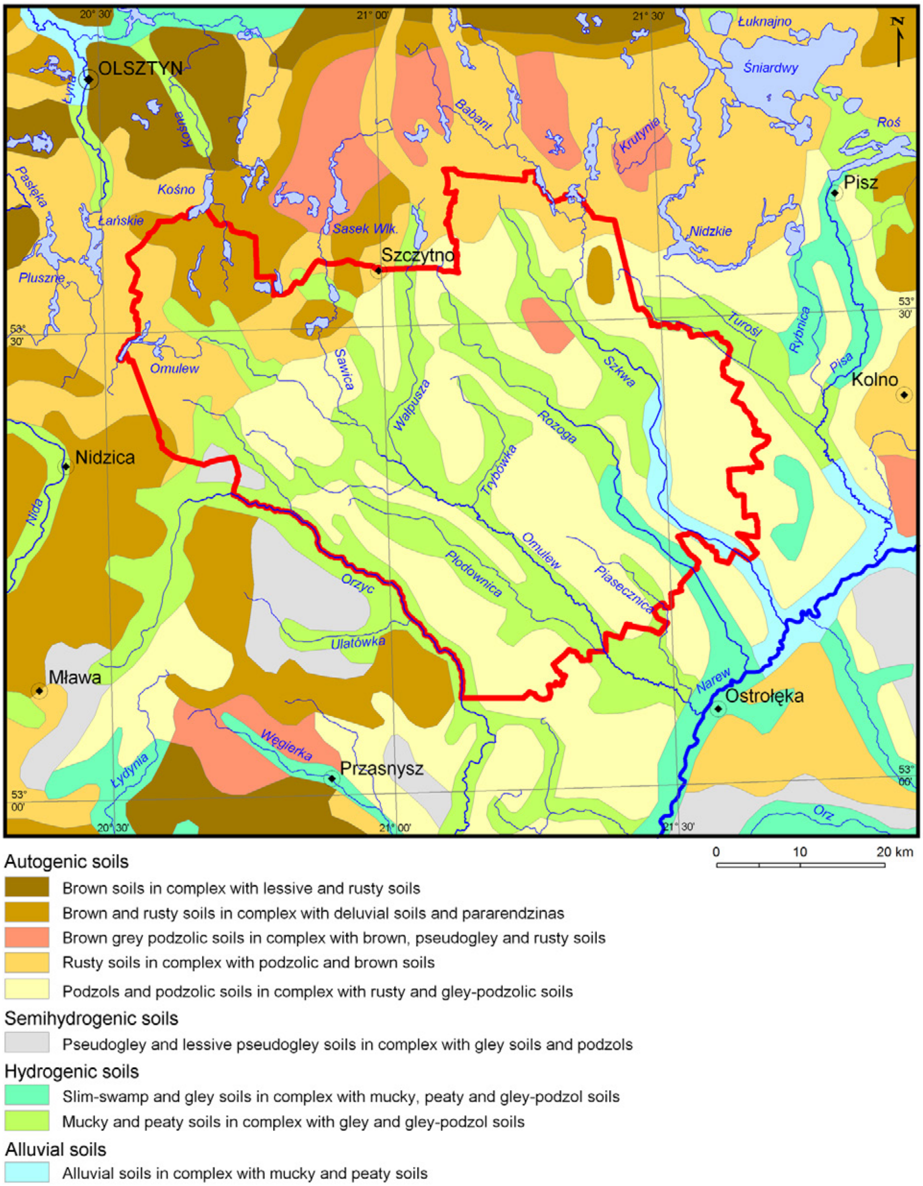


Fig. 1.3. Soil cover – complexes of main and concurrent soils

Source: own elaboration after of: Białousz (1994); *Detailed Soil Map of Poland 1:300 000* – sheets C4 Warszawa and B4 Olsztyn (*Mapa gleb...*, 1951-1960); Kuźnicki et al. (1978); Piaścik et al. (1996).

in the profiles of the brown soils, irrespective of their sort, referring to granulation, the traces are visible of the podsolisation process, and of leaching. In the terrain depressions and at the feet of elevations they are accompanied by the deluvial soils, composed mainly of the dusty sand with a deep humus layer. On the moraine mounds, having developed from the boulder deposits, containing fragments of carbonate rocks or dispersed carbonates, one can encounter the proper and brown para-rendzinas, the latter constituting an evolutionary stage between the proper sub-type and the proper brown soils (Białousz, 1978). This evolution, though, is slow in view of the significant content of the carbonate rock debris, as well as strong erosion and continuous rejuvenation of the soil profile (Konecka-Betley et al., 1999).

The wide valleys of the main, right-hand tributaries of Narew river (Orzyc, Omulew, Płodownica, Wałpusza, Rozoga, Szkwa), being typical geochemically dependent environments, are filled with sediments having granulation of sands, clays and gravels of various origins and age. On these sediments, first of all the hydrogenic interzonal soils developed in conditions of permanent wetness – the boggy soils (silt and peat soils), while on the areas temporarily drying or secondarily dewatered, where processes of mineralisation and decrease of organic matter take place – the post-boggy (marshy) ones. These are to a large extent the meadow habitats. In the middle and lower stretches of Rozoga and Szkwa rivers, and in some places also of the remaining tributaries of Narew, alluvial inflow soils dominate (river fen soils of various sub-types), as well as the semi-hydrogenic boggy soils (ground-gley soils). In the complexes here described one encounters also locally the proper gley-podsolic soils.

1.5. Surface waters

The study area is situated within the basin of the Baltic Sea. According to the hydrographic division of Poland (*Atlas podziału*…, 2005ab; *Mapa Podziału*…, 2007) the northern edge of the forest district of Jedwabno is located in the catchment of the Vistulian Lagoon and therefore belongs to the basin of Pregoła river, while the entire remaining area is located in the catchment of Narew river and thus belongs to the basin of Vistula (Fig. 1.4). The area is drained by the right-hand tributaries of Narew, and the lower-order streams, flowing into them. The main right-hand tributaries of Narew on the study area include Orzyc (which constitutes, over a significant segment, the western boundary of the study area), Omulew, Rozoga, Szkwa and Pisa.

The Masurian Lakeland is the macroregion featuring the highest total area and volume of lakes in Poland. The average indicator of lake share[6] within the Masurian Lakeland amounts to 3-4.1%, much more than the average for the entire country (0.9%), although there are catchments where this indicator reaches 10%, and in the Great Masurian Lakes (e.g. in the catchment of Węgorapa) it even exceeds 20% (Choiński, 2007; Lossow, 1996). Against this background the average lake share of the entire study area is quite limited, amounting to only roughly 1.4-1.45% – respectively for water bodies exceeding 10 hectares (37 lakes) and 1 hectare (70 lakes). The number of lakes being highly differentiated between the late- and early-post-glacial areas, where there are only small, numerous in-field and peat ponds, as well as old river beds (Choiński, 2006; Jańczak, 1999; *Mapa*

[6] This indicator carries the risk of erroneous interpretation in the comparisons. This risk is associated with application of different reference areas (catchment areas of various ranks, regions, arbitrarily defined geometric basic surfaces), scales and character of source materials, as well as the limiting magnitude criterion (e.g. in Choiński, 1999, 2006; Jańczak, 1999).

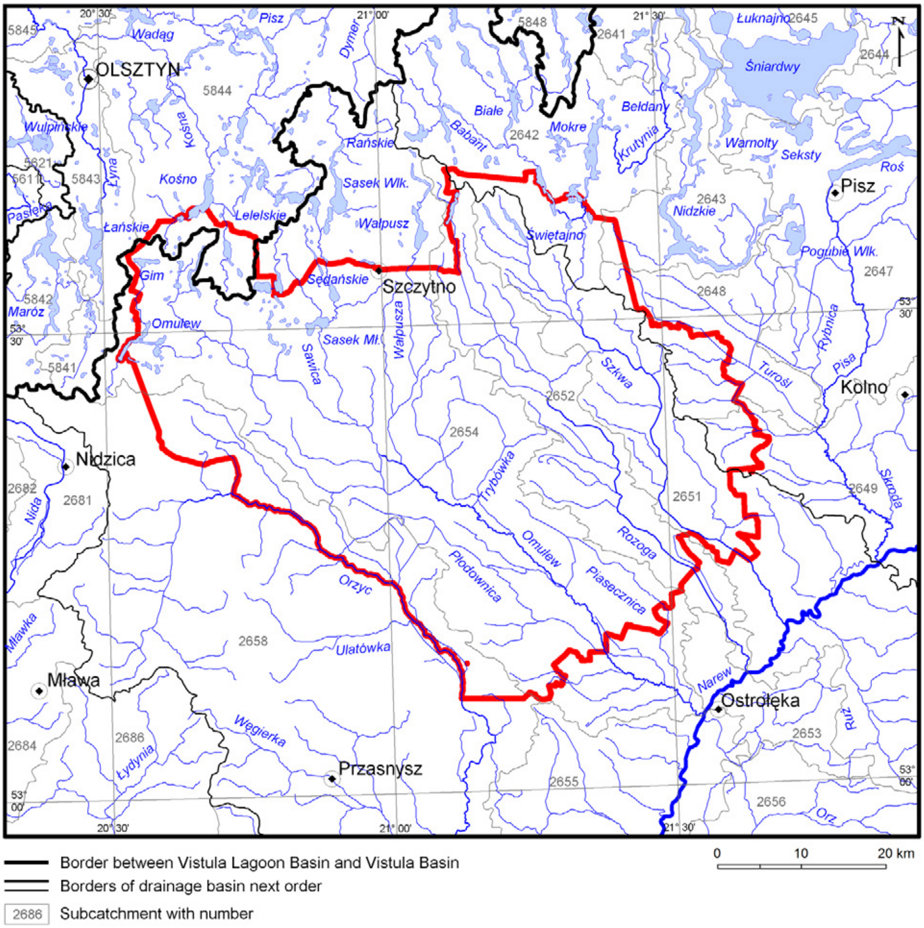


Fig. 1.4. Surface waters against a background of simplified hydrographical division

Areas (2) and hydrographical fields (3), which in the turn divide on drainage areas of lower lines (in parentheses the numbers of drainage areas distinguished on the map; all names in Polish): 2. Dorzecze Wisły: 26. Narew: 264. Pisa (2641. Jeziora i kanały od jez. Mamry do jez. Tałty, 2642. Krutynia, 2643. Zlewnia jez. Mikołajskiego i jez. Bełdany, 2644. Orzysz, 2645. Zlewnia jez. Śniardwy, 2647. Pisa od jez. Śniardwy do Turośli, 2648. Turośl, 2649. Pisa od Turośli do ujścia), 265. Narew od Pisy do zb. Dębe (2651. Narew od Pisy do Rozogi, 2652. Rozoga, 2653. Narew od Rozogi do Omulwi, 2654. Omulew, 2655. Narew od Omulwi do Orzu, 2656. Orz, 2658. Orzyc), 268. Wkra (2681. Nida do Szkotówki, 2682. Szkotówka, 2684. Mławka, 2686. Łydynia); 5. Zlewnia Zalewu Wiślanego: 56. Pasłęka: 561. Pasłęka do Giłwy (5611. Pasłęka do jez. Sarąg), 562. Giłwa (5621. Zlewnia jez. Wulpińskiego), 58. Pregoła: 584. Łyna (5841. Łyna do Marózki, 5842. Marózka, 5843. Łyna od jez. Kiernoz Wlk. i Marózki do Wadąga, 5844. Wadąg, 5845. Łyna od Wadąga do Symsarny, 5848. Guber)

Source: own elaboration on the ground of *Atlas of hydrographical division of Poland* (*Atlas podziału...*, 2005ab), *Map of hydrographical division of Poland 1:50 000* (http://mapa.kzgw.gov.pl) and materials of Department of Cartography and GIS IGSO PAS.

Podziału…, 2007). Regarding the origins of the lake bowls several types of water bodies can be distinguished:

Finger lakes, having developed in the course of glacial erosion, that is – ploughing of the bedding by the mass of mobile ice and the activity of the sub-glacial waters under hydrostatic pressure. The bowls of these lakes are characterised by significant elongation and depth, steep shores, uneven shape of the surface of the bottom, and usually poorly developed shoreline. They appear in characteristic sequences with distinctly oriented pattern, forming frequently chains of many kilometres of length.

Bottom moraine lakes, having developed due to the melting of the dead ice blocks of various dimensions, are particularly numerous within the area of Olsztyn Lakeland. They are usually characterised by large area, diversified shoreline with a lot of bays, peninsulas and islands, low and mildly sloping shores, as well as uneven configuration of the bottom and differentiated depth.

Marginal lakes, which developed owing to the melting of the dead ice blocks, chaotic accumulation of the clastic material in the marginal zone, or through damming of the outflow of the pro-glacial waters by the walls of frontal moraines. These lakes feature relatively well developed shoreline, bowls having elongated shapes (with the longer axis parallel to the moraine walls), and asymmetric shores.

Outwash lakes are typical meltwater bodies, usually rather shallow and quite large. They may have arisen from a variety of processes, like when located within the gullies eroded in the fluvioglacial formations.

Pots, having arisen due to melting of blocks of dead ice of important thickness or the evorsion deepening of the bedding by the pro-glacial waters. They are characterised by small surface areas, significant depths, conical shape of the bowl, as well as oval shape of the little developed shoreline.

In-field ponds are small and shallow water bodies of circular shape, usually peaty or covered with boggy vegetation. They may be of glacial origin, or having arisen in the deflation lows, or be a consequence of human activity. They are frequently ephemeral reservoirs, with no outflow, in which water circulation takes place only through vertical exchange (precipitation, evaporation, downward penetration).

Finally, it is worth mentioning that despite the limited – namely primarily to the northern part of the study area – surface retention capacity[7], the total retention capacity of the area considered is relatively high. This is, namely, due to the significant transitory retention (retaining of water in swamps and peat bogs) and the underground retention (advantageous conditions for infiltration on the drainless-absorbing areas, built of well permeable sandy formations). The sandy sediments of the outwashes and the sandy-gravel intermoraine sediments constitute one of the richest aquifers in Poland. At the same time, though, the number and the capacity of sources (taking mainly the form of gravitational discharges and leaks) are very low, this being linked primarily with very limited altitude

[7] The retention indicator of the partial watersheds in the study area, within which the lakes are located having the area exceeding 10 hectares, ranges from 274 mm (upper Szkwa) to 970 mm (upper Czarna Rzeka). For comparison – the average retention capacity of the Masurian Lakeland is 283 mm, of all the lake districts – 162 mm, and of the country as a whole – 60 mm (Choiński, 2007; Jańczak, 1999).

differences of the terrain. These features, along with the slow and little intensive surface runoff, significant domination of the underground supply over the surface supply, low amplitudes of flows and rare swellings, are equivalent to the comprehensively assessed water circulation types: very slow in the northern part of the study area, and transitory to differentiated type in the middle and southern parts (Dynowska & Pociask-Karteczka, 1999).

1.6. Selected elements of climate

The region of north-eastern Poland is characterised by the climate that is commonly referred to as "severe" and can be, with this respect, compared to the mountain areas (Hutorowicz et al., 1996). It is not our purpose here, though, to analyse in detail the values, spatial distribution and course in time of the particular meteorological elements, as these questions are the subject of numerous studies (e.g. Kożuchowski, 2011; Woś, 1999 – and the references therein). We shall, on the other hand, basing on selected thermal and humidity characteristics, as well as two examples of the comprehensive regionalisation approaches, consider the question whether one can speak of differentiation of climate between the Masurian and Kurpie parts of the study area.

Definitely, the different character of climatic conditions in the central- and north-eastern Poland is visible on the scale of the macroregions, and so even more at the level of the higher rank physical-geographical units. This is associated, first of all, with the general atmospheric circulation, expressed through air pressure patterns, atmospheric fronts and air masses. Geographical location determines the fact of interaction over this area of the two dominating air masses, having different thermal and humidity properties: the humid one from above the North Atlantic (mainly of polar-oceanic origin) and the relatively dry one from above Eastern Europe and Asia (polar-continental). Existence of the visible climatic differences on the macroregional scale is also facilitated by the significant parallel and meridional extent of the Masurian Lakeland and the Northern Masovian Lowland. On the other hand, differentiation of climate over smaller areas depends first of all on the uneven course of the process of exchange of energy between the atmosphere and the active surface, that is – the bedding. Thus, actually, it is the state of the atmosphere (especially its clarity) and the physical features of the terrain that determine to a high extent climatic differences between the individual mesoregions (Stopa-Boryczka & Boryczka, 2005).

The values of annual amplitudes of air temperature and of the indicator of thermal continentalism (Ewert, 1972) demonstrate a weakly continental character of climate over the entire study area (Table 1.1). The value of the indicator quoted for the weather station in Olsztyn (46.6%) is equal to the Polish average for the period 1881-1980 (Kożuchowski, 2011). The values of both characteristics, referred to, perceptibly increase in the southern direction, thus being the evidence for the influence of the azonal factors of climate, and especially the increasing domination of the polar-continental air masses over the polar-oceanic ones[8] (Table 1.1). Regarding the thermal aspect, the northern part of the study

[8] It should be noted that the share of the moist maritime air is limited. A vast majority is constituted by the already transformed masses, which, during movement and staying over the Euro-

area, represented by the weather station in Szczytno, is somewhat cooler. This is not only indicated by the values of the annual and monthly averages of air temperature (see Matuszkiewicz et al., 2013), but also by the number of days, characterised by the definite daily temperatures – averages, maxima and minima. The biggest differences between the Masurian Plain (Szczytno) and the four neighbouring mesoregions of the Masurian Lakeland (Olsztyn, Mikołajki) and the Northern Masovian Lowland (Mława, Ostrołęka), concern the higher number of days of ground frost and the shorter period between the last spring frost and the first autumn frost. In Szczytno the period without ground frost is approximately one month shorter than at the neighbouring weather stations. These characteristics are of high importance for agriculture and for vegetation development.

Table 1.1. Selected thermal characteristics from neighbouring weather stations

Name of the station	Olsztyn	Mikołajki	Szczytno	Mława	Ostrołęka
Latitude	53.46°N	53.47°N	53.34°N	53.07°N	53.05°N
Longitude	20.25°E	21.35°E	21.02°E	20.22°E	21.34°E
Average annual of air temperature [°C]	6.7	6.7	6.5	6.9	7.1
Average annual amplitude of air temperature [°C]	21.1	21.9	22.0	22.0	22.3
Number of days with ground frost with Tmin < 0°C	134	127	144	136	128
Number of frosty days with Tmax < 0°C	50	55	54	50	49
Number of days with Tmin < -10°C	27	28	33	28	27
Number of days without ground frost	149	178	125	154	155
Number of days with Tav. > 5°C (growing season)	204	204	202	204	206
Number of days with Tav. > 10°C	150	151	149	152	155
Number of days with Tav. > 15°C (thermal summer)	87	90	88	95	99
Number of hot days with Tmax > 25°C	25	21	28	33	36
Indicator of thermal continentalism (Ewert)	46.6	48.7	49.1	49.4	50.2

Source: Chomicz (1977) – periods 1951-1965 and 1951-1970; Zieliński (1986) – period 1931-1960.

Regarding humidity conditions the average annual precipitation is higher within the Masurian Plain than in the southern part of the study area, although some authors provide a bit lower values for the south-western fringe of the Masurian Lakeland than those given in Table 1.2 (550-600 mm and less), that is – such that characterise the northern edge of the Northern Masovian Lowland (Hutorowicz et al., 1996).

The distribution of average monthly precipitation in the average annual total shows a continental character of the temporal profile (maximum in summer and minimum in winter). This profile, though, is disturbed, similarly, as in many other locations in Poland, by the influence of the oceanic precipitation pattern (domination of autumn precipitation over spring precipitation), which produces, in effect, a mixed, continental-maritime character of the annual precipitation rhythm.

pean continent, lose their original thermal and humidity properties, and become similar to the masses of continental air.

Table 1.2. Selected humidity characteristics from weather and precipitation stations on the study area (*) and from neighbouring ones

Name of the station	Mesoregion	Location		Average annual of precipitation [mm]				
				year	winter	spring	summer	autumn
Olsztyn	Olsztyn Lakeland	53.46°N	20.25°E	620	107	122	235	156
Biskupiec		53.52°N	20.57°E	624	115	120	233	156
Olsztynek		53.35°N	20.17°E	607	115	121	227	144
Barczewo		53.51°N	20.42°E	592	96	114	236	146
Nawiady	Mrągowo Lakeland	53.43°N	21.20°E	590	103	119	224	144
Mikołajki	Great Masurian Lakes	53.47°N	21.35°E	565	87	116	222	140
Pisz	Masurian Plain	53.38°N	21.48°E	610	101	120	241	148
Szczytno*		53.34°N	21.02°E	610	115	122	234	139
Average				602	105	119	232	147
Mława	Mława Hills	53.07°N	20.22°E	576	118	111	217	130
Krzynowłoga Mł.		53.09°N	20.48°E	556	105	116	212	123
Dobry Las*	Kurpie Plain	53.17°N	21.52°E	551	99	111	211	130
Cierpięta*		53.11°N	21.09°E	571	115	121	205	130
Chorzele*		53.15°N	20.54°E	523	95	108	205	115
Wach*		53.18°N	21.23°E	578	110	117	217	134
Krasnosielc	Ciechanów High Plain	53.02°N	21.10°E	489	90	108	176	115
Przasnysz		53.01°N	20.53°E	459	88	96	168	107
Ostrołęka	Łomża Interfluve	53.05°N	21.34°E	555	109	119	197	130
Average				540	103	112	201	124
Average in Poland				616	108	134	236	140

Source: Chomicz (1977) – periods 1951-1965 and 1951-1970; Zieliński (1986) – period 1931-1960; Kozyra (2006).

The volume and asymmetry of the annual distribution of precipitation (that is – the so-called pluvial continentalism) of the study area constitutes, on the other hand, an example of the precipitation field of central- and north-eastern Poland, without distinct anomalies. This is expressed both through higher annual averages of precipitation, and in somewhat more pronounced domination of the autumn rains over the spring rains in the Masurian part than in the Kurpie part. Formerly, this fact was usually explained by the terrain properties of the Masurian Lakeland (late glacial hills are conducive to the occurrence of the relatively abundant precipitation originating from the maritime air masses, flowing in from the north-western direction) and the resulting presence of the "precipitation shade" in the plains. This hypothesis, though, has been recently increasingly frequently criticised, and the causes for the differentiation of the annual average precipitation are sought, instead, in the disturbances in the dynamics of the atmosphere and the action of the bedding, influencing the air movement in the friction layer. These observations are supported by the fact that the line separating the late glacial mounds from the early glacial plains is also the line of a distinct change in the dominating directions of the so-called lower winds – from the south-western (lake districts) towards western (lowlands), see Kożuchowski (2011).

Climate differentiation, however, ought to not only account for the analysis of its individual characteristics, but also for the more synthetic perspectives, which are reflected through climatic regionalisation attempts (see Paszyński & Niedźwiedź, 1999, pp. 339-343; Woś, 1999, pp. 179-183). We mention here two approaches, which – by virtue of assumptions – correspond in the highest degree to the subject matter of the studies here reported.

The first of those is the regionalisation performed for the purposes of agriculture, in which the main factors are considered of development of vegetation (warmth, light, water) and some 20 phenological indicators (Gumiński, 1998). The study area belongs to two of 21 distinguished agricultural-climatic domains: Masurian (the coldest one in Poland, except for the mountain areas) and the central one (the driest in Poland). It should be noted, though, that despite those regional "records" in terms of temperature and precipitation, the area in question is situated in the relatively warmest (south-western) part of the "cold" Masurian quarter, and in the most humid part of the "dry" central quarter, this fact significantly evening out the potential differences between the mesoregions involved.

Woś (1999) proposed a different approach to regionalisation, according to which an important source of information on the features of climate of a given area – especially in the context of vegetation development, animal life and human activity – is constituted by the observed states of weather and their repetitiveness as well as frequency. In the division, proposed by Woś, the study area belongs to two regions: the western Masurian one (forest district of Jedwabno and western parts of the forest districts of Szczytno and Wielbark), and the central Masurian (remaining part of the area). The meridionally oriented boundary between these two parts, though, is fuzzily defined, while the variability of frequencies of appearance of weather types is small or very small.

1.7. Nature conservation forms

The final element of characterisation of the study area, which, in a sense, puts together the here outlined components of the natural environment, is constituted by the nature conservation forms. Here we focus on the categories of areas and objects that are accounted for in the Nature Conservation Act. Thus, the description below is a shorthand formal characterisation of the current state of the matter. We make use first of all of the source legal acts and the registers, maintained by the Regional Directorates for Environmental Protection in Warsaw (http://warszawa.rdos.gov.pl) and in Olsztyn (https://www.gov.pl/web/rdos-olsztyn). Important information was also acquired from the geoportals, basing on the WMS (Web Map Service), as provided by the General Directorate for Environmental Protection (http://geoserwis.gdos.gov.pl/mapy), and in the framework of the Regional System of Provision of Spatial Information on State Forests in Olsztyn.

1.7.1. Nature conservation forms in the light of the Nature Conservation Act

In Poland there are nine categories of the areas and objects included in the system of legal protection conform to the Nature Conservation Act: national parks, nature reserves, landscape parks, protected landscape area, Natura 2000 sites, nature monuments, documentation sites, ecological areas, natural and scenic complexes – Figs. 1.5, 1.6; Table 1.3.

There are no **national parks** and no **landscape parks** within the study area. Only the forest district of Spychowo borders on the north-east with the Masurian Landscape Park and its protection zone.

Concerning **nature reserves**, there are ten such areas on the territory considered: eight biocoenosis reserves, including five forest areas (Dęby Napiwodzkie, Pupy, Surowe, Czarnia, Podgórze) and three peat-bog areas (Galwica, Torfowisko Karaska, Torfowisko Serafin), one landscape reserve (Lake Kośno), and one animal (bird) reserve (Małga), where crane staying places are protected, as well as tooting, feeding and nesting grounds of several other rare bird species (Fig. 1.6). In the forest reserves protection is extended over the vegetation communities of dry ground deciduous forests, alder floodplain woods and mixed pine forests (Dęby Napiwodzkie), of the old-age mixed forests with the shares of spruce, Scots pine and oak, as well as beech – outside of its natural range (Pupy), and, besides, the fragments of forest of natural origin: the spruce-and-pine forest being the remnant of the ancient Myszyniec Forest (Surowe), fresh pine forest characteristic for the ancient Kurpie Forest (Czarnia), and the spruce-and-pine woods (Podgórze).

There are two **protected landscape areas (PLA)** within the study area. The Napiwodzko-Ramucka Forest PLA occupies the entire forest district of Jedwabno and the western parts of the forest districts of Szczytno and Wielbark, while the area of Spychowo PLA – a narrow belt in the northern part of the forest district of Spychowo. Besides, the areas of Olsztyn Lakeland PLA and of Masurian Landscape Park Ruciane-Nida PLA touch upon the northern boundary of the study area, while its eastern boundary runs over a longer segment along the border of the Kurpie Plain and Lower Narew River Valley PLA.

A significant part of the Masuria-Kurpie borderland is included in the **Natura 2000** program, founded upon two EU directives, transposed in 2004 to the national legal system, these two directives being commonly referred to as the Bird directive (Dz. Urz.[9] WE L 103/1 of 25.04.1979, p. 98; currently in force – Dz. Urz. WE L 20 of 26.01.2010, p. 7) and the Habitat directive (Dz. Urz. WE L 206 of 22.07.1992, p. 7). Integral parts of these directives are constituted by the attachments, containing the periodically updated and confirmed lists of species of plants and animals, as well as natural habitats, of high value and endangered on the European scale, and those that are characteristic for the main European bio-geographical regions (see Dz.U. 2014 item 1713).

On the basis of the Bird directive, three Special Protection Areas[10] have been established within the territory considered, namely Napiwodzko-Ramucka Forest (PLB280007), Pisz Forest (PLB280008), and Omulew and Płodownica Valley (PLB140005), see Rąkowski et al. (2010). The reference material was constituted by the bird refuges of international

[9] Dz. Urz. and Dz.U. are the Polish abbreviations for the Journal of Laws and shall be used in this form also later on in the text.

[10] The Special Protection Area (SPA), meant for protection of birds, is the area determined for the protection of populations of birds living in the wild, of one or more species, within which birds have advantageous conditions for existence during entire life, during its definite periods or stages of development.

Table 1.3. List of areas and objects that are accounted for in the law on nature protection

Name	Area [ha]	Date of initiation	Forest district	District	Commune	Initiation act of law**	Actualizing act of law**
Protected Landscape Area							
Napiwodzko-Ramucka Forest PLA*	131,278.3	2003	Jedwabno, Szczytno, Wielbark	(1) Olsztyn, (2) Nidzica, (3) Szczytno	(1) Purda, Olsztynek, (2) Nidzica, Janowo, (3) Jedwabno, Szczytno, Wielbark	Dz. Urz. Woj. Warm.-Maz. 2003 no. 52 item 725	Dz. Urz. Woj. Warm.-Maz. 2017 item 4143
Spychowo PLA*	12,188.9	2003	Spychowo	Szczytno	Świętajno	as above	Dz. Urz. Woj. Warm.-Maz. 2018 item 1322
Natura 2000 – Special Protection Areas							
Napiwodzko-Ramucka Forest*	116,604.6	2004	Jedwabno, Szczytno, Wielbark	(1) Olsztyn, (2) Nidzica, (3) Szczytno	(1) Olsztynek, Purda, (2) Janowo, Nidzica, (3) Jedwabno, Pasym, Szczytno, Wielbark	Dz.U. 2004 no. 229 item 2313	Dz.U. 2011 no. 25 item 133
Pisz Forest*	172,802.1	2004	Spychowo, Szczytno	Szczytno	Świętajno, Rozogi, Szczytno	as above	as above
Omulew and Płodownica Valley*	34,386.7	2004	Myszyniec, Parciaki	(1) Szczytno, (2) Przasnysz, (3) Ostrołęka	(1) Wielbark, (2) Chorzele, Jednorożec, (3) Baranowo, Czarnia, Kadzidło	as above	as above
Natura 2000 – Sites of Community Importance							
Napiwodzko-Ramucka Refuge*	32,612.8	2011	Jedwabno, Szczytno, Wielbark	(1) Olsztyn, (2) Nidzica, (3) Szczytno	(1) Olsztynek, Purda, (2) Janowo, Nidzica, (3) Jedwabno, Pasym, Szczytno, Wielbark	Dz. Urz. UE L 33 of 8.02.2011, p. 146	Dz. Urz. UE L 28 of 31.01.2020, p. 144
Pisz Refuge*	57,826.6	2011	Spychowo	Szczytno	Świętajno, Rozogi	as above	as above
Myszyniec pasque flower forests	1,937.0	2011	Myszyniec	Ostrołęka	Łyse	as above	as above
Swampy forests and peat bogs Karaska	558.8	2011	Myszyniec	Ostrołęka	Kadzidło	as above	as above
Cup moss forests Karaska	1,124.5	2011	Myszyniec	Ostrołęka	Kadzidło, Myszyniec	as above	as above
Western Kurpie pasque flower forests	2,214.1	2011	Parciaki	Przasnysz	Jednorożec	as above	as above
Nature reserves							
Lake Kośno*	1,253.8	1982	Jedwabno	Olsztyn	Purda	M.P. 1982 no. 25 item 234	Dz. Urz. Woj. Warm.-Maz. 2017 item 3435
Dęby Napiwodzkie	36.9	1989	Jedwabno	Szczytno	Jedwabno	M.P. 1989 no. 17 item 120	Dz. Urz. Woj. Warm.-Maz. 2017 item 3436
Małga	163.9	1991	Jedwabno	Szczytno	Jedwabno	M.P. 1991 no. 38 item 273	Dz. Urz. Woj. Warm.-Maz. 2017 item 3449
Galwica	94.6	1958	Szczytno	Szczytno	Jedwabno	M.P. 1958 no. 14 item 89	Dz. Urz. Woj. Warm.-Maz. 2017 item 3433
Pupy	57.2	1995	Spychowo	Szczytno	Świętajno	M.P. 1995 no. 6 item 93	Dz. Urz. Woj. Warm.-Maz. 2020 item 1865
Surowe	4.6	1964	Myszyniec	Ostrołęka	Czarnia	M.P. 1964 no. 65 item 304	Dz. Urz. Woj. Maz. 2001 no. 269 item 6860
Podgórze	37.8	1987	Myszyniec	Ostrołęka	Podgórze	M.P. 1987 no. 7 item 55	as above
Serafin peat-bog	184.9	1998	Myszyniec	Ostrołęka	Łyse	Dz.U. 1998 no. 161 item 1101	as above
Czarnia	141.9	1964	Myszyniec	Ostrołęka	Czarnia, Myszyniec	M.P. 1964 no. 64 item 299	Dz. Urz. Woj. Maz. 2014 item 11874
Karaska peat-bog	402.7	2000	Myszyniec	Ostrołęka	Podgórze	Dz. Urz. Woj. Maz. 2000 no. 144 item 1353	Dz. Urz. Woj. Maz. 2018 item 5432
Natural and scenic complexes							
Zyzdrój*	1,335.0	2000	Spychowo	Szczytno	Świętajno	Dz. Urz. Woj. Warm.-Maz. 2000 no. 2 item 19	Dz. Urz. Woj. Warm.-Maz. 2007 no. 122 item 1698
Babant River with Białe Lake*	12,458.0	2000	Spychowo	Szczytno	Świętajno	Dz. Urz. Woj. Warm.-Maz. 2000 no. 2 item 20	Dz. Urz. Woj. Warm.-Maz. 2011 no. 110 item 1822
Ecological areas							
Tylkowo Pond Area*	194.0	1994	Jedwabno	Szczytno	Pasym	Dz. Urz. Woj. Olszt. 1994 no. 7 item 74	Dz. Urz. Woj. Warm.-Maz. 2009 no. 105 item 1725
Żabieniec	2.5	1998	Szczytno	Szczytno	Jedwabno	Dz. Urz. Woj. Olszt. 1998 no. 13 item 187	Dz. Urz. Woj. Warm.-Maz. 2009 no. 105 item 1704
Złotko	4.9	1998	Szczytno	Szczytno	Jedwabno	as above	Dz. Urz. Woj. Warm.-Maz. 2009 no. 105 item 1693
Zamulewo	5.3	1998	Szczytno	Szczytno	Jedwabno	as above	Dz. Urz. Woj. Warm.-Maz. 2009 no. 105 item 1680
Okonek	4.8	1998	Szczytno	Szczytno	Jedwabno	as above	Dz. Urz. Woj. Warm.-Maz. 2009 no. 105 item 1705
Grzybiczne	2.4	1998	Szczytno	Szczytno	Jedwabno	as above	Dz. Urz. Woj. Warm.-Maz. 2009 no. 105 item 1703
Biele	26.6	2009	Spychowo	Szczytno	Świętajno	Dz. Urz. Woj. Olszt. 1992 no. 7 item 66	Dz. Urz. Woj. Warm.-Maz. 2015 item 2376
Kosaciec	0.2	2009	Spychowo	Szczytno	Świętajno	as above	Dz. Urz. Woj. Warm.-Maz. 2009 no. 105 item 1708
Torfianka	1.0	2008	Parciaki	Przasnysz	Jednorożec	Resolution no. XIX/89/2008	Dz. Urz. Woj. Maz. 2009 no. 113 item 3242

* Areas only partly hugged the borders of the study area.

** All titles and abbreviations for the Journal of Laws are in Polish.

Source: own elaboration on the ground of Nature Protection Programs (BULiGL O/Olsztyn, 2011, 2012, 2013ab, 2015, 2016) and materials of Regional Directorates for Environmental Protection in Warsaw (http://warszawa.rdos.gov.pl) and Olsztyn (https://www.gov.pl/web/rdos-olsztyn). Information update – September 2020.

rank (the so-called Important Bird Areas): PL038 Napiwodzko-Ramucka Forest, PL039 Pisz Forest, and PL053 Omulew and Płodownica Valley (Wilk et al., 2010; see also Gromadzki et al., 1994; Jujka & Wilk, 2012; Sidło et al., 2004).

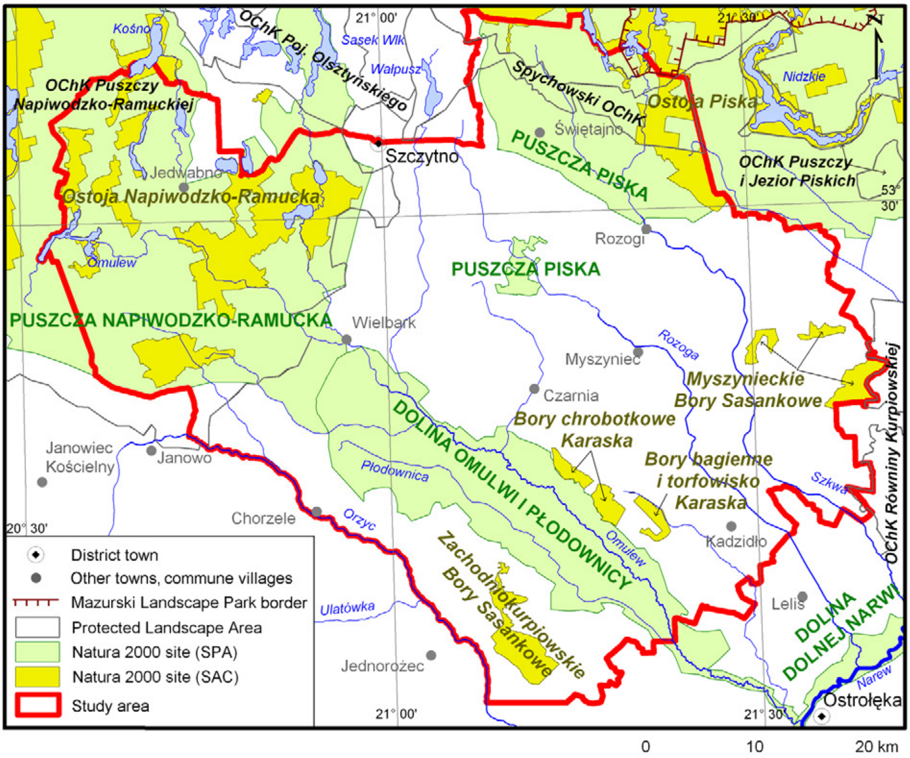


Fig. 1.5. Nature conservation forms that are accounted for in the law on nature protection

Source: own elaboration based on data of Regional Directorates for Environmental Protection in Warsaw and Olsztyn and Regional System of Provision of Spatial Information on State Forests in Olsztyn. Information update – September 2020.

Besides, based on the Habitat directive, six Sites of Community Importance[11] have been established within the study area. These sites are: Napiwodzko-Ramucka Refuge (PLH280052; 9 enclaves), Pisz Refuge (PLH280048; 6 enclaves), Swampy forests and peat bogs Karaska (PLH140046), Cup moss forests Karaska (PLH140047; 2 enclaves), Myszyniec pasque flower forests (PLH140049; 3 enclaves), and Western Kurpie pasque flower forests (PLH140052). The first two are the extensive areas featuring very high biodiversity, while the subsequent ones grant protection to, respectively: one of the biggest Polish high peat bogs with swampy forests of different degrees of development, vast phytocoenoses

[11] Site of Community Importance (SCI) is the designed Special Area of Conservation, called Habitat refuges, defined by the European Commission through a decision, but without the corresponding act of the national law.

of the dry cup moss pine forests *Cladonio-Pinetum* and the cup moss variants of the fresh pine forests *Peucedano-Pinetum*, as well as the sites of the Eastern pasque flower *Pulsatilla patens*. Detailed characterisation of the individual areas of the European Ecological Network Natura 2000 is provided in the publicly accessible documentation (http://natura2000.gdos.gov.pl/datafiles), composed of the Standard Data Forms (SDF) and the topographical maps.

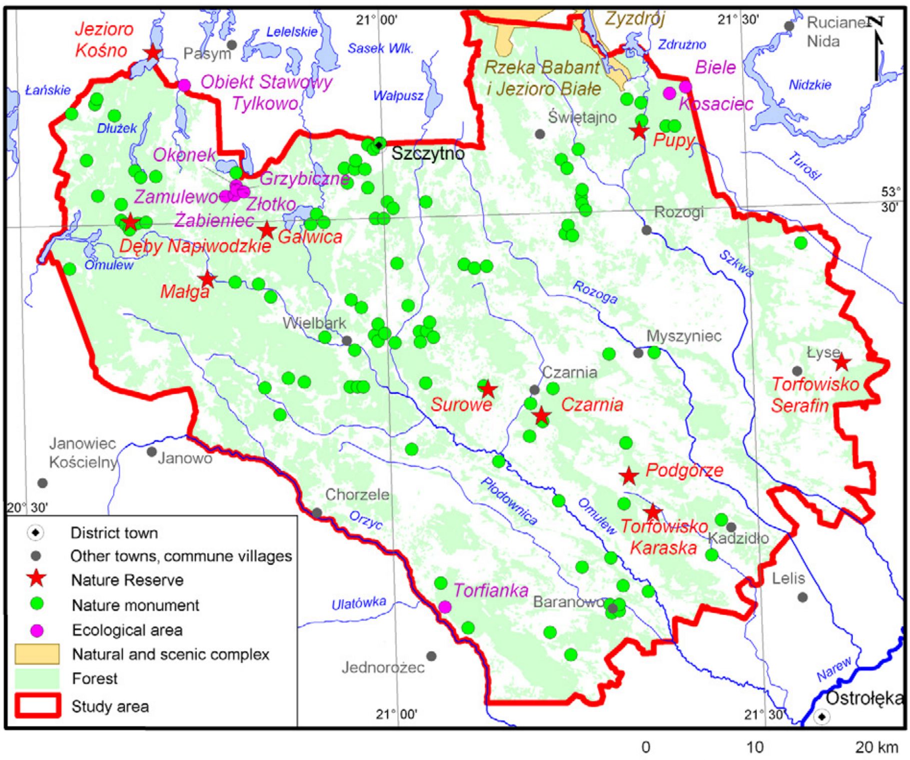


Fig. 1.6. Nature reserves and individual forms of nature protection on the study area

Source: own elaboration based on data of Regional Directorates for Environmental Protection in Warsaw and Olsztyn and Regional System of Provision of Spatial Information on State Forests in Olsztyn. Information update – September 2020 (except nature monuments – October 2012).

The most numerous objects included in the system of legal protection conform to the Nature Conservation Act on the area considered, are the living **nature monuments** (Fig. 1.6), of which there are ca. 150 (mainly single trees, but also groups and alleys). In the forest districts in question this category was assigned first of all to the pedunculate oaks, less frequently to lime trees, pines and junipers, and only sporadically to larches, elms, maples, spruces and hemlocks.

Quite numerous on the study area are also the **ecological areas**. The biggest of them – Tylkowo Pond Area is a refuge of the aquatic and wetland birds. Besides, protection has been extended over the small, distrophic and mesotrophic lakes located in the midst of forests (Żabieniec, Złotko, Zamulewo, Okonek, Grzybiczne), the sites of Siberian flag, rough cinquefoil, and southern adderstongue (Biele, Kosaciec), as well as over peat bogs (Torfianka).

The study area encompasses also the fragments of the **natural and scenic complexes** – Zyzdrój and Babant River with Białe Lake.

1.7.2. Other initiatives to nature conservation

Among other forms of nature protection, existing on the area considered, one should mention the **Forest Promotion Complex "Masurian Forests"** (118,216 hectares, including the entire forest district of Spychowo), established in 2002 for purposes of persistent preservation or re-establishment of the natural qualities of forests through application of the methods of sustainable forest management, carried out on ecological foundations, as well as integration of forest economy, active nature protection and forest education.

It is also worth mentioning that the Regional Directorate of State Forests in Olsztyn up to 2023 has the certificate of the **Forest Stewardship Council**, the international organisation promoting responsible management of forest resources of the world. This means that forests in all the forest districts here considered ought to be managed in accordance with the international standards of nature protection and care for the social values of the local population, with simultaneous preservation of the equilibrium between the business principles of conduct of forest economy and maintenance of forest ecosystems (*Zasady…*, 2010). This system of certification of forest economy, developing the fastest in the world, obliges also the forest managing bodies to identify and delimit the forests having particular natural qualities (HCVF – High Conservation Value Forests), this distinction to be carried out conform to the adopted criteria (*Kryteria…*, 2006). In the here considered forest districts the stands exist classified into five main categories, with a part of them being complementary with respect to the character and tasks of the protection forests, as defined in the Polish law (Dz.U. 1992 no. 67 item 337; Dz.U. 2017 item 1161; Dz.U. 2020 item 1463):

- HCVF 1 – Globally, regionally or nationally significant concentrations of biodiversity values, including: HCVF 1.1 – protected areas, HCVF 1.2 – refuges of the species threatened and in extinction;
- HCVF 2 – Globally, regionally or nationally significant large landscape-level forests;
- HCVF 3. Forest areas that are in or contain rare, threatened or endangered ecosystems, including: HCVF 3.1. Extremely rare and endangered ecosystems, HCVF 3.2. Rare and endangered ecosystems in Europe, but in Poland more common and large-scale;
- HCVF 4 – Forest areas that provide basic services of nature in critical situations, including: HCVF 4.1 – water protecting forests, HCVF 4.2 – soil protecting forests;
- HCVF 6 – Forest areas critical to local communities' traditional cultural identity.

In the Nature Protection Programs, constituting obligatory elements of the plans of forest management of the particular forest districts, the lists are also provided of the valuable objects of nature (which are not subject to any form of protection), the most important objects of material culture, as well as old cemeteries and archaeological plots (BULiGL O/Olsztyn, 2011, 2012, 2013ab, 2015, 2016).

Another international initiative, basing to a significant degree on the CORINE-biotopes refuges, was the **European Ecological Network, EECONET**, established initially in 1993, and then implemented as **PEEN, the Pan-European Ecological Network**. This network was a large-scale system, composed of the node areas, linked through the ecological corridors of the national and international rank. The primary objectives were to serve the purpose of shaping the coherent and spatially continuous structure of the network of areas the least transformed in terms of nature, to ensure better protection of species and habitats in Europe, threatened with extinction, and to establish the areas constituting migration routes of animals (Liro et al., 1995).

Quite soon afterwards, in the framework of the European Program of the International Union of Conservation of Nature and its Resources (IUCN), the concept was elaborated of the **National Ecological Network – ECONET-PL** (Liro, 1998). This activity was caused largely by the acceptance of stipulations of the Pan-European strategy of protection of biological and landscape diversity, announced in 1994, and ratification in the subsequent two years of the Bern Convention and the Biodiversity Convention. Conform to the initial concept almost whole study area would be contained within the confines of three nodal areas of the international rank: the Western Masurian Area (13M), the Pisz Forest Area (14M) and the Kurpie Forest Area (22M). In light of the foregoing it is surprising that both the base CORINE-biotopes and networks ECONET-PL/PEEN for years in Poland have not been developed. Anyway, one should be aware of their existence, mainly due to the developed over the years precise assumptions in the form of uniform criteria and standards, which can now form the basis of valuable initiatives of a local nature.

1.8. The most important features differentiating the northern and southern parts of the area

Summing up, it can be stated that within the confines of the study area the northern part of the Masurian Plain, with relatively well preserved marginal forms of the main stage of the Vistulian Glaciation and numerous post-glacial lakes, represents the late post-glacial relief in the strict sense, associated with the morpho-lithological specificity of the landscapes of Olsztyn and Mrągowo Lakelands. The southern part of the Masurian Plain, occupied by the Masuria-Kurpie outwash formation, constitutes a broad transitory zone, without a distinct boundary that would separate it from the Kurpie Plain. The latter represents already a typical, early post-glacial, flat outwash landscape, characterised by the existence of wide valleys, vast wet and peaty areas, numerous inland dunes, as well as dispersed, single marginal forms, having the character of the denudated erosion remnants.

The above features brought the development of definite types of spatial structure of the soil cover (soil associations), whose particular components (elementary soil areas) are linked with the topography and lithology of the terrain (Prusinkiewicz & Bednarek, 1999). Thus, one can distinguish within the study area, in particular, the "chaotic multicomponent" type (frontal moraine landscape), "ring-and-zone" type (lake district landscape with meltwater bodies), "irregular spotty" type with a share of "belt-like ordered" structures (the landscape of the flat and undulating sandy plains), or the "network-linear" variety (the landscape of the inland dunes).

The morphogenesis determines also the pattern and the differentiation of the river network on the Masurian and Kurpie Plains. Almost all of the wide and shallow outwash valleys, along which nowadays the right-hand tributaries of Narew flow, have the orientation from the north-west towards the south-east, featuring strongly boggy bottoms, occupied now by the peat bogs and wet flooded meadows. In opposition to those, there are the narrow and deep valleys of the rivers in the northern part of the study area and in the adjacent areas, namely in the central and northern parts of the Masurian Lakeland (this applying, in particular, to Pasłęka, Łyna, Guber, and Węgorapa rivers, as well as their tributaries). The natural zones of water outflow on the late glacial areas were constituted, namely, by the glacial gullies, which were linked among themselves with short gorges to form a joint system of valleys. In this context it should be noted that the pattern that emerged in this manner does not have the dendrite character, typical for the river networks, since the sub-glacial gullies do not constitute a hierarchical system.

Masurian Plain appears to be an area that is perceptibly cooler than the remaining, adjacent areas – both those within the Masurian Lakeland and within the Northern Masovian Lowland. Most probably, the sharper thermal regime of this area is associated with the island-like "thermal anomalies". According to Gumiński (1998) one of such "islands of cold" is situated exactly in the southern and south-eastern part of the Masurian Lakeland. Lack of detailed measurement data allows only for the supposition that the Kurpie Plain is also, although to a lesser degree, characterised by the anomalies mentioned, and so features more severe climate. This phenomenon can be perceived especially in winter, since a significant surface share of the boggy soils, with low thermal conductivity, seriously increases the hazard of ground frost.

Concerning the humidity conditions, higher annual averages of precipitation are registered within the Masurian Plain than in the southern part of the study area. In general, though, the distribution of the precipitation field is conform to the gradient for the entire central- and north-eastern Poland – in the northern part of the Masurian Lakeland precipitation exceeds, 700 mm (the Land of Węgorapa river), while in the south-western part of the Northern Masovian Lowland it drops to 500 mm (the Upland of Płońsk).

It should be noted, though, that the actual differentiation of the thermal and precipitation conditions might be somewhat smaller. This could result from the relatively limited extent, both meridionally and parallelly, of the area in question, from the fact that the majority of respective weather stations are located outside of the area, and from the presence of numerous features, distinguishing the Masurian Plain from the north-eastern mesoregions of the Masurian Lakeland. It is, therefore, hard to unambiguously determine, to what extent the differentiation of the here described meteorological elements on the mesoregional scale could influence the development of forest vegetation of the Masurian and Kurpie parts of the study area.

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2. PRUSSIAN, RUSSIAN AND POLISH CARTOGRAPHY OF THE BORDERLAND OF MASURIA AND KURPIE

Jacek Wolski

2.1. Introduction

The environmental and historical studies of changes in forestation within the Masuria-Kurpie borderland during the last 200 years were based on highly differentiated cartographic materials. This fact resulted from the purposes of the study, defining the range, spatial and temporal scale, and consequently – the nature of the needed spatial data. The differentiation mentioned was the source of a serious dilemma: how to choose maps that would be characterised by the sufficient similarity of properties so as to ensure that the set of these maps constitute possibly homogeneous cartographic information on the course of changes of forest cover over time?

The biggest problem was constituted by the concrete location of the study area. The borderland position caused that maps from the first half of the 20th century, and yet the earlier ones, differed as to almost every aspect – starting from the astronomical and triangulation foundations, through the mathematical construction elements, and ending with the most visible effects of the topographical and cartographic elaborates, executed on the basis of various instructions and source materials. In the case of maps from the 19th century one should add to this the relatively much bigger inaccuracy, associated with the state of knowledge at that time, the precision of instruments, methods and ways of measuring, as well as actually set requirements as to the degree of accuracy.

One should yet add to the differentiation mentioned above all kinds of errors, which are an inherent characteristic of all the secondary materials. In the anticipation of further considerations, given the use of a series of paper-based maps, we should mention, in particular, errors in location of control points, inhomogeneous selection of signs, inaccuracy of the drawing of situations and grids (with the particular case of purposeful falsification of map content), and, finally, low quality of the very printing. It ought to also be noted that this range of errors and imprecision is differentiated not only between the map series, but also often between consecutive editions or yet individual sheets forming the map series.

The focus of the present chapter is on the criteria of selection and assessment of utility of the cartographic source material, but, first of all, on characterisation of these map series, which constituted the foundations of the model developed of the changes in forest cover, or which constituted the complementary material. The scheme of procedure and the successive stages of development of the very model are described, on the other hand, in the Chapter 3.

2.2. Assessment of utility of the source materials

The initially performed analysis of needs, accounting for the scopes of the subject matter, space and time, demonstrated that there is no possibility of putting together such a homogeneous collection of maps that would fulfil the condition of comparability of scales[1]. Hence, it was assumed, after the verification of the existing cartographic sources, that materials from two scale series would be of use: from 1:25 000 to 1:100 000 (20th century) and from 1:50 000 to 1:200 000 (19th century).

In the first stage almost all of the medium-scale topographic maps, encompassing the study area, either in whole or at least on one side of the border (19th century), were collected. The subsequent step was the assessment of utility of the material acquired for further study. Conform to the Polish standard PN-87/N-02260 ("Cartography. Elaboration of maps. Nomenclature") these characteristics of maps were accounted for, which are telling for their quality: accuracy (average error of the location of points on the map), cartometric conformity (concordance of distances, angles and areas with their actual values, after the properties of projection and nonlinear paper shrinking have been taken into consideration), faithfulness (concordance of the content of the map with the actual state, with consideration of generalisation), completeness of content (the set of objects and phenomena, which ought to be represented on the map in view of its purpose and generalisation of content), legibility (capacity of fast perception of content in agreement with the purpose of the map), and the time stamp (possibility of precise dating of information provided on the map) (Jankowska & Lisiewicz, 1998; Kistowski & Iwańska, 1997; Saliszczew, 1984). This set of qualities was yet complemented with one more feature, i.e. originality of the source material. This was a very important criterion for the assessment of Polish maps of the inter-war period, since some of them were reprinted from the maps elaborated by the partitioning administrations before World War I, or were copies in terms of content, with changes concerning only legends, names or design of sheets.

The assessment of utility according to the above criteria was done primarily in the indirect manner and was based on the detailed study of respective literature. During the last several decades, namely, all of the pre-war materials were the object of interest of cartographers and historians of cartography, which resulted in monographs encompassing both maps themselves (mathematical foundations, course and accuracy of the topographical work, way of printing, scope of updating of the successive editions, etc.) and the times, in which they were elaborated, including, in particular, the purpose of the maps, as influencing their content (civilian, military, fiscal), variety of the systems of measurement, linguistic bases of onomastics, and so on. The post-war maps, except for the few rejected series with strongly falsified content, did not require such a detailed analysis of utility, as they fulfilled the quality criteria from the standpoint of objectives of the study. The main and sufficient source of information on these maps were respective technical

[1] This fact, expressed, in particular, through the influence of graphical and nominal generalisation on the number, shape, area, category, and sometimes even location of objects, was accounted for in the consecutive stages of development of the model of changes in forest cover (more on this subject in the Chapter 3).

instructions, as well as models and explanations of the signs used, published by the geodesic-cartographic services.

2.3. Selection and classification of the source materials

The maps collected were classified into two groups: the basic and the complementary materials. The criteria of this classification were the effect of the assessment of utility and the necessity of selecting the most representative time intervals in the context of the objectives of the study.

A. The basic materials – maps, constituting the information basis for the particular time slices, being the components of the model of changes in forest cover over the last 200 years (these maps were subject to calibration and vectorisation). It was decided that this group would consist, in the chronological sequence, of:
   - A1. *Topographisch-Militärische Karte vom vormaligen Neu Ostpreussen…* (1:100 000; the Textor map further on), the turn of 19th century,
   - A2. *Karte von Ost-Preussen nebst Preussisch Litthauen und West-Preussen…* (1:150 000; the Schrötter-Engelhardt map further on), the turn of 19th century,
   - A3. *Topographische Specialkarte des Preussischen Staats und der angrenzenden Länder* (1:200 000; the Reymann map further on), 1840s and 1850s,
   - A4. *Topographische Karte vom Preussischen Staate…* (1:100 000), 1860s,
   - A5. *Novaya Topograficheskaya Karta Zapadnoy Rossii* (1:84 000), 1880s,
   - A6. *Messtischblätter* (1:25 000), 1910-1940,
   - A7. topographic map "Borowa Góra" (1:100 000), 1950s,
   - A8. topographic map "1965" (1:50 000), 1970s,
   - A9. database VMap Level 2 (with resolution corresponding to the map of 1:50 000), 1990s.

B. The complementary materials – maps, constituting the source of information for verification (complementing, corrections), and not being the components of the model of changes in forest cover (they were subject only to the procedure of calibration). It was decided to include in this group, in the chronological sequence:
   - B1. *XXIX Vergrösserte Sectiones der General-Carte von dem Königreich Preussen…* (1:100 000; the Suchodolec map further on), 1730s,
   - B2. *Karte von den Provinzen Litthauen, Ost- und West-Preussen u. d. Netz-Distrikte* (1:50 000; the detailed Schrötter-Engelhardt map further on), the turn of 19th century,
   - B3. *Topograficheskaya karta Tsarstva Polskogo* (1:126 000), 1820s and 1830s,
   - B4. *Karte des Deutschen Reiches* (1:100 000), 1920s and 1930s,
   - B5. tactical map of the Military Geographical Institute (1:100 000), 1920s and 1930s,
   - B6. topographic map "1965" (1:25 000), 1970s,
   - B7. Military Topographic Map of the series M755 (1:50 000), 1990s.

The selected maps constitute representation of the forest cover states for the following seven time slices: 1800 (A1, A2, B2), 1830 (A3, B3), 1885 (A4, A5), 1928 (A6, B4, B5), 1950 (A7), 1970 (A8, B6), 2000 (A9, B7). The oldest Suchodolec map (B1) was used as historical reference material.

The remaining existing maps were not included in any of the two groups. Namely, a part of them constituted the transformations or compilations of other cartographic materials, while the remaining ones formed too narrow intervals when compared to the time periods shown in the basic and complementary materials. The first of these two groups included, for instance, *Karte des westlichen Russlands* on the scale of 1:100 000 (inhomogeneous German version of the Russian map of the scale of 1:84 000, complemented with information from the Reymann maps), or the maps "Borowa Góra" of the scale of 1:50 000 (photo-mechanical blow-up of the elaborates on the scale of 1:100 000). The second group contained, in particular, the *Voyenno-topograficheskaya karta Yevropeyskoy Rossii* on the scale of 1:126 000 (Paćko & Trzebiński, 1983, item 170), as well as the subsequent editions of the post-war military and civilian topographic maps of different settings and scales (Sobczyński, 2000). Further, materials were rejected that would not satisfy in a glaring manner the criteria of utility due to falsification of content, including, in particular, the district maps (1:25 000, 1:100 000), and the GUGiK-80 maps (1:100 000).

2.4. Characterisation of the basic source materials

The characteristics, given below, definitely selective, encompass all the series of maps, which were classified into the groups of basic and complementary materials. Attention was primarily paid to these aspects, which are to the highest degree associated with the subject of study and are decisive for the utility of the materials and the possible scope of their use. In addition, the background of development of the particular cartographic elaborates is also commented upon. The characterisation is conceived in the regional-chronological setting, which enables presenting a more holistic image of evolution of the cartographic thought and the very maps of the study area, constituting an expression of this thought.

2.4.1. The Prussian and German cartography

XXIX enlarged sections of the general map of the Kingdom of Prussia with division into four following provinces: Sambia, Natangia, Upper Prussia and Lithuania (1:100 000)
XXIX Vergrösserte Sectiones der General-Carte von dem Königreich Preüssen wie daselbe in 4. folgende Districte abgetheitet als: Samland, Natangen, Oberland und Littauen
Work on this 18th century map, being the sole source material exceeding in a clear manner the time frame adopted for the study, was carried out in the years 1732-1739 under the leadership of Jan Władysław Suchodolec, who made use of the earlier elaborates, prepared by Józef Naronowicz-Naroński in the years 1660-1678, and by his father, Samuel Suchodolec in the years 1683-1713, as well as of his own work, conducted since 1701. This map was not published in print and only three manuscript copies are known of this map, edited by the Academy of Sciences of Berlin in 1763.

The map encompasses a part of the study area, situated, conform to the administrative divisions of that time, in the districts of Upper Prussia (Oberland) – within the confines of the head counties of Ortelsburg (Szczytno nowadays) and Neidenburg (Nidzica), and a small eastern fragment of the district of Natangia (Natangen) within the boundaries of the head counties of Seehesten (Szestno) and Johannisburg (Pisz). The drawing of the situation in the South reaches beyond the boundaries of the Kingdom of Prussia, so that the fragments are included, as well, of Masovia (Fürstenthum Masow – the Duchy of Masovia), meaning, in practice, the northern parts of the present forest districts of Myszyniec and Parciaki.

The map is composed of eleven parts, which, however, can hardly be referred to as classical map sheets – the whole was, namely, apparently meant to be glued together, as demonstrated by the frames, drawn uniquely along the outer sides of the external parts. The map was developed out of 29 sections, most probably executed at the scale of approximately 1:50 000 (Szeliga, 2004, pp. 143-144), these sections, though, not being known neither from the proper cartographic image nor any kind of contemporary description. The map does not contain the cartographic (geographic) grid, nor the topographic (distance) one, and the grid that is shown there, composed of squares of 1 cm side, served to transfer the shrunk and generalised content from the original 29 sections over to the final sheets (Fig. 2.1).

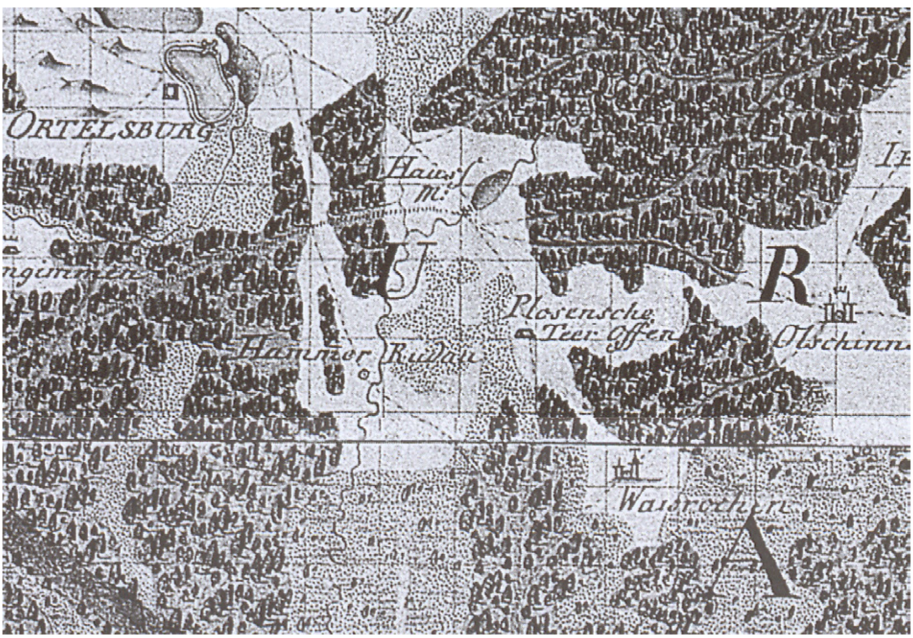

Fig. 2.1. *XXIX Vergrösserte Sectiones der General-Carte von dem Königreich Preüssen…* (compilation 1732-1739, edition 1763) – part of sections IX/23 and IX/27; original scale ca. 1:100 000

The study of accuracy of the map, carried out by Szeliga (2004) showed that the average scale[2] for the parts IX and X (used in the here reported study) and for part XI equals 1:99 000, with the actual scale values ranging from 1:88 800 to 1:113 800 (the biggest

[2] The commonly practised measurement of the global scale on ancient maps does not provide the unambiguous information on the actual metric relations, and even falsify to an extent the real situation. The ancient maps are, namely, in fact, the variable scale models (see Jankowska & Lisiewicz, 1998; Krzywicka-Blum, 1994).

divergences were noted for the vicinities of Pasym, Pisz, Szczytno and Janów). The average errors of distance are as follows: the absolute: +/- 1.68 km (for the average distance of 28.3 km), and the relative: +/- 5.9%, the latter locally (e.g. in the neighbourhood of Szczytno) reaching 10%.

The legend of this map, presented on a separate sheet[3], contains 21 signs, almost exclusively concerning buildings and structures. The description of signs does not account at all for the land use forms or types of land cover, which are of main interest in the study here reported. The same applies to water bodies, road network or relief. On the original sheets forests are designated by the signature in the form of dark green contours of deciduous trees, drawn in a lateral perspective against the light green background. All the tree stands are treated as one joint category, only in some places additional explanations are provided, informing, in particular, of the surfaces covered by the young tree stands (*Frisching*) or by bushes (*Gestrauch*). In general, there are no problems with identification of these surface distinctions, even on the black-and-white copies. Doubts only arise concerning interpretation of content regarding the meaning of the background under the inscriptions within the confines of forest surfaces – it is not always certain whether this is just the purposeful intervention of the drawing person or a really existing clearing, used for placing the text. The map presents also meadows and most probably boggy meadows, as well as cultivated fields and moorlands (Szeliga, 2004, pp. 113-114), but they can be fully identified only using the coloured manuscript sheets.

The here reported study made use of four sections of the map in the black-and-white version (IX/23, X/24, IX/27, X/28), originating from the edition published as facsimile by the Polish National Library (Szeliga, 2004).

Topographic-military map of the former New East Prussia or the present northern part of the Duchy of Warsaw and the Russian district (1:150 000)

Topographisch-Militärische Karte vom vormaligen Neu Ostpreussen, oder dem jetzigen Nördlichen Theil des Herzogthums Warschau, nebst dem Russischen Distrikt

The beginning of the proper period of the changes that are analysed in the study is signalled by the Map of the New East Prussia, as this particular material is commonly referred to. It was executed at the order from the Prussian king Frederic Wilhelm. The work on this map started in 1795 under the leadership of quartermaster major von Stein and was supervised by general-lieutenant Levin von Geusau. It resulted in the *Krieges Karte der Provinz Neu-Ostpreussen*, composed of 122 relevés on the scale of 1:33 300. Yet, the final elaborate was signed by Johann Christoph von Textor, mathematician and military cartographer, who carried out his own astronomic measurements and fragmentary triangulation. On this basis von Textor amended and reduced the relevés of von Stein, and also complemented the map with the missing fragments of Dobrzyń and Płock lands (13 new sheets), using for this purpose the relevés of David Gilly (Rutkowski, 2000). Ultimately, work was terminated in 1800, with the effect of 135 relevés on the scale of approximately 1:33 300.

[3] This particular sheet contains also the complete title of the map (see Szeliga, 2004, p. 107), and the detailed table with the administrative and ownership breakdown of the Kingdom of Prussia, as well as statistical data concerning villages, manor farms and manor houses.

These relevés served then to produce the map composed of 17 sheets (13 complete sheets and 4 halves) on the scale of approximately 1:150 000[4]. This map is known from three variants, differing as to the degree of detail. The care for the printing, done intermittently and for various portions of material in Berlin and Paris in the years 1806-1808, was taken by Daniel F. Sotzmann (Paćko & Trzebiński, 1983, item 40).

This map encompassed the areas taken away from Poland in the effect of the second partition of Poland in 1793 (lands of Dobrzyń and Płock), and during the third, final partition (northern Masovia and Podlasie, region of Suwałki, and areas up to Niemen river). Paradoxically, though, the map, when published in print, turned out in a sense outdated, for the majority of the areas it encompassed, had been lost by Prussia to the advantage of France and the then established Duchy of Warsaw (as reflected in the final title of the map).

Information on the work of topographers and cartographers during the elaboration of the map is incomplete. It is known that astronomic measurements were not done according to mathematical methods. Latitude was established using sextant, while longitude was determined with the help of the chronometer, but sometimes it was only estimated on the basis of observations of eclipses of stars by the Moon. It is also not known what source materials, except for the relevés of von Stein, were used by Johann Christoph Textor, and to what extent. The very topographical work was carried out according to the instruction authored by David Gilly, but also in this case, neither its title nor the year of publishing, are known. Regarding the study reported it is important to note that the headman of the measuring group could not allow, under the penalty of a high fee, for omission or erroneous location of even the smallest patch of forest, meadow or bushes. This, however, does not change the fact that both the methods applied at that time and the lack of trigonometric measurements, covering the areas of the relevés (there was just one single triangulation string on the territory of New East Prussia) make it necessary to apply far reaching caution regarding the accuracy of the map. This reservation is confirmed by the results of calculation of the average errors of latitude (509 metres), longitude (1329 metres) and location of points (1542 metres), which are far beyond those established for the Schrötter-Engelhardt and Quartermaster maps (Lankamer, 1967).

It is assumed that the map was executed according to conical projection of the secant cone, since there is no unambiguous information in the literature that it could be the pseudo-conical projection of Bonne. Division into sheets[5], conform as to the belts with the design of the Schrötter-Engelhardt map, was performed in such a way that no outer frame cuts across a more important locality, while vertical lines, defining columns, are parallel to the meridian, crossing Królewiec (Königsberg). On all sheets the cartographic grid

[4] The literature usually assumes, as being closer to reality, the scale of 1:155 000 (following Olszewicz, 1921), or the scale of 1:152 000 (following Lankamer, 1967). The model for the map here described might have been constituted by the manuscript version of the map composed of 11 coloured sheets on the scale of 1:114 000, described on the basis of the collection of the Prussian cultural heritage library in Berlin by Konias (2010, pp. 147-160).

[5] Sheet no. I contains full title of the map (see Lankamer, 1967, p. 194), while sheet no. IV – an outline of the reach of the map with division into sheets and the administrative boundaries, as well as most important localities (*Tableau der Karte von Neu Ost Preussen*), and also the list of units, composing Płock and Białystok departments.

is shown with the interval of 10′, while on the frames, additionally, division is provided with the step of 1′ for the longitude, starting from German Ferro[6].

The map contains complete situation rendering within the confines of New East Prussia, and outside of this area, in the narrow border-adjacent belt, settlements, roads and forests were drawn, while farther away – only more important localities with churches and names. The drawing is originally black, with coloured administrative boundaries. The legend, provided in sheet X (*Erklærung der Zeichen*), contains 46 main signatures. Distinction is kept of woods (*Wald*) and woods on wet ground (*Wald auf nassem Grunde*), their boundaries denoted with dotted line, the respective signature in the form of small tree silhouettes being sufficiently delicate not to cover other signs, which results in good legibility of the map. Of the non-forest plant formations bushes are distinguished (*Strauch*), as well as meadows (good meadows – *gute Wiese*, those with bushes – *Wiese mit Strauch*, and the wet ones with bushes – *sumpfiger Wiesengrund mit Strauch*). The drawing does not pose more important difficulties in interpretation, except for the places with the small area mosaic of forest and brushwood surfaces (Fig. 2.2). In case of black-and-white reproductions a significant difficulty is associated with the coloured boundaries, which are seen as dark-grey, broad belts, obstructing the legibility of the map content.

Fig. 2.2. *Topographisch-Militärische Karte vom vormaligen Neu Ostpreussen*… (compilation 1795-1798; edition 1806-1808) – part of sheet no VIII; original scale 1:150 000

The study reported made use of three sheets of the map (IV, VII, VIII), acquired from the Institute of History of the Polish Academy of Sciences and the library of the Faculty of Geography and Regional Studies of the University of Warsaw.

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[6] Ferro is an island in the archipelago of the Canary Islands. The western cap of this island was taken in 1864 as determining the prime meridian, in force in cartography until the prime meridian was established as crossing Greenwich in 1884. The German Ferro meridian was situated at 17°39′59.4″ to the west of Greenwich, while the Austrian – at 17°39′46″, the difference resulting from the inaccuracy of measurements (Krassowski, 1974).

Map of the Provinces of Lithuania, East and West Prussia and District of Noteć (1:50 000)

Karte von den Provinzen Litthauen, Ost- und West-Preussen u. d. Netz-Distrikte

It was already in 1796, that is – barely one year after the work on the map of the New East Prussia had been started, that analogous activities, initiated by the Prussian war minister, Friedrich Leopold Schrötter, were undertaken for the other side of the border, that is – for the territory of Lithuania, West and East Prussia and the District of Noteć. Astronomical and triangulation measurements were conducted under the direction of Johann Christoph Textor, mentioned already before, while Friedrich Bernhard Engelhardt, an experienced cartographer, War Counsellor, was responsible for taking of the relevés in the field (see Ostrowska & Ostrowski, 2000), and at the same time supervised the entire work (Grabowski, 1997).

The majority of the measurement work, encompassing both the geodesic matrix and the relevés of the situation, had a similar course as in the case of the map of New East Prussia. The fundamental difference was higher accuracy of this work, resulting primarily from the fact that eleven triangulation series were used, traced with reference to eight bases, distributed evenly over the entire charted area. Yet, one should not forget that the precision of the instruments for astronomic measurements was the same, which resulted in single errors in longitude, reaching 1'30". Likewise, the non-instrumental method of measuring distance and establishing locations of less important terrain details, which consisted in the use of the hand-held compass, counting of steps or outright guessing, remained unchanged (Szeliga, 1969). The relevés of the situation, produced according to the instruction of David Gilly, were started from the territory of East Prussia and then continued by moving westwards. It is known that during field work, the earlier maps of David Gilly of 1792 were used as the source material, along with the few maps of forest areas and the economic plans – all of them verified in the field before use (Zaborski, 1936).

The measurement work, which yielded 141 sections of the relevé of the situation, was terminated in 1802 (for the index, see Konias, 2010, Appendix 23). The entire material was transferred to Berlin, where grids were checked, along with the precision of fit along the edges. Thereafter, the whole was glued together and cut into parts again. The thus prepared sheets on the scale of approximately 1:50 000 were, however, never published. Only two coloured manuscript copies were executed for the Royal Cartographic Chamber, which were kept as secret until as late as 1925 (Paćko & Trzebiński, 1983, item 48).

This map was elaborated according to the projection that was developed specially for this purpose by Johannes Albert Eytelwein, who referred to an earlier conical secant projection of J.N. Delisle (Szeliga, 1969). Sheets do not contain any grid nor coordinates along the edges (there are no frames in the classical sense of the word) or in the corners. Investigations of Konias (2010) suggest that the true scale might be approximately 1:60 000, while measurements of distance within a single sheet showed the average error equal +/- 0.27 km.

As mentioned before, the manuscript copies were executed in colours. The complete sketch of the situation does not end at the state borders, but exceeds the borders and encompasses also a narrow border-adjacent belt. The legend was provided as a separate sheet, entitled *Erklarungen der auf der Karte von Preussen verschidentlich gebrauchten Farben* (see Konias, 2010, Appendix 24). Forests were classified into two categories: the high forests with coniferous trees (decidedly dominating, marked with dark grey colour without any additional signatures or hachures) and the low forests with alder. According to Zaborski (1936) and Osowski (1955) all the forest patches are provided with information on the properties and kind of tree stands. This, however, was only partly confirmed by the analysis of the relevés that were made use of. From among the non-forest plant formations the following ones were distinguished: dry meadows (*Wiesen trokne*), wet meadows (*Wiesen nafse*), and meadows overgrown with deciduous trees (*Wiesen mit laubholz bewachsen*) – all of them coloured in green, and also high pastures (*Hohehultung*), peat bogs (*Torf bruch*) and swamps (*Moos bruch*) – with additional division into the open ones (*kahle*) and overgrown with coniferous trees (*mit nadelholz bewachsen*). The boundaries are very well seen and distinct, which results in good legibility of the map and lack of problems with identification of location and reach of the particular types of land use (Fig. 2.3). The image is only in some places blurred by the densely marked relief, which, though, is not shown on the forest areas.

Fig. 2.3. *Karte von den Provinzen Litthauen, Ost- und West-Preussen u. d. Netz-Distrikte* (compilation 1796-1802) – part of manuscript sheet no 61; original scale ca. 1:50 000

The study reported made use of nine manuscript sheets of the map (no. 53, 54, 55, 60, 61, 62, 67, 68, 69), acquired from the collection of the National Library in Berlin (Staatsbibliothek zu Berlin).

Map of East Prussia along with Prussian Lithuania, West Prussia and the Noteć District (1:150 000)

Karte von Ost-Preussen nebst Preussisch Litthauen und West-Preussen nebst dem Netzdistrict

At the instant the work was terminated on the manuscript map of Schrötter-Engelhardt, decision was made of executing its black-and-white version on a smaller scale[7]. And so, in the years 1802-1810, based on the 141 sections described before, 25 sheets were developed on the scale of 1:150 000[8]. The content of the new map was subject to generalisation, but its time stamp was unchanged, for now, a new field work was performed. In distinction from the original relevés, the sheets contain the cartographic grid with the step of 10′, and on the frames the additional division is shown with the unit of 1′, longitude being referred to Ferro. This map is generally without colours, only administrative and political boundaries are coloured. The principles of sheet design adopted were identical as for the map of New East Prussia.

The results of the very detailed investigations into the accuracy of this map were published already (Szeliga, 1969), and so we shall only quote here some selected examples. Thus, of the twelve sheets analysed, sheet no. XVII features the lowest accuracy, and sheet no. XVIII is only slightly better with this respect – meaning two sheets out of three that were used in the study reported. The average errors are: 40.3″ φ = 1244.9 m (sheet no. XVII), 22.3″ λ = 407.5 m (sheet no. XVIII), while in terms of location of points – 1334.3 m (XVII) and 1309.8 m (XVIII). Szeliga observed also appearance of important constant errors (even at the order of 30″) and suggested that significant differences in the magnitude of these errors might have resulted from the uneven translocation of the parallels during drawing or engraving.

The legend (*Erklærung der Zeichen*), placed on sheet no. II, contains more than 40 distinctions, with a part of them bearing identical signatures, the distinguishing element being the additional descriptions (like in the case of mills or industrial plants)[9]. Forests are denoted with just one category, while out of the non-forest formations meadows (*Wiesen*), overgrowing meadows (*bewachsene Wiesen*) and swampy meadows (*morastige Wiesen*) were distinguished. The drawing of the content is very careful and clear, so that the map is well legible (Fig. 2.4). Difficulties in terms of interpretation appear only in places, where the

[7] Besides, a new edition of the map was published in Berlin in 1853, prepared for printing by Baldamus. Updating was applied only to hardened roads and railways (Paćko & Trzebiński, 1983, item 124).

[8] Calculations performed by Szeliga (1969) suggest that the scale of 1:152 600 is closer to reality and so it is proposed to assume this scale for the entire work.

[9] This particular elaborate contains also – on sheet no. III – the list of all the counties composing the provinces of Lithuania, East and West Prussia, as well as the Land of Noteć river, and, on sheet no. XXIV – the index of sections with the drawing of the triangulation network and the indication of errors in location of ten localities on the earlier maps (*General Tableau Alt Ost und Westpreussen nebst dem aufgenommenen Trigonometrischen Netz*).

small-scale mosaic of woods, overgrowing meadows and swampy areas exists, because the signatures of the first two categories are similar, while the dense hachure of the third makes unambiguous distinction of the forest and non-forest associations difficult.

Fig. 2.4. *Karte von Ost-Preussen nebst Preussisch Litthauen und West-Preussen*… (compilation 1796-1802, edition 1802-1810) – part of sheet no XVII; original scale ca. 1:150 000

The study made use of three sheets of this map (XVII, XVIII and XXIII), acquired from the Central Library of Geography and Environmental Protection of the Institute of Geography and Spatial Organization, Polish Academy of Sciences, in Warsaw.

Special topographic map of Prussia and the neighbouring countries (1:200 000)

Topographische Specialkarte des Preussischen Staats und der angrenzenden Länder

In parallel with the cartographic initiatives, described before, of J.Ch. Textor and of F.L. Schrötter and F.B. Engelhardt, the history started of another cartographic work, lasting for close to one hundred years. Here we mean the special map on the scale of 1:200 000, linked with the initiative of Daniel Gottlob Reymann, undertaken in 1806. The first edition of this map, which did not include the area of study, was entitled *Geographische Special-Karte von Deutschland und den angränzenden Ländern*. In the elaboration of this map use was made of the table ordnance relevés, constituting the source material for the *Generalstabskarte 1:100 000* (see further on). In the years 1806-1832 altogether 142 sheets were published in the form of separate fascicles, and in the meantime a part of them were amended, updated and published again. In 1836 the rights to the title were appropriated by the director of the trigonometric bureau in the General Staff – Karl Wilhelm von Oesfeld. Under his leadership eight new sheets were published, and several other ones were edited in a partly changed cutting design (Paćko & Trzebiński, 1983, item 103).

The history of the first version of the "special map" ended in 1843. It is then, after the death of K.W. von Oesfeld, that the rights were acquired by the publishing house of Carl Flemming in Głogów (Glogau) and publication started of the *Topographische Specialkarte des Preussischen Staats und der angrenzenden Länder*, which was made use of in the study here reported. Publication in the form of an atlas, being a continuation of the work, initiated by D.G. Reymann, included, additionally, the areas along rivers Niemen and Bug in the East, and the majority of work was executed under the leadership of F. Handke (who authored at least 194 sheets). The parts, encompassing the territory of the present-day Poland, appeared in the years 1844-1860 and were in majority developed anew or updated, at least with respect to the road and railway networks (Paćko & Trzebiński, 1983, item 169).

The entire map was elaborated in black-and-white, only boundaries were coloured by hand (Fig. 2.5). The sheets show the cartographic grid with the step of 15′, while the frames additionally show the division every 1′ for the longitude with regard to Ferro. Explanation of signs is given in the form of the so-called model sheet, *Musterblatt und Zeichen Erklärung*, which contains more than 100 distinctions, with a part of them having identical signatures, the distinguishing element being constituted by the additional descriptions. Forests are designated with three signatures: *Waldungen*, *Heiden* and *Gestelle*. From among the remaining non-forest formations the distinguished ones are, in particular, meadows (*Wiesen*), moorlands (*Heidekraut*), swamps and peat bogs (*Moor/Moosbruch*, *Sumpf/Morast*).

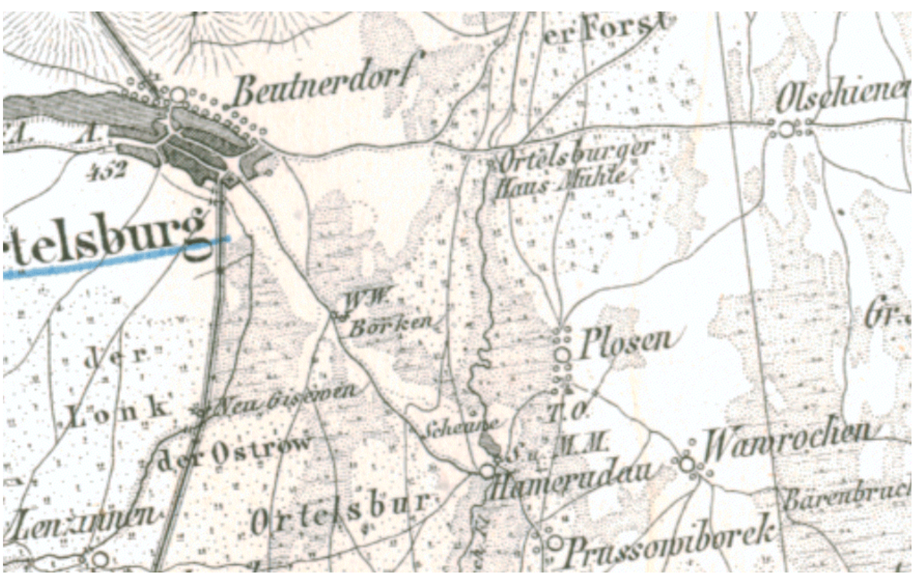

Fig. 2.5. *Topographische Specialkarte des Preussischen Staats und der angrenzenden Länder* (compilation 1844-1860, edition 1843-1873) – part of sheet O Ortelsburg; original scale 1:200 000

Reymann's map did not exert an influence on Polish cartography, and in view of numerous changes, updates and various versions of the sheet designs it does not have the character of a homogeneous rendition. Yet, notwithstanding this reservation, it was frequently used in Prussian cartography and that even until the 1920s[10].

The study reported made use of six sheets of the map (33 Osterode, O Ortelsburg, P Johannisburg, 49 Soldau, Q Chorzellen, R Ostrolenka), which were acquired from the Central Library of Geography and Environmental Protection of the Institute of Geography and Spatial Organization, Polish Academy of Sciences, in Warsaw.

German topographic maps 1:25 000

Messtischblätter

In the opinion of Konias (2010), after the map of Schrötter-Engelhardt appeared, the period ended in Prussian cartography, in which cartographic products were developed under the leadership of great personalities, acting upon own initiative or for administrative and bureaucratic needs. The same author supposes that the year 1816 marked also the beginning of the undertakings under the auspices of the state, which brought great achievements of the administrative and military cartography. It is, namely, then that the duty of preparing the topographical relevés was taken away from the Prussian Statistical Bureau by the Royal Prussian General Staff (*Königlich Preussischen Generalstabes*), which was, actually, formally established in 1821 by the king Friedrich Wilhelm III.

The very first topographical relevés on the scale of 1:25 000 started to be executed almost "at once", that is – in the years 1816-1821. Works were managed by the military cartographer Carl von Decker, who authored also the instruction entitled *Military topographical relevé* (*Das militärische Aufnehmen*). Maps of C. von Decker, known as *Quadratmeilenblätter*, had, however, a very bad opinion, even for the then contemporary quality requirements (Konias, 2010).

In 1821 general Friedrich Carl Ferdinand von Müffling became the chief of the General Staff. In the same year he published the *Instruction of topographical work of the Royal Prussian General Staff* (*Instruction für die topographischen Arbeiten des Königlich Preussischen Generalstabes*), in which he introduced, for the maps on the scale of 1:25 000, the polyhedral projection according to the central point mapping, i.e. the so-called Prussian Polyhedral Projection (*Preussische Polyeder Projektion*), see Janaszek-Pastusiak (1979). Topographical work on the subsequent relevé on the scale of 1:25 000 lasted over the period 1823-1830. This series is referred to as *Urmesstischblätter* (from the measurement table – *messtisch*). Despite the fact that almost 700 items were prepared in the manuscript form (the map was not officially published), this work was also criticised for its poor legibility and lack of accuracy (Jankowski, 1961; Konias, 2010, pp. 173-190). After 1840, a new measurement

[10] In 1874 the rights to the work were purchased by the Prussian general headquarters, who, after subsequent amendments and extensions, published an atlas, encompassing the territories of Germany, Poland and Czechia, entitled *Topographische Spezialkarte von Mitteleuropa*, which kept being updated until 1908. Besides, selected sheets were used for publication of county maps of the Prussian Kingdom in the years 1849-1865, as well as numerous regional elaborates. Yet during World War I a part of materials, by then already quite outdated, were reprinted in the framework of compilation of the *Karte des Westlichen Russland* on the scale of 1:100 000 (Krassowski, 1974; Paćko & Trzebiński, 1983, items 103, 169).

instruction was formulated and the corrections to the map were started, lasting until 1855, with, however, still an unsatisfactory effect. It ought to be emphasised, though, that given that we know nowadays all the imperfections of this work, and can account for them, it may still constitute a valuable source of information (see Jankowska, 2012).

The breakthrough took place only in the 1870s and it is then that the history of the proper *Messtischblätter* started. In 1875 the Royal Prussian Land Measurement Bureau (*Königliche Preussische Landesaufnahme*) was established and took over the technical supervision of the work done by the General Staff. In the same year, taking of the new table relevés began, according to the unified principles encompassing the triangulation, topographic and cartographic, as well as drafting procedures, and already in 1877 the first sheets were ready. In this period it was also concluded that the existing triangulation network with the initial point in Rauenberg did not fulfil the conditions set by the then current knowledge of geodesy. Thus, in 1896 new measurements were started, with the reference point in Helmertturm near Potsdam (Jankowski, 1961).

Until 1915 altogether 3307 sheets appeared, and the part of Prussia that is of interest here was covered by maps in the years 1909-1915. The situation images on the original sheets were prepared only up to the border. After the break, caused by World War I, work on the maps restarted in 1919, although now it was limited mainly to corrections and updating of the already existing sheets, without taking of new topographical relevés. The military Land Measurement Bureau was replaced in 1921 by the civilian Reich's Bureau for Land Measurement (*Reichsamt für Landesaufnahme*), which began its activity from repairing the triangulation network, destroyed during the war.

Despite the stalemate in the field work, during the entire inter-war period the maps have been changing their image. Soon after the war the kilometre grid DRG (*Deutsches Reiches Gitter*) started to be shown on the maps, and Greenwich was taken for prime meridian (for some period of time the sheets were annotated with double coordinates). In 1927 the true-angle projection of Gauss-Krüger was introduced as obligatory in all the provinces of the Reich, but the *Messtischblätter* kept to be executed in the Müffling projection and sheet design, with the sole addition of the kilometre grid in the appropriate setting of the coordinates of the new projection (Jankowski, 1961). The complete coverage of the country with the maps was achieved in 1931, while five years later the previously used continuous numbering of the sheets, not related anyhow to the designations on the scale of 1:100 000, was replaced by the notation corresponding to rows and columns.

Maps were most frequently bi-colour, with black drawing of the situation and blue water network, but already in the 1930s multicolour sheets started to be printed, as well. As mentioned already, during the entire inter-war period highly intensive work was conducted on updating of map content, as reflected in the out-of-frame descriptions of the individual sheets, facilitating significantly the establishment of their time stamps. The notes that appear on the maps used in the study here reported include the year of first edition (*Aufnahme*), year of complete updating (*Berichtingung*), year of complementing (*Nächtrage*), or of the editorial modifications (*Redaktionelle Aenderungen*).

In the first years of World War II, black-and-white reprints were published of the older versions, of poor quality, with the note "temporary edition" (*Vorlaufige Ausgabe*). In 1942 the maps started to be published by the High Command of the Landed Army (*Oberkommando* *des Heeres*, OKH) and by the General Staff (*Generalstab des Heeres*). They were of good quality, with bigger number of colours, but were meant uniquely for the military (*Deutsche Heereskarte*). The mapping zones of Gauss-Krüger were also modified during the war, and introduction of a new topographic grid (*Deutsches Heeres-Gitter*, DHG) was started.

The needs related to military operations forced the necessity of filling the empty places on the border sheets and of editing new parts, reaching farther into Poland. Within the area of the study the basic material used for the extension was constituted by the Russian maps on the scale of 1:21 000 and 1:42 000. In the first half of the 1940s high number of sheets was produced, only partly updated, on which the image of the situation originated largely from these Russian maps. While, however, in the case of use of maps on the scale of 1:21 000 attention was mainly attracted by the completely different signatures of forests, the magnification of the entire content from the scale of 1:42 000 looked truly artificially (Fig. 2.6). Despite the fact that all these sheets are included in the series referred to as *Messtischblätter*, it ought to be remembered that these particular maps were a fast response to the needs of the moment and as such should perhaps be more appropriately called *Quasimesstischblätter*. The later editions of the same items were already adapted to the standards of the entire series, at least in terms of image of the situation and the signs (Fig. 2.7).

Polish literature provides little information on the accuracy of these maps. The calculations, performed by Jankowski (1961) suggest that the average error of location of a point on the editions from the 19th century equals 0.70 φ (21 m) and 0.42 λ (7.4 m). The average values of location errors on the editions dating from the 1930s do not exceed 4 m. On the other hand, the analyses, carried out by Konias (2010) on a single sheet from the 1880s, give the average scale of 1:33 761 and the average error of distance equal 41 m (ranging between -90 and +70 m).

Vegetation cover in almost all editions was represented in black colour. An exception is constituted by the multicolour editions from the period of World War II. Three forest types were distinguished on the maps: deciduous (*Laubwald*), coniferous (*Nadelwald*) and mixed (*Mischwald*). The original signatures were very well legible, and the boundaries of forests were additionally indicated with the dotted line. Among other types of land

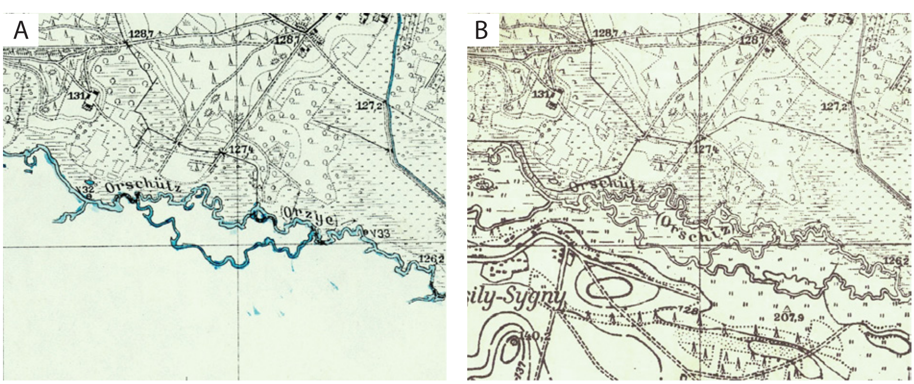

Fig. 2.6. *Messtischblätter* – part of sheet 2690 Roggen: A – original edition 1909, B – military edition 1944, compiled with Russian map 1:42 000 from 1886; original scale 1:25 000

Table 2.1. Characteristic of used *Messtischblätter* maps

Sheet name and number	I edition/source	Revision	Publication date
2389/997 Wuttrienen	1914 PL	1929 (B)	1929 RfL
2390/998 Passenheim	1914 PL	1929 (B)	1929 RfL
2392/1000 Mingfen	1914 PL	1929 RfL (B)/1938 (RA)	1944 OdH/GdH (DH)
2393/1001 Babienten	1912 KPL	1920 (N)	1920 RfL
2394/1002 Eckertsdorf	1922 PL	1929 RfL (N)	1944 OdH/GdH (DH)
2489/1093 Gimmendorf	1914 PL	1929 (B)	1929 RfL
2490/1094 Gedwangen	1915 PL	1929 RfL (B)/1938 (RA)	1938 (?)
2491/1095 Ortelsburg (West.)	no data	no data	1929 RfL
2492/1096 Olschienen	-	-	1912 KPL
2493/1097 Schwentainen	1914 PL	1929 (N)	1929 RfL
2494/1098 Farienen	1914/1919 PL	1943 (N)	1944 OdH/GdH (DH)
2589/1185 Jablonken	1909 KPL	1911	1911 KPL
2590/1186 Malga	1911 KPL	1929 RfL (B)/1938 (RA)	1944 OdH/GdH (DH)
2591/1187 Willenberg (Nord.)	1911 KPL	1927 (B)/1929 (N)	1929 RfL
2592/1188 Lindenort	1910 KPL	1927 (B)	1927 RfL
2593/1189 Liebenberg	1910 KPL	1924 (B)	1924 RfL
2594/1190 Friedrichshof	1910 KPL, 1886 rus. (42)	1927 RfL (B)/1940 (RA)	1944 OdH/GdH (DH)
2595/1191 Karpen	1910 KPL, 1886 rus. (42)	no data	1944 OdH/GdH (DH)
2689/1276 Muschaken	1911 KPL	1929 (N)	1929 RfL
2690/1277 Roggen	1909 KPL, 1886 rus. (42)	1940 RfL (N)	1944 OdH/GdH (DH)
2691/1278 Willenberg (Sud.)	1911 KPL	1927 (B)	1927 RfL
2692/1279 Gross Leschienen	1910 KPL	1927 (B)	1927 RfL
2693/1280 Tscharna	1910 KPL, 1886 rus. (42)	1940 RfL (N)	1944 OdH/GdH (DH)
2694 Myschynez	1891 rus. (21)	1943 (N)	1944 OdH/GdH (DH)
2695 Lipniken	rus. (42)	no data	1944 OdH/GdH (DH)
2696 Kuse	1891 rus. (21)	1940 RfL (B)	1944 OdH/GdH (DH)
2791/1361 Flammberg	1910 KPL	1927 (B)	1927 RfL
2792 Olschewka	1891 rus. (21)	1940 RfL (B)	1944 OdH/GdH (DH)
2793 Sawady	1891 rus. (21)	1941 RfL (B)	1944 OdH/GdH (DH)
2794 Kadsidlo	1891 rus. (21)	1943 (B)	1944 OdH/GdH (DH)
2795 Schafranken	1891 rus. (21)	1928 (B)	1944 OdH/GdH (DH)
2892 Jednoroschetz	1891 rus. (21)	1940 RfL (N)	1944 OdH/GdH (DH)
2893 Baranow	rus. (42)	no data	1944 OdH/GdH (DH)
2894 Dylewo	1891 rus. (21)	1940 (N)	1940 RfL
2992 Krasnoselz	1891 rus. (21)	1940 RfL (B)	1944 OdH/GdH (DH)
2993 Penitz	rus. (42)	no data	1944 OdH/GdH (DH)

Explanations: KPL – *Königlich Preussischen Landesaufnahme* (Royal Prussian Land Measurement Bureau); PL – *Preussischen Landesaufnahme* (Prussian Land Measurement Bureau); RfL – *Reichsamt für Landesaufnahme* (Reich's Bureau for Land Measurement); OdH/GdH – *Oberkommando des Heeres/Generalstab des Heeres* (High Command of the Landed Army/General Staff); DH – *Deutsche Heereskarte* (military edition); rus. (21) and (42) – Russian relevés in scale 1:21 000 and 1:42 000; B – *Berichtingung* (complete updating); U – *Nächtrage* (complementing); N – *Redaktionele Aenderungen* (editorial modifications). Source: own elaboration.

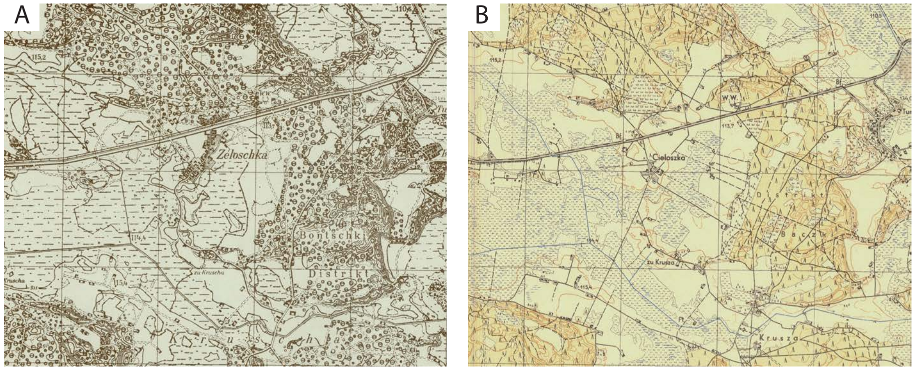

Fig. 2.7. *Messtischblätter* – examples of military editions 1944 based on Russian map 1:21 000 from 1891 (part of sheet 2696 Kuse): A – signs and drawing of the situation reproduced from Russian material, B – signs and drawing of the situation according to final *Messtischblätter*; original scale 1:25 000

cover the following ones were, in particular, distinguished: coniferous and deciduous thicket (*Nadel- und Laubholz-Dickicht*), fallow land and pastures (*Ödland und Weide*), wetlands and peat bogs (*Nasses Moor und Torfstich*), as well as meadows and wet meadows (*Wiese, nasse Wiese*). It should be remembered, though, that the *Messtischblätter* were military maps and – similarly as in the case of other cartographic elaborates of similar nature – forest reaches were charted with somewhat lower accuracy, since their usefulness for military operations was considered null.

The study made use of altogether 36 sheets of the map, acquired from the internet Archives of Maps of Western Poland (http://mapy.amzp.pl/) and from the Central Library of Geography and Environmental Protection of the Institute of Geography and Spatial Organization. Detailed characterisation of the individual items, in view of their very broad differentiation, is provided in Table 2.1.

Topographic map of the Prussian state including the lands of Thuringia and Anhalt (1:100 000)

Topographische Karte vom Preussischen Staate unter Einschluss der Anhaltinischen und Thüringischen Länder

In parallel with the work on consecutive editions of the detailed maps on the scale of 1:25 000, Prussian cartography conducted also activities aiming at covering of the country territory with the maps on the scale of 1:100 000. The first elaborates of the General Staff, i.e. the *Generalstabskarten 1:100 000, halbe Gradabteilungsblätter* (1824-1846), and the *Generalstabskarten 1:100 000* (approximately 1847-1863), did not include, though, East Prussia (Paćko & Trzebiński, 1983, item 141).

The breakthrough came in 1857, when Helmut Karl Bernhard von Moltke took over the leadership in the execution of topographical and cartographic works. Already a year after intensive work started on the new topographical relevés. For the first time since the period of the Schrötter-Engelhardt map, charting of East Prussia (1860-1872) and West Prussia (1863-1879) was undertaken, and, in the meantime, of the Kłodzko Land (1863). In the first phase the new *Topographische Karte vom Preussischen Staate* was based on the sheets of the *Generalstabskarte*, which were partly updated (railway lines, administrative boundaries). Charting of the Prussian lands was, however, already performed on the basis of the table relevés on the scale of 1:25 000 and the geodesic matrix (Paćko & Trzebiński, 1983, item 171).

Until the year 1865, of the planned 319 sheets 249 were developed, and later on, until 1875 – the subsequent 76, of which 58 concerning East Prussia – all of them attributed to the *Königlich Preussischen Generalstab* (since 1875 – the *Königlich Preussischen Landesaufnahme*). *Topographische Karte vom Preussischen Staate* constituted the immediate predecessor and at the same time model for the *Karte des Deutschen Reiches*, and, as it turned out soon afterwards – also its component part (Pasławski, 1967a).

The mathematical construction of the map based on the polyhedral projection of Müffling and the Bessel ellipsoid. The maps were originally black-and-white, and it was only on the sheets updated a couple of years after the first edition that political and administrative boundaries, as well as water bodies were coloured (Fig. 2.8). The sheets did not contain any grid, but only geographical coordinates in the corners and, additionally, the division with the step of 1′ for the longitude, referring to the Ferro prime meridian. The unified sketch of the situation fills completely the border sheets, up to the frames. Yet, the analysis of the map, performed by the present author, demonstrated that this unification applies only to the form, and not to the content. The content, namely, beyond the boundaries of Prussia, is significantly shifted (transformed?) and in some places simply does not correspond to reality. We are not aware of the basic material that might have been used in the elaboration of these maps. It could have been constituted by the maps of Textor, Reymann,

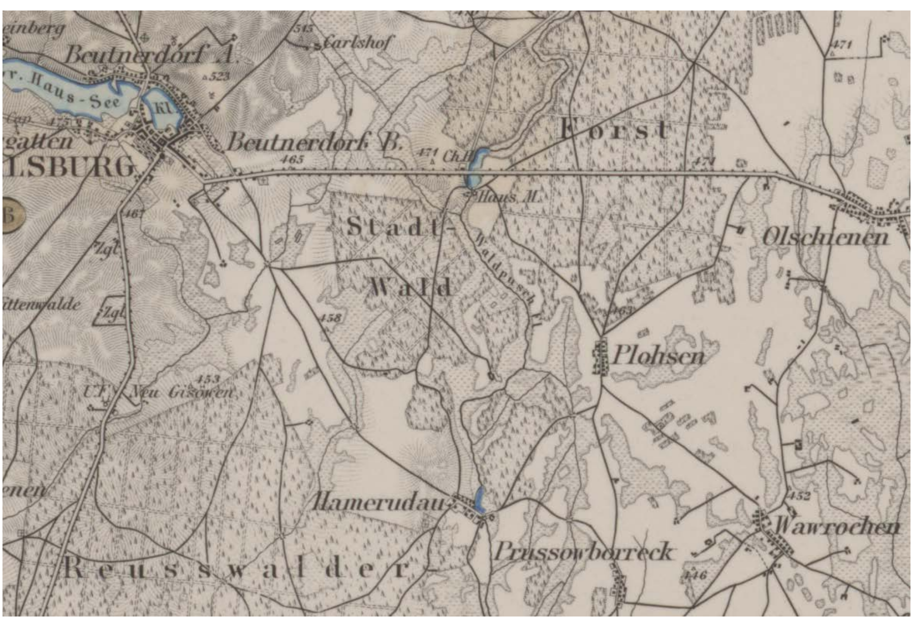

Fig. 2.8. *Topographische Karte vom Preussischen Staate…* – part of sheet no 107 (compilation 1860-1872, edition 1869, revision 1872); original scale 1:100 000

or of the Quartermaster's, but these are only suppositions, which call for a deeper insight into the respective matter (Fig. 2.9).

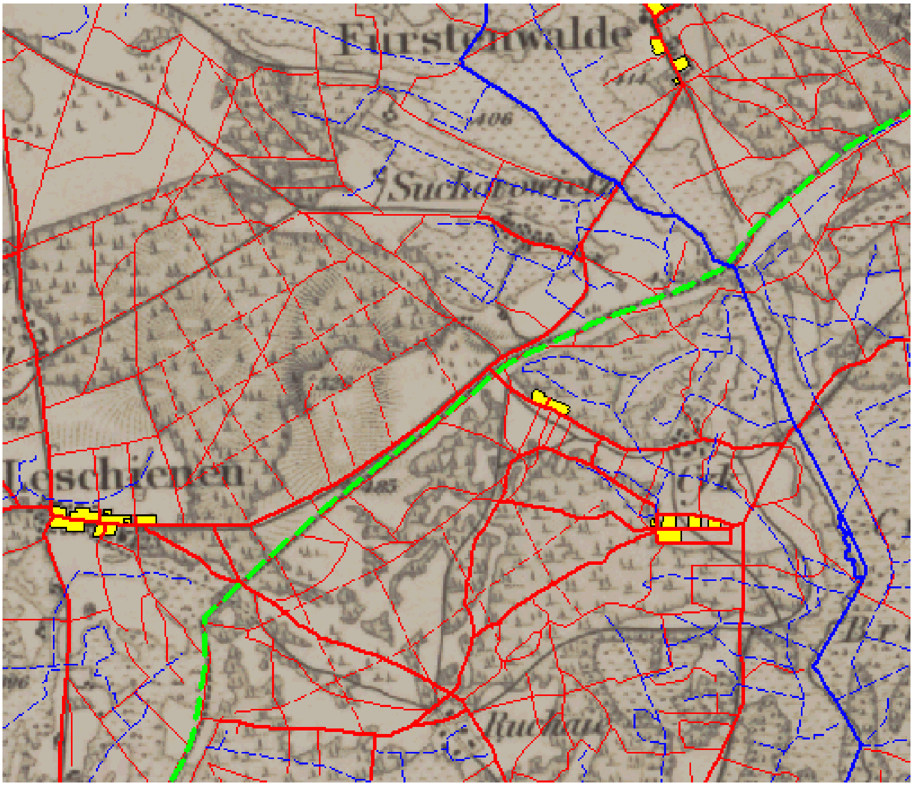

Fig. 2.9. *Topographische Karte vom Preussischen Staate…* (part of sheet no 127) – example of completely different accuracy and the faithfulness of map after both sides of the border (intermittent green line); the figure represents the calibration raster with put on road net, hydrography and buildings (vector layers from VMap Level 2); original scale 1:100 000

Alas, lack of access to the original legend makes impossible a more detailed description of the symbols used. Forests are represented with the symbols of coniferous and deciduous trees and separated clearly from other types of land cover. The drawing is generally discernible and legible despite application of the hachures as a mode of representing relief and does not pose interpretation problems.

Six sheets (106, 107, 108, 126, 127, 128) were used in the study, dated 1868-1869, four of them updated in the years 1872-1877. All of them were acquired from the collection of the National Library in Berlin (Staatsbibliothek zu Berlin).

Map of German Reich (1:100 000)

Karte des Deutschen Reiches

Year 1878 terminated the history of the *Topographische Karte vom Preussischen Staate*. It was then that the decision was taken on the 132 ready sheets to become the integral part of the new edition, that is – of the *Karte des Deutschen Reiches* (KdDR). The sole change was the updating of the road and railroad networks, and the subsequent change of the numbering used until then (Pasławski, 1967a). The list of the sheets is unknown, but most probably they originate from East and West Prussia, where maps were elaborated on the basis of the new and very up-to-date field measurements.

The basic edition, i.e. the original KdDR, commonly referred to as edition "A", appeared in the years 1878-1909. It was not a result of mechanical processing, but an elaborate executed with the method of precise generalisation of the original topographical relevés on the scale of 1:25 000, from which it inherited, anyway, the mathematical foundations, that is – the polyhedral projection of Müffling on the Bessel ellipsoid. Individual sheets were complemented with a high number of elevation points, but, at the same time, the hachures as a mode of representing relief was not abandoned, although the European cartography of that period treated such representation already as a sort of anachronism. Lehmann's method, in conjunction with dense symbols, worsened the legibility of the map, also regarding the tree formations. It is correctly noted by Pasławski (1967b) that the areas of forests make the impression of being steep, while the narrow belts of tree stands remind in some places something like the edges or the faults of the terrain. Pasławski (1967c) analysed also the accuracy of the map series in question, and compared the same sheets from the original edition with those from the end of the 1930s. The highest values of the average relative error of location of points amounted to 1.5" φ (46.3 m) and 3.7" λ (67.4 m). On the other hand, Szynkiewicz (2012) emphasises the imperfections of the applied methods of cartographic presentation regarding selected elements of the content.

Based on the original elaborate a high number of successive variants of the same map were developed, e.g. the "B" edition from the years 1889-1929 (the differences concerned the bigger number of colours applied and experimentation with the joint use of contour lines and hachures), and the "C" edition, called reprint edition (lithograph replacing the copper plates), which was being published in parallel until the moment of liquidation of the Reich Bureau for the Land Measurement (Krassowski, 1974; Pasławski, 1967c). Until today, though, the most known is the edition "D", which started to be published in 1914, and constituted a response to the current military needs, where it was often necessary to use simultaneously several sheets. In this way the joint sheets were developed, the so-called *Grossblätter*, frequently with additional overprints and security clauses (like, e.g., military edition – *Deutsche Heereskarte*, or only for official use – *Sonderausgabe! Nur für den Dienstgebrauch*). Alas, many of them feature poor quality (in view of demand from the army, the faster, but less precise offset printing was applied), and for the foreign areas other kinds of maps were made use of without any corrections, which resulted in the appearance of a variety of "patchworks" with differentiated content, drawing, grids etc. (Fig. 2.10). If we add to this the fact that scholars (see Pasławski, 1967c) distinguish among the items belonging to edition "D" several types differing by the number of sheets (two or four) and by the number of colours used, as well as one more edition, "E" (offset reprint of a number of associated coloured sheets, e.g. of the Polish Military Geographical Institute), then we can conclude that the *Grossblätter* of the *Karte des Deutschen Reiches* constituted a true mystery box.

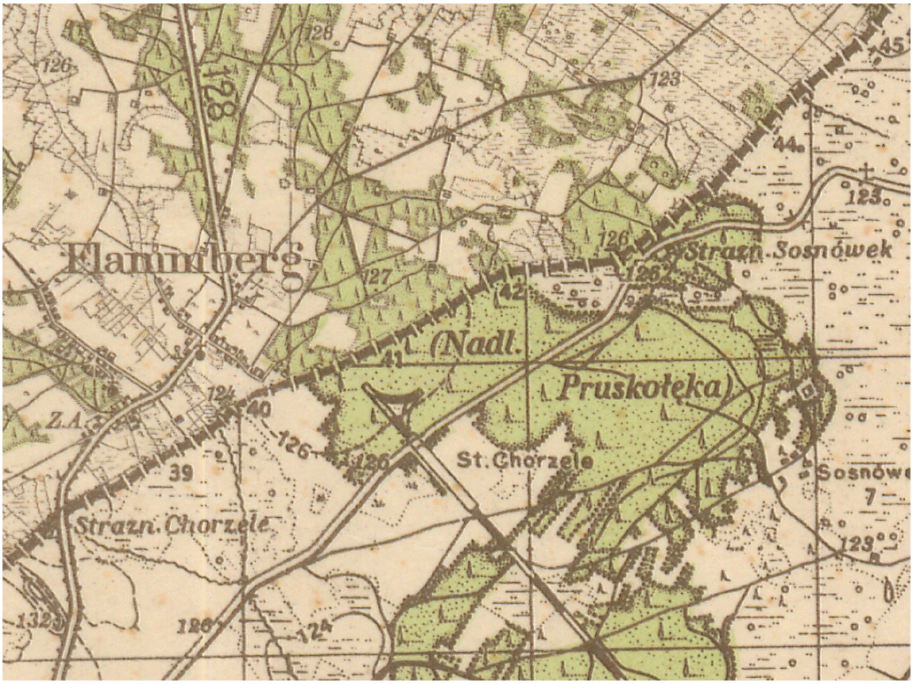

Fig. 2.10. *Karte des Deutschen Reiches* (part of sheet Grossblatt 44 Ortelsburg edition "D") – example of combination original KdDR with tactical map of the Military Geographical Institute: distinctness of the drawing of situation, conventional signs, grids and the lack of the full agreement of fitting on point of contact; original scale 1:100 000

Fig. 2.11. *Karte des Deutschen Reiches* – part of Grossblatt 44 Ortelsburg edition "D" (on base *Karte des Deutschen Reiches* 1920-1938, edition 1943); original scale 1:100 000

Symbols used on the *Karte des Deutschen Reiches* were almost identical with the ones of the *Messtischblätter* (see *Das Reichsamt*…, 1931, Tafel 11). It is, though, worth noting that while forests were represented relatively accurately, the non-forest land cover types were subject to a significant graphical and cognitive generalisation (Osowski, 1955; Pasławski, 1967b).

The study here reported made use of four joint sheets from the edition "D": 44 Ortelsburg, 45 Johannisburg, 340 Mielau, 341 Łomża. The two former are composed of the maps of the *Karte des Deutschen Reiches* from the years 1920-1938, while the two latter – of the tactical maps, elaborated at the Polish Military Geographical Institute, from the years 1930-1940 (Fig. 2.11). The sheets were acquired from the Map Archive of the Military Geographical Institute 1919-1939 (http://polski.mapywig.org) and from the Central Library of Geography and Environmental Protection of the Institute of Geography and Spatial Organization.

2.4.2. Polish and Russian cartography from before 1918

Topographic map of the Polish Kingdom (1:126 000)

Topograficheskaya karta Tsarstva Polskogo

The history of cartography under the Russian occupation, concerning the area in question, starts in the year 1822. At that time the General Quartermaster of the Polish Army began the elaboration of the topographical relevés on the scale of 1:42 000, with the aim of developing on their basis the map on the scale of 1:126 000, referred to later on as the *Topograficheskaya karta Tsarstva Polskogo*. The defeat of the Polish November Uprising against the tsarist rule and *de facto* (even though not formal) liquidation of the nominal Polish Kingdom caused the interruption of the work in 1831. Two years later this endeavour was taken over by the Russian Detachment of the Corps of Topographers for the Measurements of the Polish Kingdom and work was continued conform to the earlier measurement instructions of the Quartermaster's and with participation of the Polish specialists, having been engaged since the very beginning in the work on the map. In 1839 the last sheets were handed over for engraving, while the first printed edition of the whole is dated 1843 (Paćko & Trzebiński, 1983, item 104).

Despite the fact that this map is considered to be a milestone in the history of the Polish military cartography, it still constitutes a source of numerous mysteries, since the majority of the documentation was lost or was destroyed during World War II. It is known that before the start of the taking of topographical relevés the new triangulation chains had been established (mainly at the interfaces of the source maps), numerous astronomical measurements were performed, but, at the same time, older triangulations, conducted in connection with the border delimitation, were used, as well (Krassowski, 1978, pp. 9-10; Olszewicz, 1921, pp. 111-114). The mathematical construction was based on the Walbeck ellipsoid and the pseudo-conical equal-area Bonne projection. The proper topographical work started with the mapping of the Prussian boundary, that is – in particular – the area of the present study. Based on the total number of 408 sheets on the scale of 1:42 000, by reduction, 32 sheets on the scale of 1:126 000 were elaborated (Osowski, 1955), i.e., more or less the number that was supposedly prepared or fully finished and published[11] until 1831. The basic source material in the work on the topographical relevés of the Prussian boundary was constituted by the map of Textor, but older materials were most probably also used (Babicz, 1995, pp. 167-168). The homogeneity and the consistency of the drawing allow for the supposition that the executors were guided by a detailed instruction and a key to the topographical symbols (such materials have not been found until now). It is still an open question, though, to what extent the topographers developed new relevés, and to what extent they only updated old materials in the field (Krassowski, 1978, pp. 10-13).

The study here reported made use of the Quartermaster's map of 1863, referred to as the second edition[12]. The entire set is composed of 60 sections on 58 sheets, printed on tissue paper, and, in distinction from the first edition, on which political and administrative boundaries were hand coloured, entirely black-and-white (Paćko & Trzebiński, 1983, item 148; Szaniawska, 1997), see Fig. 2.12. On all sheets the cartographic grid was marked every 10′, and along the frames, additionally, the division into 1′ intervals of longitude was marked, referring to the prime meridian crossing Warsaw (21°00′42″ E of Greenwich). The average error of location of the points on the map is approximately equal 700-750 m, and is several times bigger for the longitude than for the latitude (Bojarowski et al., 2000; Krassowski, 1978).

The legend, provided on the sheet of column II section VIII (k2s8), contains 52 basic topographical signs. Forests were divided up into two categories: forest and swampy forest. Three non-forest formations were distinguished: thickets, meadows and swampy meadows. In places of the small-scale mosaic of forests and swampy meadows or bushes the legibility of the signatures decreases. The actual distinction of the forest types is often impossible, and the identification of the boundary of the high forest as a common category is difficult. Correct identification of designation of areas is additionally made difficult by the hachures as a mode of representing relief. When analysing these maps from the standpoint of analyses of changes in forest cover one should also remember that the military Quartermaster Map renders in a particularly precise manner the elements that are essential for the conduct of the military operations or for the strategic purposes. Forests, on the other hand, were treated less precisely, since they were considered to be unfit for the conduct of military operations.

Three sheets of the map were used in the study (k4s1, k5s1, k5s2), acquired from the Central Library of Geography and Environmental Protection of the Institute of Geography and Spatial Organization in Warsaw.

[11] The coincidence of these numbers, and even the numbers themselves, turns out, though, subject to debate, since the sheets were nor engraved in their totality, but element after element (Krassowski, 1978, p. 15).

[12] It is commonly considered that there are two editions of the map (1843 and 1863), distinguished first of all on the basis of the quality of paper (thick and tissue paper) and the technology of prints (copperplate or lithograph), and to a lesser degree by the differences in content. Krassowski (1978, pp. 24-25), though, suggests that an in-depth analysis of the latter kind of differences would lead to distinction of at least five separate editions.

Fig. 2.12. *Topograficheskaya karta Tsarstva Polskogo* – part of sheet col. IV sec. I (compilation 1822-1831, edition 1863); original scale 1:126 000

New Topographic Map of Western Russia (1:84 000)

Novaya Topograficheskaya Karta Zapadnoy Rossii

Publication of the *Topograficheskaya karta Tsarstva Polskogo* and of the *Voyenno-topograficheskaya karta Yevropeyskoy Rossii*, based on the former, satisfied to a large extent the needs of Russia, but an instant came, when lack of relevés on a bigger scale started to be acutely felt. Russia, though, did not have a uniform and equally spaced triangulation grid – chains of the first order were established in various governorships at different periods of time and according to current needs, while on forested areas the basis for the topographical relevés could only be constituted by the polygon series, their points characterised by much lower accuracy. Suffice to say that on the area of the Polish Kingdom, under Russian occupation, there were at that time five different triangulations, based on four reference points and three ellipsoids, with the inconsistencies at the joins exceeding in some places 100 metres (see Sobczyński, 2000, p. 105). It was necessary, therefore, to undertake new triangulation works, which started in 1880. Over the study area, encompassed by the Warsaw grid on the evened out Zhylinskiy ellipsoid, they lasted until 1892 (Osowski, 1955).

Simultaneously with the triangulation work, taking of new topographical relevés of the Polish Kingdom was started. Yet until 1912 the relevés were elaborated on the scale of 1:21 000; a part of sheets were published printed as the uni-colour copies of the relevé, while another part as photo-mechanical reduced images. The latter, though, turned out to be quite poorly legible, mainly owing to excessively dense altitude contour lines (drawn with the altitude step of 1 fathom, i.e. 2.13 m). While work on the maps of the scale of 1:21 000 was continued, taking of the relevés of the situation on the scale of 1:42 000 was started, and conducted until 1913. These maps were also published as copies, but much more legible ones. The topographical work for the area of the Polish Kingdom was carried out in the years 1881-1898, with the area of study having been charted in its majority in the period 1886-1887, that is – yet on the scale of 1:21 000.

Based on the materials described, through reduction and generalisation, elaboration of the *Novaya Topograficheskaya Karta Zapadnoy Rossii* on the scale of 1:84 000 was started in 1883. Its mathematical construction was based upon the Zhylinskiy ellipsoid and the pseudo-conical equal-areal projection of Bonne. The sheets did not contain the cartographic nor topographic grid, and only geographical coordinates in the corners and the division into segments of 1′ on the frames for the longitude, calculated with reference to the prime meridian in Pulkovo (30°19′39″ E of Greenwich). The maps were executed in two colours: brown (relief) and black (all other elements of the content). The entire map was published by the Cartographic Department of the Military-Cartographic Division of the General Staff in St. Petersburg in the years 1912-1915.

Fig. 2.13. *Novaya Topograficheskaya Karta Zapadnoy Rossii* – part of sheet no XVIII-9 (compilation 1885-1886, edition 1913); original scale 1:84 000

Forests were designated by a single signature, irrespective of the kind of tree stands – with well visible small circles, bounded by the distinct dotted contour (similarly as the boundaries of the agricultural cultivations). Of the non-forest formations bushy areas, thickets, felling clearings, as well as meadows and pastures were distinguished (Osowski, 1955). Drawing is generally clear and legible, and does not pose problems concerning interpretation, this facility being definitely enhanced by the separate colour used for altitude contour lines (Fig. 2.13).

The study here in question made use of four sheets (XVIII-9, XVIII-10, XIX-9, XIX-10), elaborated in the years 1885-1886 and published in 1913. All of them were acquired from the Central Library of Geography and Environmental Protection of the Institute of Geography and Spatial Organization in Warsaw.

2.4.3. Polish cartography after the year 1918

Tactical Map of the Military Geographical Institute (1:100 000)

At the instant when Poland regained independence in 1918, the coverage of the Polish territory with maps looked like an image put together with the puzzle elements coming from several boxes, featuring different dimensions and overprints. The inherited cartographic materials differed as to almost every aspect. Suffice to say that there were on the territory of Poland, at that time, six triangulation grids (Prussian, Warsaw, Grodno, Dorpat, Vienna and Lwów), based on four ellipsoids (Bessel, Walbeck, Zhylinskiy and Delambre), with eight astronomical reference points (Rauenberg, Helmertturm, Warsaw, Niemież, Dorpat I and II, Vienna and Lwów) (Krassowski, 1974; Krassowski & Tomaszewska, 1979, p. 9; Słomczyński, 1934; Sobczyński, 2000, p. 105). In addition to all this, Poland inherited, as well, a number of different implementation projections, reference levels, prime meridians, and also mutually inconsistent coordinate systems and sheet divisions, the differentiated accuracy of the very topographical-cartographic work in the particular occupied parts of Poland put apart.

Thus, the Military Geographical Institute, responsible for the resolution of this cumbersome situation, faced a very difficult task, especially insofar as: *for the development of an accurate topographic map a precise geodesic, trigonometric and altitude bases are necessary. The fundamental condition for every such base on the territory of a country is its homogeneity, that is – founding of the triangulation grid on the same initial point and the same astronomic points, and founding of the altitude base upon the same reference point measured with respect to the sea level at a precisely defined location.* (...) *This work* [the table relevés] *must, of course, be founded on the uniform reference ellipsoid, and all the maps of a given scale must be developed conform to a uniform cartographic projection* (Krassowski & Tomaszewska, 1979, p. 8).

In the light of the above facts and remarks the very first Polish cartographic undertakings, realised in the years 1920-1922 and concerning the tactical map[13] on the scale of 1:100 000, could only consist in the reproduction of the maps of the partitioning powers. In practical terms these were the photo-mechanical copies, which differed as to virtually all aspects (like construction elements, symbols used, manner of presenting relief, formats, onomastics, degree of detail, dates of development, etc.), and the sole common denominator was scale. Maps originating from this period have been called, with time, the provisory type.

[13] The study neglected entirely the detailed map on the scale of 1:25 000. This resulted from the fact that – as demonstrated by Krassowski (1982, pp. 97-98) – this map covered only the western part of the boundary with East Prussia (the boundary with area of the Free City of Gdańsk and the adjacent segment of the border). The establishment of the precise number and reach of the developed detailed maps is nowadays very difficult – can be often misleading, and sometimes is simply impossible (see Krassowski & Tomaszewska, 1979, p. 6).

Fig. 2.14. Tactical map of the Military Geographical Institute – part of sheet P34 S32 168 Ortelsburg, reproduction of *Karte des Deutschen Reiches* 1927 model 1929 (edition 1930); original scale 1:100 000

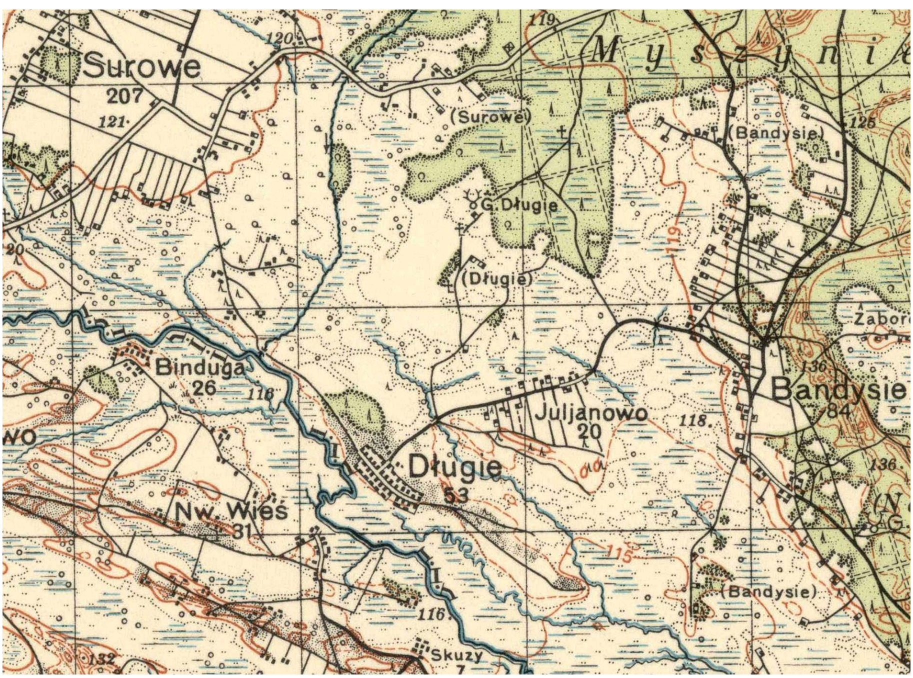

Fig. 2.15. Tactical map of the Military Geographical Institute – part of sheet P35 S32 Chorzele, normal four-colour type (compilation 1931 r., edition 1932); original scale 1:100 000

Certain changes started to be introduced in the years 1922-1926, aiming at homogenisation of the materials. They concerned, in particular, the manner of presenting the relief and the topographical signs, with a limited part of content having been subject to in-field updating. These maps did not contain the kilometre grid, and the errors of location attained several hundred metres. Until 1939 merely 4% of the territory of the country had been covered with these maps. They are referred to in the literature as the first type (model 1922).

The subsequent changes took place in the years 1926-1929. The format of sheets and the description of contour lines were unified and the prime meridian was obligatorily taken to be Greenwich. Even though the maps were elaborated with much more care in terms of graphics and there has been a widely conceived updating works done, these maps did still not satisfy the conditions set for the military products with regard to cartographic accuracy. This was made even worse by the lack of kilometre grid, necessary for the artillery. Until the year 1939 these maps, called type two (model 1926), covered only 6% of the country (Krassowski, 1974, 1982; Krassowski & Tomaszewska, 1979).

There was a breakthrough in Polish military cartography in the years 1929-1931. Already in 1928 a new, official, unified for the entire country, projection was adopted for the future military detailed and tactical maps (the so-called quasi-stereographic projection of the Military Geographical Institute, defined on the Bessel ellipsoid with the reference point in Borowa Góra)[14]. In the first years, hybrid sheets have been elaborated, in which the new topographic grid of the continuous projection of the Military Geographical Institute was applied to the maps based on the discontinuous polyhedral projection. Such kind of practice, though, was considered to be admissible, since the graphical differences were almost imperceptible (Słomczyński, 1934). In 1929 new regulations were also adopted on the preparation of the military maps and the military-geographical description, while in 1931 the topographical signs were modified. In the years 1929-1931 the maps were published in the bi- and four-colour versions. Despite the gigantic step forward, the resulting elaborate was still not homogeneous, which was not only the consequence of the consecutive changes in the mathematical foundations, but also from the differentiated course of the updating work, conducted in the field on the basis of materials featuring different scales. Until 1939 these elaborates, called type three (model 1929) covered approximately 20% of the country's area.

Then, the years 1931-1939 constitute the period, which is deeply marked in the history of Polish cartography. The tactical military map, which emerged as a result of the long-term evolution, was considered among the leading elaborates of this kind in the world. All the maps were printed uniquely in four colours (except for the tourist edition)[15], and since 1934 also in the entirety conform to the unified construction principles of the new quasi-stereographic projection of the Military Geographical Institute. Two years later,

[14] The analytical precepts of this projection were developed by L. Grabowski from the Polytechnic of Lwów, who modified the existing projection of Roussilhe (Biernacki & Słomczyński, 1932).

[15] Publication of the tourist type maps in the six-colour version started in 1933. Grey-violet colour was applied in the angular hachure of the relief in the mountains, while red colour was used to show the tourist paths. Until 1939 only 40 items were published, of which a vast majority concerned mountain areas (Osowski, 1955; Sobczyński, 2000).

a new style of the out-of-frame descriptions was introduced. Yet, the most important was the fact that the majority of the basic material was constituted by the maps on the scale of 1:25 000, verified in the field, as well as the original table relevés (although the latter to a very limited degree, namely roughly in 4%), executed by the Topographical Department of the Institute. Until 1939 these maps, called normal four-colour type (model 1931), covered approximately 80% of the area of Poland (Krassowski & Tomaszewska, 1979).

Yet, the study in question concerned also the areas, which, at that time, in the interwar period, were outside of the boundaries of Poland. For these areas publishing of maps started at the end of the 1920s. Initially these were the single-colour reproductions of the maps inherited from the occupying administrations, but starting already with 1929 they were developed according to the model of the Polish tactical map. The source material for the area here considered was constituted by the German *Karte des Deutschen Reiches*, and so a part of maps were printed in the bi-colour version, with the relief represented by the hachures. The list of topographical symbols was provided on the margin along with detailed explanations. Maps of the areas beyond the border were secret, as meant uniquely for the military – and so they bore the reservation "Solely for orderly use". Together with the classification adopted in Poland, they also had the Grossblätter number printed on them (Krassowski, 1974; Sobczyński, 2000). The sequence of publishing of the individual items was strictly dependent upon the then current geopolitical situation and the priorities of security concerning the eastern and western strategic areas. Already in 1932 the tactical map of the areas outside of Poland covered the entire boundary with East Prussia (Krassowski, 1982).

Forests were designated with three kinds of symbols, with distinction into the coniferous, deciduous and mixed forests. Among the non-forest formations the following ones, in particular, were distinguished: 1. thicket, bushes and osier beds; 2. meadows and pastures with bushes; 3. swamps and bogs with peat-bogs, and 4. empty spaces and dried-out swamps.

The study here considered made use of nine sheets of the maps, elaborated on the basis of the source materials from the years 1920-1930 (updated to a varying degree) and published in the period 1930-1932. They originated from three different editions:

- single-colour reproductions of the *Karte des Deutschen Reiches* according to the model 1929 (P34 S31 167 Passenheim, P34 S32 168 Ortelsburg, P34 S33 169 Johannisburg), see Fig. 2.14,
- the bi-colour type from the years 1929-1931 (P35 S33 Myszyniec; P36 S31 Mława; P36 S32 Przasnysz);
- the normal four-colour type from the years 1931-1939 (P35 S31 Janowo-Nibork; P35 S32 Chorzele; P36 S33 Ostrołęka), see Fig. 2.15.

All these sheets were acquired from the web-based Map Archive of the Military Geographical Institute 1919-1939 (http://polski.mapywig.org).

2.4.4. Polish cartography after the year 1945

Map of the "Borowa Góra" series (1:100 000)

Just after World War II, namely in 1947, the Military Geographical Institute started publishing a new topographic map on the scale of 1:100 000. It has become common to call this edition "Borowa Góra" (BG) in reference to the name of the system of coordinates, based on the quasi-stereographic projection of the Military Geographical Institute. Thus, both the constructive elements of the map and the division into sheets, as well as the set of symbols, were all almost identical to those for the pre-war tactical maps. These maps, anyway, constituted the primary basic material for the entire BG series, while in the case of the study area also the *Messtischblätter* 1:25 000 and the *Karte des Deutschen Reiches* 1:100 000 were used as the basic material.

Until the year 1955 almost entire area of the country (roughly 98%) was covered by these maps. In the initial phase of work the elements of the situation were being updated only cursorily in the field – with exception of the road network and the onomastics, since high importance has been attached from the very beginning to updating of these two aspects. In the subsequent years aerial photography started to be used for purposes of the in-house work, in order to update, in particular, the reach of forests, buildings, and roads of lowest categories. The symbols were also simplified – including those designating forests – and printing in five colours was started, with addition of green on the forests, and yellow or red for the roads, which enhanced considerably the legibility of the map (Fig. 2.16). Alas, already in 1952, due to new regulations concerning state and official security, the maps from the "Borowa Góra" series were made completely secret and unattainable for the private users, and this lasted for close to 40 years (Sobczyński, 2000, p. 214).

Fig. 2.16. Topographic map "Borowa Góra" – part of sheet P34 S32 (compilation and revision 1950 r., edition 1951); original scale 1:100 000

The study in question made use of nine sheets, elaborated on the basis of the source materials from the years 1927-1939, updated in the years 1950-1951 and published in the period 1951-1953. These sheets were: P34 S31 Pasym, P34 S32 Szczytno, P34 S33 Pisz, P35 S31 Nidzica, P35 S32 Wielbark, P35 S33 Myszyniec, P36 S31 Mława, P36 S32 Przasnysz, and P36 S33 Ostrołęka. All of these sheets were acquired from the Central Library of Geography and Environmental Protection of the Institute of Geography and Spatial Organization in Warsaw.

Topographic map "1965" (1977-1985) (1:50 000)

Maps on the scale of 1:50 000 in the "1965" system of coordinates, which were used in the study, originate from the edition, which appeared in the years 1977-1985 and was elaborated on the basis of the military maps in the "1942" system of coordinates, as well as using of the already existing elaborates on the scale of 1:10 000. Maps from the second mapping zone were elaborated according to the true-angle quasi-stereographic projection on Krasowski ellipsoid. Only topographic grid was shown on the sheets, with no information on the geographic coordinates. A detailed characterisation of the maps "1965" seems to be unnecessary here, for they were described many times over in the literature (see, e.g., Macioch, 1994; Podlacha, 1994).

In terms of the distinguished plant formations these maps are quite rich in content, as seven major categories along with the sub-categories, were distinguished: high forest (coniferous, deciduous, mixed), thin forest, grove, as well as dense shrubs (deciduous, coniferous), orchard, meadow (dry, swampy), and also reeds and rushes. High forest designated the area with trees of average height exceeding 4 metres, thin forest – the

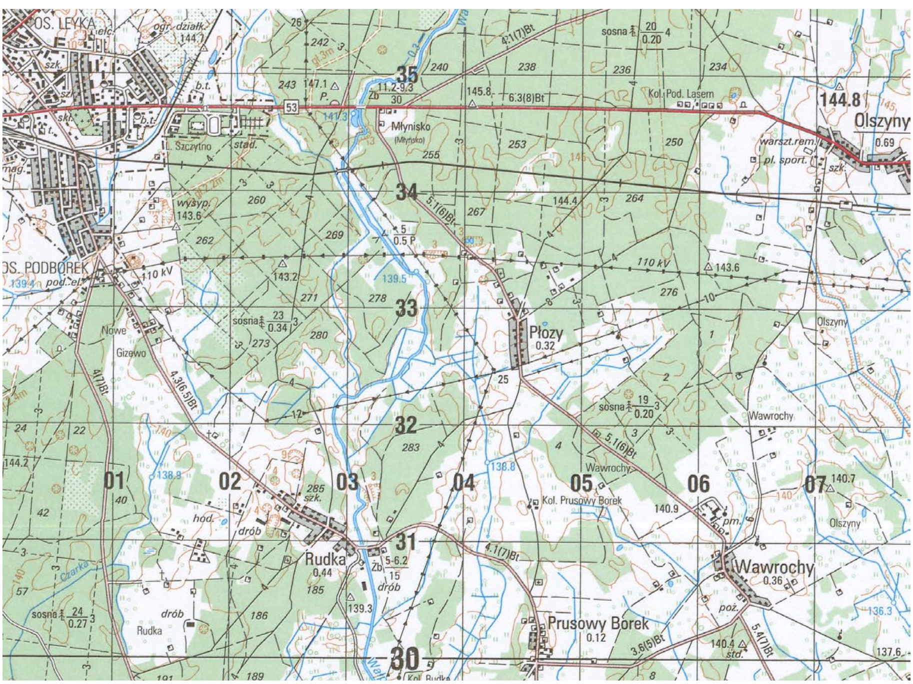

Fig. 2.17. Military Topographic Map of the series M755 – part of sheet N-34-91-AB Świętajno (compilation 1993, edition 1998); original scale 1:50 000

area, on which the average distance between trees is bigger than their average height, while groves – trees having average height below 4 metres, and forest nurseries. In the effect of generalisation of the symbols used on the maps, for the purposes of this study two categories of the forested areas were distinguished: high forest (identical with the analogous notion on the maps), and low forest (= thin forest + groves).

The study made use of 16 sheets of the map, elaborated in the years 1970-1973, and published in 1977. These were: 232.2 Olsztynek, 232.4 Nidzica, 233.1 Szczytno, 233.2 Ruciane-Nida, 233.3 Wielbark, 233.4 Myszyniec, 234.1 Pisz, 234.3 Kolno, 242.2 Działdowo, 242.4 Mława, 243.1 Chorzele, 243.2 Kadzidło, 243.3 Przasnysz, 243.4 Ostrołęka, 244.1 Nowogród, 244.3 Ostrołęka Stacja. All of them were acquired from the Central Library of Geography and Environmental Protection of the Institute of Geography and Spatial Organization in Warsaw.

Topographic map "1965" (1980-1990) (1:25 000)

The subsequent series of maps "1965", and on a bigger scale (1:25 000), was elaborated in the years 1980-1990 through re-editing of the 1:10 000 maps, updated in the 1970s. Individual sheets of this series were used in the study as the base during the in-field charting of the potential natural vegetation, and then, after the final copies were prepared, they constituted the source material for the vectorisation of the distinctions on the respective subject-oriented map. Symbols used followed the model of 1966, and so the division into the categories of the plant formations is similar to that from the maps on the scale of 1:50 000. The remaining features are common, and so a more detailed characterisation of this particular series seems to be unnecessary.

The study made use of 31 sheets of this map, elaborated in the years 1980-1982 and published in the years 1984-1985. These sheets were 232.22 Stawiguda, 232.24 Jabłonka, 232.42 Napiwoda, 232.44 Nidzica, 233.11 Pasym, 233.12 Trelkowo, 233.13 Jedwabno, 233.14 Szczytno, 233.21 Piasutno, 233.22 Ruciane-Nida, 233.23 Świętajno, 233.24 Faryny, 233.31 Kot, 233.32 Wielbark, 233.33 Janowo, 233.34 Zaręby, 233.41 Klon, 233.42 Rozogi, 233.43 Surowe, 233.44 Myszyniec, 234.31 Łacha, 234.33 Turośl, 243.11 Duczymin, 243.12 Chorzele, 243.14 Jednorożec, 243.21 Zawady, 243.22 Kadzidło, 243.23 Baranowo, 243.24 Dylewo, 243.41 Drążdżewo, 244.11 Zbójna. All of them were acquired from the Central Library of Geography and Environmental Protection of the Institute of Geography and Spatial Organization in Warsaw.

Military Topographic Map (series M755) (1:50 000)

The image of the most recent state of forest cover on the study area is represented by the military topographic maps elaborated according to the NATO standards. Their history goes back to the year 1992, when Department of Defence of the United States and the Polish Ministry of National Defence signed an agreement on cooperation and exchange of basic materials in the domains of military topography, aerial and maritime cartography, geodesy and geophysics, as well as digital data. The operational parties to this agreement were the Defence Mapping Agency (DMA) on the US side and the Topographical Board of the General Staff of the Polish Army. The process of adaptation to the new requirements included, in particular, establishment of the Military Basic and Detailed

Geodesic Grid in the WGS-84 setting, transformation of the geodesic data to the WGS-84 setting and the UTM mapping, elaboration of the theoretical and executive foundations for the new maps in the paper and digital forms, and finally the adaptation of the existing normative documents from the domains of geodesy and cartography (Graszka & Pietruszka, 2001).

The topographical service started the elaboration of the new maps in 1994. All the map emblems are composed of joint sheets, this being the specific feature of the cartographic products of NATO. Initially, maps were published in the coordinate system "1942" with the blue overprint of the kilometre grid in UTM setting – this was the so-called First adjusted edition. The second edition was prepared already according to the full NATO standards, with a part of sheets having been developed uniquely by mechanical mounting of the ready diapositives, elaborated a couple of years earlier (Fig. 2.17). The third version is constituted by the analogue derivative of the digital VMap elaborate (see further on). Along with the evolution of the successive editions and the advance of the process of adaptation to the NATO standards, consecutive modifications were being introduced, encompassing, in particular, the change of symbols and the number of colours, removal of the strictly military characteristics or extension of the out-of-frame description (Graszka & Pietruszka, 2001).

The mathematical construction of the M755 series is based on the UTM (Universal Transverse Mercator) projection and the WGS-84 ellipsoid. The sheets contain the geographical coordinates in the corners and the topographic UTM grid. Division into sheets is conform to the principles of division of the so called International Map of the World on the scale of 1:1 000 000. There are four symbols used to designate forests: deciduous, coniferous and mixed forest, as well as young forest, with additional description of tree height, thickness of trunks and distances between trees. Out of the non-forest formations the maps distinguished, in particular, mountain dwarf pine areas, dry and swampy meadows. The basic tactical topographic map on the scale of 1:50 000 served in our work as the auxiliary, analogue reference material during calibration of the raster images and as the additional source of information with respect to the content available in the digital reference base VMap Level 2, which is in some places highly generalised.

The study made use of nine sheets of the maps, elaborated in the years 1980-1993 and published, after a partial updating, in 1998. These sheets were: N-34-90-A,B Szczytno, N-34-90-C,D Wielbark, N-34-91-A,B Świętajno, N-34-91-C,D Myszyniec, N-34-92-C,D Kolno, N-34-102-A,B Chorzele, N-34-103-A,B Kadzidło, N-34-103-C,D Jednorożec, N-34-104-A,B Nowogród. All of these sheets were acquired from the Central Library of Geography and Environmental Protection of the Institute of Geography and Spatial Organization in Warsaw.

VMap Level 2 (1:50 000)

The most recent and at the same time referential material was constituted by the products from the Vector Smart Map family, whose history started in 1993. It was then that the Military Cartographic Agency of the US Army approached the military geographical services of Canada and a couple of European countries with the proposal of joint elaboration of the vector map for the entire world. The original model for the whole sequence of the scale series[16] was VMap Level 0 – the very first, in the history of contemporary cartography, homogeneous digital product of the worldwide reach and the resolution corresponding to the level of detail of the paper maps on the scale of 1:1 000 000. The cognitive model of the products from the VMap group is derived from the standard DIGEST (Digital Geographic Information Exchange Standard), encompassing, in particular, the theoretical data model, information content (including the scheme of coding of geographic objects and their attributes), data exchange format, and even the manner of their organisation in the distribution media (Gotlib et al., 2006).

The reference base[17] for all the cartographic materials in the model of changes in forest cover during the last 200 years is provided by the VMap Level 2 of the first edition, elaborated in the years 2000-2004 by the Topographical Service of the Polish Army on the basis of the diapositives of the Military Topographic Map on the scale of 1:50 000 (series (M755). This choice was dictated by the fact that in 2009 this was the sole digital map covering the entire country, developed from scratch according to the unified prescriptions, while its scope and level of detail corresponded to the purposes of the analysis.

The practical use of the reference data on objects required, though, appropriate preparations – both of the attribute data and their vector representation. In the first case this was caused by the complex structure of data, developed with the use of the hermetic standard FACC (Feature And Attribute Coding Catalogue), in which identification of an object takes place through the use of a unique, five-element alphanumerical code. Although a simplified coding scheme, FACV, was implemented in the final product, yet, it is characterised by a more complex attribute structure. It is necessary to refer to the operator instructions and vocabularies in order to correctly interpret the primary categories and classes of objects, as well as their features and attribute domains and values (more on this subject in the Chapter 3).

The second problem was constituted by the lack of cartographic visualisation. Final products of the VMap technological cycle are developed in the VPF format (Vector Product Format), which integrates in a complex manner geometry, topology and attributes in the unified, relational data structure (Gotlib et al., 2006, p. 29). The native format is reserved, though, for the narrow circle of users (state administration, military and other uniformed services, emergency management), while remaining users may obtain only the materials in the form of shapefiles. Conversion from VPF to shapefile involves removal of topology and of all cartographic signs, so that the resulting cartographic representation takes the form of a "raw" vector, i.e. the sets of objects visually unordered and shown with the use of default signs and styles. After the data are imported to the environment of standard GIS tools, their attribute and spatial re-integration and re-symbolisation, become necessary (Bac-Bronowicz et al., 2006).

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[16] Four levels of vector maps are distinguished currently, featuring accuracy and resolution corresponding to the scales from 1:1 000 000 (Level 0) to 1:25 000 (Level 3).

[17] In a broader perspective, the geographical reference data, understood as a part of the national infrastructure of spatial data, is formed by the data resource that is used by numerous individual and institutional users and constitutes the foundation for all kinds of activities associated with the processing of geo-information and with the management of space (Bac-Bronowicz et al., 2006).

VMap Level 2 is distributed in the form of double sheets with resolution corresponding to the scale of 1:50 000. When it is utilised as the reference material, attention ought to be paid not only to the above described issues associated with the internal structure of the files, but also to the specific nature of the very cartographic "output". The difference of the editorial prerequisites (especially in terms of generalisation of content) is visible in the comparison with the civilian edition of the topographic map on the scale of 1:50 000, which is characterised by more detailed content and better accuracy of location of points (Gotlib et al., 2006). Not less important are also the classification criteria and the manner of defining objects. In the context of the subject matter of the study the highest attention was paid to the distinctions made in the category of surface vegetation forms, first of all – forests (i.e. the surfaces covered in their majority by the persistent woody vegetation), grassy vegetation / meadows (surfaces covered by the herbaceous vegetation, most often used for pasturing livestock), as well as bushes / dwarf mountain pine thicket / groves (surfaces with low forest-like vegetation). One notices, in particular, the graphical generalisation of the small forest patches (all those having area below 25,000 m^2 in the forested terrain and below 10,000 m^2 in the weakly forested terrain are presented as points), the generalisation of categories regarding permanent grasslands (lack of distinction into meadows, pastures, swampy or overgrowing grassy areas) and the lack of possibility of distinguishing the areas of succession (a single class encompasses groups of bushes, areas of compact thicket, dwarf pine areas, groves, forest nurseries, as well as young woods).

The study made use of nine "sheets" of the maps (emblems like in the case of the M755 series), elaborated in the years 1980-1993 and published after a partial updating in the years 2000-2004. The respective materials were acquired from the Provincial Centres of Geodesic and Cartographic Documentation in Warsaw and Olsztyn.

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3. ELABORATION OF THE CARTOGRAPHIC MATERIALS FOR THE PURPOSES OF ANALYSIS OF CHANGES IN FOREST COVER

Jacek Wolski

3.1. Need for digital maps

Use of the Geographic Information Systems (GIS) in the historical-environmental studies has become common (see Gregory, 2005; Rumsey & Williams, 2002, and the rich literature therein). Almost unlimited capacities of processing and analysing data cannot, though, substitute for the basic conditions that have to be satisfied both by the source information (in order for it to be useful), and by the methods of acquiring it. This is very adequately expressed by one of the basic tenets of computer science, and in particular – of the GIS systems, called "GIGO" (*Garbage In, Garbage Out*). Low quality of the source materials and uncontrolled propagation of errors at the stage of data input, exert direct influence on the results, and, consequently, on the correctness of the entire reasoning. This concerns, first of all, the materials from before the epoch of mathematical cartography, but those more recent (from the 19th and 20th centuries) as well. On the other hand, though, in the quest for the maximum possible accuracy or precision[1] one should not forget that the GIS systems are not meant to create the ideally faithful "copy" of the natural environment, but only to develop its model that approximates the reality in a manner better or worse. Having in mind the above considerations, this chapter outlines in an abbreviated way the consecutive stages of developing the model of forest cover changes within the Masuria-Kurpie borderland over the last 200 years. The respective explanations are insofar important that the model developed constitutes the basis for the majority of historical-environmental analyses, carried out within the framework of the study. The stage of acquisition and selection of the cartographic source materials, along with their characteristics and assessment as to their utility was described in detail in the preceding Chapter 2.

It should also be noted that the numerical maps, contributing to the model in question should not be regarded solely as the cartographic visualisations of the digital data. The proper counterpart here is rather constituted by the database, containing (non-spatial)

[1] It is quite frequent to treat these two terms as synonymous. This is a mistake, since precision means the degree of perfection of the instruments, methods and measurement procedures (admitting the possibility of systematic errors), and also the measure of repetitiveness, while accuracy means the degree of perfection of the measurement, achieved owing to the precision of instruments, methods and measurement procedures, and, at the same time, the measure of conformity with the respective reality.

description attributes that are logically associated and describable with a query language, this database, together with the graphical representation of these attributes in the form of objects of strictly defined geometrical, topological and topographic character, forming a complementary whole.

3.2. The scheme of developing the model of forest cover changes

3.2.1. Scanning

The very first step consisted in scanning of all materials acquired in the analogue form (i.e. paper maps). This was done with the use of the Océ CS4035 Colour System scanner, periodically subject to rectification on the basis of a reference pattern, which significantly limited the deformations of the original image, associated with de-calibration of the CCD cameras. Visual assessment of the progress in scanning of the particular maps did not reveal the traces of the phenomenon of the so-called idle roller slipping. Maps, depending upon the drawing of the content, were scanned with the resolution of 400 and 600 dpi, such settings guaranteeing that the dimensions of the pixel were significantly smaller than the graphical accuracy of any of the source materials used. The 24-bit mode was applied and only the ready raster was converted to a smaller colour depth (8-bit). In view of the possibility of occurrence of information loss neither the binary mode was not applied to the greyscale images, nor thresholding (method of image segmentation), referring to the grey level, at which the distinction of the background and the proper content is set. Likewise, filtration of the pixel noise was not carried out.

3.2.2. Selecting the way to represent the environment

The subsequent stage consisted in choosing the appropriate method of digital representation of spatial data. In order to do that, it was necessary to analyse the needs and the requirements, which encompassed, in particular, the objectives and the scale of the study, the manner of collecting information, and the possible degree of generalisation of data. Priority, though, was given the very nature of the data (forests, i.e. surface objects having clearly defined boundaries and shapes) and the methods of their further consideration with application of Boolean algebra. By taking the above criteria in relative terms, the vector model was deemed to be the best way of representing the environment. This model, namely, in distinction from the raster-based one, is primarily meant for presentation of the discrete phenomena and the boundaries of objects. It is also characterised by the capacity of correct reconstruction of the location and shape of polygons, by the possibility of presenting the lines of discontinuity, facile updating of data, as well as performing geometrical transformations and editing.

3.2.3. Calibration and registering of the raster images

Beyond any doubt, the most difficult task was calibration of the individual sheets of maps. This process, serving to remove the geometrical deformations of the raster images (like, e.g., scanning errors or nonlinear deformations of the paper, caused by its shrinking) and to bring these images to their nominal dimensions, consists of two steps:

- calculation, with the least squares method, of the transformation matrix on the basis of coordinates of vectors, indicating the magnitude and the direction of translation, and performing the appropriate geometrical transformation, in which the basis is constituted by the control points, whose ground location has not undergone change in the consecutive time slices,
- interpolative resampling of the deformed image to the new raster of the regular dimensions that is rubbersheeting.

The difficulties, mentioned before, were associated first of all with broad range of different mathematical foundations for the elaboration of the particular map series. Consequently, they differed as to almost everything: the ellipsoids, the triangulation grids, the definitions of projections, finally – the coordinate systems with different prime meridians (Greenwich, German Ferro, Warsaw, Pulkovo) and the very coordinates (geodesic, the so-called ellipsoidal – B, L, and Cartesian – X, Y). Many problems were also associated with the apparently ideal and errorless, cartographic (geographic) and topographic (kilometre) grids[2]. A hard task was also posed by the transformation of the maps from the 19th century to their native settings, in connection both with the lack of the appropriately detailed information in the literature, necessary for calculations, and with the limitations to the mapping formulae, implemented in the GIS software. In several cases it turned out necessary to recalculate the coordinates "by hand", with transformation directly to the ultimate setting. Only owing to the detailed studies of literature in the field of mathematical foundations of the maps in question and to the in-depth analysis of all the sheets it became possible to avoid errors and ambiguities (or at least to minimise them), whose reasons and character cannot be described here at large due to the volume limitations of the chapter.

Generally, depending upon the kind of cartographic material and the supposed type of deformations, three models of calibration were applied: the affine (linear transformation of the first degree)[3], the biquadratic and the bicubic (nonlinear transformations of polynomial character), for more details see *ERDAS Field Guide* (1998). In a very rough simplification one can distinguish three paths of proceeding:

- affine calibration solely at the corners of the sheet, or four frames with the coordinates provided;

[2] These problems were linked, for instance, with the differences in the courses of grid lines, otherwise identical as to the principles of construction, on maps from various series (which required additional corrections before vectorisation), the lack of uniformity within the confines of the same sheet (e.g. on the *Karte des Deutschen Reiches* completely different grids appeared on two sides of the Polish-German border), or identification of the old grids drawn into the new coordinate system (frequent cases for the *Messtischblätter* and for the maps of the Polish Military Geographical Institute).

[3] The simplest Helmert transformation, which is commonly used in the case of the overlay large-scale basic maps, where the priority is on their geometrical consistency, was not applied. Although this transformation is the least "invasive" one (does not intervene in the raster matrix, but only changes the heading responsible for the scale, position in the system of coordinates and orientation in the vector space), it is completely ineffective for the case of the older cartographic materials, featuring significant nonlinear deformations.

– biquadratic or bicubic calibration regarding the crossing points of the cartographic or topographic grid;
– initial affine calibration at the corners, followed by the biquadratic or bicubic transformation applied to the control points.

For the particular map series the vector grids (projection files) were generated, while in the case of calibration regarding the control points and/or directly to the ultimate setting (i.e. with omission of the matrix setting), the reference map (VMap Level 2) was used. No multiple (even double) nonlinear transformations were practised of the same raster, in order not to give rise to the uncontrolled changes in the geometry of the image, which are particularly harmful for the comparative analyses over several points in time. The stipulations of the possibly even distribution and the appropriate number of the control points were absolutely kept to, especially during transformation with the use of the higher-order polynomials (when these stipulations are not observed, local, secondary deformations of the image may arise). The SuperEdit Pro 2.7 software, which was applied in the process, enabled dynamic tracking of the translation vectors, deformation grids, as well as partial and total values of the RMSEs (root mean square errors), which made possible a change in the character of transformation or verification of the control points yet before the proper intervention into the raster matrix.

For the individual map series the ranges of tolerated RMSE were established, depending, in particular, upon the scales and the years of publishing of the maps. It was also assumed *a priori* that these errors ought to be smaller than the graphical accuracy of the elaborates (for the 20th century) and accuracy in the sense of average errors of location of points on the source maps (for the 19th century). The results of calibration of all the materials from the last 130-140 years turned out be very good (see Table 3.1), since the mean total deviations were contained with an ample margin in the ranges of tolerance assumed, while the differences between the maximum and minimum values of the partial deviations were similar for the sheets from the particular map series. Alas, such good results could not be achieved for the oldest maps (those of Suchodolec, Schrötter-Engelhardt, Textor and Reymann). Despite undertaking various ways of proceeding (calibration of the entire sheets, as well as their fragments or the multi-sheet mosaic) the values of the mean total errors were high, while the partial deviations were even very high (from tens to more than 500 metres) and, in addition, extremely differentiated for the areas not far one from another. The re-interpretation of the locations of objects, which turned out necessary in these circumstances, done "on fly" during vectorisation, was a difficult task, for it had to account for the imperfections of the calibration as such, and for the inconsistencies associated with the accuracy and the cartometric features of the original maps. This procedure enabled reduce error values (ca. 50-80%), while still remained significantly higher compared to the maps published after 1850 (Table 3.1).

The final phase of the calibration process was registering of the prepared raster images in the ultimate, common for all the bases, and strictly defined, coordinate system. The system selected was the ETRS89/Poland CS92 (EPSG:2180), which, as of January 1st, 2010, became a part of the national system of spatial referencing and at the same time the system obligatory in Poland for all the newly developed topographical maps on the scale of 1:10 000 and smaller (thus replacing the PUWG-65 coordinate system). In practice, this operation consisted in the transformation of the individual map sheets from their native systems to the ETRS89/Poland CS92 system, performed with the use of the mapping formulae, implemented with the SuperEdit 2.7 software. According to the above procedures, calibration and registering of 155 sheets, originating from 15 map series (basic and complementary), was carried out.

Table 3.1. Calibration accuracy of selected series of the basic and the complementary maps

Map	Publication date	Scale	Number of sheets	Mean number of points/ sheet	Min. total RMSE [m]	Max. total RMSE [m]
Military Topographic Map (M755)	1998	1:50 000	9	686	2.3	2.6
Topographic map "1965"	1984-1985	1:25 000	21	185	3.0	4.1
Topographic map "1965"	1977	1:50 000	16	187	3.4	6.9
Topographic map "Borowa Góra"	1951-1953	1:100 000	9	225	7.3	10.3
Tactical map (Military Geographical Institute)	1930-1932	1:100 000	9	235	7.4	12.8
Messtischblätter	1911-1944	1:25 000	39	143	2.0	4.9
Novaya Topograficheskaya Karta Zapadnoy Rossii	1884-1887	1:84 000	5	79	14.2	28.1
Topographische Karte vom Preussischen Staate	1868-1869	1:100 000	6	88	16.4	19.0

3.2.4. Selection of objects

In the case of historical environmental studies, basing on the sequence of cartographic materials from different periods, it is necessary to interpret them beforehand from the point of view of choice of common categories, such that can be unambiguously identified and correctly interpreted in all the considered time slices. The retrospective analyses of changes in forest cover do not require standardisation of the classes selected, for in majority of cases (in this particular study as well) only two categories are actually discerned: the high forest (potentially also the felling clearings and the strongly overgrowing areas with young forest) and the non-forest areas.

Yet, in spite of this, two phenomena occurred in practice: various signs of the legend denoted the same objects in the field, or apparently the same signs of the legend had different meanings. These cases were most often linked with the differentiation of the degree of graphical and cognitive generalisation in materials of various scales and concerned primarily the objects of small areas and the "mixed" categories (e.g. the overgrowing areas). It was also not without significance what was the purpose of (who developed) the map. Thus, e.g., on the military maps the majority of categories of land cover (including forests, felled areas, clearings, or forest vistas) are perceived from the point of view of utility for the military or strategic operations (see Gąsiewicz, 1931, pp. 158-159). On the older maps one deals, in addition, with the issue of in-field identification of the characteristic features of objects, performed according to various instructions by Polish, Prussian and Russian topographers, with the effect of only seemingly consistent classification of the designates.

For purposes of elimination of or at least limitation to the serious interpretation errors, detailed literature studies were undertaken, encompassing the monographic analyses of the individual map series (especially in terms of the content and form of the drawings) and the official descriptions of topographical symbols, providing explanations to signatures (bibliographic details are given in the preceding chapter).

A different way of proceeding was chosen for the selection of the objects from the reference base, constituted by VMap Level 2 of the first edition, corresponding to the scale of 1:50 000. For this purpose, official documentation and auxiliary materials[4] were used: *Operator instructions* (for the linear, areal and point objects), together with additional indications and remarks, the tabular *Dictionary of object names for various coding schemes*, and the application *Coding dictionary VMapDict* ver. 4.02. In the first step all the classes were selected of objects appearing physically on the map sheets encompassing the study area, and then this set was trimmed to those that could be helpful in calibration and digitalisation of forests for the consecutive time slices considered. Ultimately, 60 classes were selected out of the total of 224, distinguished in the FACC coding system (Feature And Attribute Coding Catalogue), on which the cognitive model of VMap is founded. A difficulty resulted from the fact that the names of object classes and their attributes, together with their values, contained in FACC are incomprehensible without additional explanations. Although the final product of VMap is characterised by a more easily interpreted FACV coding system, but still, it turned out necessary to develop a working dictionary for purposes of the present study.

3.2.5. Designing the database

The subsequent step was to design the relational database[5], containing the descriptive attributes and constituting the foundation for the model of changes in the forest cover in the consecutive time intervals. The stage of modelling, founded on the results from the analysis of needs, performed already before, included:

- determination of the kind and scope of the data on forests that can be acquired from the individual map series,
- establishment of the structure of the new database, that is – definition of the division into tables, which would be searched and linked in terms of relations,
- definition of the names, classes and properties of attributes, as well as the unique identifiers (the primary and the foreign keys).

[4] They contain complete specification of the content of VMap Level 2: categories, classes, names and descriptions of objects, attribute classes along with values, alphanumeric codes and the corresponding graphical symbols.

[5] In the relational (geo-relational) model data are stored in tables, composed of records (rows containing "entities", i.e. everything that exists in reality or in imagination) and fields (columns, containing attribute values). Every record is distinguished by the field, containing a unique value (primary key), which, together with the foreign key serves to establish a relation, that is – a link between two tables.

3.2.6. Vectorisation and normalisation of data

The next step in the construction of the model of changes in forest cover was to develop its graphical representation in the form of objects having strictly defined geometrical and topographic character, that is – to perform vectorisation. This was done using the MapInfo 8.0 Professional software. Vectorisation was performed uniquely by hand, directly on the monitor screen, since the drawing of content on the source materials made semi-automatic vectorisation (i.e. tracing of lines) impossible. The analysis of needs, carried out already at the beginning of work, demonstrated that it would be sufficient to discretise spatial information in the form of the simple model (the so-called spaghetti data model), in which points, lines and polygons are recorded independently by coding of the sequences of coordinate pairs.

The entire process of vectorisation was conducted according to the requirements of the retrogressive approach. Adoption of this approach was necessary, because, in view of the much lower accuracy of maps from the first half of the 19th century (Schrötter, Textor and Reymann maps), it turned out impossible to digitise all the surface objects, appearing in respective time slices, strictly "following the line". In such situations, as this has been mentioned already before, it was necessary to reinterpret the location (sometimes also shape) of the polygons, performed "on fly" basing on the newer maps. Besides, the drawing of the content on the maps mentioned (especially on those of Textor and Reymann) made in some places unambiguous identification of objects, that is – distinguishing and drawing of the boundaries between the areas of dense, high forest and the overgrowing (particularly – swampy) areas, quite difficult.

The final stage of vectorisation consisted in verification of graphical errors, carried out for all the sheets in the consecutive time slices. The amendment of topology of connections (in a broad sense) was done in all cases by the same set of tools of analytical geometry from MapInfo 8.0 software. Using these tools, such operations were carried out as, e.g., identification of overlapping, cross-cutting and gaps of the surface and linear objects, pulling of nodes (including closing of polygons), removal or inclusion of the sliver polygons, and so on. A part of tools required taking of different settings separately for each sheet of a map, since application of the same parameters (e.g. boundary conditions or the range of tolerance) would lead to obtaining an apparently nice image, but, in practice, inconsistent with the required geometrical precision of the data.

During the process of vectorisation, and then after its termination (together with the verification of the graphical errors), normalisation of the attribute base was performed. It consisted in the checking of the correctness of the structure and coherence of the entire model, that is – not solely the integrity of the descriptive data, but also their conformity with the graphical representation. Normalisation encompassed, side by side with the correctness of the connections of spatial data, mentioned before, also such aspects as, for instance:

- conflicts in relations between tables (e.g. missing, erroneous or redundant identifiers),
- presence of the unnecessary or repeated entries, as well as correctness of names,
- adequacy of the format and correctness of precision of the entry (too high – unnecessary, too low – erroneous).

3.2.7. Graphical and cognitive generalisation

The purpose of the proper study and the diversity of scales of the source materials forced application of generalisation. It was attempted, though, to keep generalisation at minimum, keeping in mind that the inherent feature of this process is its subjectivity, resulting from the human knowledge and experience. Generalisation was carried out in three stages:

- during the selection of objects for digitalisation, through, in particular, rejection of all the areal and linear elements (forest patches, tree lines) having surface areas or widths too small from the viewpoint of the substantive prerequisites of the study, or such that could not be properly presented on the map in the ultimate envisaged scale;
- during the digitalisation (mainly on the oldest maps, in connection with the re-interpretation “on fly”), through, for instance, joining and moving of polygons and simplification of lines (graphical generalisation), as well as joining, selection and re-classifying of the non-spatial attributes (cognitive generalisation);
- after termination of digitalisation, in particular – during verification of errors with the use of tools of analytical geometry and in the effect of comparison with the soil and phyto-sociological materials originating from the field mapping.

3.2.8. Developing the map of the sequence of changes in forest cover

The last stage of establishment of the model in question was to develop the map of the sequence of changes in the forest cover within the Masuria-Kurpie borderland during the last 200 years. Vector maps, corresponding to the seven nominal time slices considered were put together in the ArcGIS 9.3 system, and then consecutive layers were successively intersected. The errors in geometry and topology of the each new output layer were verified. For this purpose the extension Arc4You Poly Clean 1.0 was used, dedicated to the ArcView 3.3 software. With the help of this software the gaps and the overlapping of polygons were identified and liquidated, and also the nodes were pulled and the sliver polygons were annexed (according to the rule of up to the longest boundary). Finally, the survey was performed of the database, containing descriptive characteristics of the objects forming the map of the sequence and the errors were corrected having appeared in the course of processing the consecutive vector maps.

3.3. Summary

All the stages of the development of a numerical map are prone to generation of errors. The here presented and consistently applied scheme of proceeding allowed for avoiding of the uncontrolled propagation of errors, exceeding the assumed level of accuracy, but could not eliminate the errors altogether. In the historical environmental studies, an error is not synonymous with a “mistake”, but may designate an uncertainty, which cannot be avoided in absolute terms, and which can be defined as the awareness of the researcher that there exists a difference between the collected information on the environment (the data) and the “real” environment (see Wolski, 2012). In the scheme here outlined this uncertainty was to the highest degree associated with identification of forest surfaces and calibration of materials from the first half of the 19th century, and the older ones. One should, therefore, be conscious of the fact that the final model might contain certain artifacts, which do not constitute the representation of the true changes over time, but only imperfections, being the result of the errors contained in the source materials and having arisen during the processing in the GIS systems. Yet, in the light of the purposes of the study and the ultimate scale of the resulting maps it can be proposed with a high probability that such cases do not disturb the entirety of the image of changes in the forest cover within the Masuria-Kurpie borderland, nor do they impact negatively upon the correctness of respective reasoning.

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4. POTENTIAL NATURAL VEGETATION – THE BASIS FOR HABITAT CHARACTERISATION AND ITS RELATION TO GEOLOGICAL SUBSTRATUM AND REGIONAL VARIATION

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4.1. Map of potential natural vegetation – methodological prerequisites and field works

The concept of potential natural vegetation (Faliński, 1971; Tüxen, 1956) was introduced more than 60 years ago for the ecological characteristics of habitats subject to diverse kinds of human use, and especially for the cartographic presentation of their spatial variation. This concept: (...) *is understood to denote the hypothetical state of vegetation, which could arise through natural succession and regeneration processes, provided the current man-made impact and other external disturbances stopped, and the natural tendencies of plant communities could be fully realised, leading ultimately to a stable terminal community* (Matuszkiewicz, 2007). It is indispensable as the basis for maps elaboration (see e.g. Matuszkiewicz J.M., 2008b; Matuszkiewicz W. et al., 1995), allowing for the analysis of habitat variation in landscapes and regions (Matuszkiewicz, 1979, 1981ab). In general, the diagnosis of potential natural vegetation is based on the analysis of actual vegetation and specific features of the abiotic environment.

The methods and techniques of potential natural vegetation mapping are now well developed (see Matuszkiewicz, 2007; Matuszkiewicz & Kozłowska, 1981; Matuszkiewicz & Solon, 2006; Matuszkiewicz & Werner 2000). The map of potential natural vegetation of the study area was elaborated on the basis of detailed field mapping, using the topographic materials on the scale of 1:25 000 (maps in the "1965" setting – see Chapter 2) and the digital VMap Level 2 (1:50 000) to produce its final version (Fig. 4.1). Likewise, maps of forest habitat types were also used. Field mapping was carried out in the years 2009-2011.

The types of potential natural vegetation (cartographic units of the map) are defined – with just one exception – by plant community types. Most frequently, the type of potential natural vegetation refers to plant association or sub-association, corresponding to the system of W. Matuszkiewicz (2001) and J.M. Matuszkiewicz (2001).

4.2. The list and characteristics of potential natural vegetation types

As a result of detailed field mapping, 22 cartographic units of potential natural vegetation were distinguished. The 21 of them represent 15 associations, 7 alliances, 5 orders, and 4 classes of plant communities, among which one unit represents the non-forest

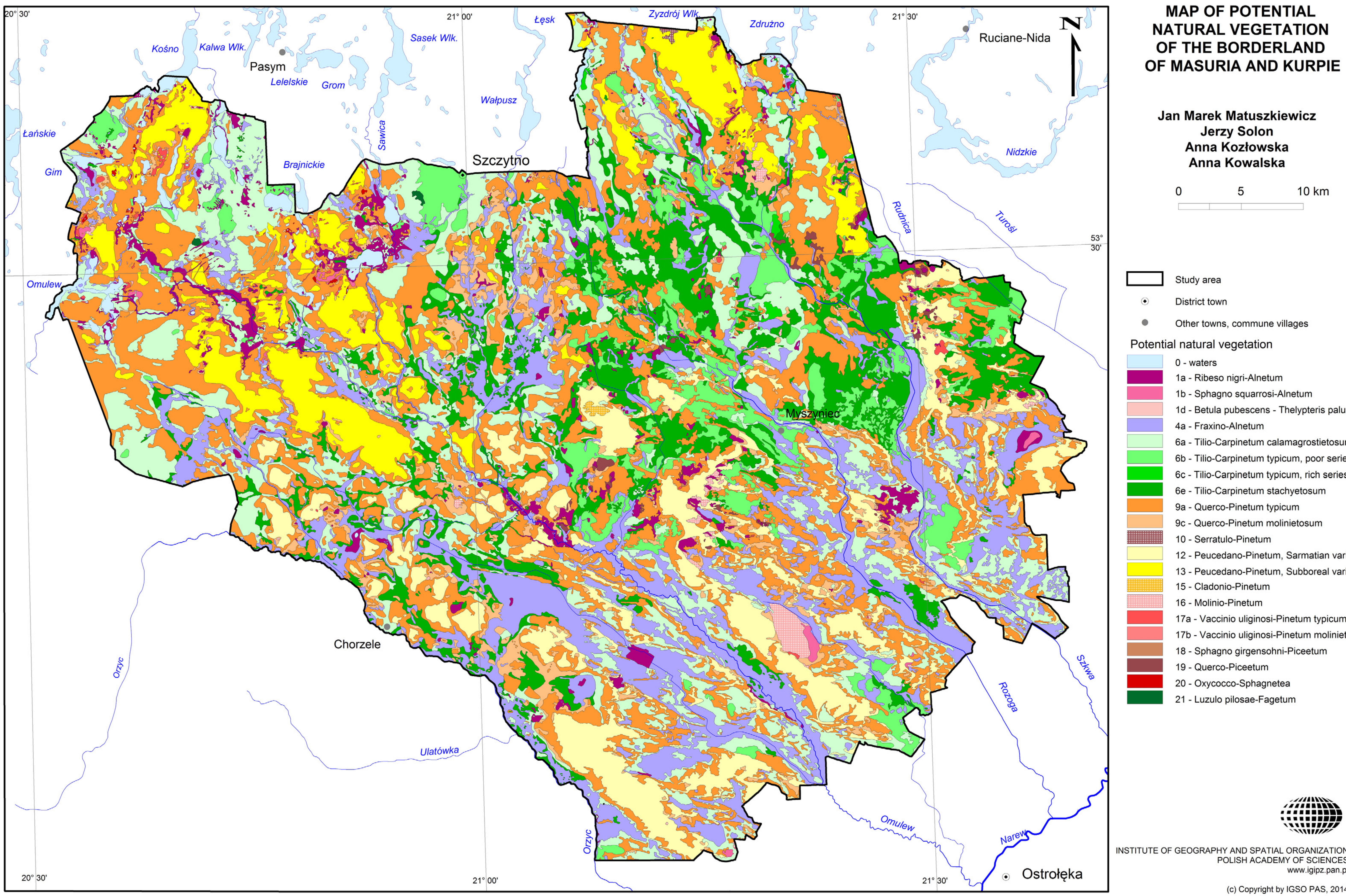

Fig. 4.1. Map of potential natural vegetation of the borderland of Masuria and Kurpie

bog community, while all the other ones correspond to forest communities. The last one – surface waters, was not classified in the categories of potential natural vegetation (Table 4.1).

The systematic classification of the distinguished units of potential natural vegetation is presented below (after Matuszkiewicz W., 2001, with supplements according to Matuszkiewicz J.M., 2001).

Class: *ALNETEA GLUTINOSAE* Br.-Bl. & R. Tx. 1943
Order: *Alnetalia glutinosae* R. Tx. 1937
Alliance: *Alnion glutinosae* (Malc. 1929) Meijer Drees 1936
Association: *Ribeso nigri-Alnetum* Sol.-Górn. (1975) 1987
Association: *Sphagno squarrosi-Alnetum* Sol.-Górn. (1975) 1987
Community *Betula pubescens-Thelypteris palustris* Czerw. 1972
Class: *QUERCO-FAGETEA* Br.-Bl. & Vlieg. 1937
Order: *Fagetalia sylvaticae* Pawł. in Pawł., Sokoł & Wallisch 1928
Alliance: *Alno-Ulmion* Br.-Bl. & Tx. 1943
Association: *Fraxino-Alnetum* W.Mat. 1952
Alliance: *Carpinion betuli* Issl. 1931 emend. Oberd. 1953
Association: *Tilio cordatae-Carpinetum betuli* Tracz. 1962 – sub-divided into four ecological-habitat forms: *T.-C. calamagrostietosum*, *T.-C. typicum* poorer variant, *T.-C. typicum* more fertile variant, *T.-C. stachyetosum*.
Alliance: *Fagion sylvaticae* R. Tx. & Diem. 1936
Association: *Luzulo pilosae-Fagetum* W.Mat. & A.Mat. 1973
Class: *VACCINIO-PICEETEA* Br.-Bl. 1939
Order: *Cladonio-Vaccinietalia* Kiell.-Lund 1967
Alliance: *Dicrano-Pinion* Libb. 1933
Association: *Cladonio-Pinetum* Juraszek 1927
Association: *Peucedano-Pinetum* Mat. (1962)1973 – sub-divided into two regional variants: sarmatian and subboreal
Association: *Molinio (caeruleae)-Pinetum* W.Mat. & J.Mat. 1973
Association: *Querco roboris-Pinetum* (W.Mat. 1981) J.Mat. 1988, divided into two sub-associations: *Q.r.-P. typicum* and *Q.r.-P. molinietosum*
Association: *Serratulo-Pinetum* (W.Mat. 1981) J.Mat. 1988
Association: *Vaccinio uliginosi-Pinetum* Kleist 1929, divided into two sub-associations: *V.u.-P. typicum* and *V.u.-P. molinietosum*
Order: *Vaccinio-Piceetalia* Br.-Bl. 1939
Alliance: *Piceion abietis* Pawł.& all. 1928 (= *Vaccinio-Piceion* Br.-Bl. 1938)
Association: *Sphagno girgensohnii-Piceetum* Polak. 1962
Association: *Querco-Piceetum* (Mat. 1952) Mat. & Pol. 1955
Class: *OXYCOCCO-SPHAGNETEA* Br.-Bl. & R. Tx. 1943
Order: *Sphagnetalia magellanici* (Pawł. 1928) Moore (1964) 1968
Alliance: *Sphagnion magellanici* Kästner & Flössner 1933 em. Dierss. 1975
Association: *Ledo-Sphagnetum magellanici* Sukopp 1959 em. Neuhäusl 1969

Table 4.1 Share of potential natural vegetation types in the study area

Potential natural vegetation – cartographic units		Masuria				Kurpie			
Code	**Name**	**area [km²]**	**share [%]**	**number of polygons**	**mean area of polygon [ha]**	**area [km²]**	**share [%]**	**number of polygons**	**mean area of polygon [ha]**
1a	*Ribeso nigri-Alnetum*	46.86	2.98	395	12.0	24.0	1.9	115	20.9
1b	*Sphagno squarrosi-Alnetum*	3.03	0.19	46	6.6	2.9	0.2	6	48.1
1d	community *Betula pubescens – Thelypteris palustris*	0.36	0.02	2	17.7	-	-	-	-
4a	*Fraxino-Alnetum (= Circaeo-Alnetum)*	155.92	9.92	297	52.5	296.5	23.3	141	210.3
Hydrogenic forests – total		**206.16**	**13.11**	**740**	**27.9**	**323.4**	**25.4**	**262**	**123.4**
6a	*Tilio-Carpinetum calamagrostietosum*	313.89	19.97	509	61.7	167.8	13.2	304	55.4
6b	*Tilio-Carpinetum typicum*, poor series	78.27	4.98	132	59.3	87.0	6.8	119	73.1
6c	*Tilio-Carpinetum typicum*, fertile series	3.27	0.21	7	46.7	0.1	0.0	1	8.5
6e	*Tilio-Carpinetum stachyetosum*	183.94	11.70	347	53.5	129.5	10.2	167	77.6
Lime-oak-hornbeam forests – total		**579.37**	**36.86**	**995**	**58.4**	**384.4**	**30.2**	**591**	**65.1**
9a	*Querco roboris-Pinetum typicum*	446.51	28.40	469	95.2	294.1	23.1	422	69.8
9c	*Querco roboris-Pinetum molinietosum*	59.16	3.76	341	17.4	50.5	4.0	264	19.6
10	*Serratulo-Pinetum*	0.82	0.05	2	41.2	-	-	-	-
Mixed oak-pine forests – total		**506.49**	**32.22**	**812**	**62.4**	**344.6**	**27.1**	**686**	**50.5**
12	*Peucedano-Pinetum* sarmatian variant	43.92	2.79	36	122.0	203.2	16.0	198	102.4
13	*Peucedano-Pinetum* subboreal variant	186.81	11.88	88	212.3	-	-	-	-
15	*Cladonio-Pinetum*	1.15	0.07	1	114.8	-	-	-	-
Dry and fresh pine forests – total		**231.88**	**14.75**	**125**	**185.5**	**203.2**	**16.0**	**198**	**102.4**
16	*Molinio-Pinetum*	3.92	0.25	67	5.9	11.3	0.9	36	31.3
17a	*Vaccinio uliginosi-Pinetum typicum*	4.22	0.27	86	4.9	1.0	0.1	10	13.2
17b	*Vaccinio uliginosi-Pinetum molinietosum*	0.13	0.01	4	3.3	0.1	0.0	1	11.7
18	*Sphagno girgensohnii-Piceetum*	0.02	0.00	1	2.0	0.1	0.0	1	11.3
19	*Querco-Piceetum*	4.22	0.27	26	16.2	3.3	0.3	27	12.1
20	*Sphagnetalia magellanici*	0.94	0.06	21	4.5	-	-	-	-
21	*Luzulo-Fagetum*	0.83	0.05	2	41.3	-	-	-	-
0	waters – no classified	33.85	2.15	127	26.7	0.2	0.0	33	0.6
Total		**1,572.03**	**100.00**	**3,006**	**52.4**	**1,271.6**	**100.0**	**1,845**	**69.0**

There are numerous differences between the two studied regions. We observe not only the higher spatial share of hygrophilous forest habitats in Kurpie (where river valleys are wide and form large, continuous structures), but also their lower fragmentation, expressed through a lower number of patches and bigger average area of the habitat unit. This results from geomorphologic differences. The south part of the study area was not influenced by any stage of Vistula glaciation (see Chapter 1), so river valleys had been formed during succeeding glaciations stages, while in the north part (Masuria) their formation time was much shorter. Much smaller differences concern lime-oak-hornbeam forests and mixed oak-pine forests. While in the case of dry and fresh pine forest habitats lower numbers of patches and bigger average habitat patch areas are characteristic of Masuria, although the overall area shares are similar to (or even slightly lower) than those in Kurpie. However, in Masuria, there are more habitats of alder carrs and swamp pine forests – a typical feature of post-glacial landscape.

Each type of potential natural vegetation displays different habitat and spatial characteristics (Table 4.2).

4.3. Relationships between potential natural vegetation and geological substratum

The very concept of potential natural vegetation assumes indication of the theoretically feasible final succcesional state of vegetation in a definite region and in definite habitat conditions. Geological substratum – and, in particular, the geological formations, which appear on the surface might undoubtedly have an important influence on the character of potential natural vegetation. However, this general principle is not easily applicable to each case, since, first, the specific features of geological substratum are not a sole factor influencing the vegetation, and, second, the geological and geo-botanical classifications display their proper specificities, which brings about a certain "fuzzyfication" of the relations. Yet, the search for relationships between the geological substratum and the types of potential natural vegetation appears to be still an interesting cognitive issue and might also be of importance for comprehensive geographical and landscape studies. That is why the research on those correlations was carried out with juxtaposed geological maps and the map of potential natural vegetation of the study area.

For the analysis the map of potential natural vegetation (1:25 000), prepared within the project was used, along with 11 sheets of the Detailed Geological Map on the scale of 1:50 000 (the respective sheets were 216, 217, 251, 252, 253, 254, 255, 256, 291, 292 and 293). These sheets do not cover the entire study area (for the remaining parts the detailed geological maps were not accessible), but they cover its important part, both within Masuria and Kurpie. Therefore, in the analyses performed, the reach of the potential natural vegetation map was also limited. Subsequently, digital maps of the environmental elements considered were intersected, and then relations were analysed on the basis of area magnitudes, taken by combinations of the studied elements. The classification units of the potential natural vegetation are the adopted, homogeneous for the study area, previously described entities, which might potentially by joined on the basis of the phytosociological typology (e.g. aggregation to associations). However,

Table 4.2. General characteristic of habitats acc. to potential natural vegetation types

Potential natural vegetation – cartographic units		Characteristic of natural plant community	Protection status of plant community acc. to Natura 2000 habitats classification	Site conditions	Vegetation landscape and common land-use types
Code	name				
1a	*Ribeso nigri-Alnetum*	Euthrophic alder forests with "hummocks and hollows" structure of undergrowth with forest and sedge species. The tree layer is dominated by *Alnus glutinosa* with *Betula pubescens* and *Picea abies* in addition. The hummocks are overgrown by shrub (*Ribes nigrum*, *Frangula alnus*, *Sorbus aucuparia*) and moderately acidophilous forest herb species. Sedges and high perennials dominate in the hollows. This is species-rich community.	no	Alder carrs with *Ribes* cover about 3% of the study area. Small forest patches appear in wide river valleys, in boggy and swampy river depressions, on peat of different thickness (from several dozen cm to few m), waterlogged.	Alder carrs habitats are only partly cover by forests, often degraded. Semi-natural stands are rare, and preserved only in small areas. Deforested parts of habitat are overgrown by moss-sedge swamps (*Scheuchzerio-Caricetea nigrae*) oraz reed vegetation (*Magnocaricion*), occasionally cut or abandoned fallows.
1b	*Sphagno squarrosi-Alnetum*	Forests with domination of *Alnus glutinosa* and greater participation of *Betula pubescens* and *Picea abies* in addition, without clear "hummocks and hollows" structure of undergrowth but with abundant moss (*Sphagnum*) layer.	code 91D0	Small forest patches appear in wide river valleys, in boggy and swampy depressions on mesotrophic peat.	Forest or fallow (sedge swamps and reed vegetation)
1d	*Betula pubescens – Thelypteris palustris* community	Swampy pine-birch forest with fern *Thelypteris palustris*. Loose stand is developed by *Betula pubescens* and *Pinus sylvestis*. A herb layer is dominated by ferns and high perennials. A moss layer is abundant.	code 91D0	Two patches in the North-East part, in the edge of river valleys, on peat of small thickness.	Forests
4a	*Fraxino-Alnetum = Circaeo-Alnetum*	Alluvial, lowland forests with domination of *Alnus glutinosa* and *Fraxinus excelsior* and *Picea abies* in the North in addition, species-rich undergrowth.	code 91E0-3	Periodically swamped brook and slowly flowing river floodplains on peat and alluvial soils. Alder-ash forests appear also after dranage on converted alder carrs habitat; wetgley and browned gley soils, mineralized fen-peats of weakly acidic or neutral soil reaction.	The majority of alluvial habitats are deforested and used as wet meadows and pastures (*Angelico-Cirsietum oleracei*, *Cirsietum rivularis*) with tall herb-rich fringe communities (*Filipendulo-Geranietum*), tall sedge meadows (*Magnocaricion*) and reed vegetation (*Phragmition*) as well as alder and willow shrubs. Forests appear only in narrow stripes along rivers and in small patches within forest complexes.
6a, 6b, 6c, 6e	*Tilio-Carpinetum calamagrostietosum*, *Tilio-Carpinetum typicum*, poor series, *Tilio-Carpinetum typicum*, fertile series (with *Asarum europaeum*), *Tilio-Carpinetum stachyetosum*	Lime-oak-hornbeam forests of two- to three-layered tree layer and species-rich undergrowth with clear seasonal aspects, especially in fertile forms.	code 9170	The most fertile habitats on glacial and fluvioglacial sediments, boulder loams and sands cover the biggest area of the study (34%). *Tilio-Carpinetum calamagrostietosum* and *Tilio-Carpinetum typicum* of poor series are the most widespread. Fertile form of *Tilio-Carpinetum typicum* appear in the North-East part. *Tilio-Carpinetum stachyetosum* habitats cover fluviatile and glacial dusty fine sands and boulder loams.	The majority of lime-oak-hornbeam forest habitats are deforested (especially in Kurpie) and used as arable lands with segetal cereal communities (*Vicietum tetraspermae*) and grass meadows (*Arrhenatherion*) with mass participation of *Holcus mollis*. Semi-natural stands of lime-oak-hornbeam forests appear only in the North of the study area.
9a, 9c	*Querco roboris-Pinetum typicum*, *Querco roboris-Pinetum molinietosum*	Mixed oak-pine forests with the undergrowth of pine forest species (dwarf-shrubs, grasses, mosses), ferns and rarely decidous forests species. Two subassociations connected with different soil conditions are distinguised.	no	Mixed oak-pine forests habitats cover almost 1/3 of the study area on loamy sands. Patches of *Querco roboris-Pinetum typicum* form large areas (100 ha in average) with small scattered patches of *Querco roboris-Pinetum molinietosum*. Typical subassociation is connected with fresh podzolized brown soils and podzoles, moister formation with pseudogleys or gley-like soils.	Mixed oak-pine forests habitats are covered by semi-natural stands as well as pine plantations or dry sandy grasslands (*Sileno otitis-Festucetum*, *Festuco psammophilae-Kolerietum glaucae*), heathlands (*Calluno-Genistetum*) and poor *Nardus* pastures (*Polygalo-Nardetum*). Arable lands are also quite frequent, especially wheat fields accompanied by segetal weed community *Arnoserido-Scleranthetum*.
10	*Serratulo-Pinetum*	Mixed oak-pine forests with *Picea abies* and species-rich herb layer. Undergrowth with numerous pine and spruce forest species, decidous forest species, grasslands and forb fringe species including many thermophilous species. Tree layer is built of pine, spruce and pedunculate oak. Herb layer with domination of dwarf-shrubs (*Vaccinium myrtillus*) and grasses (*Calamagrostis arundinacea*).	no	Two patches in the North part, on hills of the south aspect. Mixed oak-pine forests appear on glacial sands and partly podzolized and cryptopodzolized brown soils, their habitats are the warmest among all mixed oak-pine forests.	Forests
12, 13	*Peucedano-Pinetum* sarmatian variant, *Peucedano-Pinetum* subboreal variant	Continental pine forest with participation of *Picea abies* in the North part and generally species-poor but dwarf shrub and moss-rich undergrowth.	no	Pine forests appear on aeolian sands of inland dunes or sandrs with weakly podzolic sand soils, moderately dry to dry (deep groundwater level).	The majority of habitat areas are used as forests, often degraded.
15	*Cladonio-Pinetum*	Pine forest with scattered, low stand and abundant lichen layer. The habitat shows tendency towards evolution to *Peucedano-Pinetum*.	code 91T0	Potential habitats of this pine forest are smaller then their present area because degraded fresh pine forest habitats resemble poor, dry pine forests. Sizeable patch of potential dry pine forests appear between Czarnia and Zieleniec Duży. They are found on inland dune top on poor, dry podzolic sand soils.	Forests of low stand quality.
16	*Molinio-Pinetum*	Wet pine forest with *Pinus* and two *Betula* species in tree layer. Herb layer of grass-dwarf shrub character with domination of *Molinia caerulea*.	no	Small forest patches are scattered between fresh pine forests. They are located on sands in hollows with high and changeable ground-water level with gley-podzole soils (humus – hygromor type).	Forests or rarely grassland fallows.
17a, 17b	*Vaccinio uliginosi-Pinetum typicum*, *Vaccinio uliginosi-Pinetum molinietosum*	Swamp pine forest on peat with low, scattered stand of *Pinus sylvestris* and *Betula pubescens*. Herb layer with dwarf shrubs – the most characteristic: *Ledum palustre* and *Vaccinium uliginosum*. Two subassociations are distinguised: typical and with *Molinia*.	code 91D0	Small patches rarely found, more often in the North part. They are developed in local depressions with stagnant water, on peat and stagnogley soils (thick peat layer in typical variant and thin in *Molinia* subassociation).	Swamp forests
18	*Sphagno girgensohnii-Piceetum*	Boreal peat-moss spruce forest of mixed forest type on peat or wet mineral habitats. Tree layer with *Picea abies* and *Pinus sylvestris* and *Betula pubescens*. Undergrowth dominated by dwarf shrubs and mosses (*Sphagnum* mainly) with perennials.	code 91D0	Two small patches in North-East, Masurian part in shallow depressions filled with sedge-moss peat.	Swamp forests
19	*Querco-Piceetum*	Tree layer of mixed forest is built of spruce, oak and aspen, species-rich undergrowth of dwarf shurubs, forest perennials and mosses.	no	Mixed oak-spruce forests are developed in local depressions on acidic gley-podzole soils, on fine stands.	Forests
20	*Sphagnetalia magellanici*	Raised bog (*Ledo-Sphagnetum magellanici*) dominated by Sphagna hummlocks and ledum crystaltea (*Ledum palustre*) with sparse and very low pine stand.	code 7110*	Small patches of forests in North, Masurian part are developed in local depressions with peat and stagnant water.	Fallows (often protected area).
21	*Luzulo-Fagetum*	Lowland species-poor beech forests with low perennials and narrow-leaved grasses in the herb layer.	code 9110	Beech forests appear rarely in the North-West part. This is probably marginal locality of species-poor oligothrophic beech forests (documented sites are located in the vicinity of the study area). They are developed on moraines, on acidic, fresh soils.	Forests

the classification of geological substratum, presented on the maps, is more difficult, since it is not homogeneous.

4.3.1. Variation of geological substratum types in the study area

The sheets of the geological map which were developed by different author teams, and at different time points have their own legends, oftentimes differing as to the units setting. Altogether, more than three hundred types of geological units have been distinguished, tagged by appropriate symbols. In order to be able to correlate them with 19 units of potential natural vegetation, it was necessary to group them into a similar number of classes, by adopting appropriate grouping criteria. The legend of geological map puts in the first place the age of rocks, then their origins, and only then lithological properties. The age and the origin of sediments are significant for the development of plants only then, when they actually impact on their habitat conditions. On the other hand, lithological features are insofar important as they determine directly the mechanical composition of soils, that is – one of the most important ecological factors for plants. That is why the grouping of geological units was carried out conform to the lithological criterion, so as to ensure that the groups established have a similar mechanical composition, and hence, consequently, also similar fertility and hydrological properties. Additionally, the age of tills (north and middle-Polish glacial periods) has also been accounted for, having in mind the degree of their leaching, which has a direct impact on the fertility of soils developing on such a substratum. Likewise, the origin of sand was of importance, insofar as the way of sorting had an influence on the substratum fertility (e.g. the aeolian, lacustrine, fluvioglacial, or deluvial sands). The formations situated beneath the surface ones were considered as well, when they influenced water circulation (permeable or impermeable formations) and fertility (accessibility of plant nutrients – taken up through infiltration from the more fertile formations). Altogether, in the study, 19 units have been defined. Their list and the grouping manner are

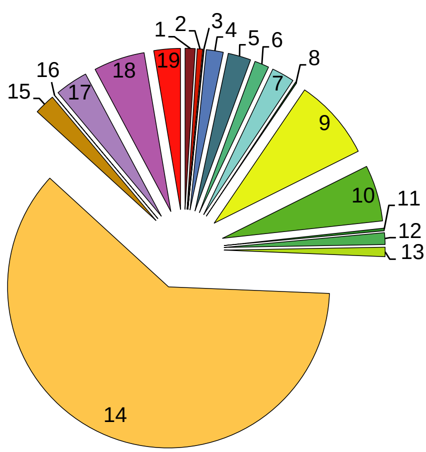

Fig. 4.2. Spatial share of geological map units [%] made for comparison with the vegetation map (see explanations in Table 4.3)

shown in Table 4.3. It is worth noting that all formations are Quaternary, in their majority originating from the Pleistocene, less frequently from the Holocene.

The distinguished categories of geological substratum occupy highly differentiated area (Fig. 4.2). First of all, the domination of the category 14 (outwash sands) is noticeable, along with the river sands of higher terraces, that is – the outwash formations of various ages – altogether occupying more than 61% of the entire area considered. Other types (categories 6-13) of sandy substratum (partly on the clay) occupy further 20% of the area. Thus, altogether, all sandy substratum types occupy more than 80% of the area. Peat substratum (categories 17-19) occupies jointly more than 11% of the area. While clay substratum occupies small surfaces.

4.3.2. The potential natural vegetation units associated with the substratum types

When analysing relations of the geological substratum with the potential natural vegetation, we calculated first the shares of potential natural vegetation units in the particular categories of geological substratum (Table 4.4).

The data received suggest that there is no strong correlation between definite substratum types and the potential natural vegetation, but certain more or less distinct regularities can be observed. Thus, on the relatively rare substratum of sands and gravels of kames and eskers (16) mixed oak-pine forests (*Querco-Pinetum*) grow uniquely. The aeolian sands (9) are occupied mainly by pine forests (*Peucedano-Pinetum*) in their sarmatian variant (within Kurpie), less frequently by typical mixed oak-pine forests (*Querco-Pinetum typicum*). Various types of richer substratum, with clays and silts (1, 2, 6, 11, 12, 13 and 15) are mainly occupied by habitats of fresh lime-oak-hornbeam forests (*Tilio-Carpinetum calamagrostietosum* and *T.-C. typicum*), less frequently by mixed oak-pine forests (*Querco-Pinetum typicum*). Humus sands (10), sandy silts (4), peaty silts (5), as well as shallow peats (17, 18), are related with habitats of moist lime-oak-hornbeam forests (*Tilio-Carpinetum stachyetosum*) or of ash-alder alluvial forests (*Fraxino-Alnetum*). Then, on fluvial and lacustrine sands (7) and on deep peats one encounters most frequently the habitats of ash-alder alluvial forests (*Fraxino-Alnetum*). On the most common substratum type – of fluvioglacial sands (14), various types of potential natural vegetation exist, which indicates low specificity degree of this substratum type.

4.3.3. Relationship between the potential natural vegetation and the geological substratum – analysis of indicators

A simple listing of the potential natural vegetation on various geological substratum types, even if providing a lot of interesting information, is not sufficient for the determination of habitat preferences of individual potential natural vegetation type. However, this is possible using several indicators, including the indicator of connection strength (Richling, 1992), calculated as

Table 4.3. Legend units of geological map aggregated for comparison with the map of potential vegetation

Code	Description	Legend symbols	Area [%]
1	tills, north-Polish glaciation	g:g(zw)-QPFL/b:p+m-QPFL; g:g(zw)-QPB3/fg:p+ż-QPB; g:g(zw)-QPFL; g:g(zw)-QPB3; g:g(zw)-QPB; fgg:g+g(p)+m-QPB; fgg:g+g(py)+m+ż-QPB3/k:p+ż+m-QPB3; fgg:g+g(py)+m+ż-QPB3; g:g(zw)-QPB2	1.01
2	tills, middle-Polish glaciation	g:g(zw)-QPW3/i+i(wg)+m+pQ+w(br)-TRMPL; g:g(zw)-QPW3/fg:p+ż1-QPW; g:g(zw)-QPW3; g:g(zw)-QPW2; g:g(zw)-QPW2	0.54
3	clays, silts, gyttias	gy-QH; i+i(wg)+m+pQ+w(br)-TRMPL; b:i+m1-QPW3; i+m+p-TRPL; kj-QH/p(h)-QH; kj-QH; b:m+p-QPW3; b:m+p+i-QPW2/ g:g(zw)-QPW1; b:m+p+i-QPW2	0.06
4	sandy silts	n(p)-QH/g:g(zw)-QPW3; n(p)-QH/i+i(wg)+m+pQ+w(br)-TRMPL; n(p)-QH/p(h)-QH;n(p)-QH/b:p+m-QPW3; n(p)-QH/fg:p+p(ż)+ż-QPB3; n(p)-QH/fg:pż-QPB3; n(p)-QH;n(p)-QH; li:n+p-QH/b:m+p+i-QPW2; li:n+p-QH	1.70
5	peaty silts	n(t)-QH/g:g(zw)-QPW2; n(t)-QH/gy-QH; n(t)-QH/i+i(wg)+m+pQ+w(br)-TRMPL; n(t)-QH/n(p)-QH; n(t)-QH/n(p)-QH; n(t)-QH/d:p-Q; n(t)-QH/f:p-QHt; n(t)-QH/fg:p-QPB3; n(t)-QH/fg:p-QPW2; n(t)-QH/p(h)-QH; n(t)-QH/p(h)+n-QH; n(t)-QH/b:p+m-QPW3; n(t)-QH/ fg:p+p(ż)+ż-QPB3; n(t)-QH/f:p+pż+n-QH; n(t)-QH/fg:pż-QPB3; n(t)-QH; li:n(t)+n(p)-QH; n(t)+n(p)-QH	2.29
6	fluvioglacial sands on tills and silts	z:p-Q/g:g(zw)-QPW3; fg-I:p-QPFPM/g:g(zw)-QPFL;fg-II:p-QPFPM/g:g(zw)-QPFL; f:p-QPB3tI/g:g(zw)-QPW2;fg-II:p-QPB3/g:g(zw)-QPW2; fg-IV:p-QPB3/g:g(zw)-QPW1; fg:p-QPB2/g:g(zw)-QPB2; fg:p-QPW2/g:g(zw)-QPW2; f:p-QPBtII/g:g(zw)-QPW1;fg-IV:p-QPB3/b:m+i-QPW2; fg-IV:p-QPB3/b:m+p+i-QPW2; fg:p-QPW2/b:m+p+i-QPW2; fg-I:p-QPFPM/b:p+m-QPFL; fg-II:p-QPFPM/b:p+m-QPFL; fg-IV:p-QPFPM/b:p+m-QPFL	1.45
7	fluvial and lake sands	li:p-QH/t-QH; f:p-QH; f:p-QHt; li:p-QH; p+m-QHt; f:p+n-QH/b:m+p+i-QPW2; f:p+n-QH/fg:p-QPB3; f:p+n-QH	2.29
8	deluvial sands	d:p-Q	0.14
9	aeolian sands	e:p-Q/fg:p-QPB3; e:p-Q/p(h)+n-QH; e:p-Q/f:p+m-QHt; e:p-Q/fg:p+p(ż)+ż-QPB3; e:p-Qw/fg:p+p(ż)+ż-QPB3;e:p-QH/fg-VI:p+ż-QPB3 e:p-Q/fg:pż-QPB3; e:p-Q; e:p-QH; e:p-Qw/fg:pż-QPB3; e:p-Qw	8.14
10	humus sands	p(h)-QH/g:g(zw)-QPW3; p(h)-QH/b:p+m-QPW3; p(h)-QH/fg:p+p(ż)+ż-QPB3; p(h)-QH/fg:pż-QPB3; p(h)-QH; p(h)+n-QH/g:g(zw)-QPW2; p(h)+n-QH/i+i(wg)+m+pQ+w(br)-TRMPL; f:p(h)+n-QH/fg-II:p-QPB3; f:p(h)+n-QH/fg:p+ż-QPW2; f:p(h)+n-QH; p(h)+n-QH; p(h)+n-QH; p(h)+n(ph)-QH/fg-V:p+ż-QPB3; p(h)+n(ph)-QH; p(h)+p+n-QH	5.64
11	dust sands	z:p(py)-Q/g:g(zw)-QPW3; d:p(py)-Q/b:p+m-QPW3; d:p(py)-Q; d:p+g-Q/fg:p+ż1-QPW3; d:p+g-Q/fg-IV:p+ż-QPB3; d:p+g-Q/ gm:p+ż+m-QPW3; d:p+g-Q; gc:p+g(zw)-QPB3; d-k:p+g+gł-Q	0.26
12	sands and silts	r:p+ż-Q/g:g(zw)-QPB; b:p+m-QPW3/g:g(zw)-QPW3; d:p+m-Q; b:p+m-QPFL; b:p+m-QPW3; k:p+m-QPW3; tk:p+m-QPW3; k:p+m-QPB3; b:p+m-QPB3; fg:p+m-QPB3; b:p+m-QPW2; k:p+m+ż-QPB	1.18
13	fluvioglacial sands and gravels on tills	fg-I:p+p(py)+ż+m-QPB3; fg-II:p+p(ż)-QPB3/g:g(zw)-QPB; fg-II:p+p(ż)-QPB3/g:g(zw)-QPB3; fg-II:p+p(ż)-QPB3/b:p+m-QPB3; fg:p+p(ż)-QPB3; fg:p+p(ż)+ż-QPB3/g:g(zw)-QPB2; g:p+p(ż)+ż-QPB3/b:p+m-QPB2; g:p+ż-QPW3/g:g(zw)-QPW3; fg:p+ż-QPB3/g:g(zw)-QPW3; fg-V:p+ż-QPB3/g:g(zw)-QPW2; fg-VI:p+ż-QPB3/g:g(zw)-QPW2; fg:p+ż-QPB3/g:g(zw)-QPB; fg:p+ż-QPB3/ g:g(zw)-QPB3; fg-I:p+ż-QPB3/g:g(zw)-QPB3; fg-II:p+ż-QPB3/g:g(zw)-QPB3; g:p+ż-QPB3/g:g(zw)-QPB3; fg:p+ż-QPW2/g:g(zw)-QPW2; r:p+ż-Q/fgg:g+g(p)+m-QPB; fgg:p+ż-QPB/fgg:g+g(p)+m-QPB; g:p+ż-QPB3/fgg:g+g(py)+m+ż-QPB3; g:p+ż-QPW3/ i+i(wg)+m+pQ+w(br)-TRMPL	0.94
14	fluvioglacial sands and sands of higher fluvial terraces	f:p+ż-Q; d-f-f:p+ż-Q; d-f:p+ż-QH; f:p+ż-QH; f:p+ż-QHt; fg:p+ż1-QPW3; fg:p+ż2-QPW3; fg:p+ż-QPW; g:p+ż-QPW3; gs:p+ż-QPW3; fg:p+ż-QPB3; fg-I:p+ż-QPB3; fg-II:p+ż-QPB3; fg-III:p+ż-QPB3;fg-IV:p+ż-QPB3; fg-V:p+ż-QPB3; fg-VI:p+ż-QPB3; g:p+ż-QPB3; gs:p+ż-QPB3; fg:p+ż-QPB3; fg:p+ż-QPB3; fg-I:p+ż-QPB3; fg-II:p+ż-QPB3; g:p+ż-QPB3; gs:p+ż-QPB3; o:p+ż-QPB3; fg:p+ż-QPW2; fg:p+ż-QPW2; g:p+ż-QPW2; g:p+ż-QPW2; fg:p+ż-QP4; fgg:p+ż-QPB;fg:pż-QPB3; r:ż+g-Q/g:g(zw)-QPW3; r:ż+g-Q/b:m+p-QPW3; r:ż+g-Q/fg:p+ż1-QPW; r:ż+g+gł-Q/fg:p+ż1-QPW3	61.15
15	end moraine sands, gravels and tills	g:p+ż+g-QPB3; gs:p+ż+g-QPB; gc:p+ż+g(zw)-QPFL; gs:p+ż+g(zw)-QPB3; r:p+ż+gł-Q; c:p+ż+gł-QPW3; gc:p+ż+gł-QPB3; gm:p+ż+gł-QPB3; gm:p+ż+gł-QPB3; gs:p+ż+gł-QPB3; c:p+ż+gł-QPW2; gc:p+ż+gł-QPB; gm:p+ż+gł-QPB; fgg:p+ż+gł+g-QPB3/ fg:p+ż-QPB; fgg:p+ż+gł+g-QPB3; gm:p+ż+gł+g-QPB; gc:p+ż+gł+g(zw)-QPW3; gm:p+ż+m- QPW3; k:p+ż+m-QPB3	2.08
16	kame and esker sands and gravels	k:p-QPB3; o:p+ż-QPW3	0.03
17	peats on tills, clays and silts	t-QH/g:g(zw)-QPW2; t-QH/gy-QH; t-QH/kj-QH; t-QH/b:m+p+i-QPW2; t-QH/n(p)-QH; t-QH/n(p)-QH; t-QH/li:n+p-QH; t-QH/p(h)-QH; t-QH/p(h)-QH; t-QH/f:p(h)+n-QH; t-QH/p(h)+n-QH; t-QH/p(h)+n-QH; t-QH/p(h)+p+n-QH; t-QH/d:p+g-Q; t-QH/b:p+m-QPFL; t-QH/b:p+m-QPW2; t-QH/f:p+m-QHt; t-QH/f:p+m-QHt; t-QH/f:p+n-QH	3.29
18	peats on sands	t-QH/d:p-Q; t-QH/f:p-QH; t-QH/f:p-QHt; t-QH/f:p-QPB3tI; t-QH/f:p-QPBt; t-QH/fg:p-QPB3; t-QH/fg:p-QPB3; t-QH/fg-I:p-QPFPM; t-QH/fg-II:p-QPFPM; t-QH/fg-IV:p-QPFPM; t-QH/li:p-QH; t-QH/fg:p+p(ż)-QPB3; t-QH/fg-II:p+p(ż)-QPB3; t-QH/fg:p+p(ż)+ż-QPB3; t-QH/f:p+pż+n-QH; t-QH/fg:p+ż-QPB3; t-QH/fg:p+ż-QPW2; t-QH/fg-I:p+ż-QPB3; t-QH/fg-II:p+ż-QPB3; t-QH/fg-VI:p+ż-QPB3; t-QH/g:p+ż-QPW3; t-QH/fgg:p+ż+gł+g-QPB3; t-QH/fg:pż-QPB3	5.13
19	peats	t-QH	2.66

$$\mathbf{W = P_{rg}/min(P_g;P_r)}$$

where

$\mathbf{P_{rg}}$ – area of the units in which vegetation category *r* and geology category *g* occur simultaneously;

$\mathbf{P_r}$ – total area of spatial units with vegetation category **r**;

$\mathbf{P_g}$ – total area of spatial units with geology category **g**.

The basis for this indicator is constituted by the ratio of the total area, occupied by the spatial units having definite (double) properties, to the maximum area, over which these properties can coincide. The value of this indicator belongs to the interval [0.1]. The maximum value of 1 is observed, when the boundaries of spatial divisions, corresponding to the properties considered, are identical. The value drops down to zero, when the properties considered do not coincide at all in space. High values of the indicator point to stable and persistent relationships, which play a leading role in the structure of the environment.

The values obtained were valorised on the five-degree scale, assuming the following intervals of indicator values, corresponding to classes (Bezkowska, 1986):

I	W = 0.0-0.2	very weak relations,
II	W = 0.21-0.4	weak relations,
III	W = 0.41-0.6	average relations,
IV	W = 0.61-0.8	strong relations,
V	W = 0.81-1.0	very strong relations.

In further interpretation the relations of class I were neglected as very weak and random. They might have resulted, for instance, from the imprecise delimitation of vegetation and geological patches.

The vast majority of potential natural vegetation communities are associated with fluvioglacial sands in the substratum (Table 4.5). This is not surprising for the outwash area, where this type of substratum occupies more than 60% of surface. The relationship is particularly strong for lime-oak-hornbeam forests (except for fertile series of the typical sub-subassociation – being rare within the study area and not displaying relation with any kind of substratum), and also with mixed pine forests, including spruce-pine forests, as well as pine forests. The mentioned types of vegetation are divided into two groups. One of them is constituted by communities, which display strong and very strong links only with the geological units in question (9c, 10, 13, 19, and also swampy pine forests – 17a, 17b). The second group includes communities, which feature distinct relation with fluvioglacial sands, but also medium or weak relations with other types of substratum: tills, end moraine formations, or dust sands – this applying to the lime-oak-hornbeam forests, or with eolic and deluvial sands, respectively the sands and gravels of kames or eskers – this applying to mixed oak-pine forests and pine forests. Peaty substratum determines the appearance of alder carrs, swampy pine-birch forests, bogs, and moist pine forests. Boreal bog spruce forests are linked with peaty silts. Alder carrs are associated with fluvioglacial sands, of course, but also with the substratum formed by clays and silts. The ash-alder alluvial forests are also linked with the peaty substratum, but their strongest links are observed with fluvial sands, followed by sandy silts and peats on sands.

The results obtained are in accordance with generally known regularities, concerning requirements of particular potential natural vegetation communities with regard to the

Table 4.4. Share of potential natural vegetation units [%] within types of geological substratum

Types of geological substratum (aggregated)			Types of potential natural vegetation (selected – comprise over 5% of any type of geological substratum)												
Code	description	area [km²]	*Querco-Pinetum molinietosum* – 9c	*Querco-Pinetum typicum* – 9a	*Tilio-Carpinetum* (all) – 6	*Tilio-Carpinetum calamagrostietosum* – 6a	*Tilio-Carpinetum typicum* (poor) – 6b	*Tilio-Carpinetum stachyetosum* – 6e	*Fraxino-Alnetum* – 4a	*Ribeso-Alnetum* – 1a	*Molinio-Pinetum* – 16	*Peucedano-Pinetum* (all) – 12+13	*Peucedano-Pinetum* sarmatian – 12	*Peucedano-Pinetum* subboreal – 13	total
16	kame and esker sands and gravels	0.7	36.0	60.4	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	96.6
9	aeolian sands	186.7	1.7	29.6	6.9	4.7	1.2	1.0	1.9	0.3	0.2	59.3	57.2	2.0	99.9
8	deluvial sands	3.3	1.2	48.0	24.9	20.2	1.8	0.2	2.5	1.9	0.1	21.6	0.0	21.6	100.0
14	fluvioglacial sands and sands of higher fluvial terraces	1,402.3	2.6	36.6	35.6	18.1	6.0	11.4	6.5	1.1	0.3	16.8	6.7	10.1	99.4
1	tills, north-Polish glaciation	23.1	0.3	19.7	78.2	49.3	23.9	4.7	1.6	0.2	0.0	0.0	0.0	0.0	100.0
2	tills, middle-Polish glaciation	12.4	0.3	4.9	87.9	27.8	53.9	6.2	6.3	0.0	0.0	0.6	0.0	0.6	100.0
3	clays, silts, gyttias	1.5	0.3	9.6	30.3	22.3	4.3	3.7	30.7	25.7	0.0	0.3	0.3	0.0	96.9
13	fluvioglacial sands and gravels on tills	21.5	5.7	29.4	52.1	38.5	7.4	4.8	4.7	0.9	0.1	6.8	0.4	6.5	99.7
11	dust sands	6.0	4.4	39.0	50.1	48.2	1.3	0.6	3.3	1.9	0.0	1.4	0.0	1.4	100.0
15	end moraine sands, gravels and tills	47.8	0.0	31.1	63.0	57.9	4.0	0.2	0.2	0.0	0.0	5.5	5.1	0.5	100.0
6	fluvioglacial sands on tills and silts	33.3	1.9	21.1	65.6	28.7	20.4	14.4	10.4	0.3	0.3	0.5	0.5	0.0	100.0
12	sands and silts	27.0	0.1	6.8	73.7	10.8	24.4	38.5	19.2	0.2	0.0	0.0	0.0	0.0	100.0
10	humus sands	129.4	4.7	4.7	51.7	9.9	4.3	37.3	36.2	2.1	0.1	0.2	0.0	0.2	99.7
4	sandy silts	39.0	4.4	6.0	44.3	7.8	6.5	30.0	41.2	3.3	0.0	0.1	0.1	0.1	99.2
5	peaty silts	52.6	4.8	6.7	42.4	7.6	4.8	29.9	36.8	6.3	1.1	1.1	0.6	0.5	99.2
7	fluvial and lake sands	52.4	2.9	5.5	17.2	10.2	1.3	5.6	67.6	6.5	0.1	0.3	0.3	0.0	99.9
17	peats on tills, clays and silts	75.5	2.3	1.6	27.6	2.4	1.8	23.4	58.1	8.1	0.4	0.1	0.1	0.1	98.2
18	peats on sands	117.7	1.7	2.6	29.0	3.1	2.1	23.8	58.5	6.5	0.2	0.4	0.4	0.1	98.9
19	peats	61.0	1.1	2.3	10.2	2.4	0.1	7.6	55.1	13.2	11.8	0.2	0.1	0.1	93.8
All types		**2,293.3**	**2.6**	**27.4**	**35.1**	**15.8**	**5.7**	**13.5**	**16.1**	**2.1**	**0.6**	**15.4**	**8.9**	**6.5**	**99.3**

Table 4.5. Indicator of relations strength between geology and vegetation units

	Vegetation map units																			
Geology map units	No	6c	1a	4a	6e	6a	6b	9a	12	9c	13	10	19	17b	18	17a	16	20	1b	1d
	14	I	II	II	III	IV	IV	V	III	IV	V	V	V	IV	II	III	II	I	I	
	1	I	I	I	I	III	II	I	I	I			I							
	2			I	I	II	III	I	I	I	I									
	6	I	I	I	I	II	II	II	I	I							I			
	8	I	I	I	I	II	I	III		I	II						I			I
	16							III		II						I	I	I	I	
	9		I	I	I	I	I	II	III	I	I		I			I	I			
	3		II	II	I	II	I	I	I	I									I	
	10	I	I	II	II	I	I	I	I	I	I		I			I			I	
	11		I	II	I	III	I	II		I	I								I	
	12		I	I	II	I	II	I		I			I				I		I	
	13	I	I	I	I	II	I	II	I	I	I	I			I	I	I		I	
	15	I	I	I	I	III	I	II	I	I	I	I		I					I	
	4		I	III	II	I	I	I	I	I	I		I				I		I	
	7	I	I	IV	I	I	I	I	I	I			I				I		I	
	18		I	III	II	I	I	I	I	I	I	I	I	I		I	I		I	
	5	I	I	II	II	I	I	I	I	I	I		I	I	III	I	I		I	
	17		I	III	II	I	I	I	I	I	I		I	I		I	I	I	I	V
	19	I	I	III	I	I	I	I	I	I	I			I	I	II	III	V	IV	

substratum. Likewise, it was confirmed that on the substratum type that is dominant in area, various types of vegetation might develop, as other factors intervene, as well (e.g. relative altitude), bringing about local habitat variation.

The indicator here used is also biased by definite statistical shortcomings (e.g. it is not symmetric) and reasoning, based only on its values, can be charged with errors, especially in case of very large differences between areas occupied by the individual types of potential vegetation and the types of geological substratum. That is why, a detailed analysis of the contingency table was carried out in addition, and the indicator was defined according to the formula: (*area occupied* – *area expected*)/*area expected*, where the "expected" values were generated under the assumption of independence of two elements considered (see Table 4.6).

The identification of relations between the potential vegetation and the geological substratum, carried out on the basis of the contingency table is much more restrictive than the reasoning conducted on the basis of the indicator of relation strength. First of all, the lack of significant positive relations between fluvioglacial sands (14) and types of potential vegetation is observed. It can also be concluded that:

- *Querco-Pinetum molinietosum* (9c) displays strong positive relation only with sands and gravels of kames and eskers (16);
- *Querco-Pinetum typicum* (9c) does not have positive habitat relations, but avoids quite a number of substratum types (2, 3, 4, 5, 7, 10, 12, 17, 18, 19);

- *Tilio-Carpinetum calamagrostietosum* (6a) has weak positive relations with regard to tills of north-Polish glaciation (1), dust sands (11), as well as end moraine sands, gravels and tills (15);
- *Tilio-Carpinetum typicum* (poor) (6b) has strong association with tills of middle-Polish glaciation (2), and weak preferences with regard to tills of north-Polish glaciation (1), and fluvioglacial sands on tills and silts (6), as well as sands and silts (12);
- *Tilio-Carpinetum stachyetosum* (6e) does not display distinct positive relations, while avoiding strongly various types of substratum (1, 2, 3, 7, 8, 9, 11, 13, 15, 16);
- *Fraxino-Alnetum* (4a) displays weak positive relation with a number of substratum types, namely fluvial and lake sands (7), peats on tills, clays and silts (17), peats on sands (18), and generally peats (19);
- *Ribeso-Alnetum* (1a) is characterised by a strong relation with respect to clays, silts, gyttias (3) and peats (19), and by a weak association regarding fluvial and lacustrine sands (7), peats on tills, clays and silts (17), as well as peats on sands (18);
- *Molinio-Pinetum* (16) displays strong possitive associations only with clays, silts and gyttias (3), and peats (19), while displaying very strong negative association with all the remaining types of habitats, except for peaty silts (5);
- *Peucedano-Pinetum* sarmatian variant (12) is associated only with the aeolian sands (9), while showing very strong negative preferences regarding all the remaining types of substratum;
- *Peucedano-Pinetum* subboreal variant (13) is characterised by weaker positive relations with the deluvial sands (8) and, simultaneously, by strong avoidance of the majority of remaining substratum types, except for fluvioglacial sands and fluvial sands of higher terraces (14).

For methodological reasons the analysis of the contingency table omitted the types of potential natural vegetation occupying a very small area. Yet, in order to determine their preferences concerning the geological substratum, a simple indicator was calculated – the ratio of the share of a given vegetation type in the surface of a particular substratum to the share of this vegetation type in the whole region (Table 4.7).

It can be concluded that:

- There is a very distinct preference of the lime-oak-hornbeam forests, especially the typical ones (*Tilio-Carpinetum typicum*) for clayey substratum (1, 2, 6, 13, 15) and also for some richer sands (8, 12);
- The moist habitat communities (alluvial forests, alder carrs, moist and swampy pine forests, as well as bogs) display the preferences for peaty substratum, and for mineral and mineral-organic ones, deposited by waters. It appears, however, that each of these potential natural vegetation units has a somewhat different set of preferred substratum types;
- Mixed pine forests are associated with sands and gravels of kames and eskers, and also with some other types of sandy substratum;
- Fresh pine forests (*Peucedano-Pinetum*) in the southern part of the study area clearly prefer aeolian sands, while in the northern part – weakly prefer fluvioglacial sands.

The analyses, carried out with three different methods, yield a similar, although not identical image of relations between the geological substratum and types of potential natural vegetation. This ought not to be surprising, since each of the methods emphasizes somewhat different kind of relationships between the features considered. The comparison performed demonstrated the usefulness of geological maps in elaboration of the potential natural vegetation maps, limited, though, to those places, where the geological substratum indicates the narrowly specialised plant communities.

Table 4.6. Relationship between potential natural vegetation types and lithological substratum types

	Geology map units	**Vegetation map units**									
		Querco–Pinetum molinietosum – 9c	*Querco–Pinetum typicum* – 9a	*Tilio–Carpinetum calamagrostietosum* – 6a	*Tilio–Carpinetum typicum* (poor) – 6b	*Tilio–Carpinetum stachyetosum* – 6e	*Fraxino–Alnetum* – 4a	*Ribeso–Alnetum* – 1a	*Molinio–Pinetum* – 16	*Peucedano–Pinetum* sarmatian – 12	*Peucedano–Pinetum* subboreal – 13
16	kame and esker sands and gravels	13.61	1.25	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
9	aeolian sands	-0.35	0.07	-0.70	-0.78	-0.93	-0.88	-0.87	-0.62	5.38	-0.69
8	deluvial sands	-0.52	0.79	0.31	-0.68	-0.98	-0.85	-0.13	-1.00	-1.00	2.38
14	fluvioglacial sands and sands of higher fluvial terraces	0.02	0.33	0.15	0.05	-0.16	-0.60	-0.51	-0.43	-0.25	0.56
1	tills, north-Polish glaciation	-0.90	-0.28	2.11	3.16	-0.65	-0.90	-0.92	-1.00	-1.00	-1.00
2	tills, middle-Polish glaciation	-0.87	-0.82	0.75	8.36	-0.54	-0.61	-1.00	-1.00	-1.00	-0.91
3	clays, silts, gyttias	-0.73	-0.65	0.45	-0.27	-0.74	0.98	11.42	-1.00	-1.00	-1.00
13	fluvioglacial sands and gravels on tills	1.24	0.08	1.46	0.31	-0.64	-0.71	-0.58	-0.84	-0.96	0.01
11	dust sands	0.74	0.41	2.03	-0.77	-0.96	-0.80	-0.15	-1.00	-1.00	-0.80
15	end moraine sands, gravels and tills	-0.98	0.14	2.67	-0.29	-0.98	-0.99	-0.98	-1.00	-0.43	-0.93
6	fluvioglacial sands on tills and silts	-0.24	-0.22	0.84	2.62	0.08	-0.35	-0.86	-0.55	-0.95	-1.00
12	sands and silts	-0.97	-0.75	-0.32	3.24	1.84	0.18	-0.90	-1.00	-1.00	-1.00
10	humus sands	0.85	-0.83	-0.38	-0.24	1.76	1.23	-0.04	-0.86	-0.99	-0.97
4	sandy silts	0.70	-0.78	-0.51	0.14	1.23	1.55	0.53	-1.00	-0.99	-0.99
5	peaty silts	0.87	-0.76	-0.52	-0.16	1.22	1.28	1.95	0.89	-0.93	-0.92
7	fluvial and lake sands	0.11	-0.80	-0.36	-0.77	-0.58	3.16	2.03	-0.91	-0.97	-1.00
17	peats on tills, clays and silts	-0.08	-0.94	-0.85	-0.69	0.76	2.64	2.86	-0.40	-0.99	-0.99
18	peats on sands	-0.35	-0.91	-0.80	-0.62	0.77	2.63	2.06	-0.60	-0.96	-0.99
19	peats	-0.56	-0.91	-0.84	-0.98	-0.40	2.61	5.58	19.64	-0.99	-0.98

Note: Red indicates very strong negative relation, navy blue – strong positive relation, blue – weaker positive relation, blank – very weak relation (positive or negative) and lack of relations.
Results of contingency table analyses. Values are calculated as: (area occupied – area expected)/area expected. Statistics: chi^2 = 195,967.972 for 162 degrees of freedom, significance: 0.0000; Cramer's V coefficient = 0.328; Goodman-Kruskal's Gamma coefficient = 0.190.

Table 4.7. Preferences of vegetation communities (potential natural vegetation units) with regard to geological substratum types

Types of geological substratum (aggregated)		Types of potential natural vegetation																				
Code	description	*Tilio-Carpinetum* (all) – 6	*Tilio-Carpinetum calamagrostietosum* – 6a	*Tilio-Carpinetum typicum* (poor) – 6b	*Tilio-Carpinetum typicum* (rich) – 6c	*Tilio-Carpinetum stachyetosum* – 6e	*Fraxino-Alnetum* – 4a	*Ribeso-Alnetum* – 1a	*Sphagno-Alnetum* – 1b	*Thelypteris – Betula* community – 1d	*Vaccinio uliginosi-Pinetum typicum* – 17a	*Vaccinio uliginosi-Pinetum molinietosum* – 17b	*Oxycocco-Sphagnetea* – 20	*Sphagno girgensohnii -Piceetum* – 18	*Molinio-Pinetum* – 16	*Querco-Piceetum* – 19	*Querco-Pinetum molinietosum* – 9c	*Querco-Pinetum typicum* – 9a	*Peucedano-Pinetum* (all) – 12+13	*Peucedano-Pinetum* sarmatian variant –12	*Peucedano-Pinetum* subboreal variant – 13	*Serratulo-Pinetum* – 10
1	tills, north-Polish glaciation	2.2	3.1	4.2	2.2	0.4	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.7	0.0	0.0	0.0	0.0
2	tills, middle-Polish glaciation	2.5	1.8	9.4	0.0	0.5	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.0	0.0	0.1	0.0
6	fluvioglacial sands on tills and silts	1.9	1.8	3.6	14.3	1.1	0.6	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.8	0.8	0.0	0.1	0.0	0.0
13	fluvioglacial sands and gravels on tills	1.5	2.4	1.3	9.7	0.4	0.3	0.4	0.9	0.0	0.2	0.0	0.0	0.3	0.1	0.0	2.2	1.1	0.4	0.0	1.0	1.6
15	end moraine sands, gravels and tills	1.8	3.7	0.7	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	1.1	0.4	0.6	0.1	0.6
12	sands and silts	2.1	0.7	4.3	0.0	2.9	1.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0
11	dust sands	1.4	3.1	0.2	0.0	0.0	0.2	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7	1.4	0.1	0.0	0.2	0.0
10	humus sands	1.5	0.6	0.8	1.2	2.8	2.2	1.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1	0.8	1.9	0.2	0.0	0.0	0.0	0.0
8	deluvial sands	0.7	1.3	0.3	18.3	0.0	0.2	0.9	0.0	0.9	0.0	0.0	0.0	0.0	0.2	0.0	0.5	1.8	1.4	0.0	3.3	0.0
4	sandy silts	1.3	0.5	1.1	0.0	2.2	2.6	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.4	1.7	0.2	0.0	0.0	0.0	0.0
5	peaty silts	1.2	0.5	0.8	0.3	2.2	2.3	3.0	0.9	0.0	0.3	0.7	0.0	20.8	1.9	1.4	1.9	0.2	0.1	0.1	0.1	0.0
17	peats on tills, clays and silts	0.8	0.2	0.3	0.0	1.7	3.6	3.8	3.8	30.3	4.6	2.9	2.4	0.0	0.6	0.0	0.9	0.1	0.0	0.0	0.0	0.0
18	peats on sands	0.8	0.2	0.4	0.0	1.8	3.6	3.1	2.8	0.0	2.1	3.7	0.0	0.0	0.4	1.0	0.6	0.1	0.0	0.0	0.0	0.0
19	peats	0.3	0.2	0.0	0.7	0.6	3.4	6.2	23.6	0.0	10.5	2.2	30.7	5.5	19.5	0.0	0.4	0.1	0.0	0.0	0.0	0.0
3	clays, silts, gyttias	0.9	1.4	0.8	0.0	0.3	1.9	12.1	16.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.0	0.0	0.0	0.0
7	fluvial and lake sands	0.5	0.6	0.2	0.7	0.4	4.2	3.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	1.1	0.2	0.0	0.0	0.0	0.0
16	kame and esker sands and gravels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.4	0.0	8.6	0.0	0.2	0.0	0.4	0.0	14.1	2.2	0.0	0.0	0.0	0.0
9	aeolian sands	0.2	0.3	0.2	0.0	0.1	0.1	0.1	0.1	0.0	0.3	0.3	0.0	0.0	0.4	0.2	0.7	1.1	3.9	6.4	0.3	0.0
14	fluvioglacial sands and sands of higher fluvial terraces	1.0	1.1	1.0	0.7	0.8	0.4	0.5	0.1	0.0	0.7	1.0	0.2	0.6	0.6	1.3	1.0	1.3	1.1	0.7	1.6	1.6

Indicator of preference (P = share of pnv in the geology type/share of pnv in the region).

4.4. Geobotanical division based on the potential natural vegetation

4.4.1. The study area in the existing geobotanical division

According to the currently accepted geobotanical division (Matuszkiewicz, 2008a), study area is situated in the Central European Province, belonging to the European Area of Deciduous and Mixed Forests, extending from Atlantic Ocean in the west up to the Urals in the east. More precisely, study area is located at the junction of two large geo-botanical regions of the divide rank: the Masovian and Polesye Divide (E) and the Masurian and Belarusian Divide (F), and then in two regions: E.2. Northern Masovian-Kurpie Region and F.1. Masuria Region (Fig. 4.3).

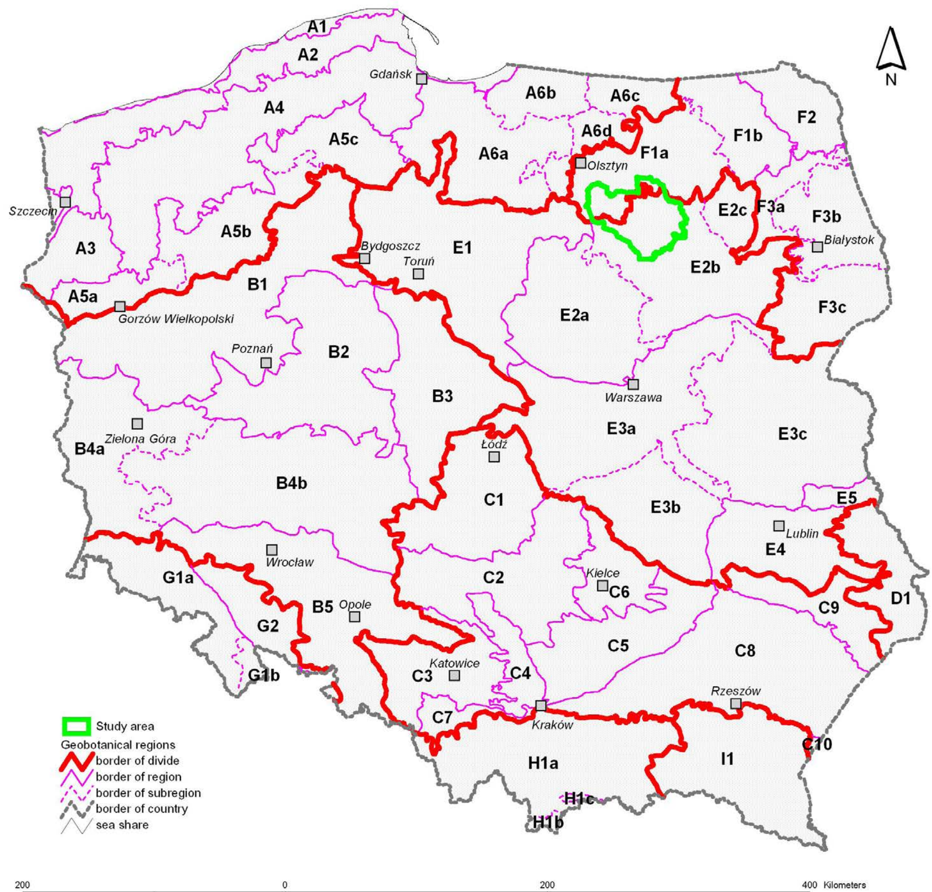

Fig. 4.3. Location of the study area against the background of general geobotanical regionalisation of Poland (acc. to Matuszkiewicz, 2008a)

More than two thirds of the study area is situated within the Masovian and Polesye Divide, Northern Masovian-Kurpie Region and Green Kurpie Forest District, while less than one third in the Masurian and Belarusian Divide, and the Masurian Region, mainly in the Napiwodzka Forest District (Table 4.8, Fig. 4.4).

Table 4.8. Geobotanical regions in the study area (acc. to Matuszkiewicz, 2008a)

Geobotanical regions in the study area, in hierarchic system (all within Central European Province, Proper Central European Subprovince)	Area within the study [km²]	Share of geobotanical unit within the study [%]	Area of geobotanical unit [km²]	% of geobotanical unit in the study area
E. Masovian and Polesye Divide, E. Masovian Subdivide*	1,971.3	69.3	73,435.5	2.7
E.2. Northern Masovian-Kurpie Region	1,971.3	69.3	20,774.2	9.5
E.2b. Kurpie Subregion	1,971.3	69.3	9,997.6	19.7
E.2b.6. Różan-Janowo District	0.6	0.0	1,351.9	0.0
E.2b.6.d. Jednorożec Subdistrict	0.6	0.0	318.6	0.2
E.2b.7. Green Kurpie Forest District	1,970.7	69.3	3,127.7	63.0
E.2b.7.a. Chorzele-Lipowiec Subdistrict	657.3	23.1	723.2	90.9
E.2b.7.b. Myszyniec Ridge Subdistrict	109.5	3.8	115.3	95.0
E.2b.7.c. Kurpie Plain Subdistrict	1,203.9	42.3	2,289.2	52.6
F. Mazurian and Belarusian North Divide*	872.4	30.7	25,247.2	3.5
F.1. Masuria Region*	872.4	30.7	10,523.8	8.3
F.1a. Masuria-West Subregion	872.4	30.7	6,558.0	13.3
F.1a.1. Olsztyn-Szczytno District	59.5	2.1	1,420.1	4.2
F.1a.1.b. Stawiguda-Butryny Subdistrict	4.1	0.1	229.3	1.8
F.1a.1.d. Pasym-Szczytno Subdistrict	55.5	2.0	645.0	8.6
F.1a.2. Napiwodzka Forest District	630.0	22.2	1,026.2	61.4
F.1a.2.a. Maróz-Kośno Subdistrict	94.9	3.3	328.9	28.8
F.1a.2.b. Omulew-Muszaki Subdistrict	138.5	4.9	226.6	61.1
F.1a.2.c. Piduń-Wielbark Subdistrict	368.4	13.0	371.1	99.3
F.1a.2.d. Kobylocha Subdistrict	28.2	1.0	99.7	28.3
F.1a.5. Pisz Forest District	182.8	6.4	1,512.0	12.1
F.1a.5.a. Babięta Subdistrict	163.8	5.8	351.3	46.6
F.1a.5.b. Nida Subdistrict	19.0	0.7	495.8	3.8

* – the part in Poland.

Location of the study area at the junction of two large geobotanical units is reflected in the variation of vegetation and in inventories of plant communities. This is visible on the survey maps of potential natural vegetation (Matuszkiewicz et al., 1995). In general, the Region of Masuria can be distinguished from the northern Masovian-Kurpie Region through the appearance of some communities of the subboreal character. These include: typical subboreal pine forests and mixed spruce-pine forests (*Querco-Piceetum* and *Sphagno girgensohnii-Piceetum* associations), as well as the subboreal variant of subcontinental lime-oak-hornbeam forests (*Tilio-Carpinetum*), which replaces in the north of the study area the Masovian variety of the same association. Likewise, the pine forests, represented by *Peucedano-Pinetum* association, also differ, in the north appearing as the subboreal variant and in the south as the sarmatian variant.

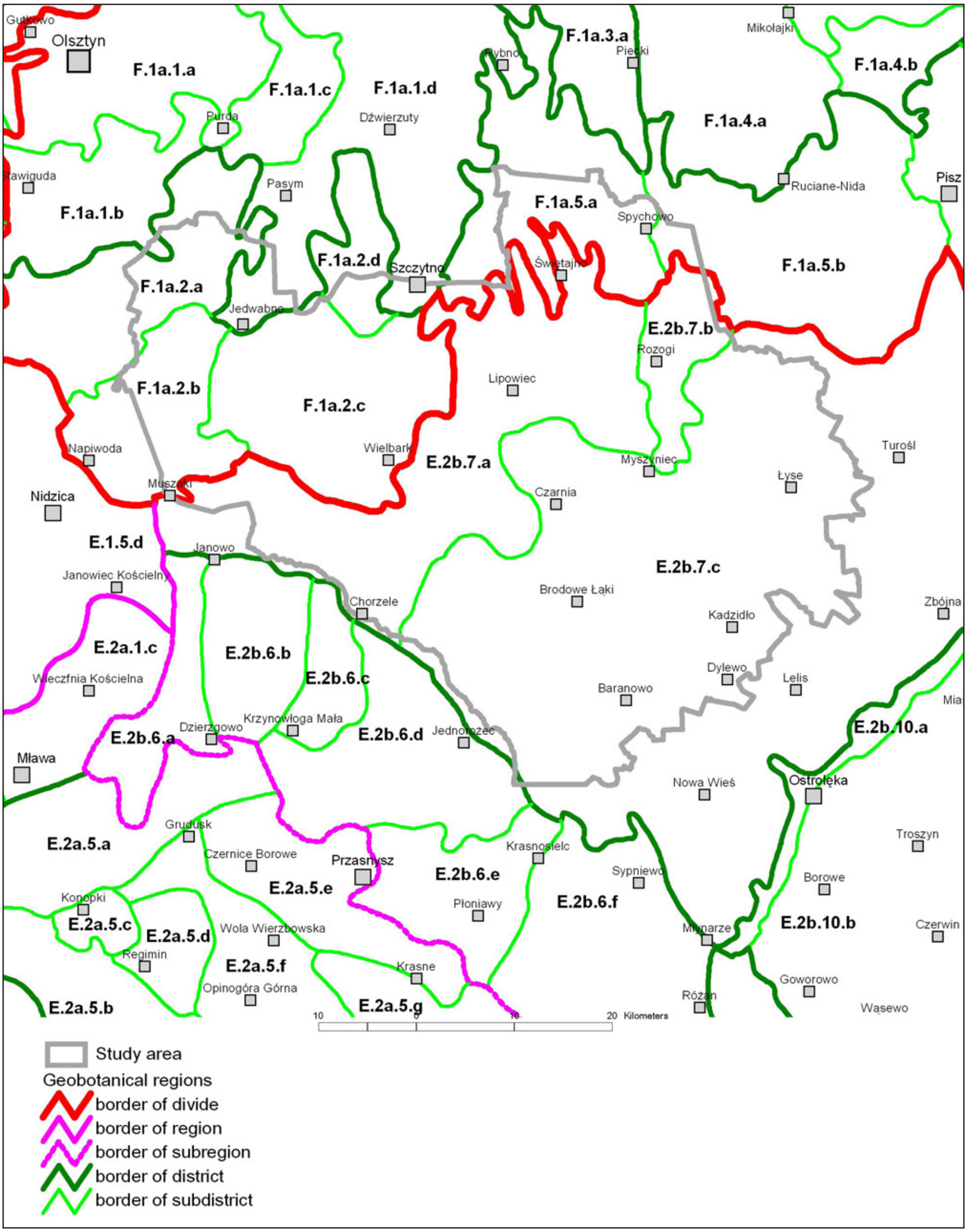

Fig. 4.4. Location of the study area among detailed geobotanical regions of Poland (acc. to Matuszkiewicz, 2008a)

The general knowledge of the plant communities inventories in large regions does not ensure, yet, that in a relatively small area it would be possible to distinguish regional variants of communities. Despite the fact that the differences between the subboreal and the Masovian variant of the *Tilio-Carpinetum* association are doubtless from the phytosociological point of view, their separation within the study area was deemed too uncertain, especially in view of relatively few patches of well-developed lime-oak-hornbeam forests in the southern part of the study area. Similarly, attempt was abandoned of distinguishing the regional varieties of the mixed oak-pine forests of *Querco-Pinetum* association. Only in the case of pine forests (*Peucedano-Pinetum*) it was deemed possible to distinguish the variants sufficiently precisely. In doing this, the shares of species characteristic of the subboreal variant (spruce *Picea abies* and moss *Ptilium crista-castrensis*) in the particular patches of pine forests were considered.

Moreover, not far from the study area the eastern fringe of another large-scale unit of the geobotanical division, namely of the Pomeranian Divide (A), included in the South Baltic Subprovince is located. This unit distinguishes itself mainly through the appearance of beech forests (*Fagion sylvaticae* alliance) and the Pomeranian association of oak-hornbeam forests (*Stellario-Carpinetum*). Conform to the general opinions the entire study area is situated outside of the natural range of beech (*Fagus sylvatica*) and beech forests (*Fagion sylvaticae*) – Boratyńska & Boratyński, 1990; Zając & Zając, 2001. Yet, this research allowed for the statement that the extreme plots where *Fagion* alliance can be found, partly owing to the human activity – beech planting, and partly owing to the natural expansion of beech eastwards, are located in the north-western part of the study area[1]. It was concluded on the basis of climatic data from Szczytno weather station that the climatic conditions correspond to the requirements of beech forests, and the expansion of beech, having gone on for more than 2500 years within Pomerania in the eastern direction might have resulted in the shift of the beech forests reach (Matuszkiewicz & Kowalska, 2017). As a result, *Luzulo pilosae-Fagetum* association is included in the inventory of potential plant communities with indication of its two sites within the study area. This statement might become the basis for the correction of geo-botanical division, consisting in the shift of two districts: Olsztyn-Szczytno District (F.1a.1) and Napiwodzka Forest District (F.1a.2) from the Masurian and Belarusian North Divide (F) to the Pomeranian Divide (A).

4.4.2. Suggestions of changes in the geobotanical division

The very detailed map of potential natural vegetation of the study area may constitute the basis for the analysis of regional vegetation variation, and also for the corrections as to the geobotanical division, having been elaborated earlier basing on the much less detailed maps. The proposal for the changes in the regional division of the study area is shown in Fig. 4.5. It suggests the distinction of new basic units and changes in the course of boundaries of some other ones. These changes would entail also some rectifications

[1] In the research sites defined as potential beech forests, beech trees were planted over hundred years ago, without a doubt, by people; but their good condition and other favorable factors seem to confirm this diagnosis.

at the level of higher regional units. In the new, amended boundaries of basic spatial units, the shares of potential vegetation types (Table 4.9) and regions similarity were determined (Fig. 4.6).

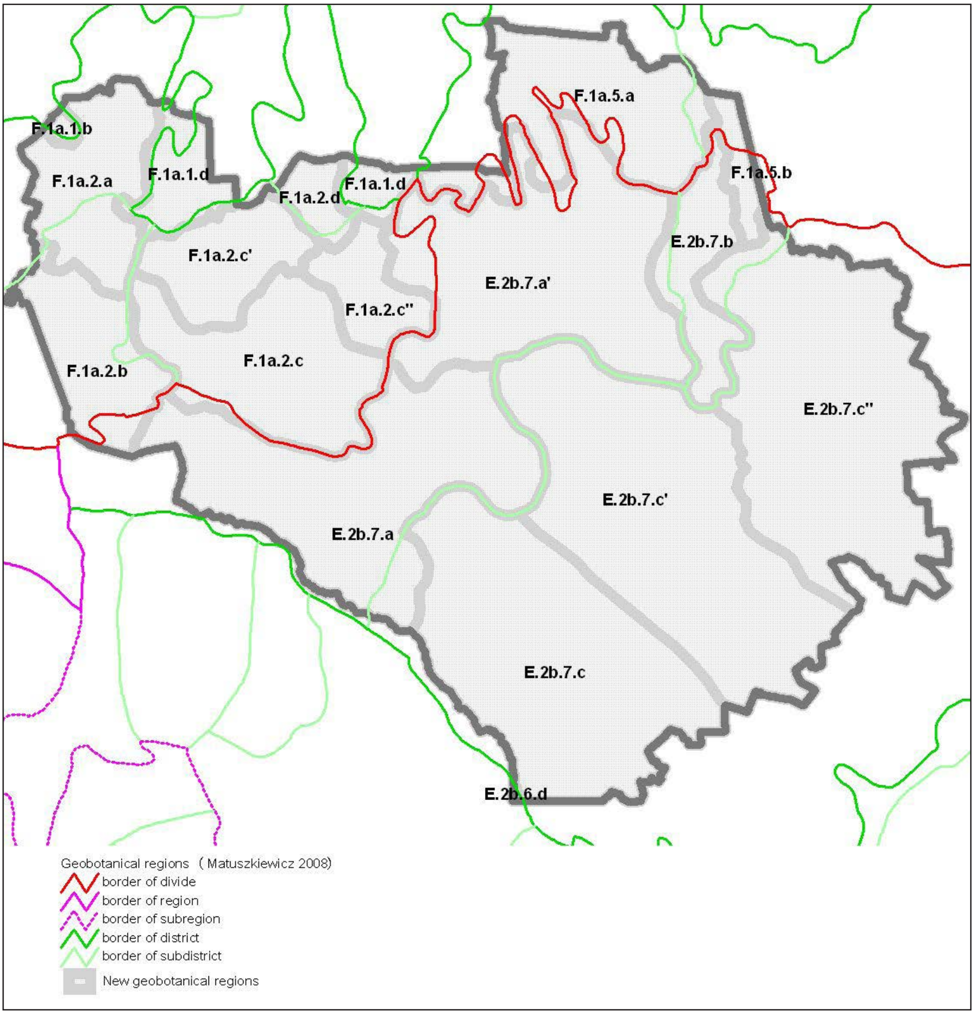

Fig. 4.5. Suggestions of changes in geobotanical divisions

Analysis of basic units similarity allowed for the determination of regional typology, provided in Table 4.10 and on the map (Fig. 4.7). The respective data shall be used in the future to a more complete rectification of the present geobotanical divsion of Poland, following the approach of Matuszkiewicz (2008a).

Table 4.9. Share of potential natural vegetation types [%] within geobotanical regions after correction

Regional geobotanical units (after change)	E2b7a	E2b7a′	E2b7b	E2b7c	E2b7c′	E2b7c″	F1a1b	F1a1d	F1a2a	F1a2b	F1a2c	F1a2c′	F1a2c″	F1a2d	F1a5a	F1a5b	Average
Area of the region [km^2]	327	330	85	372	418	410	6	79	124	112	184	93	62	30	185	27	178
Ribeso nigri-Alnetum	2.3	1.4	0.3	1.9	1.7	2.0	2.7	4.2	5.9	1.7	1.4	10.5	1.0	18.0	2.4	2.4	3.7
Sphagno squarrosi-Alnetum	0.0	0.0	0.0	0.1	0.4	0.2	0.0	0.0	0.7	0.3	0.1	1.5	0.0	0.4	0.1	0.0	0.2
Comm. *Betula pubescens – Thelypteris palustris*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0
Fraxino-Alnetum	15.7	15.9	7.3	30.1	18.5	21.8	4.1	5.7	5.9	7.8	8.6	5.4	11.3	18.6	4.7	2.8	11.5
Hydrogenic forests in total	**18.0**	**17.3**	**7.6**	**32.0**	**20.6**	**24.0**	**6.8**	**9.9**	**12.4**	**9.9**	**10.2**	**17.4**	**12.3**	**37.0**	**7.4**	**5.2**	**15.5**
Tilio-Carpinetum calamagrostietosum	14.3	18.6	21.3	16.6	11.3	12.4	18.4	57.1	12.2	36.2	12.5	18.8	23.2	22.0	17.4	0.3	19.5
Tilio-Carpinetum typicum, poor variant	3.1	9.6	14.4	0.8	9.8	8.7	71.8	23.4	0.7	0.6	0.2	0.3	2.8	1.4	2.0	0.6	9.4
Tilio-Carpinetum typicum, rich variant	0.0	0.0	2.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.6	0.2
Tilio-Carpinetum stachyetosum	13.7	26.8	16.0	4.9	8.5	17.8	2.8	0.5	0.3	2.4	6.7	1.3	17.2	0.7	5.7	4.9	8.1
Lime-oak-hornbeam forests in total	**31.1**	**55.0**	**54.6**	**22.2**	**29.7**	**39.0**	**93.0**	**81.0**	**13.2**	**39.2**	**19.5**	**20.4**	**43.2**	**24.1**	**25.4**	**6.5**	**37.3**
Luzulo-Fagetum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Querco roboris-Pinetum typicum	30.7	19.1	32.8	21.9	24.0	20.7	0.0	1.1	42.2	44.0	26.3	34.4	30.8	24.2	33.4	43.7	26.8
Querco roboris-Pinetum molinietosum	6.0	6.3	1.7	4.6	3.2	3.3	0.0	0.1	1.8	0.2	2.1	1.5	10.4	2.2	3.7	6.1	3.3
Serratulo-Pinetum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0
Mixed oak-pine forests in total	**36.7**	**25.5**	**34.5**	**26.5**	**27.3**	**24.0**	**0.0**	**1.2**	**44.0**	**44.2**	**28.4**	**35.9**	**41.1**	**26.3**	**37.6**	**49.8**	**30.2**
Peucedano-Pinetum sarmatian variant	13.5	0.8	0.1	19.2	19.5	12.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.1
Peucedano-Pinetum subboreal variant	0.0	0.9	0.9	0.0	0.0	0.0	0.0	0.0	21.8	1.0	41.8	18.4	3.4	5.4	24.6	35.4	9.6
Cladonio-Pinetum	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fresh and dry pine forests in total	**13.5**	**1.7**	**0.9**	**19.2**	**19.7**	**12.2**	**0.0**	**0.0**	**21.8**	**1.0**	**41.8**	**18.4**	**3.4**	**5.4**	**24.6**	**35.4**	**13.7**
Molinio-Pinetum	0.1	0.2	0.1	0.0	2.4	0.2	0.0	0.0	0.8	0.0	0.0	0.2	0.1	0.4	0.9	0.2	0.3
Vaccinio uliginosi-Pinetum typicum	0.0	0.1	0.0	0.0	0.1	0.2	0.0	0.0	1.5	0.3	0.1	1.0	0.0	0.4	0.2	0.7	0.3
Vaccinio uliginosi-Pinetum molinietosum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sphagno girgensohnii-Piceetum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Querco-Piceetum	0.5	0.3	2.2	0.0	0.2	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	2.2	0.4
Sphagnetalia magellanici	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.3	0.0	0.4	0.0	0.0	0.1
Waters	0.1	0.0	0.1	0.0	0.0	0.0	0.2	6.9	5.8	5.4	0.1	6.4	0.0	6.0	3.9	0.0	2.2

Table 4.10. Preferences of types of potential natural vegetation (PNV) in relation to geobotanical regions. Preferences were calculated as the ratio of the share of the PNV type in a given region to the average share in 16 regions. Input data according to table 4.9

Landscape type	**A**	**A**	**B1**	**B1**	**B2**	**B2**	**B2**	**C1**	**C1**	**C2**	**C2**	**C2**	**D**	**D**	**D**	**D**
Regional geobotanical units (after change)	**F1a1d**	**F1a1b**	**F1a2c′**	**F1a2a**	**F1a5a**	**F1a5b**	**F1a2c**	**F1a2b**	**F1a2d**	**E2b7a′**	**E2b7b**	**F1a2c″**	**E2b7c**	**E2b7c″**	**E2b7a**	**E2b7c′**
Ribeso nigri-Alnetum	1.1	0.7	2.8	1.6	0.6	0.7	0.4	0.5	4.8	0.4	0.1	0.3	0.5	0.5	0.6	0.5
Sphagno squarrosi-Alnetum	0.1	0.0	6.2	2.8	0.3	0.0	0.4	1.3	1.8	0.0	0.0	0.0	0.4	0.7	0.0	1.9
Betula pubescens – Thelypteris palustris community	0.0	0.0	0.0	0.0	16.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fraxino-Alnetum	0.5	0.4	0.5	0.5	0.4	0.2	0.8	0.7	1.6	1.4	0.6	1.0	2.6	1.9	1.4	1.6
Hydrogenic forests in total	**0.6**	**0.4**	**1.1**	**0.8**	**0.5**	**0.3**	**0.7**	**0.6**	**2.4**	**1.1**	**0.5**	**0.8**	**2.1**	**1.5**	**1.2**	**1.3**
Tilio-Carpinetum calamagrostietosum	2.9	0.9	1.0	0.6	0.9	0.0	0.6	1.9	1.1	1.0	1.1	1.2	0.8	0.6	0.7	0.6
Tilio-Carpinetum typicum, poor variant	2.5	7.6	0.0	0.1	0.2	0.1	0.0	0.1	0.2	1.0	1.5	0.3	0.1	0.9	0.3	1.0
Tilio-Carpinetum typicum, rich variant	0.0	0.0	0.0	0.0	1.4	2.4	0.0	0.0	0.0	0.0	12.1	0.0	0.0	0.0	0.1	0.0
Tilio-Carpinetum stachyetosum	0.1	0.3	0.2	0.0	0.7	0.6	0.8	0.3	0.1	3.3	2.0	2.1	0.6	2.2	1.7	1.0
Lime-oak-hornbeam forests in total	**2.2**	**2.5**	**0.5**	**0.4**	**0.7**	**0.2**	**0.5**	**1.1**	**0.6**	**1.5**	**1.5**	**1.2**	**0.6**	**1.0**	**0.8**	**0.8**
Luzulo-Fagetum	16.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Querco roboris-Pinetum typicum	0.0	0.0	1.3	1.6	1.2	1.6	1.0	1.6	0.9	0.7	1.2	1.1	0.8	0.8	1.1	0.9
Querco roboris-Pinetum molinietosum	0.0	0.0	0.5	0.5	1.1	1.8	0.6	0.0	0.6	1.9	0.5	3.1	1.4	1.0	1.8	1.0
Serratulo-Pinetum	0.0	0.0	0.0	0.0	16.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mixed oak-pine forests in total	**0.0**	**0.0**	**1.2**	**1.5**	**1.2**	**1.7**	**0.9**	**1.5**	**0.9**	**0.8**	**1.1**	**1.4**	**0.9**	**0.8**	**1.2**	**0.9**
Peucedano-Pinetum sarmatian variant	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	4.7	3.0	3.3	4.8
Peucedano-Pinetum subboreal variant	0.0	0.0	1.9	2.3	2.6	3.7	4.4	0.1	0.6	0.1	0.1	0.4	0.0	0.0	0.0	0.0
Cladonio-Pinetum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.0
Fresh and dry pine forests in total	**0.0**	**0.0**	**1.3**	**1.6**	**1.8**	**2.6**	**3.1**	**0.1**	**0.4**	**0.1**	**0.1**	**0.2**	**1.4**	**0.9**	**1.0**	**1.4**
Molinio-Pinetum	0.0	0.0	0.5	2.4	2.5	0.4	0.1	0.0	1.1	0.5	0.3	0.2	0.1	0.7	0.4	7.0
Vaccinio uliginosi-Pinetum typicum	0.0	0.0	3.4	5.4	0.6	2.6	0.2	1.1	1.5	0.2	0.0	0.0	0.0	0.7	0.0	0.2
Vaccinio uliginosi-Pinetum molinietosum	0.0	0.0	0.0	0.0	4.7	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	10.6	0.0	0.0
Sphagno girgensohnii-Piceetum	0.0	0.0	0.0	0.0	4.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.5
Querco-Piceetum	0.1	0.0	0.0	0.0	0.2	6.0	0.0	0.0	0.0	0.7	6.0	0.0	0.0	0.9	1.5	0.5
Sphagnetalia magellanici	0.0	0.0	4.7	5.0	0.5	0.0	0.3	0.0	5.3	0.0	0.0	0.2	0.0	0.0	0.0	0.0
Waters	3.2	0.1	2.9	2.7	1.8	0.0	0.0	2.5	2.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0

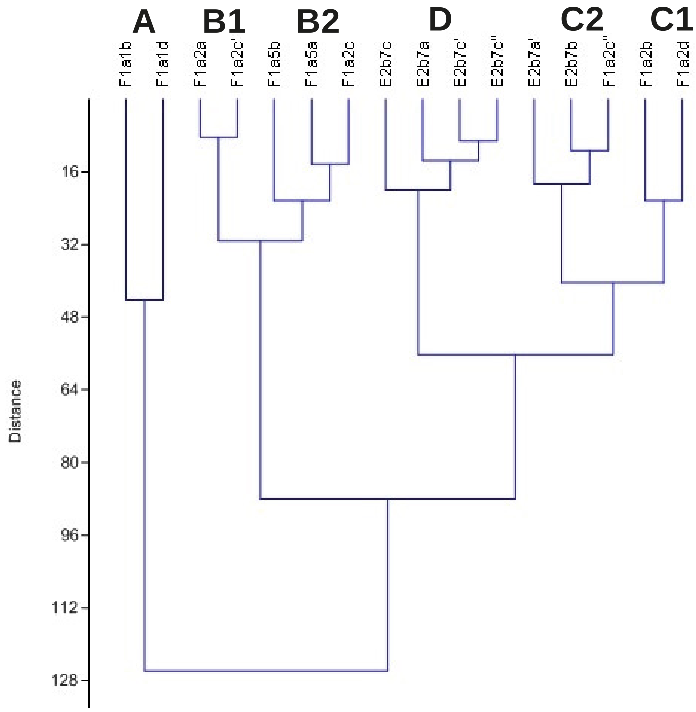

Fig. 4.6. Similarity of geobotanical regions (Table 4.9) in terms of potential natural vegetation communities; vertical axis: statistical distance between compared units, horizontal axis: units grouped by Ward's method

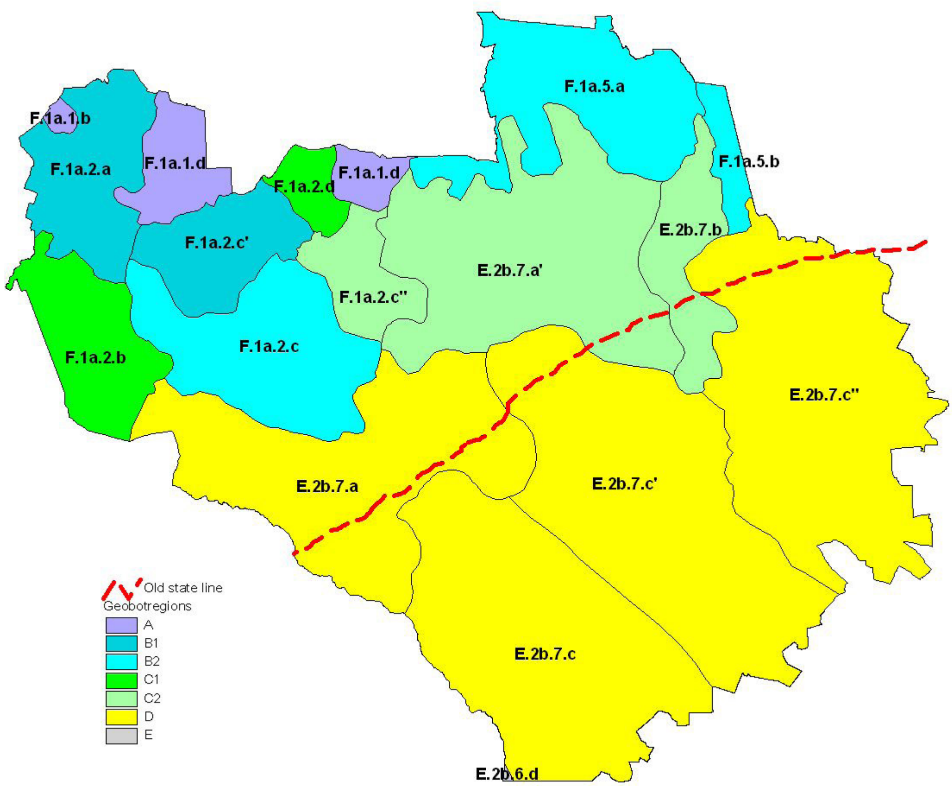

Fig. 4.7. Typology of geobotanical regions based on the share of potential natural vegetation types acc. to Table 4.10

In general, the regions variation regarding the shares of potential vegetation units is as follows:

- Type A is distinguished by the over-representation of lime-oak-hornbeam forest habitats, especially those of typical subassociation (*Tilio-Carpinetum typicum*);
- Type B is distinguished through the over-representation of subboreal pine forests (*Peucedano-Pinetum*). Here, sub-type B1 is distinguished by the over-representation of alder carrs (*Ribeso-Alnetum* and *Sphagno squarrosi-Alnetum*), bogs (*Oxycocco-Sphagnetea*), swampy pine forests (*Vaccinio uliginosi-Pinetum typicum*), and lakes, while sub-type B2 is lacking an additional common group of communities;
- Type C does not have a common distinguishing habitat. Sub-type C1 is distinguished through over-representation of lakes, while sub-type C2 – of moist lime-oak-hornbeam forests (*Tilio-Carpinetum stachyetosum*);
- Type D is clearly distinguished by the over-representation of pine forest (*Peucedano-Pinetum*) in its sarmatian variant and of ash-alder alluvial forests (*Fraxino-Alnetum*).

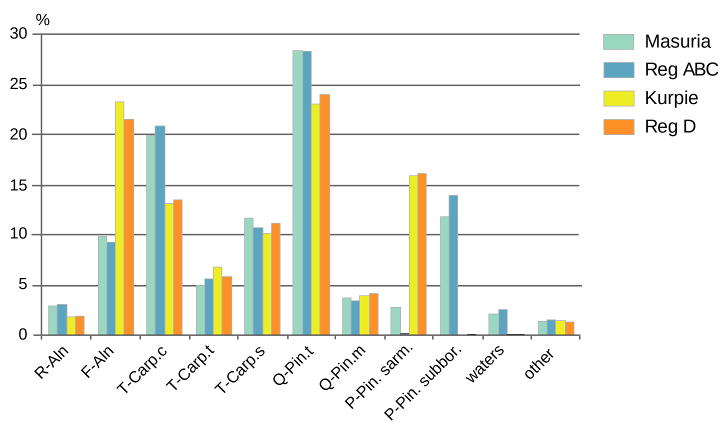

Fig. 4.8. Convergence of the study area division in terms of 2 criteria: administrative-historical, and geobotanical (Reg. ABC – Reg. D)

The landscape-wise differentiation of potential natural vegetation, defined by its quantitative relations (Fig. 4.7) displays a systematic pattern of change from the north-west towards the south-east. The difference between types A, B and C on the one hand, and type D on the other is especially distinct. It is there that the boundary runs between the late glacial and post-glacial areas. Moreover, it is generally similar to the old political boundary, dividing the study area into Masurian and Kurpie parts. Analysing the potential natural vegetation, the changes in forest cover over the last two centuries and other elements of the environment in Masurian and Kurpie parts, we can assume that the division mentioned does not differ significantly from the one that could be proposed as resulting from the habitat variation. The similarity of the study area division into two parts according to the administrative and natural precepts is demonstrated through Fig. 4.8. It can be seen that the northern part displays a clear difference with respect to the southern part, for the majority of habitat types, irrespective of the division criterion. This is particularly visible in the case of two variants of pine forests (*Peucedano-Pinetum*), and also for ash-alder alluvial forests (*Fraxino-Alnetum*), poor lime-oak-hornbeam forests (*Tilio-Carpinetum calamagrostietosum*), and the fresh mixed oak-pine forests (*Querco-Pinetum typicum*). On this basis we can assume that the historical-administrative division, which is still the reference for a part of division into forest districts (four in the north and two in the south), and which was used in this research, has also its rationale in terms of nature.

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5. DEFORESTATION AND AFFORESTATION PROCESSES OF THE MASURIA-KURPIE BORDERLAND

Jan Marek Matuszkiewicz, Anna Kowalska

5.1. Changes in forest cover within last 200 years

The historical maps collected, showing the study area (see Chapter 2), make it possible to determine the forest cover in the past. The respective analysis can be conducted with reasonable accuracy as far back as up to the year 1800. The maps, developed at that time encompassed the entire study area, and were sufficiently accurate to observe the forest reach that could be compared to the one shown on the present-day maps on the scale of around 1:100 000. From a collection of historical maps a subset was selected (Table 5.1), meant to represent the forest cover at seven nominal time points, since the year 1800, through 1830, 1885, 1928, 1950, 1970, up till 2000. These dates ought to be regarded as nominal, since they result from the approximate dating of the state they actually represent. The dating of the historical maps is, however, often unclear and, in principle, in no case could be established with the accuracy of a single year.

Following the procedure, described in Chapter 3, the forest reach was determined (with numerous difficulties concerning calibration and interpretation of maps) at the consecutive dates assumed. The territory was divided in a dichotomous manner – into "forest" and "non-forest" (Fig. 5.1-5.7). Further, big forest complexes were distinguished, that is – the ones having area exceeding 10 km^2. The polygon area displayed on the digital map was taken into account. The gaps, resulting from existence of surface waters as well as meadows and swamps within the forest complexes, were not accounted for. It should be mentioned that it is decidedly more difficult to establish precisely the forest reach on the maps, presenting the states from the first half of the 19th century than on the later ones. Not until the year 1885 the maps can be considered effectively comparable with those showing the current state of forest cover.

Based on digital maps, total forest area of the entire territory considered was calculated, as well as of the two distinguished parts – the northern (Masuria) and the southern (Kurpie). Changes in the size of the selected big forest complexes were also analysed (Table 5.2).

Total afforested area comprised in the year 1800 approximately 1146 km^2, that is – slightly more than 40% of the total study area (Fig. 5.1). Twelve large forest complexes were distinguished. Within the territory of East Prussia (nowadays – Masuria) two relatively compact forest complexes existed at that time – in the eastern and in the western parts. They constituted parts of the past forest complexes, extending beyond the study area. These were the large forests of the kings of Prussia: the eastern (3), indicated on the map as *Königliche Puppensche Forst*, being a part of a great forest, designated in Prussia as *Johannisburgerheide*, and called nowadays "Puszcza Piska" (Forest of Pisz), while the western (1) is designated on the map from the year 1800 as the *Königliche Napiwodasche Forst*. Besides, in the middle part, to the south of Szczytno (then Ortelsburg) a dismembered complex (2) existed, composed mainly, as well, of the property of kings of Prussia, formally belonging to the forest districts of *Königliche Napiwodasche Forst* (the western part), *Königliche Corpellensche Forst* (the northern, middle and southern parts), and *Königliche Fridrichsfeldsche Forst* (the eastern part). The forests formed very distinct clusters. The broadly understood valleys of the rivers: Orzyc, Omulew, Rozoga, Szkwa were relatively most deforested. Forests concentrated mainly along the watersheds. On the other hand, there was strongly deforested area between the rivers Orzyc and Omulew to the west of Wielbark.

Table 5.1. Cartographic data used to ascertain the origin of each wood

Approximate date	Name of the map	Scale	Scope of the map	Description of the map in:
1800	*Topographisch-Militärische Karte vom vormaligen Neu Ostpreussen, oder dem jetzigen Nördlichen Theil des Herzogthums Warschau, nebst dem Russischen Distrikt*	1:150 000	southern part – Kurpie	2.4.1
	Karte von Ost-Preussen nebst Preussisch Litthauen und West-Preussen nebst dem Netzdistrict	1:50 000; 1:150 000	northern part – Masuria	2.4.1
1830	*Topographische Specialkarte des Preussischen Staats und der angrenzenden Länder*	1:200 000	the whole area	2.4.1
1885	*Topographische Karte vom Preussischen Staate unter Einschluss der Anhaltinischen und Thüringischen Länder*	1:100 000	northern part – Masuria	2.4.1
	Novaya Topograficheskaya Karta Zapadnoy Rossii	1:84 000	southern part – Kurpie	2.4.2
1928	*Messtischblätter*	1:25 000	almost the whole area, except a part of Kurpie	2.4.1
	Polish map of Military Institute of Geography	1:100 000	a part of Kurpie region	2.4.3
1950	Topographical map of the General Staff in "Borowa Góra" reference system	1:100 000	the whole area	2.4.3
1970	Polish topographical map in "1965" reference system	1:25 000	the whole area	2.4.3
2000	VMap Level 2 – vector reference map	1:50 000	the whole area	2.4.3

In the southern part of the study area (Kurpie), nine large forest complexes can be distinguished. The biggest of them were situated in the eastern part (7) in the vicinity of Łyse, and in the southern part (8), to the west of Baranowo – one of few villages in Kurpie, where a church existed already at that time. These forests were in their majority the property of Polish kings, taken over then by the rulers of Prussia. Similarly as in East Prussia, forests concentrated in between the river valleys, but there were also large complexes within the confines of the valleys (4, 12). There were relatively more forests than in the northern part, but they formed smaller complexes.

The spread of forests at around the year 1830 (Fig. 5.2) differed only slightly from the one in the earlier period. Generally, forest area decreased a bit, to less than 40% of the total area, with the changes concerning mainly the smaller complexes, while the

Table 5.2. Changes in forest area within 200 years, especially of big complexes

Approximate date	**1800**		**1830**		**1885**		**1928**		**1950**		**1970**		**2000**	
	no	**area [km²]**	**no**	**area [km²]**	**no**	**area [km²]**	**no**	**area [km²]**	**no**	**area [km²]**	**no**	**area [km²]**	**no**	**area [km²]**
Big forest complexes (over 10 km²) distinguished in the figures 5.1-5.7	5	16.8	5	17.1	5	23.8	5a	6.4	5a	5.2	5a	6.4	5a	6.4
							5b	17.2	5b	17.7	1 + 2abc + 5b + 14 + 15	592.9	1 + 2abc + 5b + 14 + 15	612.7
	1	106.1	1	106.4	1	92.9	1 + 14	199.8	1 + 14	212.4				
	-	-	-	-	14	17.3								
	-	-	-	-	-	-	15	12.4	15	13.0				
	2	161.1	2	159.8	2a	24.6	2ab	94.3	2ab	96.2				
					2b	37.7								
					2c	24.1	2c	20.6	2c	23.5				
					(2d)	9.0	(2d)	9.2	(2d)	9.3	2d	20.6	2d	20.6
					(2e)	5.0	(2e)	6.3	(2e)	6.7	2e	11.0	2e	10.6
	3	185.6	3	200.8	3	143.5	3	152.4	3	160.7	3	193.2	3	194.5
	4	57.9	4a	12.4	-	-	-	-	-	-	-	-	-	-
			4b	17.4	4b	17.2	(4b)	9.8	4b	10.8	4b	12.3	4b	12.3
	6	78.1	6	82.6	6	46.2	6	39.4	6 + 9	72.7	6 + 9 + 10a	92.2	6 + 9 + 10a	92.6
	9	38.5	9	38.5	9	28.5	9	28.6						
	10	42.7	10	43.5	10a	7.4	10a	10.3	10a	10.6				
					10b	10.0	(10b)	8.9	(10b)	8.9	10b	10.1	(10b)	9.8
	7	142.1	7	138.4	7a	10.5	7a	10.1	7a	14.2	7	58.3	7	57.8
					7b	26.8	7b	17.8	7b	20.1				
					7c	18.7	7c	11.6	7c	17.5				
	8	129.8	8	131.3	8	99.4	8a	52.2	8a	58.5	8a	63.5	8a	61.6
							8b	10.8	8b	15.8	8b	16.4	8b	16.6
	11	16.1	11	16.3	11	14.1	(11)	8.2	(11)	9.0	11	11.9	11	12.1
	12	13.5	12	13.5	-	-	-	-	-	-	-	-	-	-
	-	-	13	10.3	-	-	-	-	-	-	-	-	-	-
	-	-	-	-	-	-	-	-	-	-	16	26.0	16	28.5
Total – big complexes (over 10 km²)	988.2		988.4		625.5		677.4		743.9		1108.3		1119.8	
The biggest complexes (over 100 km²)	724.6		736.7		143.5		352.2		373.1		786.1		807.2	
Total – small complexes (below 10 km²)	157.7		128.3		248.8		252.5		237.3		196.3		212.2	
Total forest area	1145.9		1116.7		874.2		929.9		981.2		1304.6		1331.9	

borders of the big complexes remained almost unchanged. Yet, one of the big complexes (4 – in the Płodownica valley) got split into two smaller ones, quite distant one from another (4a, 4b). A new large complex (13) appeared, as well.

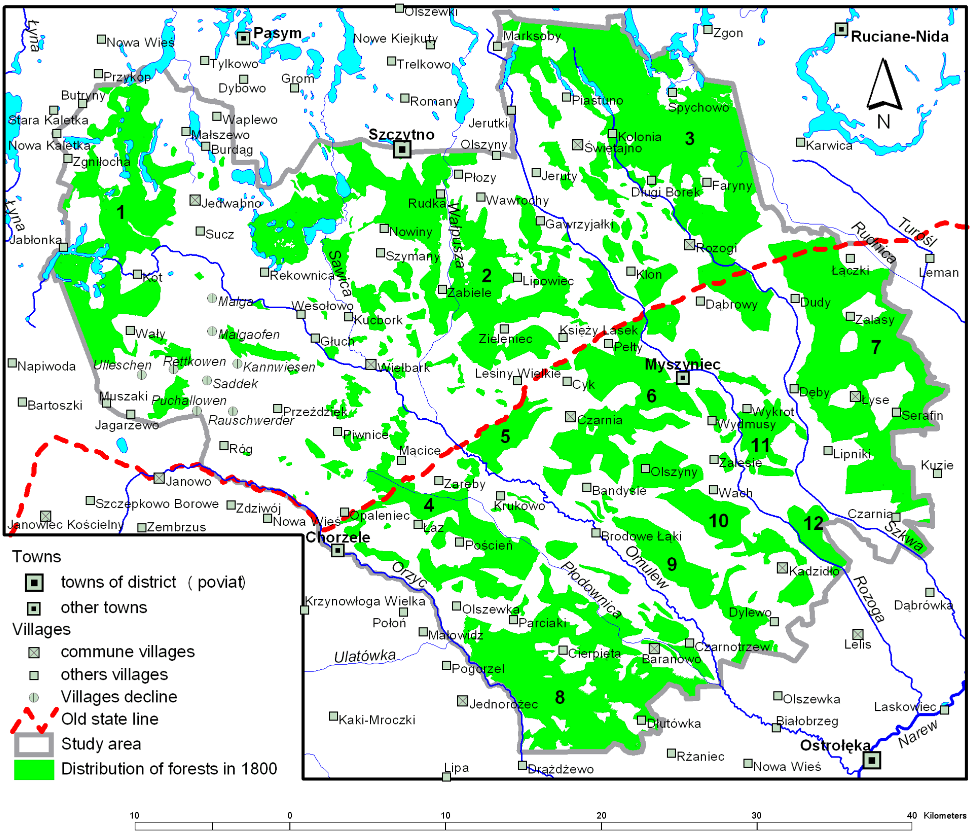

Fig. 5.1. Range of forests in the study area around 1800. Forest complexes over 10 km^2 are marked with numbers

The forest cover range dated for the year 1885 (Fig. 5.3), is based on more reliable data than in the two preceding cases. Yet, the actual dating of the maps of the northern and southern parts is different and can hardly be unambiguously established. The reach of forests is clearly different than in the two preceding time slices. The overall share of forest area dropped to only a bit more than 30%. Significant changes concerned also the large forest complexes. The complex, situated to the south of Szczytno (2) was split into three smaller ones (2a, 2b and 2c), still exceeding 10 km^2, and two yet smaller ones (2d, 2e) – of less than 10 km^2. Forest complex no 7 got split into three parts, and complex no 10 – into two parts. Complex no 12 disappeared. All these changes can be interpreted as a result of the deforestation and fragmentation of forest complexes. Such processes can be observed in both the northern part (East Prussia belonging to the Kingdom of Prussia) and the southern part (at that time – Kingdom of Poland belonging to the Russian Empire). At the same time, though, a large forest complex (14) appeared on the post-agricultural areas to the west of Wielbark.

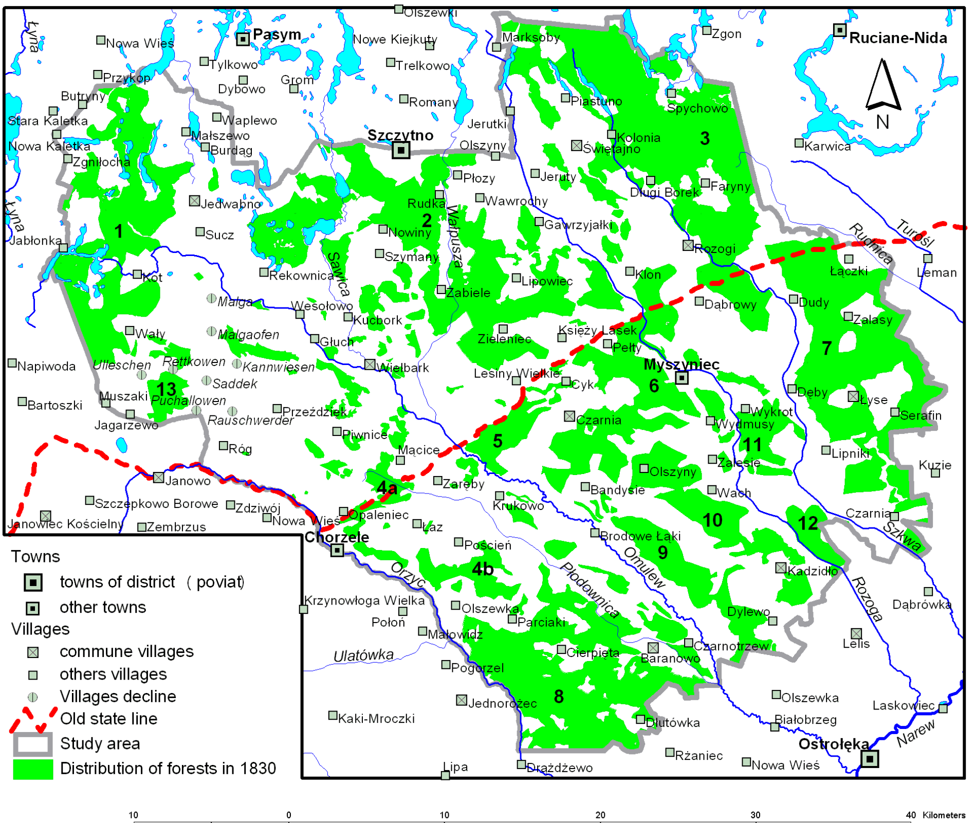

Fig. 5.2. Range of forests in the study area around 1830. Forest complexes over 10 km² are marked with numbers, including the numbers from Fig. 5.1

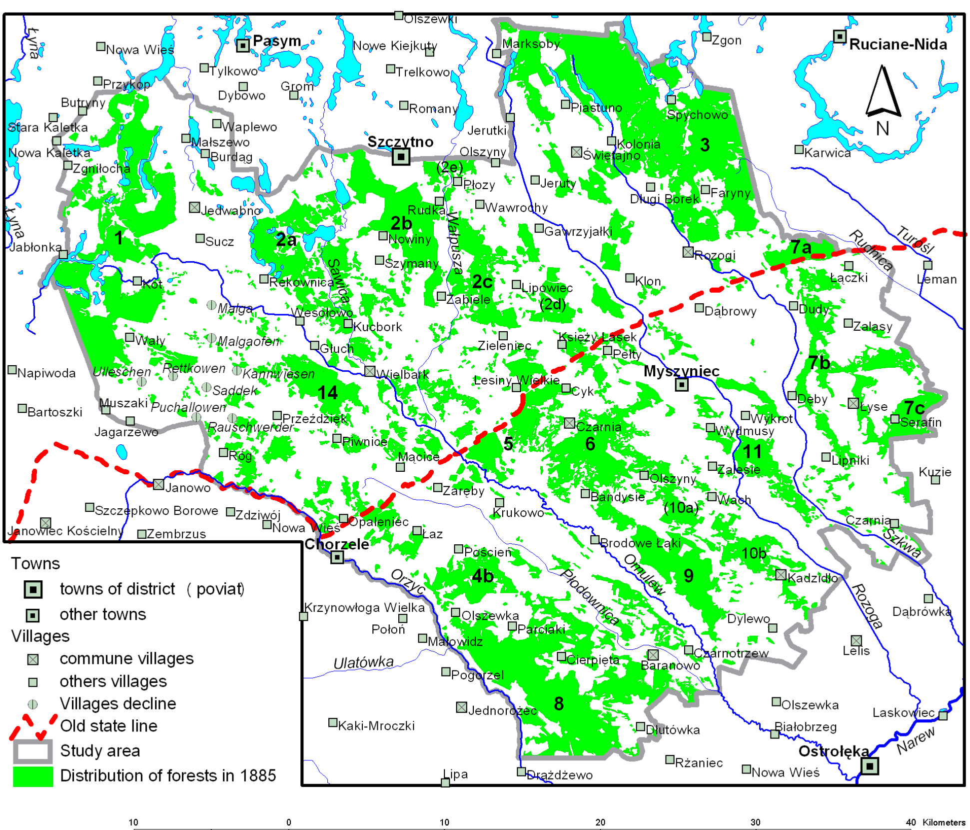

Fig. 5.3. Range of forests in the study area around 1885. Forest complexes over 10 km² are marked with numbers, including the numbers from Figs. 5.1-5.2

The general proportion of the forest cover about year 1928 (Fig. 5.4) increased in comparison with the preceding time instant up to more than 32%. However, the opposite tendencies were noted on the two sides of the Polish-German border. In the northern part (German East Prussia) there was a visible increase in the area of forest complexes. The complexes 1 and 14 were joined, the complex consisting of 2a and 2b was re-established, a new big (exceeding 10 km^2) complex appeared to the south-east of Wielbark (15). On the other hand, in the southern part (i.e. in Poland) the large forest complex fragmentation and decrease of forest area were still observed. Complex no. 8 got divided up, complexes 4b and 11 diminished considerably. Quite a similar state of forest cover was registered in 1950 (Fig. 5.5), that is – a couple of years after the end of the World War II, when the entire area belonged already to one state, Poland. A slight increase in the forest cover, to more than 34% was observed. The large forest complexes changed only a bit. In the southern part of the area complexes 6 and 9 were joined and the complex 4b increased to more than 10 km^2.

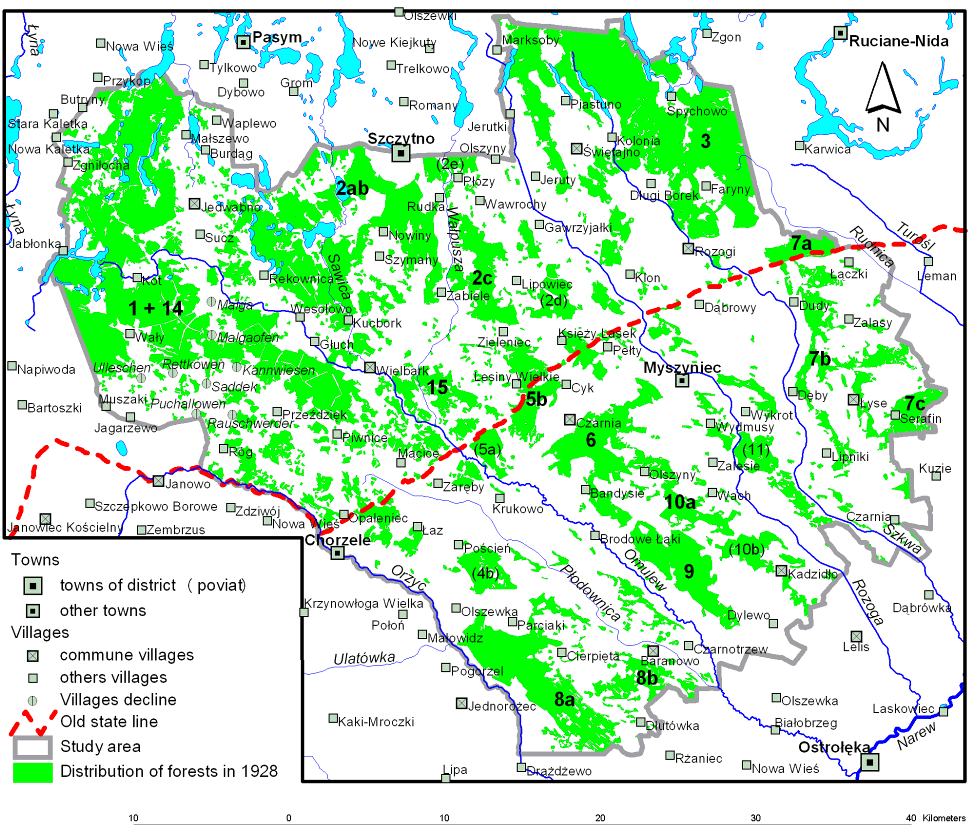

Fig. 5.4. Range of forests in the study area around 1928. Forest complexes over 10 km^2 are marked with numbers, including the numbers from Figs. 5.1-5.3

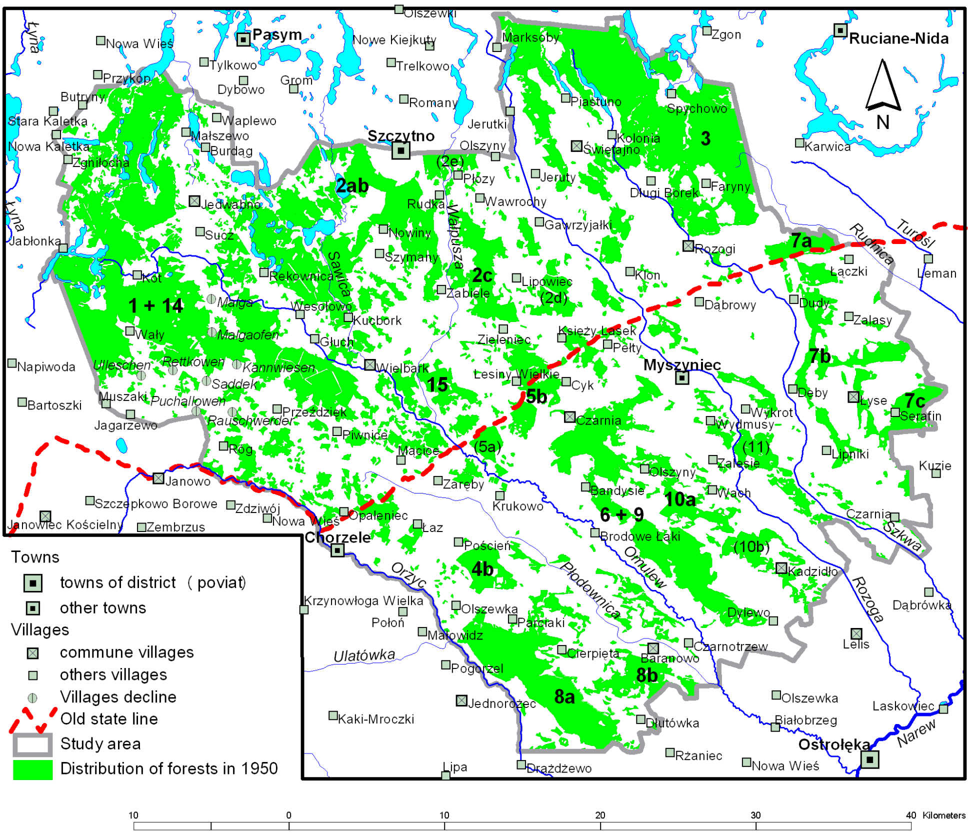

Fig. 5.5. Range of forests in the study area around 1950. Forest complexes over 10 km² are marked with numbers, including the numbers from Figs. 5.1-5.4

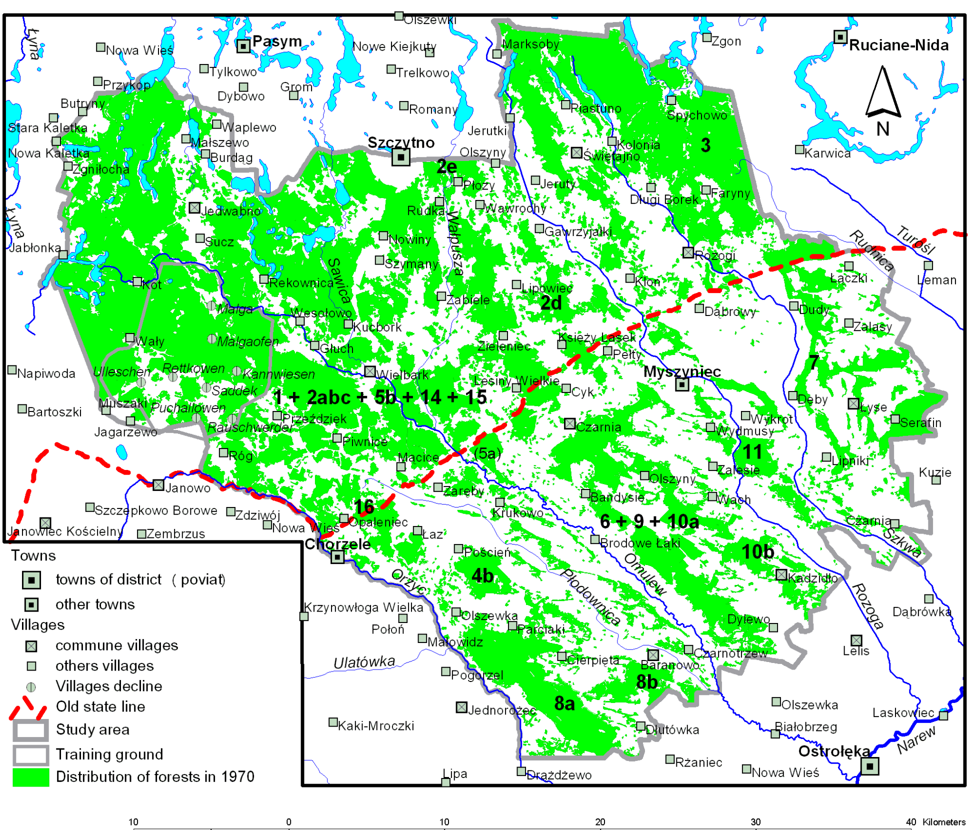

Fig. 5.6. Range of forests in the study area around 1970. Forest complexes over 10 km² are marked with numbers, including the numbers from Figs. 5.1-5.5

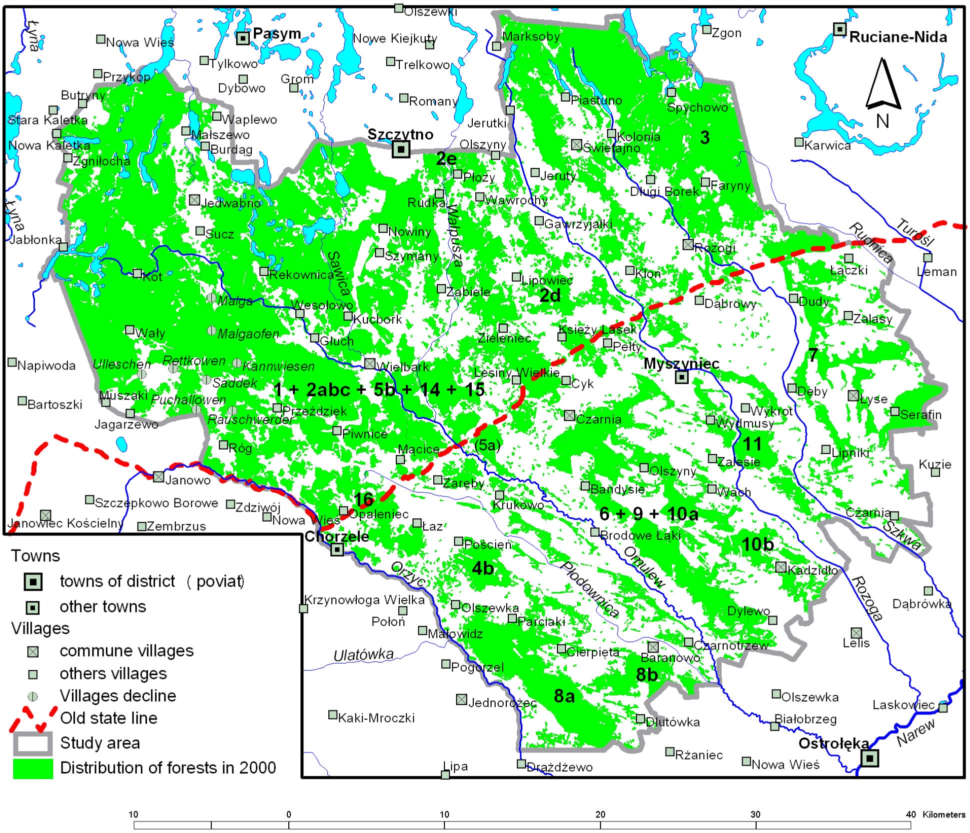

Fig. 5.7. Range of forests in the study area around 2000. Forest complexes over 10 km^2 are marked with numbers, including the numbers from Figs. 5.1-5.6

Very distinct changes in the forest cover were observed in 1970 (Fig. 5.6). The overall proportion of the forest cover increased to almost 46%, which means that it exceeded considerably the initial state from 1800. The large forest complexes in the northern part increased and joined together to a large extent. In particular, it can be observed the merging of the complexes no. 1, 2abc, 5b, 14 and 15 into one very extensive complex. This vast complex included, in particular, the area of the military exercise grounds, established at the beginning of the 1950s. In order to create this military zone a number of villages were displaced, of which the biggest one was Małga. This village was one of nine localities in the northern part of the study area with a church, shown on the map from the nominal year 1800. Other large forest complexes (2d, 2e) increased, as well. Similarly, in the southern part of the study area the forest complexes were merged (complex 7 got united again, complexes 6, 9 and 10 merged) and their area grew. In addition, a new large complex (16) appeared to the north of the town Chorzele. A very similar image is presented on the maps dated for the year 2000 (Fig. 5.7). Just a slight increase of the total forest cover can be noticed, to more than 46%.

The data on the afforestation degree of the research area within the study period (Fig. 5.8), allow for distinguishing three essential sub-periods:

– first half of the 19th century – forest cover was quite stable, at around 40%, with a slight downward tendency,
– period between the middle of the 19th century and the middle of the 20th century – distinctly lower forest area, with the minimum of about 30%, but featuring an increase,
– since the middle of the 20th century – forest cover of about 46%, quite stable, with a weak upward tendency.

A similar interpretation might also be extended to the share of the large and very large forest complexes (Fig. 5.9). Here, as well, division into three sub-periods can be observed. A very pronounced role of the large forest complexes, both at the beginning of the 19th century and nowadays is visible. The second sub-period, lasting approximately one hundred years, is characterised by the drop of the forest area and the fragmentation of large forest complexes.

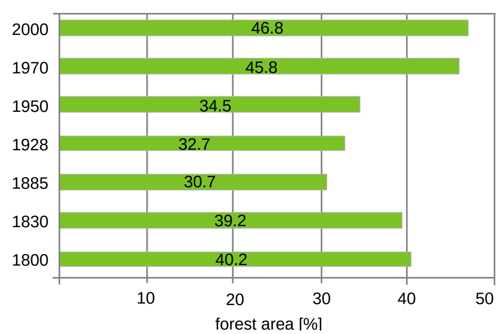

Fig. 5.8. Afforestations in the study area between 1800 and 2000

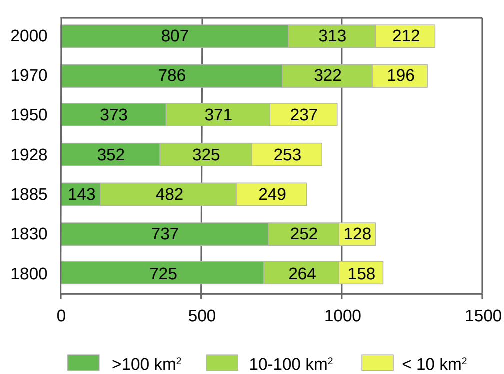

Fig. 5.9. Forest cover in the study area taking into account the size of forest complexes

The above general outline of the historical changes in forest cover ought to be considered separately for two parts of the study area, the history of which took separate courses for political reasons (Fig. 5.10). At the beginning of the 19th century the forest share in the southern part (Kurpie) was distinctly higher (by more than 10%) than in the northern part (Masuria). By the middle of the 19th century forest cover on the entire area decreased, but much more so in the southern part. Consequently, the proportion of forests between the two parts reversed, and this situation persists until today. Nowadays, forest share in Masuria is by more than 28% higher than in Kurpie. On the area of Kurpie the minimum of forest cover took place during the first half of the 20th century. Since that time a slow increase has been observed, which, though, did not bring back the initial state of the forest cover from 1800. The difference between the initial state and the terminal one amounts to almost -16%. On the area of Masuria the minimum of forest cover occurred around the middle of the 19th century. Afterwards, two afforestation periods took place: one at the end of the 19th century and at the beginning of the 20th century, and the second in the later part of the 20th century. The difference between the initial and the final states observed is +24%.

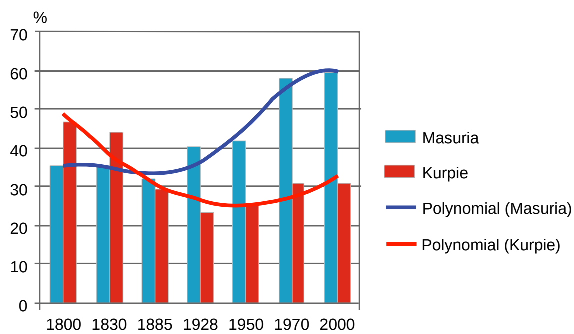

Fig. 5.10. Afforestations in the northern (Masuria) and southern (Kurpie) parts between 1800 and 2000. Masuria: $y = -0.211x^4 + 3.138x^3 - 14.29x^2 + 23.99x + 22.52$; $R^2 = 0.955$. Kurpie: $y = 1.550x^2 - 15.17x + 62.62$; $R^2 = 0.864$

Summing up the results of analysis of forest cover changes, one can note the following:

- division into periods – three sub-periods were observed, consisting in two quite similar initial states, deep transformations of the late 19th century and the first half of the 20th century, followed by stabilisation of the two recent states;
- diversification of the regions – increasing difference and the unlike nature of changes in Kurpie and in Masuria;
- asynchronous timing of changes in the two regions;
- processes of fragmentation and then concentration of the large forest complexes.

5.2. Sequences of "forest – non-forest" states

The analysis of changes in forest cover between 1800 and 2000, allowed for the determination of the sequences consisting of seven states, referred to as "forest" or "non-forest" (Matuszkiewicz et al., 2013b). A map of polygons containing identical sequencing was developed and analysed afterwards. Theoretically, given seven dates and two possible states, altogether 128 sequences can be obtained. In practice, in 23,555 polygons,

Tabela 5.3. Sequence of "forest – non-forest" changes

Sequence – "forest" (F), "non-forest" (n)							Description	Area and share of the sequence					
								Masuria		Kurpie		total	
1800	1830	1885	1928	1950	1970	2000		km²	%	km²	%	km²	%
F	F	F	F	F	F	F	always forest	342.6	21.77	184.2	14.46	526.2	18.50
F	n	F	F	F	F	F	forest, temporarily deforested 1830	1.0	0.06	0.7	0.06	1.7	0.06
F	n	n	n	n	F	F	forest, temporarily deforested 1830-1950	3.7	0.23	0.7	0.05	4.4	0.15
F	F	n	F	F	F	F	forest, temporarily deforested 1885	25.2	1.60	11.9	0.94	37.1	1.31
F	F	n	n	F	F	F	forest, temporarily deforested 1885-1928	5.2	0.33	7.7	0.61	12.9	0.45
F	F	n	n	n	F	F	forest, temporarily deforested 1885-1950	34.2	2.17	20.7	1.62	54.8	1.93
F	F	n	n	n	n	F	forest, temporarily deforested 1885-1970	6.4	0.41	5.4	0.42	11.8	0.41
F	F	F	n	n	n	F	forest, temporarily deforested 1928-1970	1.2	0.07	1.5	0.12	2.7	0.09
F	F	F	n	F	F	F	forest, temporarily deforested 1928	2.1	0.14	13.7	1.07	15.8	0.56
F	F	F	n	n	F	F	forest, temporarily deforested 1928-1950	8.2	0.52	9.0	0.71	17.2	0.61
F	F	F	F	n	F	F	forest, temporarily deforested 1950	1.3	0.08	4.3	0.34	5.6	0.20
F	F	F	F	F	n	F	forest, temporarily deforested 1970	0.7	0.04	1.1	0.08	1.8	0.06
F	?	?	?	?	?	F	total – forests temporarily deforested	92.4	5.87	80.1	6.29	172.5	6.06
n	F	F	F	F	F	F	afforested in 1830	7.5	0.48	3.5	0.27	11.0	0.39
n	n	F	F	F	F	F	afforested in 1885	91.3	5.80	52.6	4.13	143.6	5.05
n	n	F	F	n	F	F	afforested in 1885 (without 1970)	3.2	0.20	2.7	0.21	5.9	0.21
n	n	F	n	F	F	F	afforested in 1885 (without 1928)	3.1	0.19	4.3	0.33	7.3	0.26
n	n	F	n	n	F	F	afforested in 1885 (without 1928-1950)	10.7	0.68	9.3	0.73	19.9	0.70
n	n	n	F	F	F	F	afforested in 1928	130.3	8.28	8.2	0.64	138.5	4.87
n	n	n	F	n	F	F	afforested in 1928 (without 1950)	5.9	0.37	0.9	0.07	6.8	0.24
n	n	n	n	F	F	F	afforested in 1950	26.7	1.70	4.3	0.33	31.0	1.09
n	n	n	n	n	F	F	afforested in 1970	184.9	11.75	32.7	2.56	217.2	7.64
n	n	n	n	n	n	F	afforested in 2000	32.8	2.08	9.6	0.76	42.4	1.49
n	?	?	?	?	?	F	total afforested	502.5	31.93	131.6	10.33	634.1	22.27
n	F	n	n	n	n	n	forest temporarily in 1830	9.3	0.59	2.4	0.19	11.7	0.41
n	F	F	n	n	n	n	forest temporarily in 1830-1885	0.5	0.03	0.9	0.07	1.4	0.05
n	n	F	n	n	n	n	forest temporarily in 1885	5.1	0.32	20.3	1.59	25.3	0.89
n	n	F	F	n	n	n	forest temporarily in 1885 and 1928	0.1	0.01	2.5	0.19	2.6	0.09
n	n	n	F	n	n	n	forest temporarily in 1928	1.7	0.11	0.9	0.07	2.6	0.09
n	n	F	F	F	n	n	forest temporarily in 1885-1950	0.7	0.05	4.4	0.34	5.1	0.18
n	n	F	F	F	F	n	forest temporarily in 1885-1970	1.7	0.11	2.1	0.17	3.9	0.14
n	n	n	F	F	F	n	forest temporarily in 1928-1970	1.4	0.09	0.5	0.04	1.8	0.06
n	n	n	F	F	n	n	forest temporarily in 1928-1950	2.0	0.13	0.6	0.05	2.6	0.09
n	n	n	n	F	n	n	forest temporarily in 1950	0.8	0.05	1.5	0.11	2.2	0.08
n	n	n	n	n	F	n	forest temporarily in 1970	6.7	0.43	3.7	0.29	10.4	0.37
n	?	?	?	?	?	n	total – temporary forests	31.6	2.01	42.4	3.33	74.0	2.60
F	n	n	n	n	n	n	deforested in 1830	12.9	0.82	36.0	2.83	48.9	1.72
F	F	n	n	n	n	n	deforested in 1885	84.6	5.37	235.0	18.45	318.7	11.21
F	F	n	n	F	n	n	deforested in 1885 (temporary forest in 1950)	0.4	0.03	3.0	0.24	3.5	0.12
F	F	n	n	n	F	n	deforested in 1885 (temporary forest in 1970)	1.6	0.10	2.1	0.16	3.7	0.13
F	F	F	n	n	n	n	deforested in 1928	7.6	0.48	31.8	2.50	39.4	1.39
F	F	F	n	F	n	n	deforested in 1928 (or in 1970)	0.1	0.01	4.6	0.36	4.7	0.16
F	F	F	F	n	n	n	deforested in 1950	0.1	0.01	2.7	0.21	2.9	0.10
F	F	F	F	F	n	n	deforested in 1970	0.9	0.06	4.1	0.32	5.0	0.18
F	F	F	F	F	F	n	deforested in 2000	7.7	0.49	3.7	0.29	11.4	0.40
F	?	?	?	?	?	n	total – deforested area	119.1	7.57	329.4	25.86	448.5	15.75
n	n	n	n	n	n	n	lakes	33.9	2.15	0.2	0.02	34.1	1.20
n	n	n	n	n	n	n	never forest	451.9	28.71	505.8	39.71	956.2	33.58

43 sequences of 128 possible and 122 recorded are presented, in "total" the sequences not presented but belonging to the type are included.

resulting from the analysis, the total of 121 distinct sequences were registered. Out of these, 43 sequences were considered to be the most important since they covered almost 99% of the study area (Table 5.3). They were divided into six groups, of which two are entirely homogeneous, since they are characterised by the constant (i.e. seven times) presence of forest or the constant lack of forest. In the latter group lack of forest was distinguished as associated with existence of lakes, and with other land-cover types in majority linked with human activity. Four groups of sequences, featuring differentiated states "forest – non-forest" were distinguished on the basis of conjunction of two criteria: whether there was forest at the beginning (in 1800) and whether there has been forest at the end (in 2000) of the study period. The spatial distribution of the six basic types, depending upon the sequences of states "forest – non-forest" is shown in Fig. 5.11, while the area shares of the individual sequence types within the study area are shown in Fig. 5.12 (Masuria) and Fig. 5.13 (Kurpie).

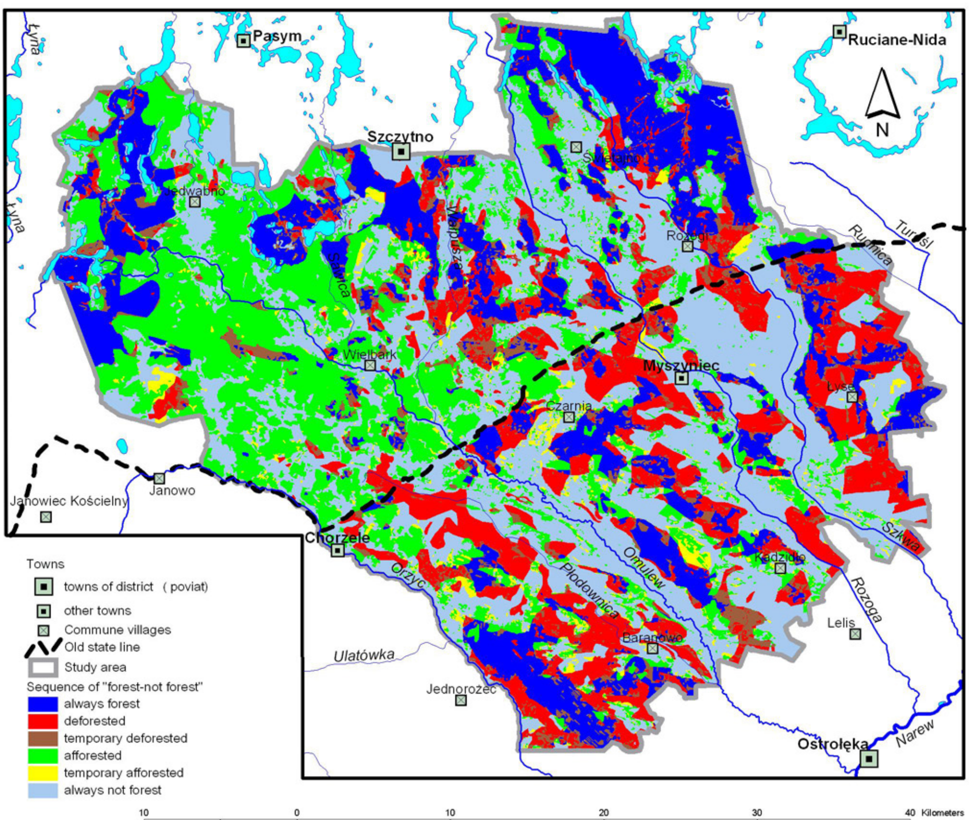

Fig. 5.11. Sequences of forest changes in the study area – spatial distribution

The following conclusions can be drawn:

– the areas, which have not undergone any change over the period of 200 years encompass more than half of the entire study area, surprisingly similarly in Masuria (52.6%) and

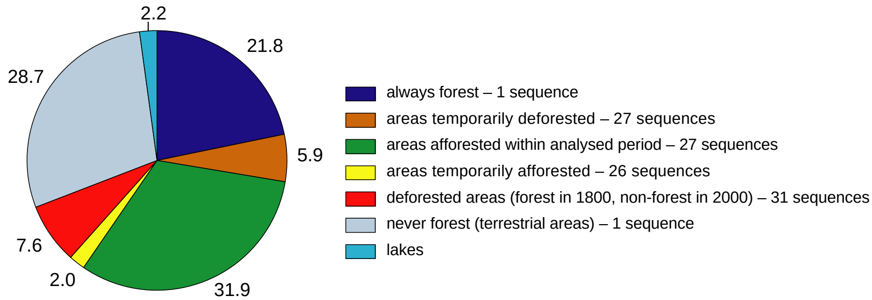

Fig. 5.12. Sequences of forest changes in the northern part of the study area (Masuria) – spatial distribution

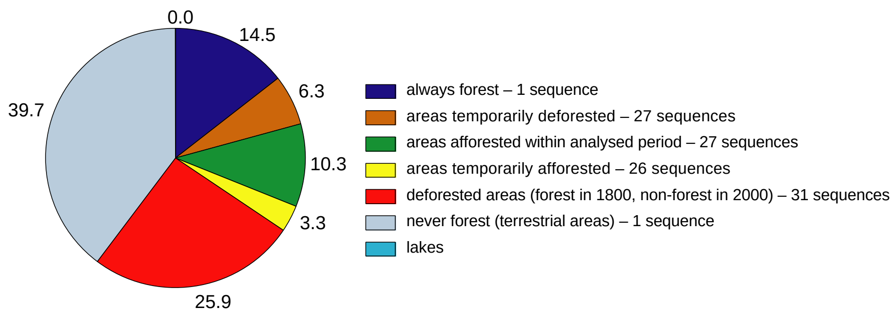

Fig. 5.13. Sequences of forest changes in the southern part of the study area (Kurpie) – spatial distribution

in Kurpie (54.2%); these two regions differ, though, essentially, as to the character of the persistent land cover; in Masuria persistent forests occupy only a little less of area than the persistent forestless areas (22% compared to 29%), while in Kurpie the area of persistent forests is decidedly smaller than that of persistently forestless (15% and 40%, respectively);

- the persistent forests occur only along the watersheds of bigger rivers, while the persistently deforested areas concentrate primarily in the river valleys; this being especially well visible in the region of Kurpie;
- forest areas, characterised by a shorter or longer period of deforestation occupy around 6% of the study area, quite similarly in the two regions; classification of the sequences of "forest – non-forest" to this type might have been problematic because of the specific features of the maps. Due to application of various land cover classifications there occurred difficulties in establishing whether a given area should be considered forest, when it was designated as sparse forest, thicket, felling clearing, or separate trees. Similarly, the different precision of depicting contours might have brought about the doubts. The areas, corresponding to sequences of this type concentrate along the watersheds. The relatively biggest areas are associated with the sequence, in which the period of deforestation encompasses the second half of the 19th century and the first half of the 20th century, that is – the period of "great transformations". Chapter 6 contains description of these changes in relation to habitat diversity;

- large areas were deforested in 1800 and are now under forests; however an essential difference can be observed between the two parts of the study area. The share of such areas in Masuria is equal approximately 32%, while in Kurpie – only roughly 10%. In Masuria the most frequent in this group are the areas afforested in the second part of the 20th century, before 1970 (close to 12%); and quite frequent the areas afforested at the turn of the 20th century (more than 8%) and around the middle of the 19th century (close to 6%); in the region of Kurpie the biggest afforestetions date from the middle of the 19th century (more than 4%) and from the 1950s and 1960s (close to 3%);
- the areas of the limited afforestations in the region of Kurpie concentrate along the watersheds, while the large scale afforestations in Masuria encompassed different landscapes in the vicinity of Jedwabne and Wielbark, also primarily within the watersheds, but close to the rivers, as well;
- the non-forest areas, with a temporary episode of forest presence, occupy a small portion of the area studied (approximately 2-3%). They are scattered over various places. On the scale of the entire study area the relatively most frequent is the sequence "nnFnnnn"; it corresponds to the fragments of the area without forest registered on the oldest maps (and, at the same time, those relatively least certain) but with forests in 1870s and 1880s (and then without them on the subsequent maps). Thus, deforestation in the 20th century can be taken as certain, but lack of forests at the very beginning of the 19th century is not so sure;
- the areas having undergone deforestation during the period considered (i.e. afforested in 1800 and deforested in 2000) are rather limited within Masuria (below 8%), while quite vast in Kurpie (almost 26%). The deforestation of these areas in Masuria dates in an absolute majority (more than 5%) from the middle of the 19th century (in 1830 they were still covered by forests, while in the 1870s they were already deforested). In the remaining periods the deforestations in Masuria are very limited; on the other hand, it is well visible that extensive deforestation took place in Kurpie in the first half of the 19th century; more than 21% of the respective area is constituted by the land designated as forest on the maps from the year 1800, which is no longer afforested on the maps from around the year 1885. Less extensive, but still significant (2.5%) areas got deforested at the turn of the 20th century.

The analysis, outlined above, indicates a clear distinction between the two parts of the study area regarding the relation between the forests and non-forest land in consecutive sub-periods. Analysing the areas occupied by the most frequent sequences of "forest – non-forest" (taking more than 5% of area share in the region) – see Fig. 5.14 – we can observe:

- higher share of persistent forest sequences in Masuria,
- higher share of constantly deforested sequences in Kurpie,
- high share of sequences with the appearance of forests since 1885, 1828 and 1870 in Masuria,
- much higher share of sequences with deforestation since 1885 in Kurpie than in Masuria,
- higher shares of the rare sequences in Kurpie.

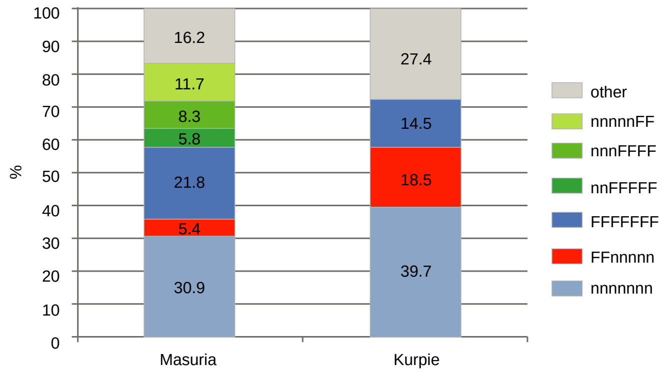

Fig. 5.14. Sequences "forest – non-forest" – spatial distribution in the regions (sequences over 5% are distinguished)

5.3. Identification of the ancient forests reach

The above analysis of changes in the forest cover allowed for the distinction of such areas that have been afforested incessantly for the last 200 years, i.e. since the year 1800. Among these forests, ancient forests can be sought. This term refers to remnants of natural forests that have persisted in the landscape at least since the last several centuries (Peterken, 1977; Rackham, 1980). The environmental transformations, caused by cultivation of the soil, are negative for numerous plant species and in many cases very persistent. Forest restoration, either spontaneous or through planting, cannot counterbalance these changes for decades or even centuries (Bossuyt et al., 1999b; Brunet et al., 2000; Degórski, 1990; Falkengren-Grerup et al., 2006; Hermy & Stieperaere, 1981; Honnay et al., 1999ab; Koerner et al., 1997; Puchalski & Prusinkiewicz, 1975; Verheyen et al., 1999). They are visible not only in the soil profile, but also in the floristic composition and the structure of plant associations (see, for the area in question, the study by Matuszkiewicz et al., 2013a). There are species, which occur only in ancient forests – their refuges (Bossuyt et al., 1999a; Bossuyt & Hermy, 2000; Dzwonko, 1993, 2001abc; Dzwonko & Gawroński, 1994; Matlack, 1994; Orczewska, 2010abc; Orczewska & Fernes, 2011; Schmidt et al., 2014; Wulf & Kolk, 2014). That is why identification of ancient forests among currently existing woodlands constitutes a very important part of landscape structure recognition.

Identification of the ancient forests is based on two data sets:

- contemporary and historical cartographic materials;
- results of field investigations, concerning, first of all, the identification of plough horizon in the soil.

The ancient forest suppose, by definition, to persist incessantly in a given place since the earliest state, registered on maps that allow for a precise identification of its reach. Therefore, ancient forests can be sought, in our case, only among those that featured the sequence "7 times forest" (Table 5.3). This is a necessary, but not sufficient condition. The particular fragments ought to be verified using earlier maps (if they exist). Such verification could be carried out for the northern part of the study area (Prussia) using the quite detailed map (scale of 1:100 000), presenting the state as of around 1730 (see Section 2.4.1).

Based on this analysis there were indicated the areas (among those persistently forested since 1800), which were deforested at the beginning of the 18th century, and so cannot be classified as ancient forest.

The ancient forest criterion was not fulfilled, neither, by these forests having persisted since 1800 (or even since 1730), in which the plough horizon was observed in the soil. Identification of a plough horizon is quite simple and unambiguous in poorer and drier habitats. However, it may be more difficult and doubtful in fertile and distinctly humid soils. Additionally, there was a problem with the determination of locations, where recognition ought to be carried out. With this respect, it turned out very helpful to consult old maps and, at the same time, to look in the field for earth walls, which were formed in the past at borders of forest complexes, especially if they were a royal domain. When the remnants of the earth walls were found, it was usually possible to determine quite precisely the reach of ancient forests.

The plough horizon research was carried out within the study area in approximately 800-900 points (Matuszkiewicz et al., 2013a). Cartographic analysis and field works all together allowed for the development of the map of ancient forest reach (Fig. 5.15). It was assumed that the minimum area of identified patch is one hectare.

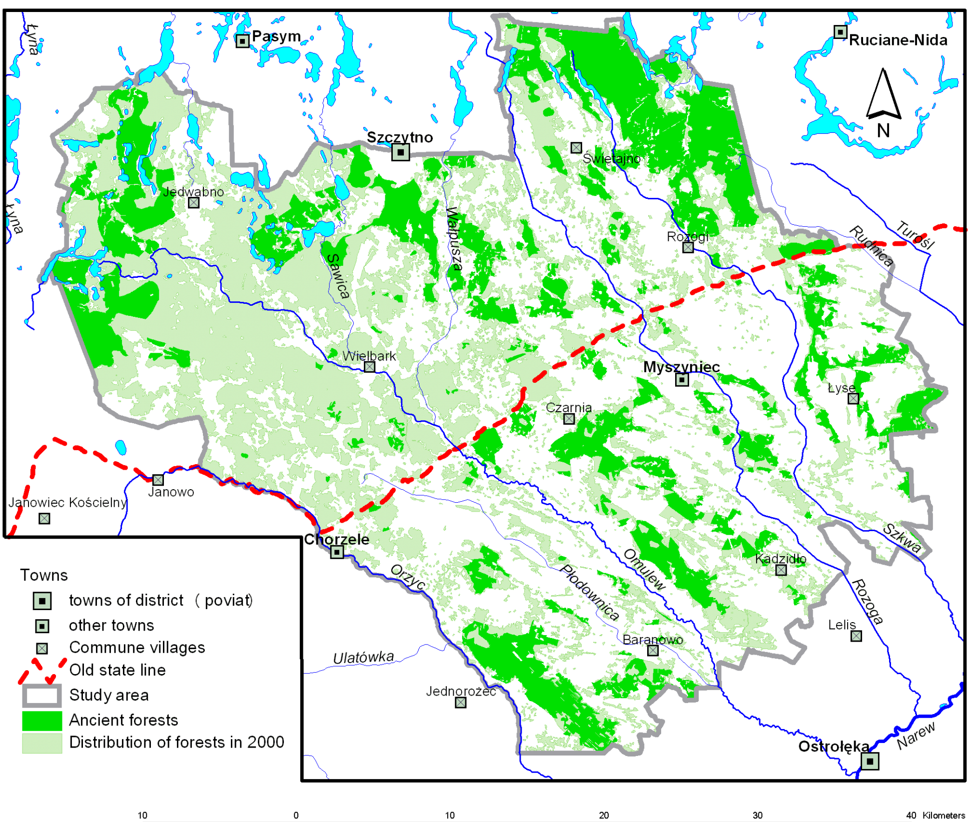

Fig. 5.15. Range of ancient forests in the study area

The area occupied by the ancient forests in the northern part (Masuria) is almost twice as big as in the southern part (Kurpie) – Fig. 5.16. Likewise, the share of these forests in total area is bigger in Masuria (more than 20%) than in Kurpie (close to 14%). Yet, if one relates the area of ancient forests to the total forest area nowadays, then the conclusion is that they play a bigger role in Kurpie (45%) than in Masuria (34%).

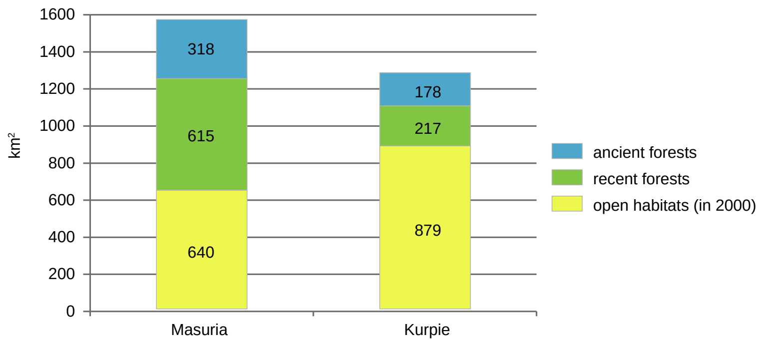

Fig. 5.16. Proportion between ancient, recent forests and open habitats in the regions studied

It is also worth to consider the size of complexes, in which the ancient forests were preserved (Table 5.4). We can observe (Fig. 5.17) numerous smaller complexes and few large ones. In particular, one very large complex is located in Masuria, encompassing a part of the Forest of Pisz (*Johannisburgerheide* in the past). It occupies more than 100 km^2, and accounts for more than one third of all ancient forests in the Masurian part of the study area. Then, there are much smaller three complexes (two in Masuria and one in Kurpie), encompassing the area of 30-40 km^2 each. The subsequent class is constituted by four complexes having between 15 and 20 km^2. The complexes having between 1 and 10 km^2 have a large share within both parts of the study area. There are 50 of them altogether, and they occupy the total area of 170 km^2. The smallest complexes, with area below 1 km^2, occupy altogether similar total area in the two regions. They constituted – and still constitutes – the forest "islands", on which the forest plant species could survive during the periods of more intensive deforestation.

Table 5.4. Differences in a forest area of ancient forest complexes in Masuria and Kurpie

Classes of forest complex area [km^2]	Masuria		Kurpie	
	no of complexes	total area	no of complexes	total area
0.01-1.00	49	14.8	54	14.8
1.01-10.20	26	102.6	24	71.2
15.30-20.50	1	20.4	3	51.0
28.00-41.00	2	64.7	1	40.7
> 100.00	1	115.8	-	-

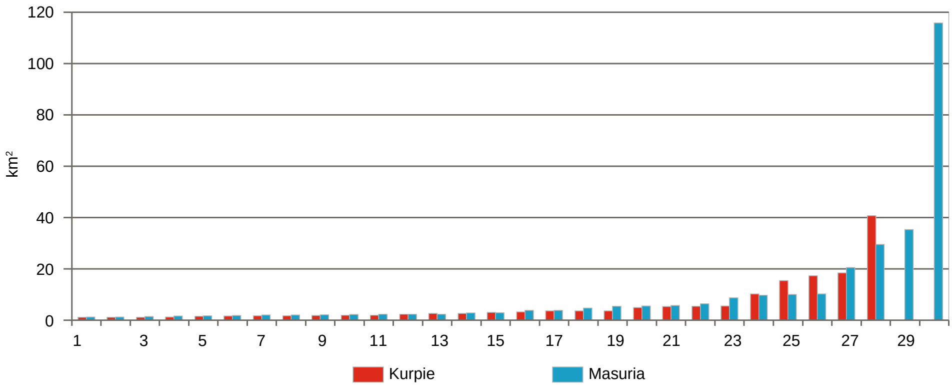

Fig. 5.17. Number of ancient forest complexes ranged according to their area in two regions studied (complexes below 1 km^2 are skipped)

As we compare Masuria and Kurpie in terms of the ancient forests reach (Fig. 5.18), we can notice that the area of small and medium complexes (up to 20 km^2 each) is very similar. The essential difference consists in a very large forest complex in Masuria – the Forest of Pisz. This complex, like, anyway, also other ancient forests, is a remnant from the prehistoric times (before the 13th century), when the study area was covered by almost continuous forest complex, referred to as the Great Forest or the Forest of Galindzi.

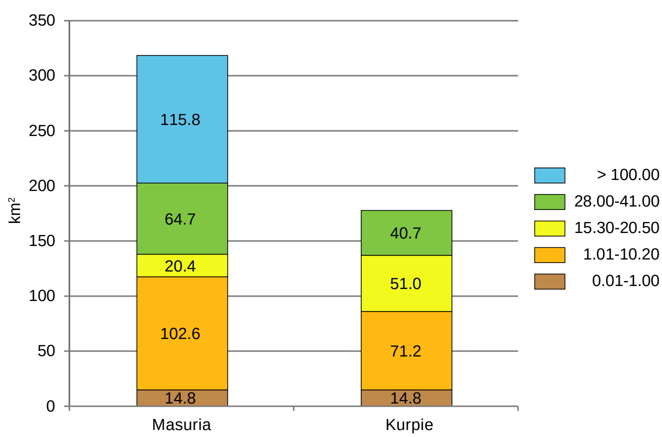

Fig. 5.18. Cover of ancient forests in the regions classified according to the size (km^2)

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6. CHANGES IN FOREST COVER REGARDING HISTORICAL REGIONS AND HABITAT TYPES

Jan Marek Matuszkiewicz, Anna Kowalska

6.1. Changes in forest cover within habitats

Even a cursory analysis of changes in the distribution of forests in the area considered indicates that the deforestations observed are not randomly distributed and are to a certain degree associated with the environmental variability, described by the potential natural vegetation (Tüxen, 1956) and presented on the map (Fig. 4.1). Hence, the association between forest cover and the habitat variability was considered as the relation linking forest reaches and the types of potential natural vegetation. Taking into account the distinct differences between the northern and the southern parts of the study area in terms of history of forest cover changes, and, to a lesser degree, in terms of the potential natural vegetation, the analysis was carried out separately for Masuria and Kurpie.

The intersection of the maps of forest reaches in seven nominal time slices with the map of potential natural vegetation allowed for tracking of changes in forest cover within the habitats during the last 200 years. It should be noted, though, that this was the juxtaposition of the current and past forest reaches with the current habitat distribution. The environmental changes, introduced by people, especially those related to regulation of water conditions, brought about significant habitat transformations. In this context one should mention, first of all, as the significant interventions, river regulations and drainage works, entailing persistent lowering of the groundwater levels. Shifting hydrological conditions bring about changes in vegetation and in soils. This sometimes results in the change of potential natural vegetation. The boggy habitats turn into humid ones, while humid turn into fresh ones. The most frequent habitat transformations of this kind are: transition from the alder carr habitats (*Ribeso-Alnetum*) to the alluvial ash-alder forest habitats (*Fraxino-Alnetum*), and from the alluvial ash-alder habitats to the lime-oak-hornbeam forest habitats (*Tilio-Carpinetum*). There are also quite frequent transitions from the habitats of alder forests to the moist mixed oak-pine forests (*Querco-Pinetum molinietosum*), or from the swampy pine forests (*Vaccinio uliginosi-Pinetum*) to the moist pine forests (*Molinio-Pinetum*). The opposite situation, when habitat becomes more humid, or even swampy is less frequent. Possible historical transformations of landscape should be taken into account anyway.

6.1.1. Changes in forest cover within different habitats of Masuria

Forest cover in the habitats between 1800 and 2000 in the Masurian part is shown in Table 6.1. This data allow for the analysis of changes in the forest cover in the habitats, of differences between the habitats in particular time slices, and of the tendencies in the forest cover changes.

The changes in the forest cover in the swampy habitats, or the slightly swampy ones, corresponding to the alder carrs (*Ribeso-Alnetum*) or alder-ash forests (*Fraxino-Alnetum*) are presented in Fig. 6.1. A roughly similar course of the changes in forest cover can be seen, with the difference that the forest cover in the *Ribeso-Alnetum* habitats has been always a dozen percentage points higher than in the *Fraxino-Alnetum* habitats. This difference is understandable, since the habitats of alluvial ash-alder forests are definitely more attractive for agriculture and usually used as meadows and pastures (wet marigold meadows *Calthion* alliance or less productive, but floristically rich moor grass meadows *Molinion* alliance). In the deforested habitats of alder carrs the poor low sedge meadows *Scheuchzerio-Caricetea nigrae* class or the hard to use tall sedges *Magnocaricion* alliance occure. Forest cover in alder forest habitats, which amounted at the beginning of the 19th century to more than one third, dropped by half until the middle of the 19th century. Since then, the upward trend in forest cover started, and accelerated significantly in the second half of the 20th century. In alluvial ash-alder forest habitats the decrease of forest cover took place at the same time and was even deeper, while its increase began in practice only in the second half of the 20th century and was much weaker. It should be noted that the vast deforestations of the alluvial forest habitats in the middle of the 19th century could be associated with the drainage works, conducted at that time. Therefore, it cannot be excluded that during that period a part of the former habitats of *Ribeso-Alnetum* type shifted to the *Fraxino-Alnetum* type, as it is observed nowadays. Comparing the changes in the forest cover in these two habitats, we can also observe that the forest cover in the alder forest habitats, after secondary afforestations, distinctly exceeded the share from 200 years ago, while the habitats of alluvial ash-alder forests are still less afforested than at the beginning of period analysed. The rather small initial difference in the forest cover in these two habitat types increased considerably.

The changes in the forest cover in the lime-oak-hornbeam forest (*Tilio-Carpinetum*) habitats are presented in Fig. 6.2. At the beginning of the 19th century forest cover in these habitats was close to 30% and did not differ significantly between the sub-associations. An intensive deforestation of these habitats, especially the moist variants, took place in the second half of the 19th century. It was less intensive in the typical lime-oak-hornbeam forest habitats, and the least intensive in the poor ones. Since that time the course of changes in forest cover displayed a clear differentiation between the sub-associations. In the poor lime-oak-hornbeam forest habitats, an increase of forest cover was observed at the beginning of the 20th century, and in the second half of the 20th century it was particularly pronounced. At the end of the period considered forest cover in the habitats of poor sub-association significantly exceeded the initial one (from the turn of the 19th century). This phenomenon can be explained by little agricultural utility of these habitats, due to lower soil fertility and relatively frequent strongly diversified relief, which is not advantageous for farming activity. It was only in the period of strongest agricultural pressure that the deforestation of these habitats somewhat increased, but when the pressure started to recede, quite important afforestation followed.

Table 6.1. Habitat area and forest cover between 1800 and 2000 in Masuria

Habitats				Forest cover on habitats during 200 years [%]						
Code	**name**	**latin name**	**area [km²]**	**1800**	**1830**	**1885**	**1928**	**1950**	**1970**	**2000**
0	waters not classified	-	34.16	-	-	-	-	-	-	-
1a	Alder carr with *Ribes*	*Ribeso nigri-Alnetum*	46.67	37.1	37.2	18.6	23.7	25.0	42.2	48.9
1b	Peat-moss alder carr	*Sphagno squarrosi-Alnetum*	3.03	37.7	37.8	13.4	30.6	30.2	40.8	62.8
1d	Birch carr with *Pinus sylvestris*	*Betula pubescens – Thelypteris palustris* community	0.35	62.8	62.8	22.1	12.5	52.4	68.5	71.1
4a	Alder-ash forest	*Fraxino-Alnetum*	155.93	26.0	26.4	8.2	8.5	8.6	16.6	18.8
6a	Lime-oak-hornbeam forest, poor subasso-ciation	*Tilio-Carpinetum calamagrostietosum*	313.94	28.7	27.6	21.8	23.3	25.3	44.6	46.8
6b	Lime-oak-hornbeam forest, typical subas-sociation, poor series	*Tilio-Carpinetum typi-cum*, poor series	78.27	26.0	28.8	17.3	15.9	16.1	24.9	25.9
6c	Lime-oak-hornbeam forest, typical subasso-ciation, fertile series	*Tilio-Carpinetum typicum*, fertile series (with *Asarum*)	3.27	68.1	68.1	48.4	48.7	48.5	70.1	71.2
6e	Lime-oak-hornbeam forest, moist subas-sociation	*Tilio-Carpinetum stachyetosum*	185.51	30.4	29.4	10.7	10.6	10.9	20.2	21.4
6	Lime-oak-hornbeam forest put together	*Tilio-Carpinetum*	580.99	29.1	28.5	17.8	18.4	19.6	34.3	36.0
9a	Subcontinental mixed pine-oak forest, typical subassociation	*Querco roboris-Pine-tum typicum*	446.60	43.2	43.6	43.8	55.6	58.4	84.5	85.7
9c	Subcontinental mixed pine-oak forest, moist subassociation	*Querco roboris-Pine-tum molinietosum*	59.30	57.1	59.3	54.3	59.4	60.3	78.6	78.0
10	Sarmatian pine-oak forest	*Serratulo-Pinetum*	0.82	99.4	99.4	99.3	97.7	97.1	97.6	99.4
12+13	Continental pine forest	*Peucedano-Pinetum*	230.73	37.7	38.6	59.0	88.6	90.6	99.6	98.2
15	Dry pine forest with *Cladonia*	*Cladonio-Pinetum*	1.15	25.2	34.4	88.2	96.7	95.1	100.0	87.1
16	Moist pine forest	*Molinio-Pinetum*	3.92	73.1	73.3	65.6	76.8	76.9	87.9	87.3
17a	Swampy pine forest, typical subassociation	*Vaccinio uliginosi-Pinetum typicum*	4.22	72.3	72.7	59.3	74.6	75.7	88.4	92.4
17b	Swampy pine forest, *Molinia* subassociation	*Vaccinio uliginosi-Pinetum molinietosum*	0.13	94.1	94.1	33.4	37.2	32.8	100.0	85.9
18	Boreal peat-moss spruce forest	*Sphagno girgensoh-nii-Piceetum*	0.02	13.1	13.1	57.7	58.0	58.0	57.8	65.2
19	Boreal spruce-oak forest	*Querco-Piceetum*	4.22	72.6	72.5	81.8	82.0	82.0	91.3	90.0
20	*Sphagnum magellani-cum* – raised bog	*Sphagnetalia magel-lanici*	0.95	19.7	14.4	11.8	13.1	12.0	19.1	27.7
21	Lowland beech forest	*Luzulo-Fagetum*	0.83	99.2	99.2	99.0	99.0	99.0	99.0	99.0
Total			**1,574.04**	**35.2**	**35.3**	**31.8**	**40.2**	**41.8**	**58.1**	**59.3**

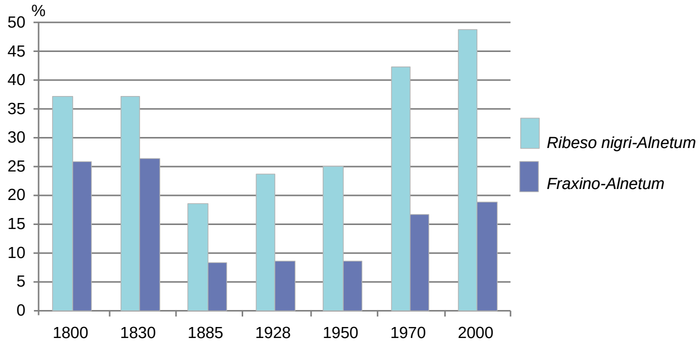

Fig. 6.1. Changes in the forest cover in two main hydrogenic habitats in Masuria

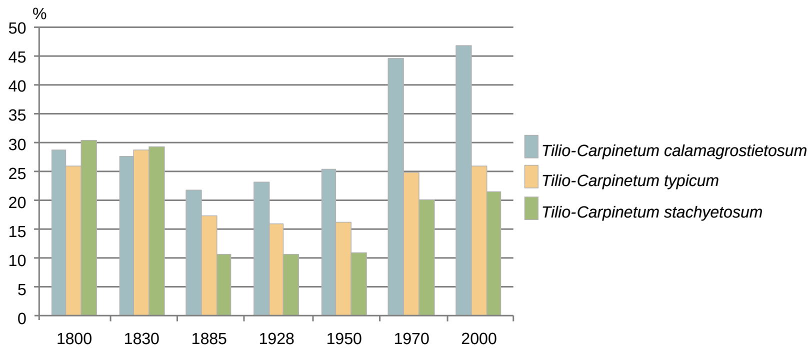

Fig. 6.2. Changes in the forest cover in three habitats of lime-oak-hornbeam forest sub-associations in Masuria

The changes in the forest cover were quite different in the richer habitats of lime-oak-hornbeam forests. They were more deforested and the increase in forest cover appeared in them only in the second half of the 20th century but did not regain the state of 1800. The habitats of moist lime-oak-hornbeam forests were particularly strongly deforested. They are especially useful for meadows, less so for the arable lands. The strong deforestation of these habitats since the middle of the 19th century indicates the agricultural pressure expressed through the replacement of forests by meadows, needed for cattle and horse breeding. Moreover, the drainage of the small watercourse valleys, made these habitats more accessible for the farming activity.

The course of changes in the forest cover in the habitats of fresh pine forests (*Peucedano-Pinetum*), as well as the mixed pine-oak forests (*Querco-Pinetum*), both fresh (*Q.-P. typicum*) and moist (*Q.-P. molinietosum*), as shown in Fig. 6.3, was distinctly different from that two groups commented upon before. A consistent increase in the forest cover is observed in each of these habitats over the analysed 200 years. The relatively smallest changes took place in the moist mixed pine-oak forest. 200 years ago these habitats were the most afforested (close to 60%), while nowadays their forest cover is the lowest among the three here compared (less than 80%). A bigger afforestation occurred late, namely only in the second half of the 20th century. In the fresh mixed pine-oak forest habitats the initially even forest cover started to increase at the beginning of the 20th century, and then even more in the second half of the 20th century. The overall increase amounted to more than 40%. The habitats of pine forests were 200 years ago relatively most deforested (forest cover below 40%), while now they are in almost 100% covered with forests. The increase of forest cover took place in these habitats in the middle of the 19th century already. It is interesting to observe the ratio of forest cover in the pine forest and fresh mixed pine-oak forest habitats. The former are very poorly fit for farming and that is why they are now almost entirely afforested, while the latter are moderately fit for farming and so their agricultural use persists until today. Yet, 200 years ago habitats of pine forests were so attractive for agriculture that their deforestation attained 2/3 and was even slightly higher than that of the mixed pine-oak forest habitats. This implies that the agricultural pressure on these habitats was exceptionally strong at the beginning of the 19th century, compared with the present situation, and a rapid decrease of this pressure was observed in the middle of the 19th century. In these habitats (the oligotrophic pine forest and the mesotrophic mixed pine-oak forest) the initial even state turned into a distinct variation, which then shrank again. The changes in the forest cover in the mixed pine-oak forest habitats delayed about half a century with respect to those observed for the pine forests.

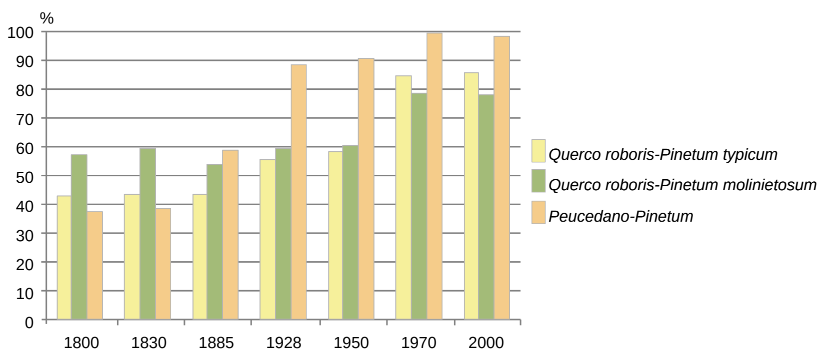

Fig. 6.3. Changes in the forest cover in pine and mixed oak-pine forest habitats in Masuria

The forest cover in four relatively rare types of oligo- or mesotrophic moist or swampy habitats, presented in Fig. 6.4, is worth noting as well. These habitats are in their majority of little farming usefulness, and so they were usually to a high extent afforested, except, solely, for the mesotrophic *Sphagno-Alnetum* habitat. In its case, the forest cover in the particular periods was similar to that of alder carr habitats (Fig. 6.1). Generally, in this habitat group, increase in afforestation, and – though less pronounced – a minimum of the forest cover in the middle of the 19th century are visible. This signifies that under the strongest pressure even rather useless habitats might have been deforested.

When analysing the dynamics of forest cover in all the habitats in the Masurian part (Fig. 6.5), one can notice that the variability of afforestation degree 200 years ago – even though quite distinct – was lower than 150 years ago and later. The differentiation of the habitats between those highly deforested (*Fraxino-Alnetum, Tilio-Carpinetum, Ribeso-Alnetum, Sphagno-Alnetum*) and little deforested ones (*Peucedano-Pinetum,* *Molinio-Pinetum, Querco-Piceetum, Vaccinio uliginosi-Pinetum*, later on also *Querco-Pinetum*) was the largest at the turn of the 20th century. The change in *Peucedano-Pinetum* habitats, and then in the *Querco-Pinetum* as well was the most spectacular. In the second half of the 20th century the habitats of alder carrs and of the poor lime-oak-hornbeam forests separated from the group of strongly deforested ones and became moderately deforested.

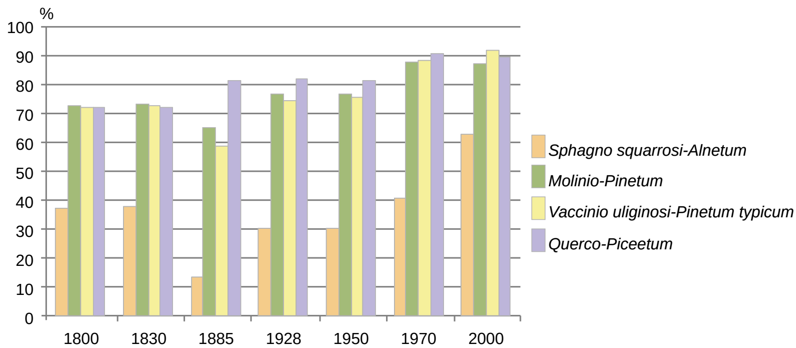

Fig. 6.4. Changes in the forest cover in rare swampy forests habitats in Masuria

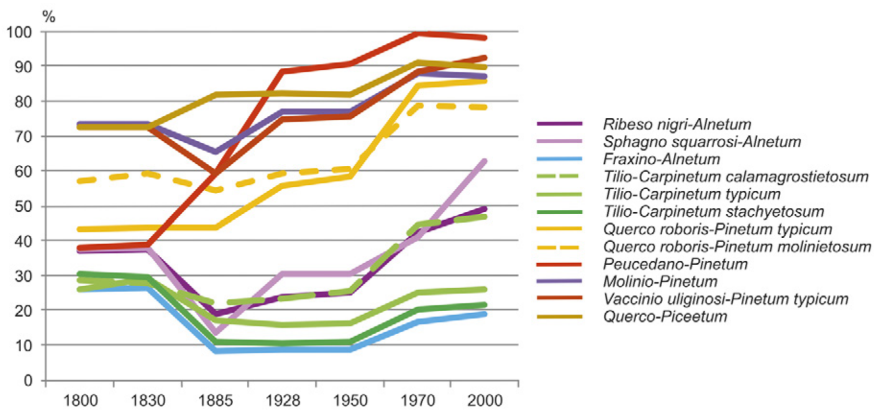

Fig. 6.5. Dynamics of changes in the forest cover in the dominant potential natural vegetation habitats in Masuria

6.1.2. Changes in the forest cover within different habitats in Kurpie

The dynamics of change in forest cover in hydrogenic habitats of the alluvial ash-alder forests (*Fraxino-Alnetum*) and those of alder carrs (*Ribeso-Alnetum*) is different over the last 200 years (Table 6.2, Fig. 6.6). The habitats of alluvial forests, afforested 200 years ago in around 40%, were almost completely deforested in the middle of the 19th century, and even more so in the first half of the 20th century, and this situation persists until today. This is the effect of drainage works and establishing meadows, which are the basis for cattle breeding, the main income of farmers in the vast river valleys. The habitats of alder carrs (*Ribeso-Alnetum*) have undergone less intense deforestations at the turn of the 20th century, after which partial afforestation took place in the second half of the 20th century.

Very extensive changes in forest cover affected also the habitats of lime-oak-hornbeam forests (*Tilio-Carpinetum*), see Fig. 6.7. These habitats, afforested at the beginning of the

Table 6.2. Habitat area and forest cover between 1800 and 2000 in Kurpie

Habitats				Forest cover on habitats during 200 years [%]						
Code	**name**	**latin name**	**area [km²]**	**1800**	**1830**	**1885**	**1928**	**1950**	**1970**	**2000**
0	waters not classified	-	0.20	32.6	33.8	23.6	8.4	13.2	8.3	6.9
1a	Alder carr with *Ribes*	*Ribeso nigri-Alnetum*	24.03	46.6	46.3	39.3	32.8	34.1	40.4	40.4
1b	Peat-moss alder carr	*Sphagno squarrosi-Alnetum*	2.89	23.1	23.4	47.7	42.8	48.8	37.7	22.1
4a	Alder-ash forest	*Fraxino-Alnetum*	296.48	39.7	32.2	7.1	3.0	3.2	4.1	3.7
6a	Lime-oak-hornbeam forest, poor subassociation	*Tilio-Carpinetum calamagrostietosum*	168.31	35.1	33.6	11.3	3.5	5.9	6.5	7.1
6b	Lime-oak-hornbeam forest, typical subassociation, poor series	*Tilio-Carpinetum typicum*, poor series	86.99	30.3	29.2	6.8	1.8	1.4	3.6	4.3
6e	Lime-oak-hornbeam forest, moist subassociation	*Tilio-Carpinetum stachyetosum*	129.56	40.9	35.8	6.7	2.2	2.2	3.3	3.7
6	Lime-oak-hornbeam forest put together	*Tilio-Carpinetum*	384.94	36.0	33.3	8.8	2.7	3.6	4.8	5.3
9a	Subcontinental mixed pine-oak forest, typical subassociation	*Querco roboris-Pinetum typicum*	294.36	46.9	46.7	35.2	25.6	28.8	40.8	42.5
9c	Subcontinental mixed pine-oak forest, moist subassociation	*Querco roboris-Pinetum molinietosum*	51.86	62.2	61.5	53.3	38.4	42.5	50.5	51.1
12	Continental pine forest	*Peucedano-Pinetum*	202.83	71.8	72.7	80.8	78.9	84.1	94.5	94.3
16	Moist pine forest	*Molinio-Pinetum*	11.28	46.5	46.7	84.9	89.2	92.0	73.8	68.7
17a	Swampy pine forest, typical subassociation	*Vaccinio uliginosi-Pinetum typicum*	1.32	94.5	95.1	65.0	77.8	74.5	88.2	100.0
17b	Swampy pine forest, *Molinia* subassociation	*Vaccinio uliginosi-Pinetum molinietosum*	0.12	100.0	100.0	0.1	40.1	40.1	53.5	52.8
18	Boreal peat-moss spruce forest	*Sphagno girgensohnii-Piceetum*	0.11	99.7	99.7	89.7	90.1	100.0	99.9	100.0
19	Boreal spruce-oak forest	*Querco-Piceetum*	3.26	82.1	82.2	83.7	73.2	70.2	81.1	72.0
Total			**1,273.69**	**46.6**	**44.1**	**29.4**	**23.3**	**25.4**	**30.7**	**31.0**

19th century in roughly 1/3, at the beginning of the 20th century were covered by forests in just a couple of percent. The biggest deforestation took place in the moist lime-oak-hornbeam habitats – their forest cover having dropped from more than 40% to mere 2%. It was the result of drainage works in the river valleys, where such habitats are mainly presented. Somewhat smaller, but also very serious changes affected the habitats of typical and poor lime-oak-hornbeam forests. The minimum forest cover occurred in all types of lime-oak-hornbeam forest habitats in the first half of the 20th century, with the following increase being very small. It can be assumed that these habitats are almost entirely deforested nowadays in the Kurpie region.

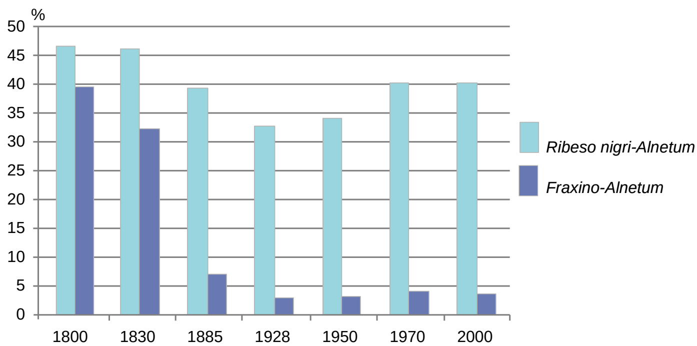

Fig. 6.6. Changes in the forest cover in two main hydrogenic habitats in Kurpie

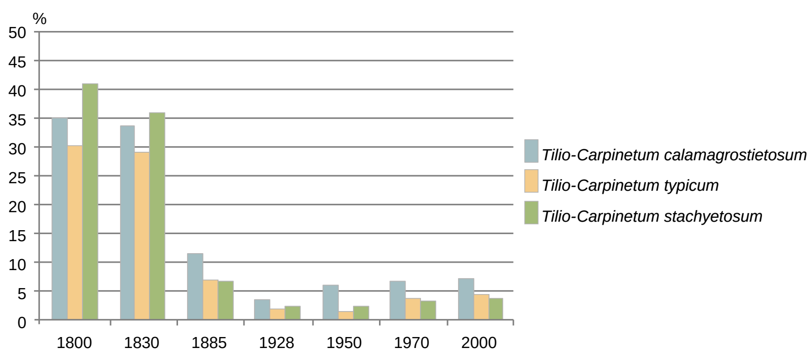

Fig. 6.7. Changes in the forest cover in three habitats of lime-oak-hornbeam forest sub-associations in Kurpie

The habitats of pine forests (*Peucedano-Pinetum*) and of mixed pine-oak forests (*Querco-Pinetum*) have not gone through such a significant evolution as those commented upon before (Fig. 6.8). In the pine forest habitats a limited, but quite consistent increase in the forest cover has been observed over the studied period. The initial deforestation of these habitats was only partly associated with the agricultural land-use. The non-forest areas in pine forest habitats had been wastelands in the past, having remained after the illegal tree cutting, fires etc. Hence, the changes in the forest cover in these habitats ought to be linked not so much with the decrease of agricultural pressure as with the regulation of forest management[1]. On the other hand, the habitats of mixed pine-oak forests, initially more deforested, passed through a period of stronger deforestation at the beginning of the 20th century, and thereafter their forest cover increased partly. These changes ought to be linked with the changes in agricultural pressure. The habitats considered were partly deforested during the period of "land dearth", to then get partly afforested again[2].

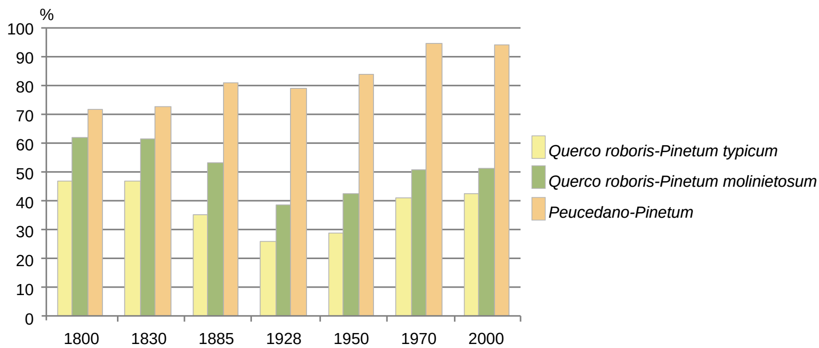

Fig. 6.8. Changes in the forest cover in pine and mixed oak-pine forest habitats in Kurpie

The changes of forest cover in rare moist habitats (Fig. 6.9) do not display any regularities. This is most probably the effect of their limited area, which means that the forest cover could change randomly.

The comparison of the forest cover dynamics in the habitats of the Kurpie region (Fig. 6.10) allows for the observation of the clear habitat variability, which appeared at the turn of the 20th century and persists until today. While afforestation of the particular habitats was, definitely, differentiated 200 years ago, one could hardly indicate distinct habitat groups. Then, in the second half of the 19th century a clear distinction into three habitat groups developed:

- the strongly deforested ones (with forest cover of just a couple of percent) – alluvial and lime-oak-hornbeam forests (*Fraxino-Alnetum*, *Tilio-Carpinetum* in three sub-types);
- moderately afforested (with forest cover of 30-50%) – mixed pine-oak forests and alder carrs (*Querco-Pinetum*, *Ribeso-Alnetum*, *Sphagno-Alnetum*);
- significantly afforested (with forest cover of 70-100%) – fresh, moist and swampy pine forests, as well as spruce forests on peat (*Peucedano-Pinetum*, *Molinio-Pinetum*, *Vaccinio uliginosi-Pinetum* and *Querco-Piceetum*).

[1] To a large extent, such areas were a consequence of intentional economy in the production of potash, charcoal and amber (around Wielbark are huge deposits of this mineral).

[2] In particular, they could result from changes in the type of agricultural pressure. The border area was famous for cloth production (Wielbark, Chorzele, Maków).

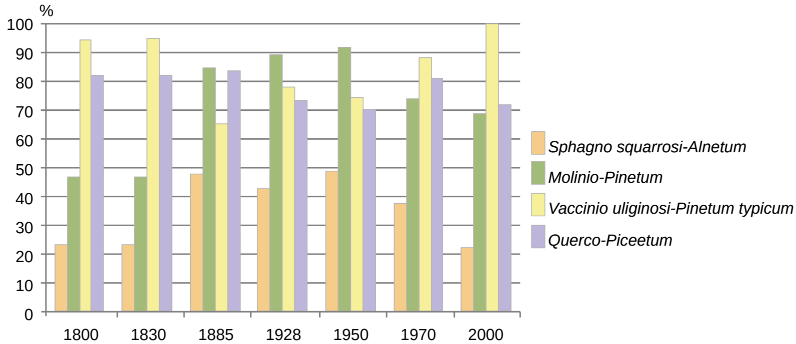

Fig. 6.9. Changes in the forest cover in rare swampy forests habitats in Kurpie

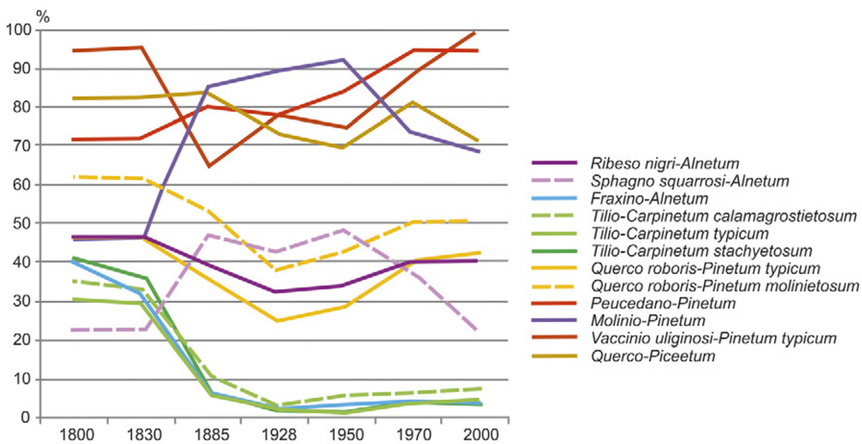

Fig. 6.10. Dynamics of changes in the forest cover in the dominant potential natural vegetation habitats in Kurpie

6.1.3. The differences of the forest cover changes in the regions

The strength of agricultural pressure on habitats might be measured with the degree of its deforestation. Based on this yardstick one could distinguish very small pressure (80-100% of forest cover), small pressure (60-80% of forest cover), moderate pressure (40-60% of forest cover), quite strong pressure (20-40% of forest cover), and the very strong pressure (0-20% of forest cover). Analysis of changes, shown in Fig. 6.11 makes possible formulation of the following statements.

The strongest pressure was exerted on habitats of alluvial and lime-oak-hornbeam forests in Kurpie and, to a lesser degree, on those of alluvial forests in Masuria. They went from the strong pressure under the very strong pressure, with the apex at around the middle of the 19th century. In particular, alluvial and lime-oak-hornbeam forest habitats in Kurpie got deforested (1928) in approximately 97% and this situation did not change much in the second half of the 20th century.

In Masuria, forest cover in these habitats increased over the last several decades, notably after the World War II.

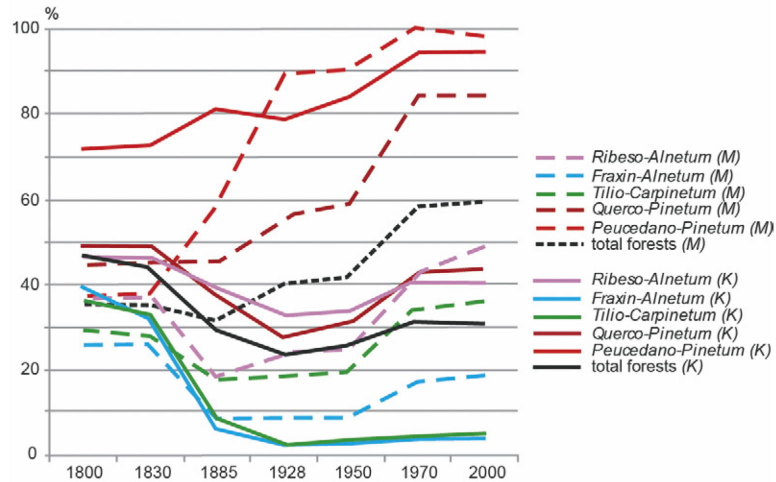

Fig. 6.11. Changes in the forest cover within 200 years on 5 dominant habitat types (area 96.6% M, 98.5% K) and in the whole forest cover in Masuria (M) and Kurpie (K)

There has been a significant decrease in the pressure on habitats of pine and mixed pine-oak forests in Masuria and, to a lesser degree, on habitats of pine forests in Kurpie. They went from the moderate or even quite strong pressure to the very small one.

In the mixed pine-oak forests and alder carrs habitats in Kurpie, as well as alder carrs and lime-oak-hornbeam forests in Masuria a pressure significantly increased between the middle of the 19th century and the middle of the 20th century, followed by the pressure decrease in the second half of the 20th century.

During the 200 years a diversification of the agricultural pressure on forest habitats took place. All habitats, except for the pine forests in Kurpie, were deforested at the beginning of the 19th century in 25-50%. If we account for the pine forests in Kurpie, the difference between the most deforested habitat (*Fraxino-Alnetum* in Masuria) and the most afforested one (*Peucedano-Pinetum* in Kurpie) amounted to 46%, while in the year 2000 the analogous difference between *Fraxino-Alnetum* in Kurpie and *Peucedano-Pinetum* in Masuria is more than twice as big, namely 94.5%.

Changes in the forest cover in particular habitats can be considered in the perspective of divergence from the average forest cover in the region. The diagram (Fig. 6.12) indicates relatively small differences between habitats at the beginning of the 19th century, very big differences at the beginning of the 20th century and slow decrease of these differences (which remain, though, quite pronounced) towards the end of the 20th century. The group of alluvial forest (*Fraxino-Alnetum*) and of lime-oak-hornbeam forest (*Tilio-Carpinetum*) habitats stands definitely out as being particularly strongly deforested. The habitat of mixed pine forest (*Querco-Pinetum*) in both regions, and of rather rare alder carrs (*Ribeso-Alnetum*) in Kurpie, diverge relatively the least from the average. The highest forest cover, in relative terms, characterises the habitats of pine forests, *Peucedano-Pinetum*. It ought to be noted that the increase in forest cover in these habitats started already in the middle of the 19th century, while a distinct increase in forest cover in the habitats of mixed pine-oak forests has been observed only in the second half of the 20th century.

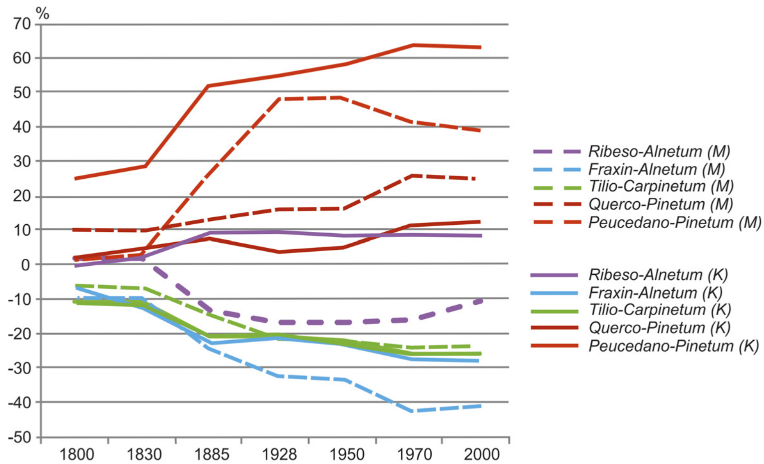

Fig. 6.12. Relative changes in the forest cover within 200 years on 5 dominant habitat types in Masuria and Kurpie. Differences between the forest cover on the habitat type and the whole forest cover in the particular time period are presented

A similar course of changes in forest cover has also been observed in the 19th and 20th centuries in the Forest of Kampinos and on the surrounding areas (Kowalska, 2006). In the eutrophic habitats, subject to the strongest pressure, the lowest forest cover was noted in the middle of the 19th century, and this situation has not been changing much in the course of the 20th century, although in the majority of habitats, especially the most humid ones, forest cover has been increasing. In the oligotrophic habitats more pronounced differences were noted between the complex of the Kampinos Forest and the surrounding areas. During the entire period analysed much stronger pressure was observed in the habitats outside of the Forest itself. The course of changes was similar in the more fertile habitats of the mixed pine-oak forest – the biggest deforestation took place in the second half of the 19th century, and lasted until the middle of the 20th century, after which forest cover increased. In the poorer habitats of fresh pine forests in the Kampinos Forest the course of changes was akin, while outside of the Forest pressure on these habitats decreased significantly already in the second half of the 19th century, to then yet weaken in the second half of the 20th century.

6.2. The sequences "forest – non-forest" in main habitat types

It is interesting to see what is the connection between the "forest – non-forest" sequences (see Chapter 5) and the most important habitat types, defined through the potential natural vegetation (see Chapter 4).

We analysed the potential natural vegetation types, which cover the area exceeding 10 km^2 (meaning approximately 1% of area in the regions, see Table 4.1). Given this criterion, the analysis accounted for the following units of potential natural vegetation: the alder carrs (*Ribeso nigri-Alnetum*), ash-alder alluvial forest (*Fraxino-Alnetum*), lime-oak-hornbeam forests (*Tilio-Carpinetum*) – the poor type (*T.-C. calamagrostietosum*), typical in the poorer series (*T.-C. typicum*) and moist (*T.-C. stachyetosum*), mixed pine-oak forests (*Querco-Pinetum*) – typical, fresh (*Q.-P. typicum*) and moist (*Q.-P. molinietosum*), as well as fresh pine forests (*Peucedano-Pinetum*), without distinction into regional units. Besides, the moist pine forest (*Molinio-Pinetum*) habitat was accounted for in Kurpie, occupying in that region more than 11 km^2.

The relations between the habitats and the sequences of "forest – non-forest" states were analysed separately in Kurpie and Masuria, due to the clear differences between these regions as concerns the changes in forest cover.

6.2.1. The sequences of changes in the habitats of Masuria

The observed sequences of the "forest – non-forest" states were classified into: permanent forests, areas permanently deforested, forests with transitory deforestation (forest at the beginning and at the end, and a shorter or longer period of deforestation in the meantime), afforestation, occasional (ephemeral) afforestations and deforestations (Table 6.3). The sequences that occupied the area smaller than 1 km^2 of the region were analysed in total.

The two stable sequences are, on the one hand – the permanent forest cover, and on the other hand – the permanent deforestation occupy jointly between more than 30% and more than 70% on particular habitats (Fig. 6.13). The proportion between the "variable" and "stable" sequences is definitely worth analysing (Fig. 6.14). In the Masurian part, the habitats can be divided into two groups: higher stability characterises the habitats of lime-oak-hornbeam forest (especially in their typical form) and of ash-alder alluvial forests, while lower stability characterises the alder carrs, typical mixed pine-oak forests and pine forests. In the habitat of moist mixed pine-oak forest (*Querco-Pinetum molinietosum*) the shares of the "variable" and "stable" sequences are similar. It is also worth noting that the stability of the first habitat group mentioned and of the alder carr habitat results, first of all, from the persistence of deforestations, while in the second group – stability is primarily due to the influence of the permanent forest covers.

The area share taken by the stable sequences and the proportion between permanent forest and permanent deforestation make it possible to classify the habitats into two essential groups: the habitats of deciduous forests (stable sequences occupy between approximately 45% and more than 70%, with the permanent forest occupying less than 20%) and those of the pine and mixed pine-oak forests (stable sequences occupying less than 50%, but permanent forest areas taking between 30 and 40%). It is interesting to note that the habitats of pine forests (*Peucedano-Pinetum*) display the highest share of the unstable sequences.

When considering the shares of particular types of the variable sequences, attention ought to be paid to the proportions between the sequences leading to afforestation and the sequences resulting in deforestation (Fig. 6.15). Domination of deforestation over afforestation is observed in the habitats of the ash-alder alluvial forests (*Fraxino-Alnetum*),

Table 6.3. Sequences "forest – non-forest" in eight main habitat types in Masuria; sequences that occupied the area smaller than 1 km² of the region were analysed in total

Sequence type	Symbol	Habitat types															
		Ribeso--Alnetum (RA)		*Fraxino--Alnetum (FA)*		*Tilio-Carpinetum calamagrostietosum (TCc)*		*Tilio-Carpinetum typicum (TCt)*		*Tilio--Carpinetum stachyetosum (TCs)*		*Querco-Pinetum typicum (QPt)*		*Querco--Pinetum molinietosum (QPm)*		*Peucedano--Pinetum (PP)*	
		km²	% of habitat	km²	% of habitat	km²	% of habitat	km²	% of habitat	km²	% of habitat	km²	% of habitat	km²	% of habitat	km²	% of habitat
Permanent forest	FFFFFFF	5.2	11.1	5.4	3.5	53.0	16.9	9.7	12.3	11.2	6.1	148.8	33.3	22.9	38.7	75.9	32.9
Deforested permanently	nnnnnnn	16.2	34.6	90.7	58.2	141.1	44.9	46.3	59.1	102.4	55.7	44.9	10.1	6.9	11.7	0.6	0.2
Total stable sequences		**21.4**	**45.7**	**96.2**	**61.7**	**194.0**	**61.8**	**55.9**	**71.4**	**113.7**	**61.8**	**193.7**	**43.4**	**29.9**	**50.5**	**76.4**	**33.1**
Deforested temporarily	FFFnnFF	0.2	0.5	0.4	0.2	1.7	0.6	0.3	0.4	0.6	0.3	2.9	0.7	0.8	1.3	0.9	0.4
	FFnFFFF		0.0		0.0		0.0	0.3	0.4	1.3	0.7	8.6	1.9	2.2	3.6	0.0	0.0
	FFnnFFF	0.3	0.6	0.1	0.1	1.5	0.5	0.1	0.1	0.4	0.2	1.9	0.4	0.2	0.4	0.4	0.2
	FFnnnFF	1.7	3.7	2.4	1.5	6.9	2.2	1.4	1.8	4.6	2.5	13.2	2.9	1.9	3.3	1.2	0.5
	FFnnnnF	1.2	2.5	1.5	1.0	0.8	0.3	0.3	0.4	1.0	0.5	0.9	0.2	0.3	0.5	0.0	0.0
	FnnnnFF	0.2	0.4	0.1	0.1	1.1	0.3	0.1	0.1	0.4	0.2	1.6	0.4	0.1	0.2	0.1	0.0
	total	**3.6**	**7.7**	**4.5**	**2.9**	**12.0**	**3.8**	**2.6**	**3.3**	**8.3**	**4.5**	**29.1**	**6.5**	**5.5**	**9.4**	**2.6**	**1.1**
Afforestations	nFFFFFF	0.2	0.4	0.3	0.2	0.8	0.3	0.3	0.4	0.1	0.1	2.7	0.6	1.1	1.9	1.8	0.8
	nnFFFFF	1.1	2.4	1.1	0.7	4.8	1.5	0.6	0.8	1.9	1.0	27.2	6.1	2.4	4.1	50.4	21.9
	nnFFnFF	0.0	0.0	0.1	0.1	0.2	0.0	0.1	0.1	0.0	0.0	1.0	0.2	0.1	0.2	1.8	0.8
	nnFnFFF	0.0	0.0	0.1	0.0	0.4	0.1	0.0	0.0	0.0	0.0	1.2	0.3	0.2	0.3	1.0	0.5
	nnFnnFF	0.2	0.5	0.3	0.2	1.4	0.4	0.3	0.4	0.3	0.2	4.5	1.0	0.6	1.0	3.0	1.3
	nnnFFFF	1.3	2.7	2.1	1.3	7.9	2.5	0.5	0.6	1.2	0.6	49.7	11.1	2.8	4.7	63.3	27.4
	nnnFnFF	0.1	0.2	0.3	0.2	0.6	0.2	0.0	0.0	0.2	0.1	2.7	0.6	0.3	0.5	1.6	0.7
	nnnnFFF	0.4	0.8	0.6	0.4	4.5	1.4	0.2	0.3	0.5	0.3	13.1	2.9	0.8	1.3	6.6	2.9
	nnnnnFF	5.9	12.6	8.4	5.4	47.0	15.0	4.1	5.2	10.0	5.4	90.0	20.2	6.4	10.8	11.5	5.0
	nnnnnnF	2.8	6.0	4.7	3.0	9.2	2.9	1.3	1.6	3.8	2.1	8.6	1.9	1.4	2.4	0.1	0.0
	total	**12.0**	**25.6**	**18.0**	**11.5**	**76.9**	**24.5**	**7.4**	**9.4**	**18.1**	**9.8**	**200.7**	**44.9**	**16.1**	**27.2**	**141.2**	**61.2**
Ephemeral forests	nFnnnnn	0.1	0.2	2.1	1.4	0.7	0.2	2.6	3.3	2.9	1.6	0.9	0.2	0.1	0.1	0.0	0.0
	nnFnnnn	0.1	0.2	1.0	0.7	1.2	0.4	0.4	0.5	1.1	0.6	0.8	0.2	0.3	0.5	0.1	0.0
	nnnnnFn	0.2	0.4	1.1	0.7	2.0	0.6	0.3	0.4	1.2	0.7	1.3	0.3	0.3	0.5	0.1	0.0
	total	**0.4**	**0.9**	**4.3**	**2.8**	**3.8**	**1.2**	**3.3**	**4.2**	**5.2**	**2.9**	**3.0**	**0.7**	**0.6**	**1.1**	**0.2**	**0.1**
Deforestations	Fnnnnnn	0.1	0.3	2.2	1.4	3.3	1.0	1.1	1.5	5.1	2.8	0.9	0.2	0.1	0.2	0.0	0.0
	FFnnnnn	5.0	10.6	23.5	15.1	13.4	4.3	5.3	6.8	25.7	14.0	7.8	1.7	2.1	3.5	0.0	0.0
	FFFFFFn	0.5	1.1	1.0	0.6	0.8	0.3	0.3	0.4	1.4	0.7	1.9	0.4	1.1	1.9	0.5	0.2
	total	**5.6**	**12.1**	**26.7**	**17.1**	**17.5**	**5.6**	**6.8**	**8.7**	**32.2**	**17.5**	**10.6**	**2.4**	**3.3**	**5.6**	**0.5**	**0.2**
Rare sequences		3.8	8.1	6.3	4.1	9.7	3.1	2.3	2.9	6.4	3.5	9.4	2.1	3.7	6.3	9.8	4.2
Total changing sequences		**25.4**	**54.3**	**59.8**	**38.3**	**119.8**	**38.2**	**22.4**	**28.6**	**70.3**	**38.2**	**252.8**	**56.6**	**29.3**	**49.5**	**154.3**	**66.9**
Total habitat type		46.9	100.0	155.9	100.0	313.9	100.0	78.3	100.0	183.9	100.0	446.5	100.0	59.2	100.0	230.7	100.0

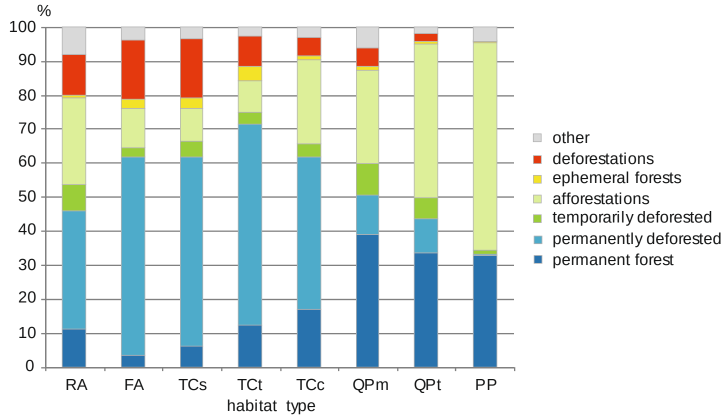

Fig. 6.13. Share of selected types of sequences "forest – non-forest" in dominant habitat types in Masuria

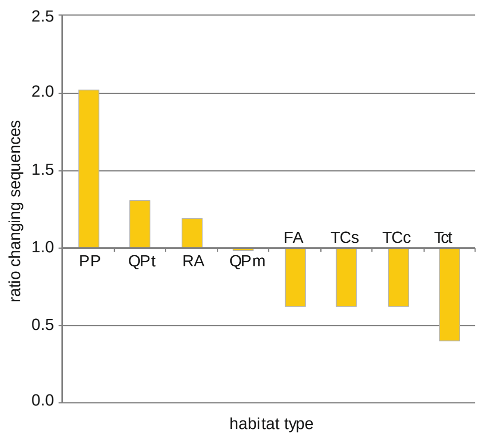

Fig. 6.14. Share of change sequences in relation to stable sequences in Masuria

as well as moist lime-oak-hornbeam forests (*Tilio-Carpinetum stachyetosum*). This fact can be explained in the following manner: these habitats are generally highly useful for agriculture, but in some situations their use might be constrained by the water conditions (excess of water, difficult access, periodical flooding). During the 200 years water conditions have been undergoing significant changes, turning the humid habitats into agricultural land – mainly grasslands – and the increased pressure on forests.

In the case of typical lime-oak-hornbeam forests, proportions between afforestations and deforestations are roughly even, while the remaining habitats display a bigger or lesser domination of afforestations over the deforestations. As regards the mixed oak-pine forest habitats, a distinct domination of afforestation is observed, and this domination becomes extreme for pine forests (*Peucedano-Pinetum*). Habitat ordering according to the proportion of afforestations and deforestations corresponds to the ordering according to the habitat fertility, from pine forests, through mixed oak-pine forests, alder carrs, poor and then typical lime-oak-hornbeam forests, up to the moist lime-oak-hornbeam forests and ash-alder alluvial forests.

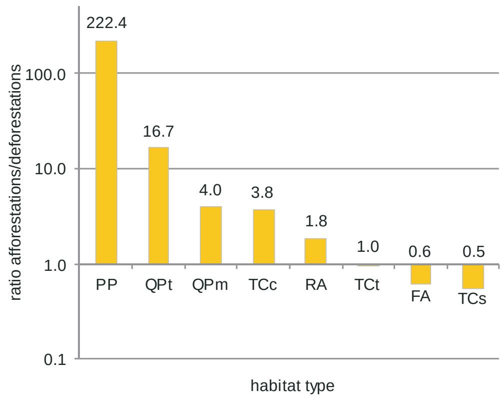

Fig. 6.15. Share of sequences resulted in afforestation in relation to sequences resulted in deforestation in Masuria

It is worth noting (Fig. 6.13) that the sequences of the ephemeral forests appear mainly in the relatively most fertile (eutrophic) habitats – those of typical lime-oak-hornbeam forest and ash-alder alluvial forests. Then, the sequences of forests with transitory deforestation are relatively most frequent in the mesotrophic habitats, particularly the mixed oak-pine forests and the alder carrs.

When analysing the "variable" sequences in Masuria (Fig. 6.16) one can notice that quite old afforestations (around the middle of the 19th century) are visible first of all in the habitats of pine forests (*Peucedano-Pinetum*), much less so in the habitats of mixed oak-pine forests (*Querco-Pinetum*) and the alder carrs (*Ribeso-Alnetum*). The afforestations from the turn of the 20th century are clearly observed in the habitats of pine forests, less so in the habitats of typical mixed oak-pine forests, and yet less in the habitats of moist mixed oak-pine forests. The afforestations from the first half of the 20th century usually having low significance, are relatively more notable in the oligo- and meso-trophic habitats. On the other hand, the afforestations from the second half of the 20th century are distinctly visible in the habitats of mixed oak-pine forests, alder carrs and poor lime-oak-hornbeam forests, while much less in the other habitats. In the pine forests this results from earlier high forest cover. Generally, it can be stated that the poorer the habitat, the earlier were afforestations.

The deforestations from the first half of the 19th century are rare. Their shares are relatively the highest in the habitats of lime-oak-hornbeam forests and the ash-alder alluvial forests. The distinct deforestations from the middle of the 19th century played a significant role in the moist habitats, i.e. of alluvial forests, moist lime-oak-hornbeam forests and alder carrs. This is probably related to the drainage works carried out, which made moist habitats available for farming. Deforestations are not observed in the pine forest habitats and rarely in the remaining habitats of lime-oak-hornbeam forests, and in those of mixed pine-oak forests.

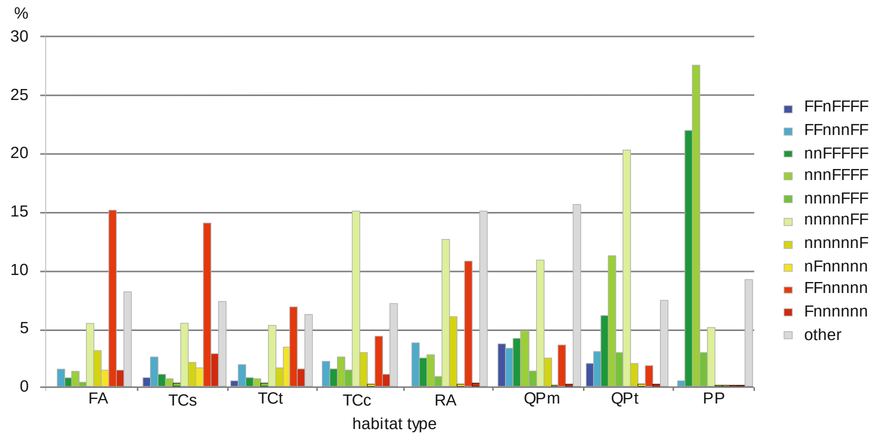

Fig. 6.16. Share of dominant change sequences in main habitat types in Masuria (10 dominant sequences from Table 6.3)

The transitory deforestations, mainly of the 19th century, are visible in the mesotrophic habitats of mixed oak-pine forests and alder carrs, while the transitory afforestations from the first half of the 19th century took place in the fertile habitats. Further, numerous, different variable sequences, of small areas, play the relatively highest role in the habitats of moist mixed pine-oak forests (*Querco-Pinetum molinietosum*) and of alder carrs (*Ribeso-Alnetum*). Both habitats are quite inconvenient for farming, mainly in view of water conditions, and hence, most probably, the variable agricultural pressure.

In general, the shares of the "variable" sequences in Masuria could be described as follows:

– in the first half of the 19th century moderate deforestations of moist and fertile habitats took place, which might be linked with the improvement of agricultural utility of some areas due to the water conditions amelioration as well as with "land dearth" with increasing rural population;
– in the second half of the 19th century and at the beginning of the 20th century intensive afforestation of oligotrophic habitats took place; this could be attributed to the socio-economic transformations and the mass afforestation actions, undertaken in the Prussian, and then German state;
– in the second half of the 20th century moderate afforestation took place in the mesotrophic habitats and very limited afforestation of eutrophic habitats; this is most probably the effect of the socio-economic transformations, including population decrease after the World War II, as well as establishment in the 1950s, and thereafter abandonment, of the large military exercise ground.

6.2.2. The sequences of changes in the habitats of Kurpie

The observed sequences of the "forest – non-forest" states were classified into: permanent forests, areas permanently deforested, forests with transitory deforestation (forest at the beginning and at the end, and a shorter or longer period of deforestation in the meantime), afforestation, occasional (ephemeral) afforestations and deforestations (Table 6.4). The habitat type of moist pine forest (*Molinio-Pinetum*) as more frequent in Kurpie then in Masuria was added to the analysis.

Taking the main sequences "forest – non-forest" (Fig. 6.17), the habitats in Kurpie can be classified into 3-4 groups (Table 6.4). This classification, though, is not unambiguous. It becomes more understandable when additional coefficients are introduced into the analysis. The proportion between the shares of "variable" and "stable" sequences (Fig. 6.18) gives a clear distinction of two habitat groups: those with domination of "variable" sequences (*Querco-Pinetum typicum* and *Q.-P. molinietosum*, as well as *Molinio-Pinetum*), and those with domination of the "stable" sequences (the remaining habitat types). On the other hand, relation between the sequences yielding afforestation and the ones leading to deforestation (Fig. 6.19), splits the habitats into three groups: the first one, with distinct domination of afforestations over deforestations, includes highly oligotrophic habitats of fresh and moist pine forests (*Peucedano-Pinetum* and *Molinio-Pinetum*), the second group, featuring a slight domination of deforestations, would contain the mesotrophic habitats of mixed pine-oak forests and alder carrs (*Querco-Pinetum* and *Ribeso-Alnetum*), while the third group is composed of eutrophic habitats of ash-alder alluvial forests and lime-oak-hornbeam forests (*Fraxino-Alnetum* and *Tilio-Carpinetum*), which feature very significant domination of deforestations over afforestations.

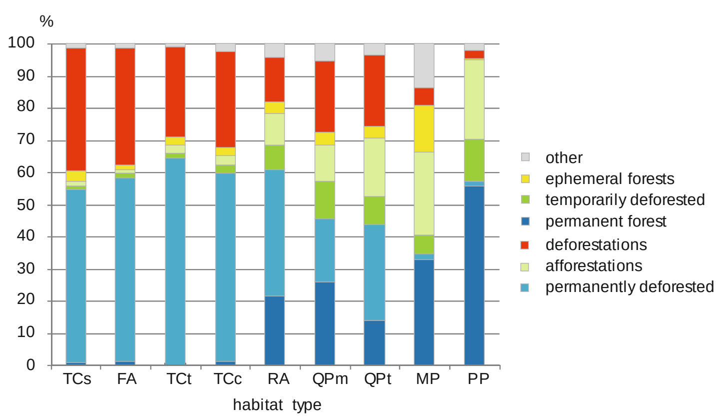

Fig. 6.17. Share of selected types of sequences "forest – non-forest" on dominant habitat types in Kurpie

The eutrophic habitats of lime-oak-hornbeam forests and ash-alder alluvial forests constitute quite a distinct and uniform group where the "stable" sequences dominate over the "variable" ones, and in the category of the "stable" ones – the permanently deforested are by far more common. In this habitat group the very extensive deforestations were also visible, having taken place during the 200 years analysed. Other sequences types are of marginal significance. Most typical of this group is the alluvial forest habitat (F*raxino-Alnetum*), in which permanent non-forest area occupies more than 57%, while

Table 6.4. Sequences "forest – non-forest" in nine main habitat types in Kurpie; sequences that occupied the area smaller than 1 km^2 of the region were analysed in total

Sequence type	Symbol	Habitat types																	
		Ribeso-Alnetum (RA)		*Fraxino-Alnetum (FA)*		*Tilio-Carpinetum calamagrostietosum (TCc)*		*Tilio-Carpinetum typicum (TCt)*		*Tilio-Carpinetum stachyetosum (TCs)*		*Querco-Pinetum typicum (QPt)*		*Querco-Pinetum molinietosum (QPm)*		*Peucedano-Pinetum (PP)*		*Molinio-Pinetum (MP)*	
		km^2	*% of habitat*	km^2	*% of habitat*	km^2	*% of habitat*	km^2	*% of habitat*	km^2	*% of habitat*	km^2	*% of habitat*	km^2	*% of habitat*	km^2	*% of habitat*	km^2	*% of habitat*
Permanent forest	FFFFFFF	5.2	*21.6*	3.3	*1.1*	2.0	*1.2*	0.2	*0.2*	0.9	*0.7*	40.9	*13.9*	13.1	*26.0*	112.9	*55.5*	3.7	*32.8*
Deforested permanently	nnnnnnn	9.4	*39.3*	169.7	*57.2*	98.1	*58.5*	55.9	*64.3*	70.0	*54.0*	87.4	*29.7*	9.8	*19.5*	3.5	*1.7*	0.2	*1.7*
Total stable sequences		**14.6**	***60.9***	**173.0**	***58.4***	**100.1**	***59.7***	**56.1**	***64.5***	**70.9**	***54.7***	**128.3**	***43.6***	**23.0**	***45.5***	**116.4**	***57.3***	**3.9**	***34.5***
Deforested temporarily	FFnnnnF	0.1	*0.4*	0.6	*0.2*	0.9	*0.5*	0.4	*0.4*	0.4	*0.3*	2.3	*0.8*	0.4	*0.8*	0.3	*0.2*	0.0	*0.1*
	FFnnnFF	0.7	*2.8*	1.2	*0.4*	1.4	*0.8*	0.5	*0.5*	0.7	*0.5*	8.8	*3.0*	1.8	*3.6*	5.3	*2.6*	0.2	*1.9*
	FFnnFFF	0.1	*0.2*	0.2	*0.1*	0.2	*0.1*	0.0	*0.0*	0.1	*0.1*	2.7	*0.9*	0.6	*1.2*	3.7	*1.8*	0.1	*0.9*
	FFnFFFF	0.2	*1.0*	0.1	*0.0*	0.2	*0.1*	0.1	*0.1*	0.1	*0.0*	3.7	*1.2*	0.6	*1.2*	6.6	*3.3*	0.2	*1.6*
	FFFnnFF	0.2	*0.9*	0.6	*0.2*	0.8	*0.4*	0.1	*0.2*	0.2	*0.1*	3.9	*1.3*	1.0	*2.0*	2.2	*1.1*	0.0	*0.3*
	FFFnFFF	0.4	*1.8*	0.5	*0.2*	0.9	*0.5*	0.0	*0.0*	0.0	*0.0*	3.6	*1.2*	1.1	*2.2*	6.6	*3.3*	0.1	*1.1*
	FFFFnFF	0.1	*0.5*	0.5	*0.2*	0.2	*0.1*	0.0	*0.0*	0.0	*0.0*	1.4	*0.5*	0.4	*0.7*	1.4	*0.7*		*0.0*
	total	**1.8**	***7.7***	**3.7**	***1.2***	**4.6**	***2.7***	**1.2**	***1.4***	**1.5**	***1.1***	**26.2**	***8.9***	**5.9**	***11.7***	**26.2**	***12.9***	**0.7**	***6.0***
Afforestations	nFFFFFF	0.0	*0.0*	0.0	*0.0*	0.1	*0.1*	0.0	*0.0*		*0.0*	0.7	*0.2*	0.3	*0.5*	2.3	*1.1*	0.0	*0.1*
	nnFFFFF	1.1	*4.6*	0.5	*0.2*	0.4	*0.2*	0.2	*0.3*	0.5	*0.4*	16.9	*5.7*	2.7	*5.4*	27.4	*13.5*	2.3	*20.8*
	nnFFnFF	0.1	*0.5*	0.1	*0.0*	0.1	*0.1*	0.2	*0.3*	0.1	*0.1*	1.1	*0.4*	0.1	*0.1*	1.0	*0.5*		*0.0*
	nnFnFFF	0.1	*0.4*	0.1	*0.0*	0.2	*0.1*	0.0	*0.0*	0.0	*0.0*	2.1	*0.7*	0.3	*0.7*	1.2	*0.6*	0.1	*0.5*
	nnFnnFF	0.1	*0.6*	0.2	*0.1*	0.3	*0.2*	0.2	*0.3*	0.2	*0.2*	4.2	*1.4*	0.6	*1.2*	3.2	*1.6*	0.1	*0.7*
	nnnFFFF	0.0	*0.2*	0.0	*0.0*	0.2	*0.1*	0.1	*0.1*	0.0	*0.0*	2.8	*0.9*	0.2	*0.3*	4.5	*2.2*	0.3	*3.1*
	nnnnFFF	0.1	*0.2*	0.1	*0.0*	0.2	*0.1*	0.1	*0.1*	0.1	*0.1*	2.3	*0.8*	0.2	*0.3*	1.3	*0.6*	0.0	*0.0*
	nnnnnFF	0.5	*1.9*	1.2	*0.4*	1.9	*1.1*	0.7	*0.8*	0.6	*0.5*	18.2	*6.2*	1.1	*2.1*	8.1	*4.0*	0.1	*0.5*
	nnnnnnF	0.3	*1.2*	0.7	*0.3*	0.9	*0.6*	0.5	*0.6*	0.4	*0.3*	5.2	*1.8*	0.3	*0.6*	1.1	*0.6*	0.0	*0.1*
	total	**2.3**	***9.6***	**3.0**	***1.0***	**4.3**	***2.6***	**2.2**	***2.5***	**1.9**	***1.5***	**53.4**	***18.2***	**5.7**	***11.3***	**50.1**	***24.7***	**2.9**	***25.7***
Ephemeral forests	nFnnnnn	0.0	*0.1*	1.0	*0.4*	0.4	*0.2*	0.0	*0.0*	0.5	*0.4*	0.4	*0.1*	0.0	*0.1*	0.0	*0.0*		*0.0*
	nnFFFnn	0.0	*0.2*	0.5	*0.2*	0.3	*0.2*	0.1	*0.1*	0.1	*0.1*	0.9	*0.3*	0.1	*0.2*	0.1	*0.1*	1.6	*14.1*
	nnFFnnn	0.1	*0.4*	0.4	*0.1*	0.1	*0.1*	0.2	*0.2*	0.3	*0.2*	1.1	*0.4*	0.2	*0.3*	0.1	*0.1*		*0.0*
	nnFnnnn	0.5	*1.9*	2.5	*0.8*	3.2	*1.9*	1.8	*2.0*	2.8	*2.2*	7.0	*2.4*	1.6	*3.2*	0.8	*0.4*	0.1	*0.5*
	nnnnnFn	0.3	*1.2*	0.7	*0.2*	0.4	*0.2*	0.1	*0.1*	0.2	*0.1*	1.2	*0.4*	0.1	*0.2*	0.2	*0.1*		*0.0*
	total	**0.9**	***3.7***	**5.1**	***1.7***	**4.4**	***2.6***	**2.2**	***2.5***	**3.8**	***2.9***	**10.6**	***3.6***	**2.0**	***3.9***	**1.3**	***0.6***	**1.6**	***14.6***
Deforestations	Fnnnnnn	0.1	*0.3*	22.7	*7.6*	2.9	*1.7*	0.9	*1.1*	7.0	*5.4*	1.8	*0.6*	0.6	*1.2*	0.0	*0.0*		*0.0*
	FFnnnnn	2.4	*10.1*	74.5	*25.1*	38.4	*22.9*	21.3	*24.5*	40.1	*30.9*	48.6	*16.5*	6.7	*13.3*	2.5	*1.2*	0.1	*1.0*
	FFnnFnn	0.0	*0.1*	0.5	*0.2*	0.8	*0.5*	0.0	*0.0*	0.2	*0.1*	1.0	*0.4*	0.4	*0.7*	0.1	*0.0*	0.0	*0.1*
	FFFnnnn	0.4	*1.5*	7.1	*2.4*	5.8	*3.5*	2.1	*2.4*	2.1	*1.6*	10.7	*3.7*	2.6	*5.2*	0.8	*0.4*	0.0	*0.4*
	FFFnFnn	0.1	*0.5*	1.2	*0.4*	1.5	*0.9*		*0.0*	0.1	*0.1*	1.1	*0.4*	0.3	*0.6*	0.1	*0.1*	0.0	*0.2*
	FFFFFnn	0.2	*0.9*	0.8	*0.3*	0.5	*0.3*	0.0	*0.0*	0.3	*0.2*	1.2	*0.4*	0.3	*0.6*	0.2	*0.1*	0.4	*3.1*
	FFFFFFn	0.1	*0.6*	0.4	*0.1*	0.1	*0.1*	0.1	*0.1*	0.0	*0.0*	0.6	*0.2*	0.3	*0.5*	1.0	*0.5*	0.1	*0.9*
	total	**3.4**	***14.0***	**107.2**	***36.2***	**50.1**	***29.8***	**24.4**	***28.1***	**49.8**	***38.5***	**65.0**	***22.1***	**11.2**	***22.1***	**4.7**	***2.3***	**0.6**	***5.6***
Rare sequences		1.0	*4.2*	4.5	*1.5*	4.3	*2.5*	0.9	*1.1*	1.6	*1.2*	10.6	*3.6*	2.8	*5.5*	4.6	*2.3*	1.5	*13.6*
Total changing sequences		**9.4**	***39.1***	**123.5**	***41.6***	**67.7**	***40.3***	**30.9**	***35.5***	**58.7**	***45.3***	**165.9**	***56.4***	**27.5**	***54.5***	**87.4**	***43.0***	**7.4**	***65.5***
Total habitat type		24.0	*100.0*	296.5	*100.0*	167.8	*100.0*	87.0	*100.0*	129.5	*100.0*	294.1	*100.0*	50.5	*100.0*	203.2	*100.0*	11.3	*100.0*

deforestation amounted to more than 36%. Hence, only 6-7% is left for all the other sequences types (including that of permanent forest). Generally, the history of these habitats is simple: what had not been deforested 200 years ago – got deforested later on.

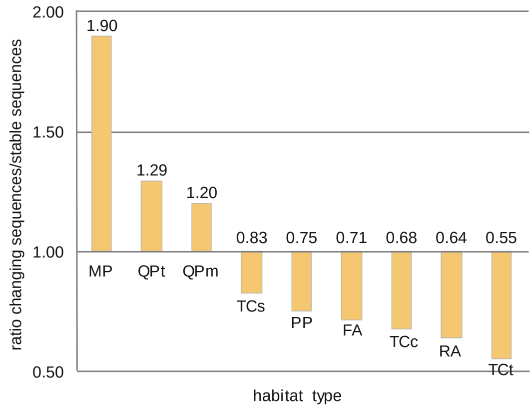

Fig. 6.18. Share of change sequences in relation to stable sequences in Kurpie

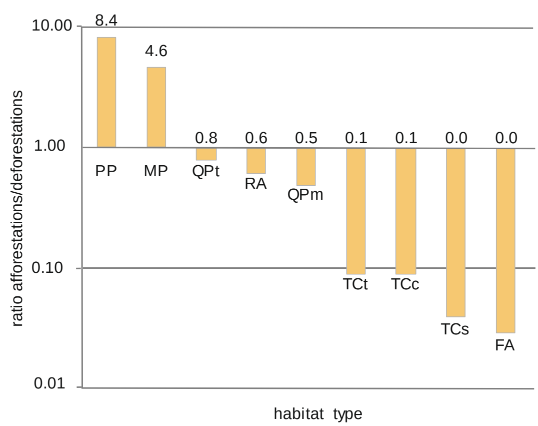

Fig. 6.19. Share of sequences resulted in afforestation in relation to sequences resulted in deforestation in Kurpie

The second, less distinct and relatively diversified group is constituted by the mesotrophic habitats of two mixed pine-oak forests and alder carrs. The "stable" sequences encompass both the permanent forest and permanent deforestation. Among the "variable" sequences deforestations dominate slightly over afforestations. The sequences with transitory deforestation, those with ephemeral forests and deforestations, and other types are also present.

The main categories of sequences are different for the oligotrophic habitats of fresh pine forest (*Peucedano-Pinetum*). The domination of the "stable" over the "variable" sequences is founded on the domination of permanent forest. Among the "variable" sequences, afforestations also decidedly dominate over the deforestations. There is also quite an important share of forest sequences with transitory deforestation, while there are no ephemeral forests. Hence, the simplified history of these habitats can be described as persistence and recovery of forests during 200 years.

The categories of sequences in the quite rare oligotrophic habitats of moist pine forest (*Molinio-Pinetum*) are to some extent similar to those in fresh pine forest habitats though there is definitely less of permanent forest, more of deforestations, and relatively high share of the ephemeral sequences, and of the other ones. This habitat type displays, as well, the highest share of the "variable" sequences – close to 65%.

As we subject the "variable" sequences in Kurpie to a more detailed analysis (Fig. 6.20), we note, first of all, the high or even very high shares of deforestations in the middle of the 19th century. They were most pronounced in the eutrophic habitats of moist lime-oak-hornbeam forests, and slightly less in the habitats of mixed pine-oak forests and alder carrs. The earlier deforestations, from the first half of the 19th century, were much less frequent and affected almost exclusively the habitats of moist lime-oak-hornbeam forests and of alluvial forests, while later deforestations, from the turn of the 20th century (also infrequent) affected the meso- and eutrophic habitats, wherein most intensively the humid mixed pine-oak forests.

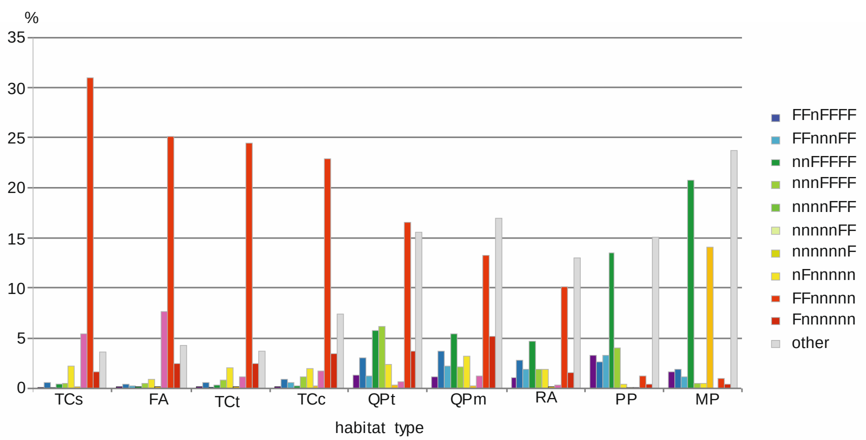

Fig. 6.20. Share of dominant change sequences in main habitat types in Kurpie (10 dominant sequences from Table 6.4)

The afforestations took place solely in the meso- and oligotrophic habitats. Their highest share is observed in the habitats of fresh and moist pine forests at the end of the 19th century, less so in the habitats of fresh mixed pine-oak forests and fresh pine forests in the second half of the 20th century.

The short-lived afforestations of the middle of the 19th century are visible in the mesotrophic habitats and less so in the eutrophic habitats, lasting longer (between the middle of the 19th century and the middle of the 20th century) only in the habitats of moist pine forest. On the other hand, the transitory deforestations took place in the meso- and oligotrophic habitats in between the middle of the 19th century and the middle of the 20th century, that is – in the period of the most intensive "land dearth".

The region of Kurpie is characterised by the relatively important share of the "variable" sequences featuring diverse patterns and occupying relatively small area of the meso- and oligo-trophic habitats. This is most probably the effect of quite random use of these habitats, which at one time would be covered by forest and then be deforested. In Masuria there were less of such pieces of land.

The shares of the "variable" sequences within Kurpie can be described as follows:

- the period between the first decades of the 19th century and the first decades of the 20th century – with special emphasis on the middle of the 19th century – was marked by the almost complete deforestation of eutrophic habitats (alluvial and lime-oak-hornbeam forests), and a moderate deforestation of poorer mesotrophic habitats of mixed pine-oak forests and alder carrs; all this constitutes the evidence for a very strong agricultural pressure;
- the period of the second half of the 19th century and the beginning of the 20th century saw intensive afforestations of the oligotrophic habitats (pine forests) and to a limited degree of the mesotrophic habitats (mixed pine-oak forests, alder carrs), leading to the changes in forest management and afforestation of wastelands;
- the period of the second half of the 20th century has been the time of moderate afforestations of the mesotrophic and fresh oligotrophic habitats, associated with the decrease of the agricultural pressure in the region, caused by the social and economic transformations.

6.2.3. The differences between regions regarding the frequencies of sequences of "forest – non-forest" in the most important habitats

The "forest – non-forest" sequences are the expression of changes in land use and depend upon the intensity of farming, population density, customs of the society inhabiting a given area, structure of land ownership, law regulating spatial development, economic conditions, and many other factors. They depend, as well, upon the habitat type being more or less useful for farming, and hence subject to different intensity of deforestation pressure. The analysis of similarities and differences in the frequencies of states "forest – non-forest" shifts in the same habitat type was carried out in the two regions with respect to the impact from the anthropogenic factors, superposed over the habitat features. A constant set of sequences was adopted over which the shares (in %) were analysed in the habitat types.

The area of Masuria stands out with small, but visible share of afforestations from the second half of the 20th century (Fig. 6.21). Fig. 6.22 shows, on the other hand, very high similarity of the habitats of ash-alder alluvial forests (*Fraxino-Alnetum*) in two regions considered.

When comparing the habitats of lime-oak-hornbeam forests (*Tilio-Carpinetum*) (Fig. 6.23), one observes the differences consisting in the limited, but perceptible share of the sequences of persistent forests and the sequences of afforestations since 1970 in Masuria.

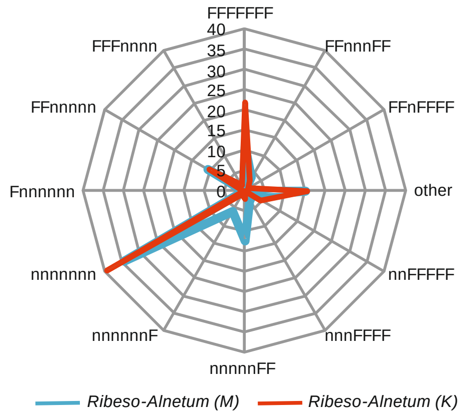

Fig. 6.21. Share of dominant sequences "forest – non-forest" in alder carrs (*Ribeso nigri-Alnetum*) habitats in Masuria (M) and Kurpie (K)

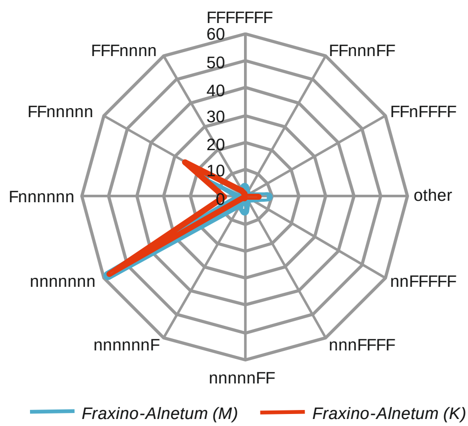

Fig. 6.22. Share of dominant sequences "forest – non-forest" in ash-alder alluvial forest (*Fraxino-Alnetum*) habitats in Masuria (M) and Kurpie (K)

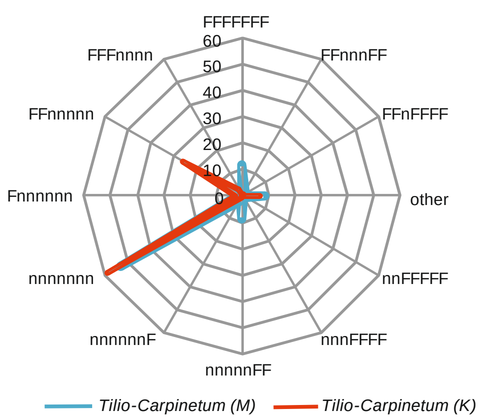

Fig. 6.23. Share of dominant sequences "forest – non-forest" in lime-oak-hornbeam forest (*Tilio-Carpinetum*) habitats in Masuria (M) and Kurpie (K)

Different sequences are observed in the habitats of fresh mixed pine-oak forests (*Querco-Pinetum typicum*), Fig. 6.24. The habitats of the mixed pine-oak forest in Masuria are much more frequently permanently afforested or afforested since the middle of the 19th century, the first half of the 20th century, and especially in the second half of the 20th century. In Kurpie, though, these habitats are much more frequently permanently deforested or deforested since the middle of the 19th century. A similar difference is observed in moist mixed pine-oak forests (*Querco-Pinetum*), see Fig. 6.25.

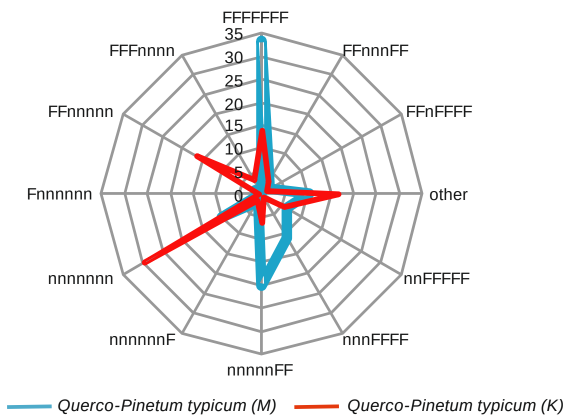

Fig. 6.24. Share of dominant sequences "forest – non-forest" in mixed oak-pine forest (*Querco-Pinetum typicum*) habitats in Masuria (M) and Kurpie (K)

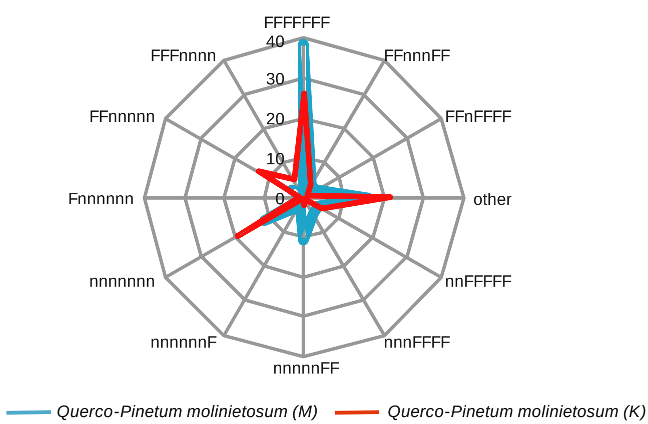

Fig. 6.25. Share of dominant sequences "forest – non-forest" in moist mixed oak-pine forest (*Querco-Pinetum molinietosum*) habitats in Masuria (M) and Kurpie (K)

In the fresh pine forests habitat (*Peucedano-Pinetum*), there are visible differences between regions (Fig. 6.26) concerning the share of afforestations from the middle of the 19th century, and especially those from the beginning of the 20th century in Masuria, as well as the relatively higher share of the permanent forests in Kurpie.

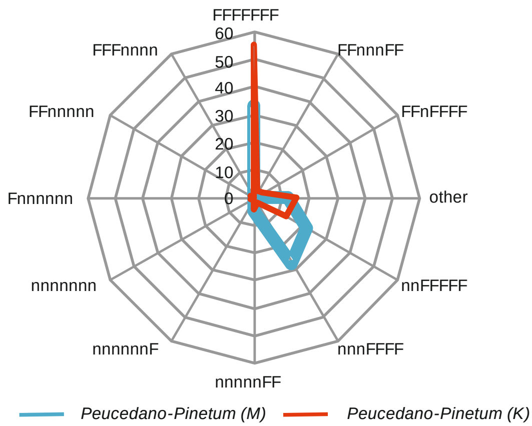

Fig. 6.26. Share of dominant sequences "forest – non-forest" in pine forest (*Peucedano-Pinetum*) habitats in Masuria (M) and Kurpie (K)

6.2.4. Frequency of habitat types on areas with definite sequences of "forest – non-forest" states

To understand the historical landscape transformations over the study area it is necessary not only to establish the nature of transformations (as expressed through the frequency of definite sequences of "forest – non-forest" states), which have been taking place in the habitat types, but also the opposite relation – i.e. the differentiation of transformation types (sequences of "forest – non-forest" states) in the particular habitat types should be considered. Thus, Tables 6.5 (Masuria) and 6.6 (Kurpie) present the areas and the shares of the most important habitats, related to the areas, on which a given sequence of transformations has been taking place. The data show the uneven distribution of habitats on the areas corresponding to the various sequences of "forest – non-forest" states. Likewise, one easily notices the differences between regions.

In order to better reflect the differentiation an W_{ia} indicator of habitat preferences for the sequences of "forest – non-forest" states was adopted, showing the ratio of the share of a given habitat type in the area occupied by a given sequence of states and the share of this habitat in the region. Thus, the formula applied, after transformation, was:

$$\mathbf{W_{ia} = (h_{ia} R) / (S_a H_i)}$$

where:

$\mathbf{h_{ia}}$ – area of habitat **i** within the area of sequence **a**,

R – area of the region,

$\mathbf{S_a}$ – area occupied by the sequence **a** in the region,

$\mathbf{H_i}$ – area of habitat **i** in the region.

Values around 1 are obtained for the habitats having share in the area occupied by a given sequence similar to that of their average share in the region. Higher values

Table 6.5. Share of habitat types in the area of "forest – non-forest" sequences in Masuria

"Forest – non-forest" sequences in Masuria		Habitat types																	
		Ribeso-Alnetum		*Fraxino-Alnetum*		*Tilio-Carpinetum calamagrostietosum*		*Tilio-Carpinetum typicum*		*Tilio-Carpinetum stachyetosum*		*Querco-Pinetum typicum*		*Querco-Pinetum molinietosum*		*Peucedano-Pinetum*		*Molinio-Pinetum*	
Sequence symbol	**area [km²]**	**km²**	**%**	**km²**	**%**	**km²**	**%**	**km²**	**%**	**km²**	**%**	**km²**	**%**	**km²**	**%**	**km²**	**%**	**km²**	**%**
FFFFFFF	343.2	5.2	*1.5*	5.4	*1.6*	53.1	*15.5*	9.7	*2.8*	11.3	*3.3*	149.0	*43.4*	23.0	*6.7*	76.3	*22.2*	2.3	*0.7*
FFnFFFF	25.9	1.4	*5.3*	0.6	*2.2*	2.7	*10.5*	0.3	*1.4*	1.3	*5.2*	8.6	*33.3*	2.2	*8.3*	7.6	*29.2*	0.2	*0.6*
FFFnFFF	2.1	0.0	*0.9*	0.1	*5.5*	0.5	*22.8*	0.0	*1.5*	0.2	*9.2*	0.7	*31.3*	0.3	*14.9*	0.3	*12.6*	0.0	*0.4*
FFnnnFF	34.2	1.7	*5.1*	2.4	*6.9*	6.9	*20.1*	1.4	*4.2*	4.6	*13.3*	13.2	*38.5*	1.9	*5.7*	1.2	*3.6*	0.0	*0.1*
nnFFFFF	91.3	1.1	*1.2*	1.1	*1.3*	4.8	*5.3*	0.6	*0.6*	1.9	*2.0*	27.2	*29.8*	2.4	*2.7*	51.0	*55.9*	0.1	*0.1*
nnnFFFF	129.6	1.3	*1.0*	2.1	*1.6*	7.9	*6.1*	0.5	*0.4*	1.2	*0.9*	49.7	*38.4*	2.8	*2.2*	63.3	*48.8*	0.3	*0.3*
nnnnFFF	26.7	0.4	*1.5*	0.6	*2.1*	4.5	*16.9*	0.2	*0.9*	0.5	*1.8*	13.1	*48.9*	0.8	*2.9*	6.6	*24.6*	0.0	*0.0*
nnnnnFF	184.8	5.9	*3.2*	8.4	*4.6*	47.0	*25.5*	4.1	*2.2*	10.0	*5.4*	90.0	*48.7*	6.4	*3.5*	11.5	*6.2*	0.3	*0.2*
nnFnnFF	10.7	0.2	*2.0*	0.3	*2.8*	1.4	*13.1*	0.3	*2.7*	0.3	*3.0*	4.5	*42.1*	0.6	*5.6*	3.0	*28.2*		*0.0*
nnnnnnF	32.7	2.8	*8.6*	4.7	*14.5*	9.2	*28.1*	1.3	*3.8*	3.8	*11.7*	8.6	*26.3*	1.4	*4.3*	0.1	*0.4*	0.1	*0.3*
Fnnnnnn	12.9	0.1	*1.1*	2.2	*17.0*	3.3	*25.4*	1.1	*8.8*	5.1	*39.8*	0.9	*6.8*	0.1	*0.8*	0.0	*0.1*		*0.0*
FFnnnnn	83.7	5.0	*6.0*	23.5	*28.1*	13.4	*16.0*	5.3	*6.4*	25.7	*30.7*	7.8	*9.3*	2.1	*2.5*	0.0	*0.0*	0.1	*0.1*
FFFnnnn	7.6	0.4	*4.7*	1.7	*22.5*	1.9	*24.5*	0.7	*9.8*	1.6	*21.2*	0.8	*10.2*	0.4	*4.8*	0.0	*0.3*	0.0	*0.1*
nnFnnnn	5.1	0.1	*2.1*	1.0	*20.5*	1.2	*22.9*	0.4	*7.9*	1.1	*22.4*	0.8	*15.2*	0.3	*5.3*	0.1	*1.1*		*0.0*
nnnnnnn	485.2	16.2	*3.3*	90.7	*18.7*	141.1	*29.1*	46.3	*9.5*	102.4	*21.1*	44.9	*9.2*	6.9	*1.4*	0.6	*0.1*	0.2	*0.0*
Other	96.3	5.0	*5.2*	11.0	*11.4*	15.0	*15.6*	5.9	*6.2*	12.8	*13.3*	26.9	*27.9*	7.6	*7.9*	10.3	*10.7*	0.3	*0.3*
Total region	1,572.0	46.9	*3.0*	155.9	*9.9*	313.9	*20.0*	78.3	*5.0*	183.9	*11.7*	446.5	*28.4*	59.2	*3.8*	231.9	*14.8*	3.9	*0.2*

Table 6.6. Share of habitat types in the area of "forest – non-forest" sequences in Kurpie

"Forest – non-forest" sequences in Masuria		Habitat types																	
		Ribeso-Alnetum		*Fraxino-Alnetum*		*Tilio-Carpinetum calamagrostietosum*		*Tilio-Carpinetum typicum*		*Tilio-Carpinetum stachyetosum*		*Querco-Pinetum typicum*		*Querco-Pinetum molinietosum*		*Peucedano-Pinetum*		*Molinio-Pinetum*	
Sequence symbol	**area [km²]**	**km²**	**%**	**km²**	**%**	**km²**	**%**	**km²**	**%**	**km²**	**%**	**km²**	**%**	**km²**	**%**	**km²**	**%**	**km²**	**%**
FFFFFFF	184.4	5.2	*2.8*	3.3	*1.8*	2.0	*1.1*	0.2	*0.1*	0.9	*0.5*	40.9	*22.2*	13.1	*7.1*	112.9	*61.2*	3.7	*2.0*
FFnFFFF	11.9	0.2	*2.1*	0.1	*0.7*	0.2	*1.7*	0.1	*0.9*	0.1	*0.5*	3.7	*30.8*	0.6	*4.9*	6.6	*55.5*	0.2	*1.5*
FFFnFFF	13.7	0.4	*3.2*	0.5	*3.7*	0.9	*6.7*	0.0	*0.2*	0.0	*0.3*	3.6	*26.6*	1.1	*8.1*	6.6	*48.4*	0.1	*0.9*
FFnnnFF	20.6	0.7	*3.3*	1.2	*5.6*	1.4	*6.9*	0.5	*2.2*	0.7	*3.3*	8.8	*42.5*	1.8	*8.9*	5.3	*25.7*	0.2	*1.0*
nnFFFFF	52.3	1.1	*2.1*	0.5	*0.9*	0.4	*0.7*	0.2	*0.4*	0.5	*1.0*	16.9	*32.2*	2.7	*5.2*	27.4	*52.4*	2.3	*4.5*
nnnFFFF	8.2	0.0	*0.5*	0.0	*0.5*	0.2	*2.8*	0.1	*1.2*	0.0	*0.1*	2.8	*33.9*	0.2	*2.1*	4.5	*54.3*	0.3	*4.2*
nnnnFFF	4.3	0.1	*1.2*	0.1	*1.9*	0.2	*5.2*	0.1	*2.0*	0.1	*1.7*	2.3	*53.4*	0.2	*3.7*	1.3	*30.1*	0.0	*0.1*
nnnnnFF	32.4	0.5	*1.4*	1.2	*3.8*	1.9	*5.7*	0.7	*2.1*	0.6	*1.9*	18.2	*56.1*	1.1	*3.3*	8.1	*25.1*	0.1	*0.2*
nnFnnFF	9.2	0.1	*1.5*	0.2	*2.1*	0.3	*3.3*	0.2	*2.5*	0.2	*2.5*	4.2	*45.1*	0.6	*6.6*	3.2	*34.8*	0.1	*0.8*
nnnnnnF	9.6	0.3	*3.1*	0.7	*7.8*	0.9	*9.7*	0.5	*5.7*	0.4	*4.1*	5.2	*54.2*	0.3	*3.3*	1.1	*11.6*	0.0	*0.1*
Fnnnnnn	36.0	0.1	*0.2*	22.7	*62.9*	2.9	*8.0*	0.9	*2.6*	7.0	*19.5*	1.8	*4.9*	0.6	*1.7*	0.0	*0.1*		0.0
FFnnnnn	235.0	2.4	*1.0*	74.5	*31.7*	38.4	*16.3*	21.3	*9.1*	40.1	*17.1*	48.6	*20.7*	6.7	*2.8*	2.5	*1.0*	0.1	*0.0*
FFFnnnn	31.8	0.4	*1.1*	7.1	*22.4*	5.8	*18.2*	2.1	*6.7*	2.1	*6.5*	10.7	*33.8*	2.6	*8.2*	0.8	*2.6*	0.0	*0.1*
nnFnnnn	20.2	0.5	*2.2*	2.5	*12.2*	3.2	*15.8*	1.8	*8.7*	2.8	*13.9*	7.0	*34.6*	1.6	*7.9*	0.8	*4.0*	0.1	*0.3*
nnnnnnn	505.0	9.4	*1.9*	169.7	*33.6*	98.1	*19.4*	55.9	*11.1*	70.0	*13.9*	87.4	*17.3*	9.8	*1.9*	3.5	*0.7*	0.2	*0.0*
Other	96.9	2.6	*2.7*	12.1	*12.5*	11.0	*11.3*	2.3	*2.4*	4.0	*4.2*	32.1	*33.2*	7.4	*7.7*	18.5	*19.1*	3.8	*4.0*
Total region	1,271.6	24.0	*1.9*	296.5	*23.3*	167.8	*13.2*	87.0	*6.8*	129.5	*10.2*	294.1	*23.1*	50.5	*4.0*	203.2	*16.0*	11.3	*0.9*

of the indicator imply a more or less pronounced preference of the given sequence for the given habitat – since the share of the habitat within the sequence is higher than on the average in the region. The values of this indicator were used to analyse the association of the habitats with the selected, most common sequences. Four groups of sequences were distinguished:

- sequences consisting in afforestation of the initially deforested area (Figs. 6.27 and 6.28),
- sequences leading to deforestation of earlier afforested area, as well as sequences with ephemeral forest (Figs. 6.29 and 6.30),
- sequences with transitory deforestation of the area, which had been afforested at the beginning and was also afforested at the end (Figs. 6.31 and 6.32),
- the stable sequences of the permanent forest and permanent deforestation, along with all the sequences not analysed in detail (Figs. 6.33 and 6.34).

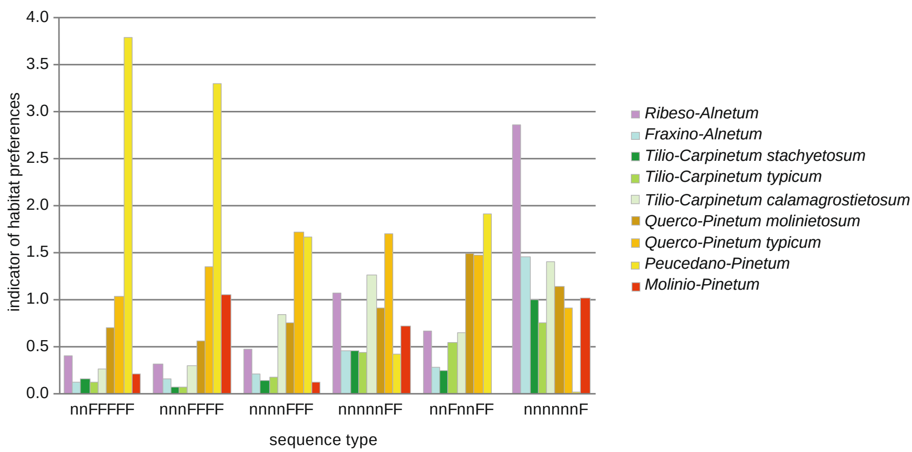

Fig. 6.27. Indicators of habitat preferences for sequences "forest – non-forest" in Masuria – dominant sequences resulted in afforestation

When analysing the habitat preferences of the sequences leading to forest in Masuria (Fig. 6.27) one notices that the habitats of *Peucedano-Pinetum* association were particularly preferred for afforestation in the second half of the 19th century and in the first half of the 20th century (sequences with afforestations since 1885 or 1928). Afterwards, such preferences were less pronounced, due to the significant shrinking of the non-forest areas in these habitats. So, the fact that this habitat does not appear in the most recent afforestations (between the years 1970 and 2000) results from their earlier virtually complete afforestation.

An interesting observation concerns the preference for the alder carr habitats (*Ribeso-Alnetum*), and, to a lesser extent, the alluvial forest habitats (*Fraxino-Alnetum*), regarding the sequences of the relatively latest afforestations, those occurring between 1970 and 2000.

The entire image of the Masurian region, makes apparent the division of sequences yielding forest cover into three groups:

– the sequences yielding permanent forest since 1885 or 1928, characterised by a distinct preference for the oligotrophic habitats of pine forests, or, a bit less clearly, of mixed pine-oak forests, with only marginal share of eutrophic and moist habitats;
– the sequences yielding permanent forest in the post-war period, between the years 1950 and 1970, which display relatively smaller differentiation of preferences among habitats;
– the sequence, yielding forest after 1970, which is characterised by the preference for moist habitats, and by lack of a clear preference between eutrophic and oligotrophic habitats, except for the pine forest habitats, which could not be subject to afforestation, as they had been entirely afforested before.

In Kurpie the preferences of the sequences leading to afforestation display somewhat different tendencies, although some similarities can also be noted (Fig. 6.28) and the division of sequences into three groups can also be performed.

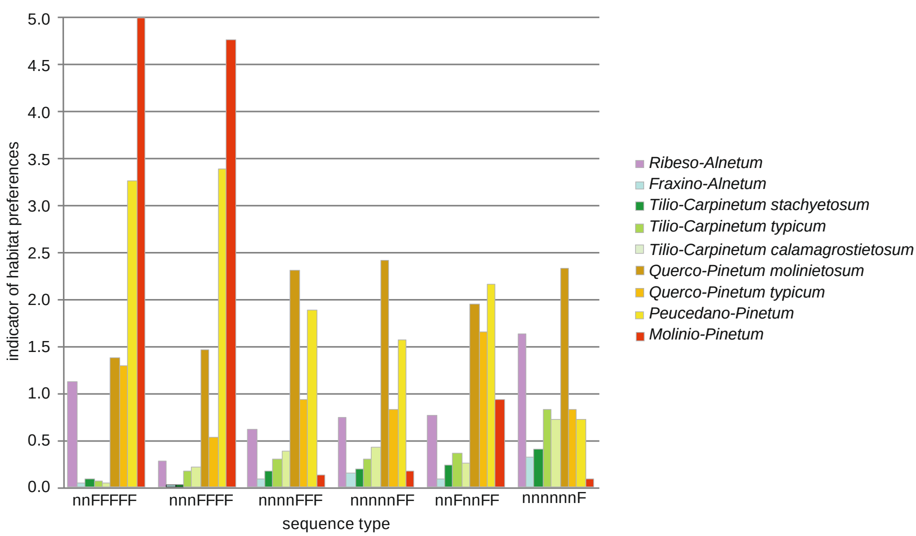

Fig. 6.28. Indicators of habitat preferences for sequences "forest – non-forest" in Kurpie – dominant sequences resulted in afforestation

In the group of sequences, which yield forest cover since 1885 or 1928, the preference is visible for fresh pine forest (*Peucedano-Pinetum*) habitats, particularly pronounced for the habitats of moist pine forests (*Molinio-Pinetum*), and much lower for the habitats of moist mixed pine-oak forests (*Querco-Pinetum molinietosum*) and yet even lower for those of fresh mixed pine-oak forests (*Q.-P. typicum*). These sequences have virtually not occurred in the eutrophic habitats.

The sequences, associated with afforestations introduced around 1950 or 1970, display a moderate preference for oligotrophic habitats (moist mixed pine-oak forests, fresh pine forests). Preferences are, on the other hand, quite different for the sequences yielding forest cover after 1970. This is apparent for habitats of moist mixed pine-oak forests and alder carrs, with a small, but significant decrease of the "negative preference" for eutrophic habitats.

Observation of habitat preferences for the sequences leading to deforestation, both in Masuria (Fig. 6.29) and in Kurpie (Fig. 6.30) shows that eutrophic and moist habitats were particularly preferred for deforestation. The older the deforestation (particularly regarding those from the first half of the 19th century), the more clear is this preference. In Masuria the preference was earlier associated with the habitats of moist lime-oak-hornbeam forests, and then with ash-alder alluvial forests, while in Kurpie the situation was opposite: the oldest deforestations took place in the alluvial forest habitats, and only then in the habitats of moist lime-oak-hornbeam forests. One can also notice an increase in the deforestation of moist mixed pine-oak forest habitats, and also of fresh mixed pine-oak forest habitats in Kurpie. In Kurpie, the relatively stronger agricultural pressure is visible in comparison to Masuria, consisting in deforestation of oligotrophic habitats of pine and fresh mixed pine-oak forests.

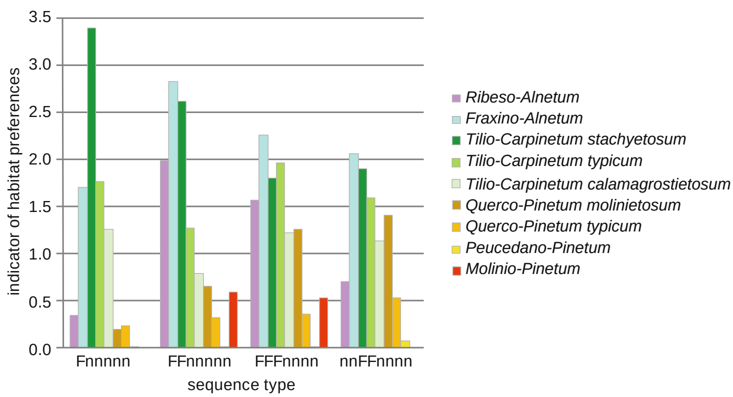

Fig. 6.29. Indicators of habitat preferences for sequences "forest – non-forest" in Masuria – dominant sequences resulted in deforestation

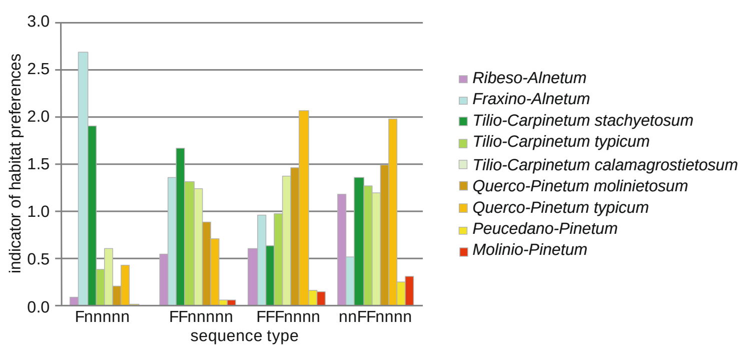

Fig. 6.30. Indicators of habitat preferences for sequences "forest – non-forest" in Kurpie – dominant sequences resulted in deforestation

The analysis of the most frequent sequences, characterised by the transitory deforestation, in Masuria (Fig. 6.31) and Kurpie (Fig. 6.32) indicates that these sequences preferred the oligotrophic habitats, especially moist and swampy ones. This means that these habitats, usually of little use for farming, were deforested during the period of chaotic spatial management and the biggest "dearth of land" at the turn of the 20th century. The reasons behind this deforestation, hardly distinguished on topographical maps were both related to agricultural land-use and to plundering cutting of trees, without any recovery.

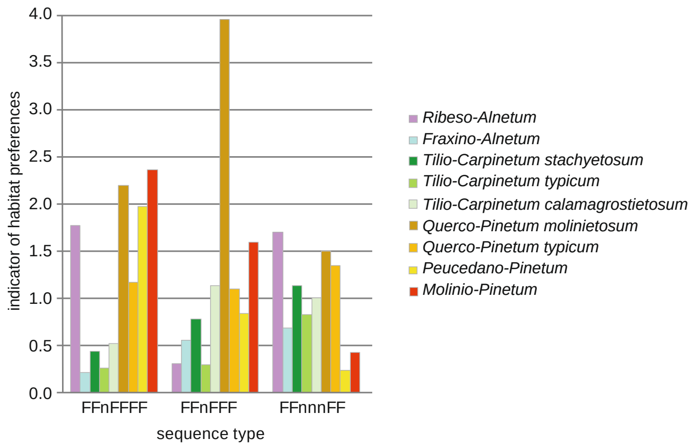

Fig. 6.31. Indicators of habitat preferences for sequences "forest – non-forest" in Masuria – dominant sequences of transitory deforestation

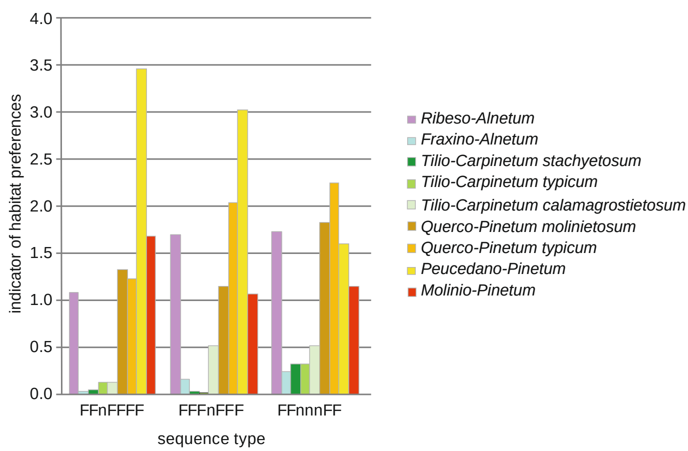

Fig. 6.32. Indicators of habitat preferences for sequences "forest – non-forest" in Kurpie – dominant sequences of transitory deforestation

The analysis of the "stable" sequences, shown in Figs. 6.33 and 6.34, makes it possible to notice that permanent forests preferred oligotrophic habitats. This is well visible both in Masuria and Kurpie, although the ordering of preferences is different. Thus, in Masuria, the habitats of moist pine forest can be considered as distinctly preferred by the permanent forests, while in Kurpie – the fresh and moist pine forest habitats. This preference can be extended in Masuria, to the habitats of fresh pine forests, and of fresh and moist mixed pine-oak forests, and in Kurpie – the habitats of fresh mixed pine-oak forests and of alder carrs.

Permanent deforestation characterises eutrophic habitats – the ash-alder alluvial forests and lime-oak-hornbeam forests. This is visible both in Masuria and in Kurpie, with the very little difference between regions.

The various sequences of limited reach, treated jointly and not included in the detailed analysis, might indicate the instability of the setting of "forest – non-forest" in different habitats. Such instability is observed for the habitats of moist mixed pine-oak forests and alder carrs in Masuria, as well as for the habitats of moist pine forests, fresh and moist mixed pine-oak forests, and alder carrs in Kurpie.

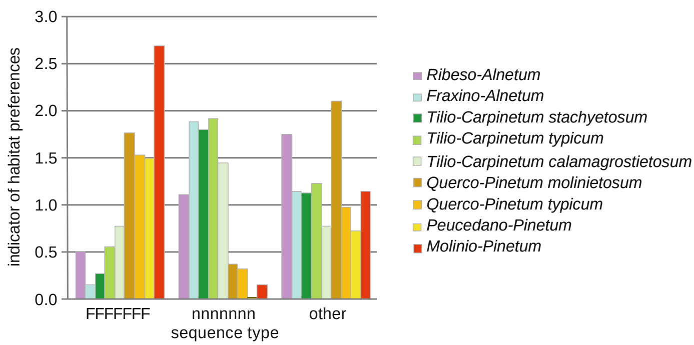

Fig. 6.33. Indicators of habitat preferences for sequences "forest – non-forest" in Masuria – dominant sequences of permanent forest or permanent deforestation and the remaining ones

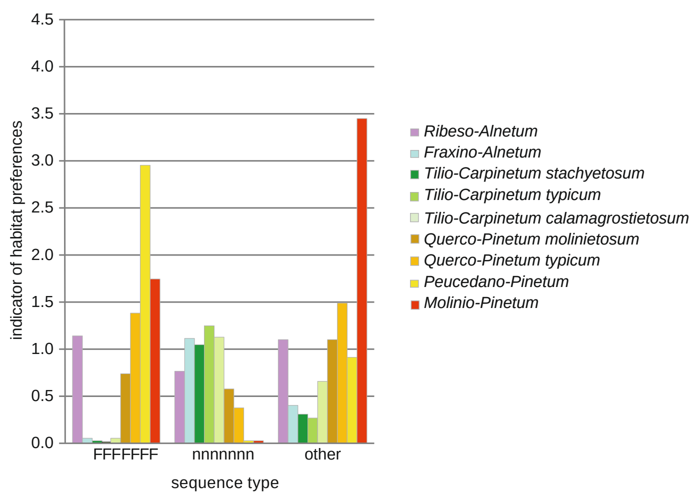

Fig. 6.34. Indicators of habitat preferences for sequences "forest – non-forest" in Kurpie – dominant sequences of permanent forest or permanent deforestation and the remaining ones

6.2.5. The relationships between habitat types and sequences of "forest – non-forest" states

When characterising the habitat preferences, which are displayed by the main sequences of "forest – non-forest" states, reflecting the time-varying agricultural pressure, the regularities can be indicated as outlined below.

Thus, the **habitats** can be divided into two essential groups: those **non-attractive for farming** (oligotrophic or hard to use in farming for other reasons) and those **attractive for farming** (eutrophic). The non-attractive habitats encompass those of pine forests (*Peucedano-Pinetum*), moist pine forests (*Molinio-Pinetum*), mixed pine-oak forests (*Querco-Pinetum*), and swampy alder carrs (*Ribeso-Alnetum*). On the other hand, the attractive habitats include those of the ash-alder alluvial forests (*Fraxino-Alnetum*) and of lime-oak-hornbeam forests (*Tilio-Carpinetum*). The share of almost all sequences is different in the two groups. The non-attractive habitats were in their majority afforested 200 years ago, and thereafter afforestation processes dominated over deforestations. On the contrary, the habitats attractive for farming were in their majority deforested 200 years ago, and it has yet increased afterwards. It has been only in the last half century that these habitats have showed a slight tendency towards afforestation.

There is also a distinct **division into periods within the change course**, consisting in the intensification of afforestation or deforestation processes in definite time periods, which resulted in the different reaches of the sequences.

In Masuria, one can distinguish the following periods of changes in the forest cover of habitats.

- At the beginning of the 19th century (between 1800 and 1830) slight deforestation of eutrophic habitats is observed (about 1.0-2.8% of particular eutrophic habitat types).
- In the middle of the 19th century (between 1830 and 1876) a significant and persistent deforestation took place in eutrophic and moist habitats (*Fraxino-Alnetum* – 15.1%, *Tilio-Carpinetum stachyetosum* – 14.0%, *Ribeso-Alnetum* – 10.6%), and lower in the fresh eutrophic habitats (*Tilio-Carpinetum typicum* – 6.8%, *Tilio-Carpinetum calamagrostietosum* – 4.3%) and in the mesotrophic humid ones (*Querco-Pinetum molinietosum* – 3.5%). Simultaneously, in the same period, the persistent afforestation of oligotrophic and mesotrophic habitats starts – the following habitats were afforested: *Peucedano-Pinetum* in 21.9%, *Querco-Pinetum typicum* in 6.1%, and *Querco-Pinetum molinietosum* in 4.1%.
- At the turn of the 20th century (between 1876 and 1928) the afforestation of poorer habitats intensified. 27.4% of the *Peucedano-Pinetum* habitats, 11.1% of *Querco-Pinetum*, and 4.7% of *Querco-Pinetum molinietosum* were afforested. Less intensive afforestation of these habitats lasted also in the first half of the 20th century.
- In the second half of the 20th century (between 1950 and 1970) the afforestations encompassed many habitats. New forests occurred in the mesotrophic habitats (*Querco-Pinetum typicum* – 20.2%, *Querco-Pinetum molinietosum* – 10.8%, and *Ribeso-Alnetum* – 12.6%), and in the poorer eutrophic ones (*Tilio-Carpinetum calamagrostietosum* – 15.0%). This partly applied to the unequivocally eutrophic habitats (*Fraxino-Alnetum* and *Tilio-Carpinetum typicum* as well as *stachyetosum* – each around 5%), and to the still not afforested part of oligotrophic habitats (*Peucedano-Pinetum* – approximately

5%). This tendency persisted in the second half of the 20th century (between 1970 and 200), although the range of afforestations was smaller.

- In Masuria there has been a non-forest sequence, with, however, ephemeral forest in the eutrophic habitats around 1830. This probably refers to the regional depopulation, which took place in East Prussia due to Napoleon's wars at the beginning of the 19th century. This is, though, merely a hypothesis, since the precision of land cover reconstruction from the map representing this period is quite limited.

Then, concerning the region of Kurpie, four periods of changes in forest cover of habitats can be distinguished.

- At the beginning of the 19th century (between 1800 and 1830) not very extensive, but persistent deforestation took place in the most eutrophic habitats, that is – those of moist lime-oak-hornbeam forests (*Tilio-Carpinetum stachyetosum*) in 5.4%, and of alluvial forests (*Fraxino-Alnetum*) in 7.6%.
- In the middle of the 19th century (between 1830 and 1885) an extensive and persistent deforestation took place in all eutrophic habitats (*Tilio-Carpinetum*, *Fraxino-Alnetum*) – ranging from 22.9% in poorer lime-oak-hornbeam forests to 30.9% in moist lime-oak-hornbeam forests. The persistent deforestations in mesotrophic habitats were somewhat smaller, ranging from 10.1% in alder carrs to 16.5% in the fresh mixed pine-oak forests. Limited deforestations occurred in the habitats of oligotrophic fresh and moist pine forests. At the same time, persistent afforestation took place in strongly oligotrophic habitats – in 13.5% in fresh pine forests (*Peucedano-Pinetum*) and in 20.8% in moist pine forests (*Molinio-Pinetum*). Afforestations encompassed to a limited degree (in roughly 5%), mesotrophic habitats, as well. This was the period of the biggest changes in the area considered.
- At the turn of the 20th century (i.e. between 1870 and 1928) limited persistent deforestations took place in approximately 2.5% of some mesotrophic and eutrophic habitats.
- In the second half of the 20th century (between 1950 and 1970) small, but persistent afforestations affected the habitats of mixed pine-oak forests and fresh pine forests (*Querco-Pinetum typicum* – 6.2%, and *Peucedano-Pinetum* – 4.0%). At the same time, more than 14% of habitats of moist pine forests (*Molinio-Pinetum*), temporarily afforested since the middle of the 19th century, got deforested again.

It is possible to show the **asynchronous transformations of forest landscape** in the regions regarding the proportions of forest cover in the particular habitat types. In eutrophic habitats, in both regions, at around the middle of the 19th century (between 1830 and 1876-1885) distinct deforestation took place. Yet, while in Masuria the deforestation of these habitats stopped at the turn of the 20th century, it continued in Kurpie, even though being less intensive.

Likewise, the agricultural attractiveness of oligotrophic and mesotrophic habitats (*Peucedano-Pinetum* and *Querco-Pinetum*) was changing at different time slices in two regions. Thus, 200 years ago oligotrophic habitats, and especially the habitats of pine forests, were used for farming more often in Masuria than in Kurpie. Around 1800 the *Peucedano-Pinetum* habitats in Masuria were deforested in 62%, while in Kurpie – in 28%, and the *Querco-Pinetum typicum* habitats were deforested in Masuria in 57%, while in Kurpie – in 53%. The differences between the regions could be partly due to the difference in the substratum and the geomorphological forms of pine forest habitats. The outwash plains in Masuria offered better conditions for farming than the dunes areas in Kurpie. Soon afterwards, though, namely on a massive scale already in the middle of the 19th century, afforestation of oligo- and meso-trophic habitats in Masuria started. On the other hand, in Kurpie, the mesotrophic habitats of *Querco-Pinetum* were still used in farming and deforested at the beginning of the 20th century. Only in the second half of the 20th century this tendency reverted and afforestations began to dominate.

Hence, in comparison of the regions, the "delay" of some 50-100 years in Kurpie, as compared to Masuria, can be seen in terms of transformation of the forest cover related to habitat types.

6.3. The share of "ancient forests" according to habitat types in the regions

The distribution of ancient forests, considered in its general already in Chapter 5.3, is worth analysing also in the perspective of habitat-related variability (Figs. 6.35 and 6.36). In the ancient forests of Masuria the highest share (around 50%) is taken by the mesotrophic habitats of mixed pine-oak forests (*Querco-Pinetum*), while the shares of the oligotrophic habitats of pine forests (*Peucedano-Pinetum*) and of the eutrophic habitats of lime-oak-hornbeam forests (*Tilio-Carpinetum*) exceed each slightly 20%. On the other hand, in the ancient forests of Kurpie, the poor habitats of pine forests and of mixed pine-oak forests

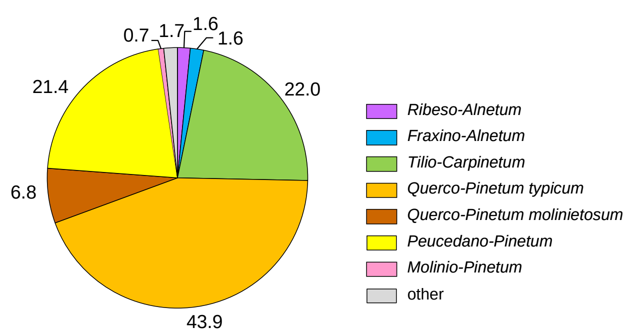

Fig. 6.35. Share of dominant potential natural vegetation types in ancient forests in Masuria

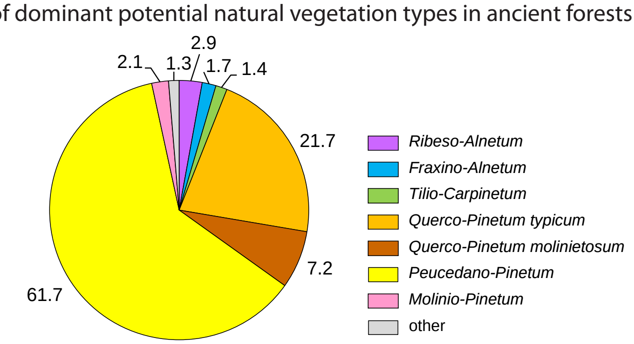

Fig. 6.36. Share of dominant potential natural vegetation types in ancient forests in Kurpie

decidedly dominate, taking together more than 90%, while the share of lime-oak-hornbeam forest habitats is very small. Whereas, the share of hydrogenic habitats of ash-alder alluvial forests, alder carrs and moist pine forests is quite limited in both regions.

As mentioned already, in the analysis of the forest cover and the share of ancient forests in the particular habitat types, the degree of deforestation can be treated as a measure of the current agricultural pressure exerted on the habitats, while the share of ancient forests – as the measure of historical pressure and the degree of habitat preservation. This is important because a number of typical forest species are associated with ancient forests and their survival in most cases depends on the existence of these refugia.

In Masuria (Fig. 6.37) the habitats are divided into two groups: the habitats of deciduous forests and those of coniferous and mixed forests. In the first group the ancient forests constitute between a bit more than 3% of the habitat area (*Fraxino-Alnetum*) and more than 16% in the poor lime-oak-hornbeam forests (*Tilio-Carpinetum calamagrostietosum*). In the second group the share of ancient forests is above 30% (*Peucedano-Pinetum*, *Querco-Pinetum typicum*), and may even attain 60% (*Querco-Piceetum*).

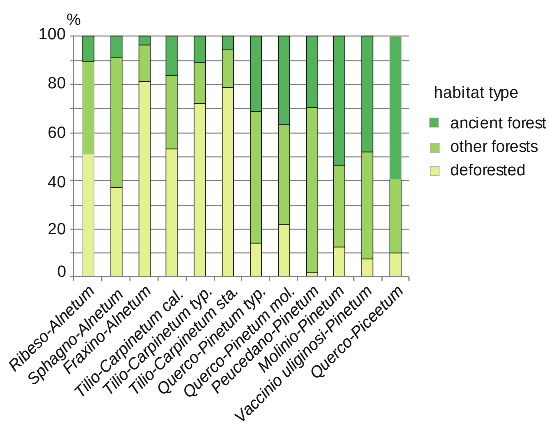

Fig. 6.37. The rate of forest cover (including ancient forests) in selected habitat types in Masuria

In Kurpie (Fig. 6.38) the diversification of habitats in terms of the ancient forests share is even bigger, but their division into groups is not so unambiguous. Very low shares of ancient forests are observed in the habitats of ash-alder alluvial forests (roughly 1%), and of lime-oak-hornbeam forests (between 0.2 and 1%, depending upon the subassociation). This means that the agricultural pressure on these habitats could constrain significantly the biological diversity, leading to elimination or serious limitation of some typical forest species occurrence.

The state of ancient forests preservation in the oligo- and meso-trophic habitats in Kurpie is quite similar to that observed in Masuria, although definite differences between two regions can be pointed out.

The historical socio-economic development brought a selective and significant transformation of the habitats, with almost complete elimination (in the case of Kurpie) of the permanent forest in lime-oak-hornbeam and the ash-alder alluvial forests habitats.

In Masuria, the permanent forests have survived in all habitat types, although – in the ash-alder alluvial forests – the ancient forests happen to be very rare.

Elimination of the ancient forests in some habitat types imply the **unsustainable development in the past**. The marginal forest cover in eutrophic habitats of Kurpie suggests that the state of unbalanced agricultural pressure on these habitats would yet persist longer. In Masuria, the perspective of improvement is already in sight.

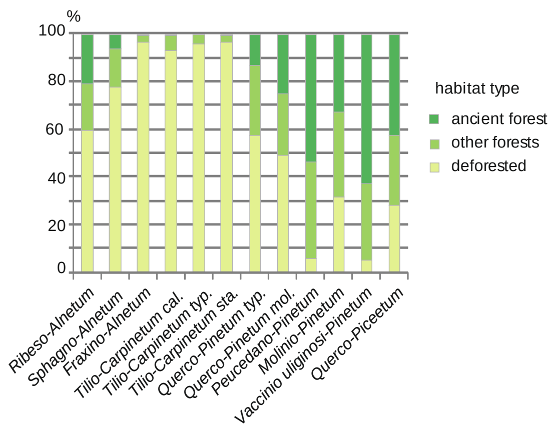

Fig. 6.38. The rate of forest cover (including ancient forests) in selected habitat types in Kurpie

6.4. Evaluation of changes in the forest cover in habitats using the "sustainable landscape" criteria

6.4.1. "Sustainable landscape" – what does it mean?

The notion of "natural landscape", irrespective of the more detailed definitions (see Ostaszewska, 2002; Richling & Solon, 2011) denotes the landscape with the vegetation constituted solely by natural communities, not dependent upon human activity. Such vegetation might be referred to as the potential natural vegetation (Tüxen, 1956). In the natural conditions of Central Europe, and so also on the study area, the potential natural vegetation – of terrestrial habitats – is constituted in a vast majority by forest communities. Rarely, non-forest community fulfills the criteria of natural vegetation. This is documented, in particular, by the survey map of the natural potential vegetation of Poland (Matuszkiewicz et al., 1995; Matuszkiewicz, 2008), as well as by the map, developed in this research (see Chapter 4), where all types of terrestrial natural vegetation, except for bogs (from the *Oxycocco-Sphagneta* class), are forest associations.

The areas which could be (at least in an approximation) classified as "natural landscape" are indeed only very few in this part of Europe. They can be encountered, in particular, on the areas of strict protection (like in the National Park of Białowieża). Landscapes that significantly differ from the "natural" ones are, of course, much more frequent. In practice, one deals with landscapes that are transformed by human activities, with vegetation differs more or less from the "natural" state. This is the consequence of the economic activities that change the natural vegetation into the secondary one through various direct and indirect actions (e.g. trees cutting and planting of selected forest species, transformation of forests into arable land or grasslands, deforestation for establishment of settlements, construction of roads and other infrustructure, changes in water conditions causing transformation of forests, and many other). Human impact differs often with respect to particular habitats, which differ as to their attractiveness, accessibility or utility for a given activity type. At the same time – these are not the sole conditions influencing deforestation. It is often so that the actual land-use type depends more upon the ownership or the administrative and political circumstances than upon its utility.

It is beyond doubt that for a very long period of time (since the Mesolithic) landscape remains under the very strong impact of farming activities, resulting in deforestation. Hence, the **degree of deforestation is to some extent the measure of human pressure**[3]. In this context, one should account for the habitat variability, existing in the landscape and the degree of deforestation of each habitat type separately. On this basis only, an evaluation of a landscape deformation away from the natural state can be performed. Two issues ought to be considered in this perspective: on the one hand, the habitat importance in landscape (e.g. from the point of view of biodiversity, or sensitivity to degradation), and on the other hand – the agricultural utility and productivity of habitats. In the light of the first issue a negative assessment is attached to the deforestation of rare habitats, strongly vulnerable to degradation, providing biotope for numerous and specific plant and animal species, or other entities important for the natural landscape. Thus, a postulate can be formulated that the habitats, which are particularly valuable or exposed to degradation ought to be possibly little deforested. The second aspect inclines to consideration of the agricultural capacities of particular habitats, their fertility and utility for specific forms of farming use. Agricultural activity is necessary, and that is why it ought to be carried out first of all in these habitats, in which it might be most effective. Joint consideration of these two – partly diverging – postulates should result in finding of the formula of the "**sustainable landscape**", that is – the one, which, on the one hand, ensures protection of nature, and on the other hand – does not exclude agricultural land-use, presuming the preservation of harmony of natural systems and elements introduced by people (Leser & Rodd, 1991). This kind of approach is the consequence of the sustainable development concept, defined in many ways (Stanny & Czarnecki, 2011, pp. 23-25). One of the definitions specifies that sustainable development is such a development of the social, economic and natural systems, which guarantees that these systems remain in mutual harmony in a way so as to fully protect biodiversity (Burchard-Dziubińska, 1994).

Based on the knowledge of natural value of particular habitats, defined by their potential natural vegetation and their agricultural utility, the minimum forest cover shares in the habitats were determined. The values below these thresholds would be treated as a shortage of forest cover and thus a negative element of landscape evaluation (Fig. 6.39).

[3] This statement does not mean that the afforested area could be automatically considered as covered by natural vegetation, since forest management may also very strongly deform the vegetation.

However, the forest cover exceeding the minimum share is not considered to be a positive element of the evaluation.

To date there is no research on threshold values of forest cover, adequate for the studied habitats that would provide objective criteria. Therefore, we adapted *ad hoc* criteria resulted from the knowledge of the study area. Thus, it was assumed that no habitat should be afforested to a degree lower than 20%. This value corresponds to the present forest cover in the most deforested habitats of Masuria and seems to ensure the development of natural forest communities what was observed in Masuria. However, the observed forest communities rarely resemble natural phytocenosis. The majority of them were planted and represent immature stands or even clearings. Additionally, in eutrophic habitats, planted tree species are frequently extraneous, insuitable for habitat conditions (e.g. coniferous instead of deciduous), so natural forest communities are very rare and they constitute a small percentage of the habitat area. Based on the field observations, it was assumed that the probability of occurrence of big patches (not single) of well-developed forest is minimal if forests cover below 20% of the habitat. Therefore, this value was accepted as a threshold value for the most attractive for agriculture and the most deforested eutrophic habitats.

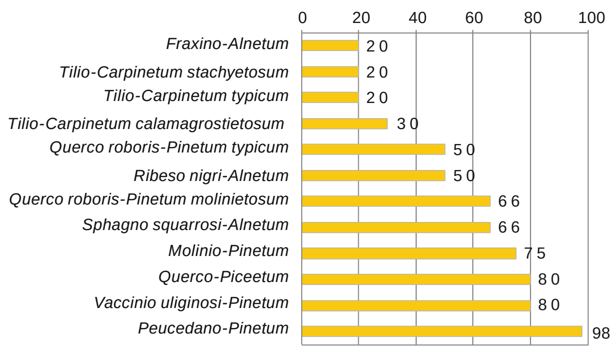

Fig. 6.39 Arbitrary minimal values of the forest cover in selected habitat types in "sustainable landscape"

All habitats were ranked according to decreasing agricultural attractiveness (acc. to present-day criteria) what corresponds approximately to their decreasing trophy (from eutrophic to oligotrophic). A number of habitat substitute communities was also considered. It is known that eutophic habitats have more semi-natural and antropogenic substitute communities (so called *dynamic circle of vegetation communities*) then oligotrophic habitats. Therefore, richness of habitat dynamic circle – numerous non-forest communities can be positive for regional biodiversity. These two factors were considered when the lowest threshold values of forest cover were adopted for eutrophic habitats of lime-oak-hornbeam forests and ash-alder forests and the highest for oligotrophic and having limited dynamic circle of substitute vegetation communities pine forest *Peucedano-Pinetum* habitats and swamp pine forest *Vaccinio uliginosi-Pinetum* habitats. The latter, rather useless in agriculture has important substitute communities (fens and bogs). The intermediate values were adopted for remaining habitats.

For particular habitats the following minimum requirements as to the forest cover were formulated.

Eutrophic habitats (*Fraxino-Alnetum*, *Tilio-Carpinetum*) are, on the one hand, valuable as natural forests (protected Natura 2000 habitats No. 91E0 – Alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior* (*Alno-Padion*, *Alnion incanae*, *Salicion albae*), 9170 – *Galio-Carpinetum*, *Tilio-Carpinetum* oak-hornbeam forests)[4], and, on the other hand, they are highly useful for agriculture, both as arable land and as grasslands. It was assumed that the minimum forest cover should be at 20% or 30%. Such a low value is the compromise between the needs of nature protection and the economic demand. The non-forest communities in those habitats might also represent a significant natural value, especially when they are meadows (the protected Natura 2000 habitats No. 6410 – *Molinia* meadows on calcareous, peaty or clayey-silt-laden soils (*Molinion caeruleae*), 6510 – Lowland hay meadows – *Alopecurus pratensis*, *Sanguisorba officinalis*).

The mesotrophic habitats of alder carrs and mixed pine-oak forests (*Ribeso-Alnetum*, *Sphagno-Alnetum*, *Querco-Pinetum*), which are moderately or poorly useful for agriculture, should be covered by forests in not less than 50 or 66%, depending upon the habitat fertility. They have undoubtedly a value as the forests, and as some types of the non-forest semi-natural communities like the Natura 2000 habitats No. 4030 – European dry heaths, 6410 – *Molinia* meadows on calcareous, peaty or clayey-silt-laden soils (*Molinion caeruleae*), 7140 – Transition mires and quaking bogs, 7210 – Calcareous fens with *Cladium mariscus* and species of the *Caricion davallianae*.

The habitats of moist oligotrophic coniferous forests (*Molinio-Pinetum*, *Vaccinio uliginosi-Pinetum*, *Querco-Piceetum*), having high natural value as forests (Natura 2000 habitat No. 91D0 Bog woodland), but almost entirely useless as arable land and grasslands, ought to be afforested in at least 75-80%. However, a limited share of the non-forest areas in these habitats is advantageous since it increases biodiversity. The typical non-forest associations encompass the Natura 2000 habitats No. 7120 – Degraded raised bogs still capable of natural regeneration, 7140 – Transition mires and quaking bogs.

The oligotrophic habitats of fresh pine forests (*Peucedano-Pinetum*), whose agricultural use is hardly justified, and brings long-lasting negative effects for the habitat and the biocoenosis, ought to be covered by forest in a vast majority. It was assumed that 98% of forest cover is optimal, since it ensures proper use of the habitat as a forest (usually commercially exploited), and, at the same time, enables existence of non-forest associations of dry sandy grasslands – important for the protection of psammophile flora and fauna (Natura 2000 habitats No. 2330 – Inland dunes with open *Corynephorus* and *Agrostis* grasslands, 4030 – European dry heaths).

The sustainable landscape ought to be characterised, therefore, by an appropriate proportion of forests in the particular habitat types.

[4] The codes are conform to the Interpretation Manual of European Union Habitats – EUR27, in the version containing amendments adopted in 2007, and provided in the Polish by-law, issued by the Minister of the Environment on August 9, 2012, which modified the by-law concerning the natural habitats and the species being the subject of interest of the Community, as well as criteria of selection of the areas qualifying for the admission or delimitation as the Natura 2000 areas.

6.4.2. Changes in the share of forest cover in habitats and in the regions according to criteria of sustainable landscape

To evaluate the degree of landscape deformation away from the model pattern of the "sustainable landscape", the differences were calculated between the actual forest cover in the habitats and the assumed threshold values characterising their optimal state between 1800 and 2000 (Table 6.7). In addition, joint assessment of the forest cover shortage in the habitats, accounting for the habitat area share in the regions was made (Fig. 6.40).

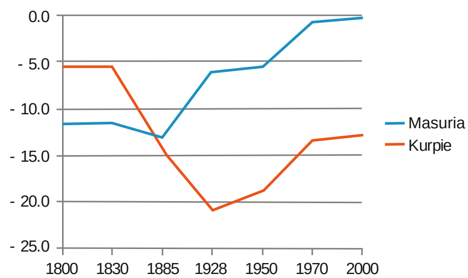

Fig. 6.40. Changes in the forest cover shortages in the habitats of the regions analyzed

In the Masurian part the 200-year period can be divided into three sub-periods:

1. In the first (1800, 1830), the eutrophic habitats (*Fraxino-Alnetum*, *Tilio-Carpinetum*) display sufficient forest cover, the mesotrophic habitats display either moderate (*Querco-Pinetum*) or pronounced (*Ribeso-Alnetum*, *Sphagno-Alnetum*) shortages of forest cover, while the habitats of fresh pine forests (*Peucedano-Pinetum*) show dramatically large shortage of forest cover.
2. During the second sub-period (1885, 1928, 1950) changes are observed. The forest cover in eutrophic habitats (especially *Fraxino-Alnetum*) drops below the threshold assumed; situation in the oligotrophic and mesotrophic habitats gets worse than before, while it improves in the fresh habitats, especially in the very common fresh pine forest and mixed pine-oak forest habitats.
3. During the third sub-period (1970, 2000) a distinct improvement takes place in all habitats. For most of them the proportion of forest cover is adequate for the sustainable landscape. Small divergences with this value remain only in humid habitats (*Fraxino-Alnetum*, *Ribeso-Alnetum*, *Sphagno-Alnetum*).

In Kurpie, the studied period can be divided, though less clearly, into 3 sub-periods:

1. In the first, the situation is similar to that observed in Masuria. The eutrophic habitats are sufficiently afforested, while some of oligotrophic and mesotrophic habitats display insufficient forest cover.
2. During the second sub-period the situation is worse in eutrophic habitats and in the majority of mesotrophic ones, while there is an improvement in the oligotrophic habitats.
3. In the third sub-period an improvement takes place in some of oligo- and mesotrophic habitats, and this concerns, in particular, the habitats of pine forests and mixed

Table 6.7. Forest cover deficiency in relation to the minimal values adopted for sustainable landscape (in habitats and subsequent dates)

Habitat type	Minimal model forest cover	Habitat share in the region	Forest cover deficiency [%]						
			1800	1830	1885	1928	1950	1970	2000
Masuria									
Ribeso nigri-Alnetum	50	3.0	-12.9	-12.8	-31.4	-26.3	-25.0	-7.8	-1.1
Sphagno squarrosi-Alnetum	66	0.2	-28.3	-28.2	-52.6	-35.4	-35.8	-25.2	-3.2
Fraxino-Alnetum	20	9.9	0.0	0.0	-11.8	-11.5	-11.4	-3.4	-1.2
Tilio-Carpinetum calamagrostietosum	30	19.9	-1.3	-2.4	-8.2	-6.7	-4.7	0.0	0.0
Tilio-Carpinetum typicum	20	5.2	0.0	0.0	-1.5	-2.8	-2.6	0.0	0.0
Tilio-Carpinetum stachyetosum	20	11.8	0.0	0.0	-9.3	-9.4	-9.1	0.0	0.0
Querco roboris-Pinetum typicum	50	28.4	-6.8	-6.4	-6.2	0.0	0.0	0.0	0.0
Querco roboris-Pinetum molinietosum	66	3.8	-8.9	-6.7	-11.7	-6.6	-5.7	0.0	0.0
Peucedano-Pinetum	98	14.7	-60.3	-59.4	-39.0	-9.4	-7.4	0.0	0.0
Molinio-Pinetum	75	0.2	-1.9	-1.7	-9.4	0.0	0.0	0.0	0.0
Vaccinio uliginosi-Pinetum typicum	80	0.3	-7.7	-7.3	-20.7	-5.4	-4.3	0.0	0.0
Querco-Piceetum	80	0.3	-7.4	-7.5	0.0	0.0	0.0	0.0	0.0
Kurpie									
Ribeso nigri-Alnetum	50	1.9	-3.4	-3.7	-10.7	-17.2	-15.9	-9.6	-9.6
Sphagno squarrosi-Alnetum	66	0.2	-42.9	-42.6	-18.3	-23.2	-17.2	-28.3	-43.9
Fraxino-Alnetum	20	23.3	0.0	0.0	-12.9	-17.0	-16.8	-15.9	-16.3
Tilio-Carpinetum calamagrostietosum	30	13.2	0.0	0.0	-18.7	-26.5	-24.1	-23.5	-22.9
Tilio-Carpinetum typicum	20	6.8	0.0	0.0	-13.2	-18.2	-18.6	-16.4	-15.7
Tilio-Carpinetum stachyetosum	20	10.2	0.0	0.0	-13.3	-17.8	-17.8	-16.7	-16.3
Querco roboris-Pinetum typicum	50	23.1	-3.1	-3.3	-14.8	-24.4	-21.2	-9.2	-7.5
Querco roboris-Pinetum molinietosum	66	4.1	-3.8	-4.5	-12.7	-27.6	-23.5	-15.5	-14.9
Peucedano-Pinetum	98	15.9	-26.2	-25.3	-17.2	-19.1	-13.9	-3.5	-3.7
Molinio-Pinetum	75	0.9	-28.5	-28.3	0.0	0.0	0.0	-1.2	-6.3
Vaccinio uliginosi-Pinetum typicum	80	0.1	0.0	0.0	-15.0	-2.2	-5.5	0.0	0.0
Querco-Piceetum	80	0.3	0.0	0.0	0.0	-6.8	-9.8	0.0	-8.0

pine-oak forests as well as the alder carrs (*Ribeso-Alnetum*). The forest cover is still too small in eutrophic habitats. An improvement that is observed, though, does not lead, in case of almost all habitats, to the satisfactory levels.

In both regions the initial state of the first decades of the 19th century appears to be stable. Then, a period of deep transformations starts, consisting in the diversification of the pressure on the habitat types, which is followed by a stabilisation in the second half of the 20th century. Permanent deforestation occurs mainly in euthrophic habitats of ash-elm forests and lime-hornbeam forests in both regions. Differences between Masuria and Kurpie are very small.

To sum up, total shortages of forest cover in the habitats (Fig. 6.40) indicate as follows:

- a constant growth of forest cover in Masuria, from a shortage of more than ten percent to the satisfactory state;
- an initially not too serious shortage of forest cover in Kurpie gets much deeper at the end of the 19th century, and then starts to improve in the middle of the 20th century, but is still far from the satisfactory level;
- the processes of regeneration and improvement of landscape structure according to the criteria of "sustainable landscape" both in Masuria and in Kurpie; with roughly 50 years of delay at the beginning and a slower course and scope in Kurpie.

The results document the essential hypothesis of the present part of the work about:

- diversification of agricultural pressure, causing deforestations, among the habitats;
- regional and temporary differentiation of the human pressure on the particular habitat types;
- asynchronous character of landscape transformations in the regions with the essentially similar nature of those transformations;
- regeneration of landscape during the last 150 years (Masuria) and 80 years (Kurpie).

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7. DIRECTIONS OF HISTORICAL LANDSCAPE CHANGES – FRAGMENTATION AND CONSOLIDATION OF FORESTS IN THE YEARS 1800-2000 WITHIN THE MASURIA-KURPIE BORDERLAND

Jerzy Solon

7.1. Types of forest area changes

Changes in the forest cover on a definite area may be considered from several different points of view, some of which are represented in this book. One of the feasible approaches to the issue is to treat forest as a set of patches in the environment of a certain background, encompassing the remaining forms of land cover. Despite doubtless simplification, such an approach provides a lot of valuable information, concerning the state of the entire landscape, and, given appropriate interpretation – also of the ecological processes and the factors influencing them.

From the formal point of view the changes in the forest cover result from the increases and decreases in the areas of the individual forest patches. Several main categories of such changes can be distinguished (Forman, 1995; Jaeger, 2000; Pietrzak, 2001; Richling & Solon, 2011; Solon, 2009), each displaying different specific features and influencing in a different manner the structural-functional characteristics of the individual patches and of the entire landscape. For the purposes of the present study the set of categories, provided in the handbook by Richling and Solon (2011) was modified and made more detailed (Table 7.1), encompassing four main kinds of decrement and – correspondingly – of the increment to the surface area of the patches:

1. Attrition (coded 1A[1]) – meaning the replacement of the entire patch by another form of the land cover, constituting an element of the landscape matrix. This leads, in effect, to a decrease in the number of patches, and also entails, on a local scale, an increase of distances between the remaining forest patches.
2. Perforation (coded 1P) – means formation of dots ("holes"), differing as to the kind of use or as to the features of the natural environment within the confines of the previously uniform patch. This process leads to the increase of the total length of the patch boundary (appearance of the so-called internal boundary), while the number of patches of the initial type does not change. It is important that perforation, while causing even a limited decrease of the patch area, may bring about a very significant drop (down to the disappearance) in the so-called patch core area.

[1] Coding used in the legends of the maps and diagrams.

Table 7.1. Typology of changes of patch area and shape. Detailed description in the text

Decrement		
Attrition	Attrition	1A
Perforation	Perforation	1P
Subdivision	Narrow subdivision	1RW
	Singular wide subdivision	1RS
	Multiple wide subdivision	1RS2
Shrinkage	Distal shrinkage	1ZK
	Lateral shrinkage preserving patch shape	1ZB0
	Lateral shrinkage with patch shape complication	1ZB2
	Lateral shrinkage with patch shape simplification	1ZB1
	Incision	1W

Increment		
Creation	Creation	2A
Filling	Filling	2P
Integration	Integration	2R
Accretion	Distal accretion	2ZK
	Lateral accretion preserving patch shape	2ZB0
	Lateral accretion with patch shape complication	2ZB2
	Lateral accretion with patch shape simplification	2ZB1

3. Subdivision (1R) consists in the splitting of one patch into two or more, relatively mutually isolated. Consequently, the number of patches increases, the average patch area, as well as the patch core area, decrease, and there is a distinct increase of the overall length of boundaries (while the shape changes may be very different). Depending upon the shape and area of the dissection, several subtypes can be distinguished:
   - 3a. Narrow subdivision (1RW), in which the length of the split is distinctly bigger than its width. The most frequent cause of the narrow subdivision is introduction of the clearly artificial linear anthropogenic structures. In many cases the degree of isolation of the thus formed neighbouring patches is not too high.
   - 3b. Singular wide subdivision (1RS) consists in the splitting of one patch into two, with the length of the split distinctly smaller than its width. This subdivision arises most frequently from a persistent change of the land cover (deforestation) of a more extensive area, leading to the splitting of the forest complex into clearly isolated parts.
   - 3c. Multiple wide subdivision (1RS2) consists of the splitting of one patch into at least three much smaller patches, with the length of the subdivision being distinctly smaller than the width. Similarly as the singular wide subdivision, it arises most often due to a persistent change of the land cover (deforestation) of a large area, leading to the division of the forest complex into distinctly isolated parts (dissipation).
4. Shrinkage (1Z) consists in shrinking of the patch area without a change in the number of patches. Depending upon the shape and location of the disappearing fragments, shrinkage can be accompanied by the shortening or elongation of the patch boundary, and the corresponding change of the shape index. On this basis the following types can be distinguished:
   - 4a. Distal shrinkage (1ZK), which causes distinct shortening of the longer axis of the patch.
   - 4b. Lateral shrinkage without a change of boundary shape (1ZB0), which leads to a shrinking of the area, but without changes – or with only insignificant changes

– in the values of the basic shape indices (like fractal dimension, ratio of circumference to area, or MBR[2]).

4c. Lateral shrinkage with complication of the boundary (1ZB2), which leads to increased complexity of the shape, expressed through the increase of the boundary length (with the shrinking area) and the increase of values of the shape indices.

4d. Lateral shrinkage with evening out of the boundary (1ZB1), which entails lower degree of complication of the boundary, so that the shape of the patch becomes more regular, and the long segments of the boundary assume the character of straight lines.

4e. Incision (1W), which is a specific kind of the lateral shrinkage with complication of the boundary. It consists in the replacement of a part of the patch, from the boundary inwards, by another kind of surface, but without the splitting of the patch into parts. Due to incision, the boundary of the patch gets significantly longer and the values of the shape indices change in a specific manner (e.g. the fractal dimension increases, but the MBR index does not change significantly). Besides – similarly as in the case of perforation – a relatively small decrease of the patch area may be associated with a very important decrease (down to disappearance) of the patch core area.

For each of the above processes, leading to a general increase of fragmentation of the area the reverse processes can be indicated, leading to the increase of patch area, and – in effect – most frequently to the simplification of the spatial structure, namely:

5. Creation (2A) – that is, emergence of new patches, leading to the increase of the number of patches, and – at least in local terms – to the decrease of the average distance to the nearest neighbour.
6. Filling (2P) is the process opposite to perforation, leading to the decrease (down to disappearance) of the internal boundary of the patch, with the increase in the area of the basic patch and the increase in the core area of the patch.
7. Integration (2R) is the process opposite to all kinds of splits, and as such, it leads to the increase of the patch area, decrease of the number of patches and decrease of the overall length of boundaries in the landscape.
8. Accretion (2Z) is the process opposite to shrinkage, and so leading to the increase of the patch area, without a change in the number of patches, and, most often, to the increase of the overall length of the boundaries. Depending upon the shape and location of the accretion to a patch we can distinguish – in analogy to the process of shrinkage – separate sub-categories of accretion (see Table 7.1). It is worth emphasising that in such a perspective the process opposite to incision is lateral accretion with simplification of the boundary.

The typology here outlined was used for the analysis of changes in forest cover within the Masovian-Kurpie borderland in the years 1800-2000. The source of information on the distribution and areas of forests was constituted by the topographical maps dating from different periods, executed in different scales and with varying precision. The detailed description of the cartographic materials made use of, their quality and the procedure

[2] MBR – Minimum Bounding Rectangle index – ratio of the polygon (patch) area and the area of the minimum bounding rectangle (Moser et al., 2002).

of processing is provided in Chapters 2 and 3. We must only indicate here that for the purposes of analysis it was assumed that the time slices considered correspond to the years 1800, 1830, 1885, 1928, 1950, 1970 and 2000. The categories of the decrements and increments of the forest cover were determined for each period between the two consecutive states illustrated by the maps. The detailed procedure was composed of several steps: a) determination of the areas of increments and decrements as resulting from the overlaying of maps, corresponding to two consecutive time slices; b) determination of the area of each of the thus distinguished patches; c) assignment of the typological category of change to each patch separately. Additionally, in order to make the analysis more detailed, each patch was characterised in terms of potential vegetation. Information on potential vegetation originates from the detailed map, developed on the basis of field studies. Complete description of this map, along with characterisation of the respective units is provided in Chapter 4. The majority of analyses were carried out for the entire study area, and for the separate parts of this area as well. These parts correspond, in principle, to the forest districts, but the boundaries of the parts considered were slightly modified with respect to those of the forest districts. In particular, the course of the boundary between the forest districts of Myszyniec and Spychowo was changed so as to preserve the course of the historical boundary between Prussia and Polish Crown on its entire respective length. Besides, a fragment of the forest district of Korpele, making a part of the study area, was incorporated into the areas of Szczytno and Jedwabno forest districts (Fig. 7.1).

The analyses performed constituted a component of a broader subject of investigation, consisting in the determination of the course of changes in the landscape and finding of the repetitive regularities in the changes of the ways, in which land is used. The particular objectives of the analysis of changes in forest cover with distinction of fragmentation types, habitats, periods, and areas, included a number of study issues, the most important of which can be formulated as follows:

- what types of fragmentation dominated on the entire area of study and on its particular parts in the successive sub-periods?
- does there exist a relation between the habitats, the magnitude of the deforested / forested area, and the types of fragmentation?
- what were the changes of the selected landscape metrics over the entire area and within its particular parts in the successive periods?
- is there a relation between the change of average values of the metrics and the area of the particular types of fragmentation?
- to what extent each of the distinguished parts of the study area is characterised by a specific, independent of the other ones, pattern of change over time, and to what extent are such patterns common for a group of regions?
- is there a possibility of describing the sequence of changes using just one, generalised model, and can such a model be parameterised for each of the areas distinguished?

A comprehensive answer to the above questions constitutes also a contribution to the analysis of the three questions, namely:

(a) the differences between the Masurian and the Masovian parts regarding the change processes taking place during the entire analysed period of two hundred years;

(b) the role of the political and social factors, and of the natural and habitat conditions in the shaping of the spatial structure of landscape;
(c) the criteria for determination of the level of sustainability of landscape in the ecological sense, based on the nature, direction and rate of changes in the forest cover in particular parts of the study area and sub-periods.

Fig. 7.1. The division of the area into regions, assumed as reference units for detailed analyses

All the analyses were carried out in the environment of ArcView 3.3 and ArcGis 9.3. Values of landscape metrics were calculated with PatchAnalyst 3.1, Spatial Statistics Toolbox and V-LATE 1.1. The names, acronyms used and explanations concerning metrics are presented in Table 7.2.

Table 7.2. Abbreviations of landscape metrics calculated for forest patches

Abbreviation	Name	Formula
Area	Area of a patch	
Number	Number of patches	
MaxPatch	Area of the biggest patch	
NND	Nearest Neighbour Distance	
SI	Shape Index	SI = Perimeter $[2(\pi \text{ Area})^{0.5}]^{-1}$
PAR	Perimeter-Area Ratio	PAR = Perimeter Area^{-1}
FD	Fractal Dimension	FD = 2ln(Perimeter) $[\ln(\text{Area})]^{-1}$
PROX	Proximity Index	PROX = SUM(Area Distance^{-2})
DIVISION	Division Index	DIVISION = 1 - SUM$[\text{Area }(\text{Total_Area})^{-1}]^2$
SPLIT	Splitting Index	SPLIT = $(\text{Total\_Area})^2$ $[\text{SUM}(\text{Area}^2)]^{-1}$
MESH	Effective Mesh Size	MESH = $[\text{SUM}(\text{Area}^2)]$ $(\text{Total\_Area})^{-1}$

7.2. General characterisation of changes

During 200 years, forests, growing on the study area, underwent far reaching changes. The overall number of patches, registered on the maps, increased from 129 in the year 1800 to 825 in the year 1885, to then drop down to 632 in 1950, and then increased to as many as 1722 in the year 2000 (Fig. 7.2). In the initial period the changes concerned the relatively large surfaces, while since 1950 the increase of the number of patches has been caused first of all by the appearance – due to various processes – of a significant number of small patches. This is evidenced by the changes in the number of patches having more than 3 hectares of surface. This number was at 128 in 1800, at 596 in 1885, at 558 in 1950, and at 722 in 2000, this being equivalent, respectively, to 99%, 72%, 88% and 42% of the total number of patches.

The changes in the numbers of patches were, naturally, associated with the changes in their areas. Irrespective of small fluctuations between the successive states, registered on the maps, the average area of a patch displays a distinct decreasing trend, from 886 hectares in 1800, through 106 hectares in 1885, and 155 hectares in 1950, down to 77 hectares in 2000 (Fig. 7.2).

The changes in the areas of the larger patches took an entirely different course. The biggest registered patch had in the year 1800 the area of more than 184 km^2. Its area dropped to 143 km^2 by 1885, to then systematically increase to 210 km^2 in 1950 and to 507 km^2 in 2000. A similar course of changes has been observed for the average area of the patches, calculated for the 50 and 100 biggest patches: in the year 1800 these values were, respectively, 22 and 11 km^2, in 1885 – 15 and 8 km^2, in 1950 – 17 and 9 km^2, to then increase by the year 2000 to, respectively, 24 and 12 km^2 (Fig. 7.2).

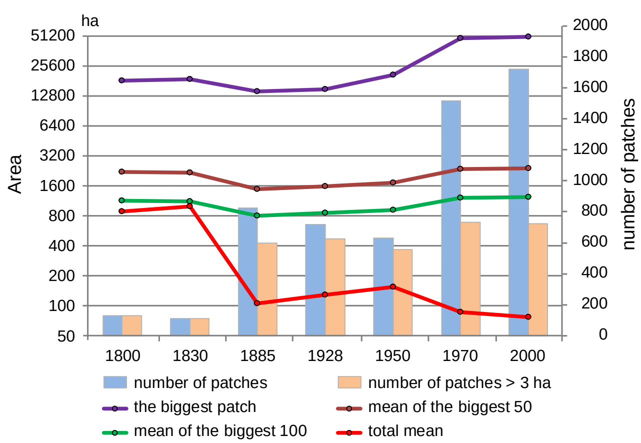

Fig. 7.2. Changes of number and area of patches in years 1800-2000 for all the analyzed area

Changes in the forest cover were, of course, the effect of decrements and increments of the surfaces of individual patches. In the years 1800-1830 the decrements were almost twice as big as the increments, with the dominating type among the decrements being the wide singular subdivision (1RS), and among the increments – lateral accretion without the change of boundary shape (2ZB0) (Table 7.3, Fig. 7.3).

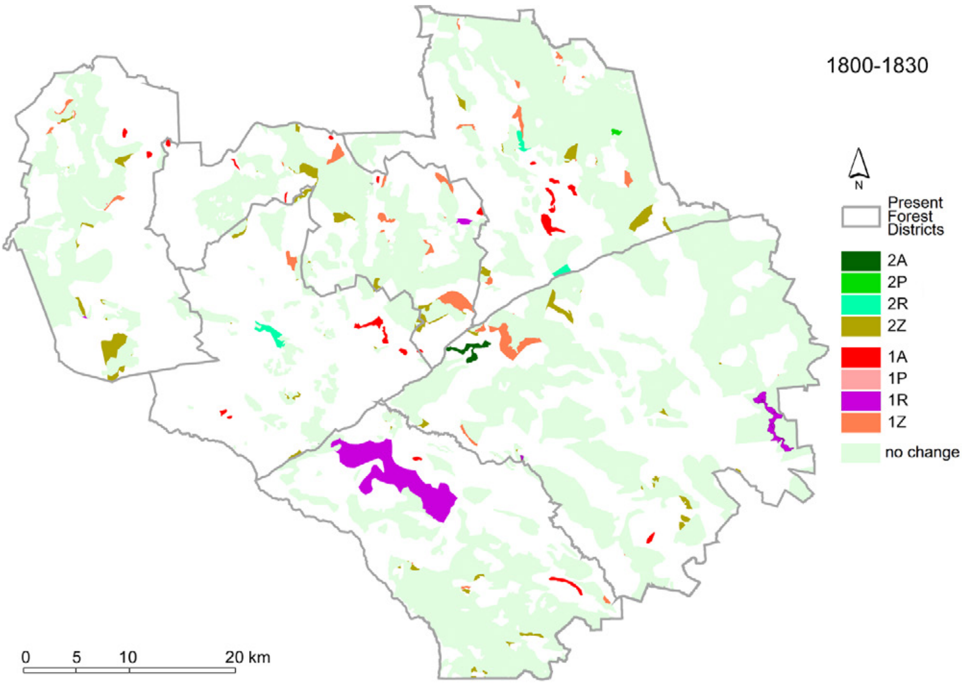

Fig. 7.3. Processes of the forest surface decrements and increments in years 1800-1830

Table 7.3. Surface area (hectares) of different categories of patch decrement and increment

Category of change	Period					
	1800-1830	1830-1885	1885-1928	1928-1950	1950-1970	1970-2000
1A	864.6	1,561.0	1,706.8	815.5	131.2	534.7
1P	1.5	1,447.8	718.5	80.6	272.5	624.6
1RS	2,925.4	3,086.8	1,318.9	245.6	344.1	297.5
1RS2	0.0	31,974.8	2,310.9	50.3	576.9	244.0
1RW	350.6	289.4	156.8	47.5	38.7	122.1
1W	0.0	1,604.4	984.8	331.2	201.9	606.3
1ZB0	748.9	655.9	357.8	181.7	132.0	82.5
1ZB1	400.5	638.5	5,130.7	956.1	306.9	457.8
1ZB2	26.7	3,461.6	1,098.5	227.5	983.2	729.5
1ZK	662.7	2,002.8	600.9	332.9	221.6	218.6
2A	223.0	6,405.2	2,720.7	782.6	5,212.7	903.5
2P	36.7	146.8	399.3	608.2	881.2	533.4
2R	369.8	5231.0	8,673.7	1,948.9	13,374.1	1,096.5
2ZB0	1,284.7	468.0	519.4	138.1	890.9	362.4
2ZB1	475.2	535.1	1,916.9	2205.1	3,321.5	1,429.4
2ZB2	599.9	9,459.1	5,156.5	1,923.5	9,050.9	1,792.0
2ZK	37.8	106.6	639.8	785.6	2,862.1	537.1

In the subsequent period, that is – in the years 1830-1885, exceptionally important changes took place in the distribution of forests, encompassing altogether 690 km^2, of which two thirds were the decrements. The dominating form was wide multiple subdivision (1RS2), corresponding to close to 70% of area of all the decrements. The increments were associated primarily with the lateral accretion types with complication of boundaries (2ZB2), accounting for more than 40% of area of all the increments (Table 7.3, Fig. 7.4).

The years 1885-1928 constitute the period, when for the first time the increases dominated over the decreases. In the process of forest shrinking the most important role was played by the lateral and distal shrinkages (jointly 50% of the area), and more precisely – by the lateral shrinkage with evening out of the boundary (1ZB1), corresponding to 36% of all the decrements. Contrary to the two preceding periods, when increments consisted mainly in the lateral accretion, in the years 1885-1928 the dominating process was integration (2R), which took place on 43% of the area of all the increases (Table 7.3, Fig. 7.5).

The subsequent period, that is – the years 1928-1950 – was characterised by the decrements taking place mainly through lateral shrinkages with evening out of the boundary (1ZB1) – 29%, and an important role played by the attrition of the entire small patches (1A) – 25% of the area of decrements. The increments, which dominated over decrements, took place first of all due to three processes: integration (2R) and the lateral accretion with evening out and with complication of the boundary (2ZB1 and 2ZB2). Each of these three processes encompassed more than 23% of the total forest cover area increment (Table 7.3, Fig. 7.6).

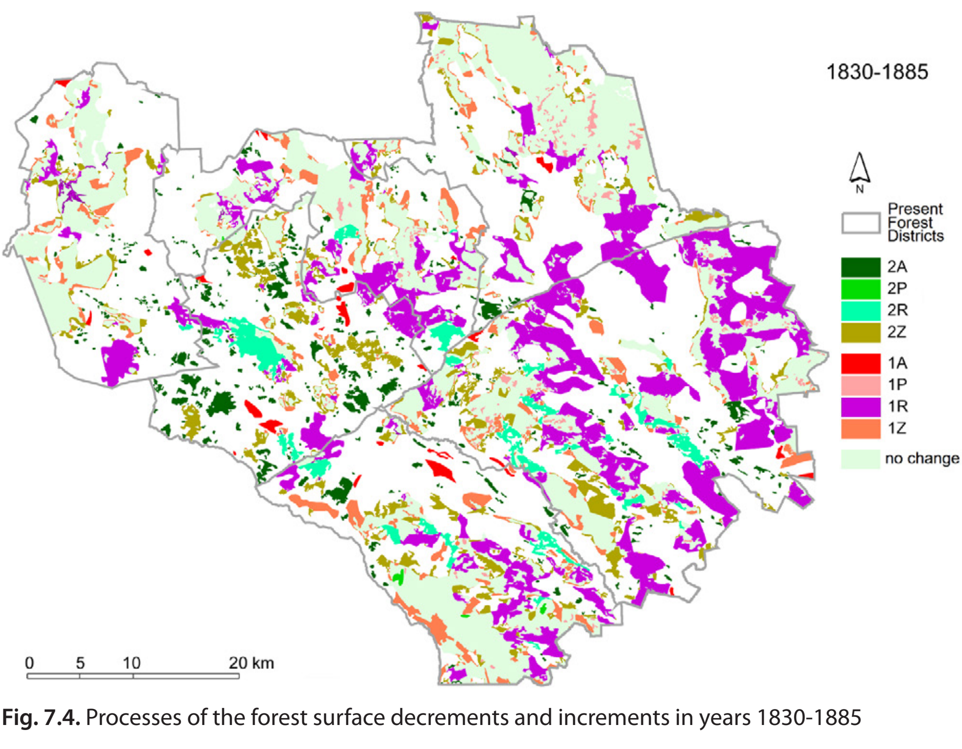

Fig. 7.4. Processes of the forest surface decrements and increments in years 1830-1885

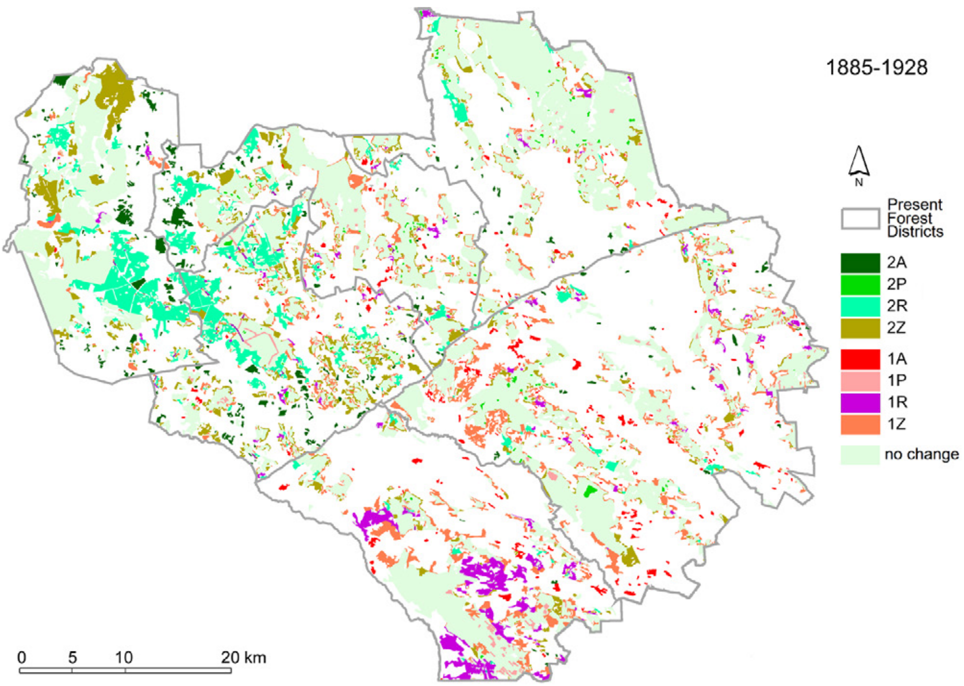

Fig. 7.5. Processes of the forest surface decrements and increments in years 1885-1928

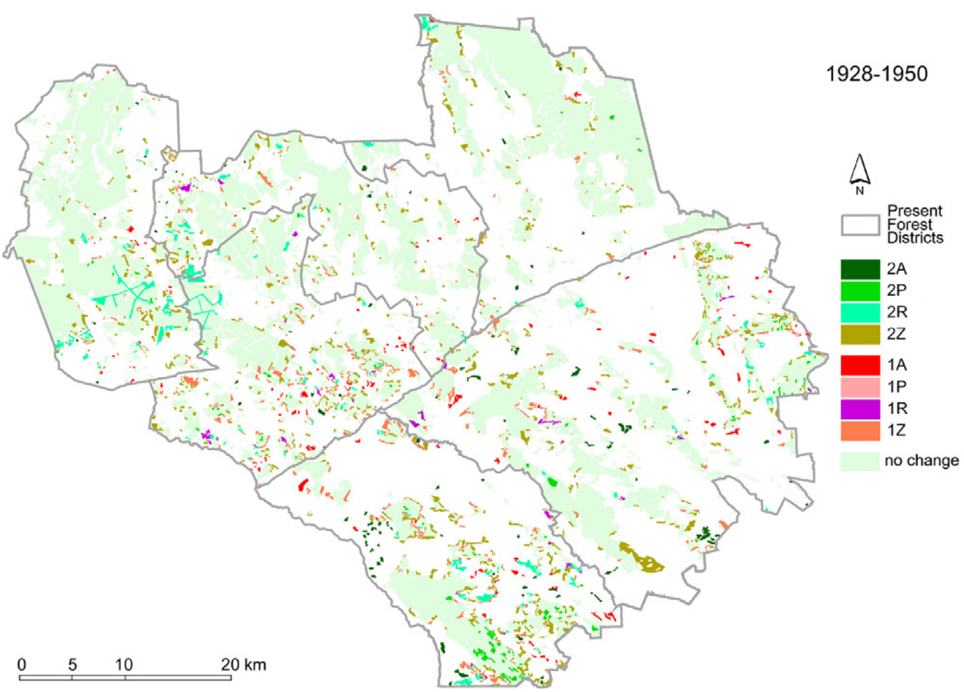

Fig. 7.6. Processes of the forest surface decrements and increments in years 1928-1950

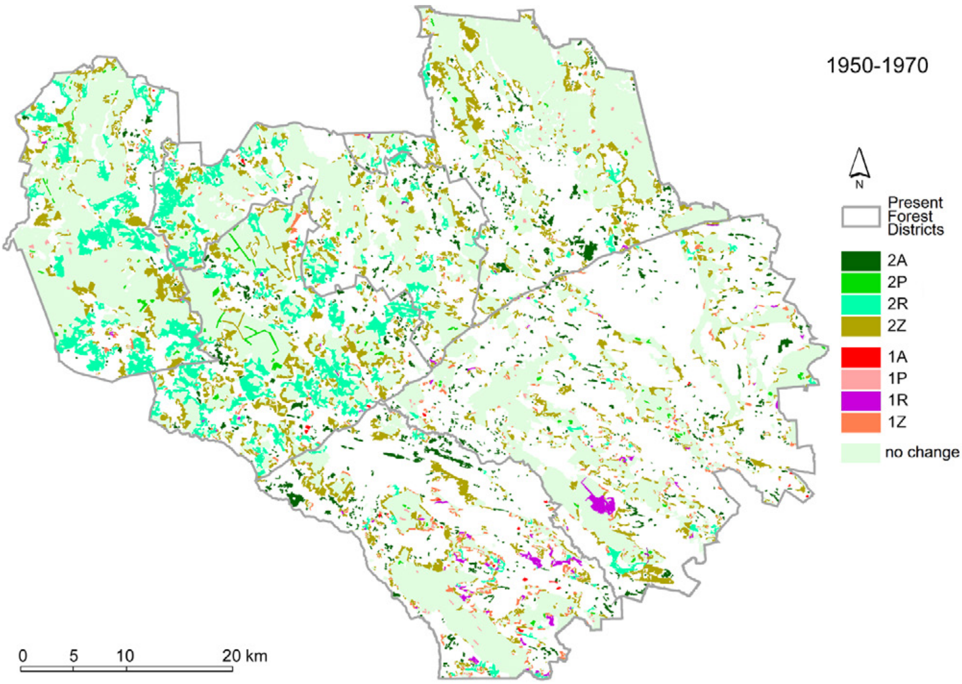

Fig. 7.7. Processes of the forest surface decrements and increments in years 1950-1970

Years 1950-1070 were characterised by the smallest decrements and the biggest increases of the forest cover, compared with all other periods analysed. The decrements were primarily due to the lateral shrinkages with complication of the boundary (1ZB2) – 31% of the respective area. The increments, which encompassed altogether 356 km^2, occurred mainly through integration (2R) – 38%, lateral accretion with complication of the boundary (2ZB2) – 25%, and creation of new patches (2A) – 15% of the area of increments (Table 7.3, Fig. 7.7).

The last period analysed, that is – 1970-2000 – was characterised by the smallest changes in the magnitude and distribution of the forest cover, these changes having occurred only over altogether 106 km^2, of which two thirds were increments. In terms of decrements, patch shrinkages (54% of the area) dominated in general categories, but if one looks at the more detailed categories, it turns out that the roles of the lateral shrinkages with complication of the boundary (1ZB2), incisions (1W), perforations (1P) and attrition of small patches (1A) were very similar, all being contained in the interval of 14-19% of the total respective change. Concerning increments, they were primarily due to the accretion of the patches (altogether 62% of the total increment area), mainly through lateral accretion with complication and with evening out of the boundaries (27% and 22%, respectively). Other categories played a distinctly smaller role (Table 7.3, Fig. 7.8).

The processes, which brought about the changes in the numbers and magnitudes of the forest patches, caused also visible changes in the values of numerous landscape metrics. Interpretation of the significance of these changes is not always unambiguous. In order to ensure comparability with other reports, detailed interpretation of the respective indicators, carried out by McGarigal (McGarigal, 2002; McGarigal & Marks, 1995), was referred to.

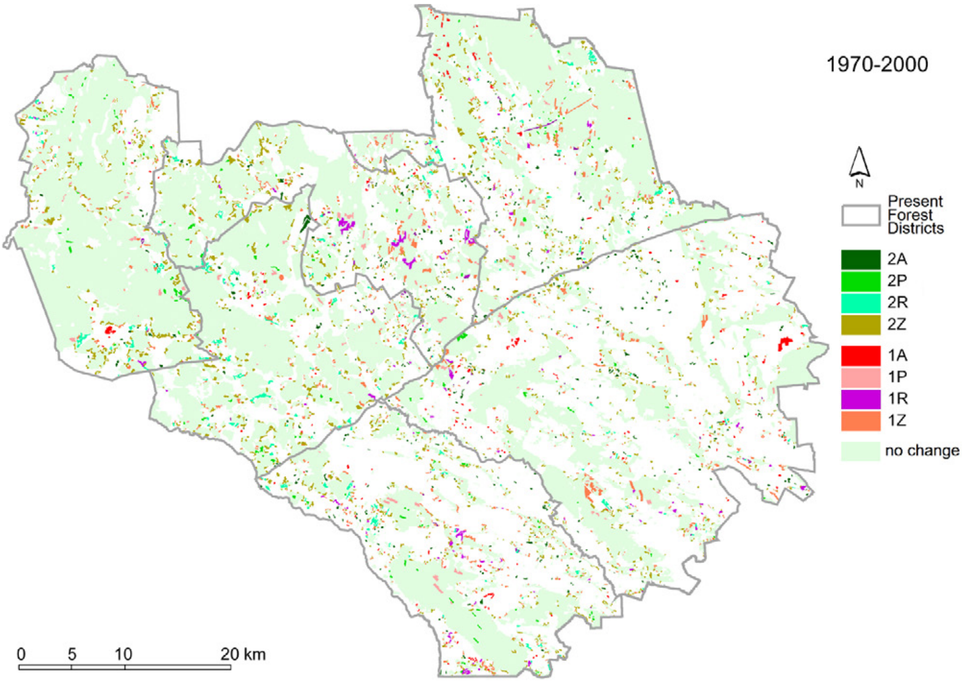

Fig. 7.8. Processes of the forest surface decrements and increments in years 1970-2000

And so, in particular, the metrics related to the degree of complication (irregularity) of the patch shape changed. A more detailed analysis suggests two periods of more pronounced changes, corresponding to the maximum of deforestations (years 1830-1885) and of the forestations (years 1950-1970).

The simplest indicator from this group is PAR, generally interpreted as the indicator of shape complexity. It took the lowest values in the years 1800 and 1830, and amounted, respectively, to 0.0075 and 0.0073, with the difference between the respective averages being statistically insignificant. Between the years 1830 and 1885 there has been a distinct increase of the value of this indicator (0.021), followed by a slow, but significant decrease, observed in the years 1928 and 1950 (0.019 and 0.017, respectively). Then, a clear and significant increase was registered again in 1970 (0.029). This statistically significant upward trend continued also until the year 2000, when the value of PAR was at 0.033 (Fig. 7.9).

The course of variations of the FD indicator was, in principle, analogous. This indicator shows the rate of increase of the patch circumference for the unit increase of its area, assuming preservation of the shape. FD was the lowest in the years 1800 and 1830, amounting to 1.25, with no significant differences between these averages. There has been a slight increase until 1885, followed by stabilisation until 1950, at the level of 1.28-1.29. By 1970 the value of FD significantly increased, reaching 1.31, and then in 2000 it amounted to 1.32, the difference being again significant (Fig. 7.9).

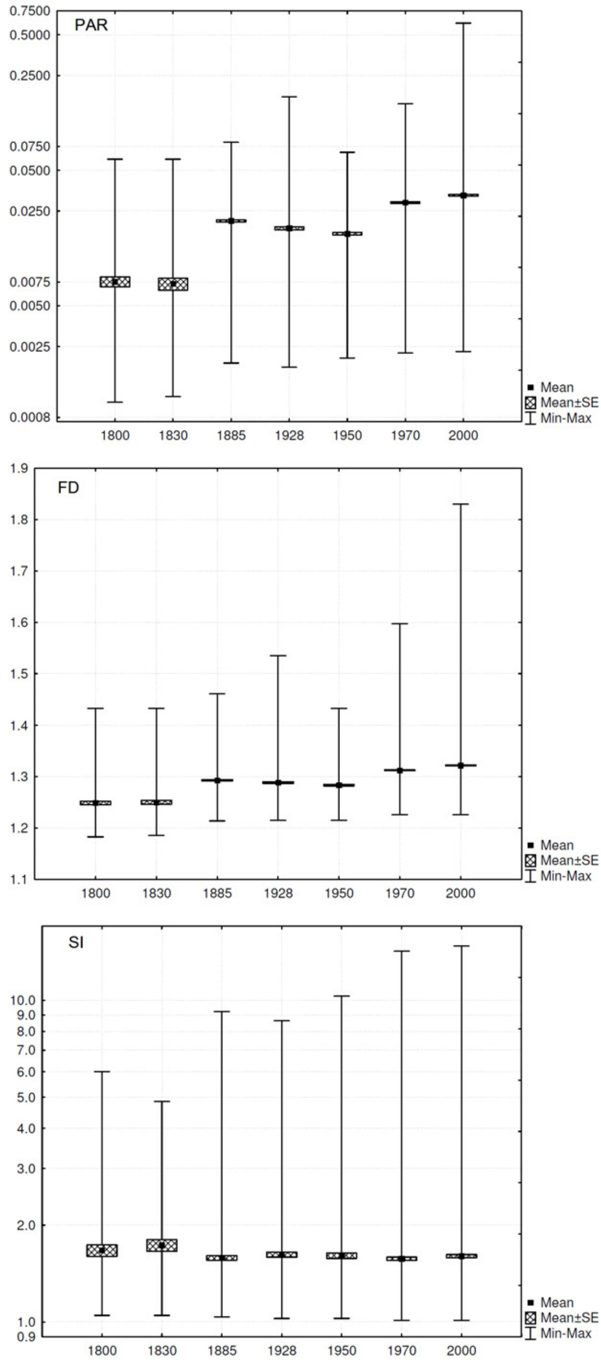

Fig. 7.9. Changes of patch shape metrics in years 1800-2000

A different course of changes was taken by the values of SI, i.e. the indicator showing the extent, to which the shape of the patch differs from the regular circular one. Between the years 1800 and 1830 there was a slight, insignificant increase of the value of this indicator (from 1.57 to 1.73), followed by the decrease to 1.58 by the year 1885. Later on, up till the year 2000, changes had the character of the statistically insignificant fluctuations, with the values of SI contained in the interval 1.57-1.62. The sole symptom of changes in this period was, in principle, the systematic increase of the maximum values of SI (from 9.22 in 1885 to 14.75 in 2000), see Fig. 7.9.

Side by side with the changes of shapes it is important to look at the degree of dispersion and at the distribution of patches in space (NND, Std.Dev/NND and PROX indicators). It should be emphasised that in opposition to the above mentioned indicators of shape complexity, in the case of the analysed indicators of the degree of dispersion one does not observe changes that would correspond so clearly to the periods with maxima of deforestations and forestations, and each metric displays a specific pattern of variability over time.

The values of NND have been changing in an uneven manner. At the two first time slices considered the average values were relatively high (411 m and 455 m, respectively), and their difference was not statistically significant, although in the year 1830 the maxima were distinctly higher (4.9 km, compared to 3.1 km in 1800). In 1885 a significant drop of the average value of NND was observed, followed by a small, statistically insignificant increase until the year 1950 (respectively, 186 m, 186 m, and 210 m). Then, years 1970 and 2000 have been characterised by the lowest values of the average NND (131 m and 122 m, respectively), significantly differing from those observed in the preceding periods, while the difference between these two years was insignificant (Fig. 7.10).

The ratio of the standard deviation to the mean value of NND (Std.Dev/NND), which might be interpreted as a measure of regularity of the spatial distribution of patches (the lower the value, the more regular the distribution) changed from the lowest value (1.12) in the year 1800 to the highest (1.46) in 1830, indicating the relatively most uneven distribution of the patches. By the year 1885 this value dropped to 1.31. The subsequent periods were characterised by the consecutive decreases and increases of this indicator value, with the preservation of the generally downward tendency (Fig. 7.10).

The third indicator from this group, PROX, corresponds to the filling of space with patches. Value of this indicator is bigger for a given neighbourhood area when the number of patches and the area of patches increase, while the distance between them decreases. Variations of this indicator displayed a very characteristic temporal course. In the initial periods there was a systematic increase, from around 2000 in 1800 to 15,000 in 1885. Then, there was an abrupt jump to 3.1 million in 1928 and then to 3.6 million in 1950. Afterwards, the value of this indicator decreased, down to approximately 28,000 in 2000 (Fig. 7.10).

The indicators of dispersion, commented upon above, are additionally complemented by the indicators DIVISION, SPLIT and MESH.

DIVISION corresponds to the probability that two randomly selected points in landscape are not located in the same patch. The value of this indicator systematically increased between 1800 and 1885 (from 90.7 to 94.6), and then quite regularly decreased until the

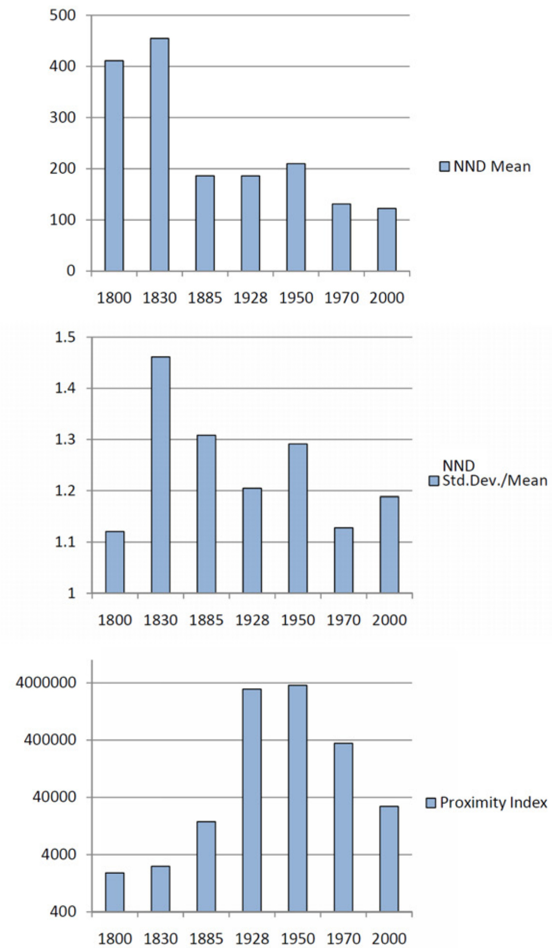

Fig. 7.10. Changes of patch distribution metrics in years 1800-2000

year 1950, attaining the value 90.8. The two last time slices, 1970 and 2000, were characterised by the relatively low and insignificantly differing values of the indicator (82.7 and 82.4), see Fig. 7.11.

SPLIT is calculated as the hypothetical number of patches of equal area, preserving the actual total areas of patches and the observed value of DIVISION indicator. The course of values of this metric is identical to that of DIVISION. Three separate periods can be distinguished. The first one encompasses the years 1800 and 1830 and is characterised by the insignificant difference of values of the indicator, equal, respectively, 10.8 and 11.1. The subsequent period, encompassing the years 1885, 1928 and 1950, was characterised initially by a distinct increase, and then regular decrease of the indicator values (18.5, 14.9 and 10.9, respectively). The two last dates (1970 and 2000) were characterised by the relatively low and insignificantly differing values of SPLIT (5.8 and 5.7), see Fig. 7.11.

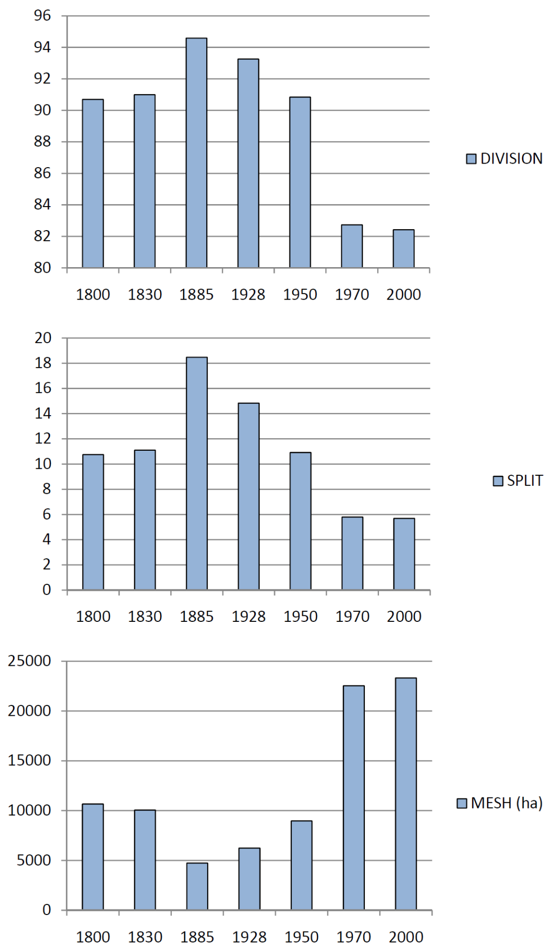

Fig. 7.11. Changes of patch dispersion metrics in years 1800-2000

MESH is the hypothetical magnitude of patches for the given value of SPLIT. The temporal course of values of this indicator has the character opposite to that of the two metrics previously commented upon. In the years 1800 and 1830 the value of this indicator was slightly above 10,000, while in the year 1885 it dropped to 4730, to then slowly increase up to not quite 9000 in the year 1950. The two most recent time slices, 1970 and 2000, were characterised by the highest values of the indicator, approximately 23,000 (Fig. 7.11).

Summarising the above detailed considerations we can state that for the study area treated as a whole we may distinguish three separate periods of relative stability or slow changes: the years 1800-1830, 1885-1950 and 1970-2000, and two periods of fast changes of revolutionary nature – years 1830-1885 and 1950-1970, which feature differences in the course of processes of fragmentation and consolidation of forests, and different directions of changes in the values of landscape metrics. An heuristic summary of these changes is provided in Table 7.4.

Table 7.4. Synthetic characteristics of main processes in course of forest distribution changes

Processes and indices		Periods				
		1800-1830	**1830-1885**	**1885-1950**	**1950-1970**	**1970-2000**
Deforestation	Area	small	very big	big	small	small
	Dominating process	1R	1R	1Z	1Z	1Z
	Subdominating process	1Z	1Z	1R	1R	1R, 1P, 1A
Aforestation	Area	small	big	big	very big	small
	Dominating process	2Z	2Z	2Z	2Z	2Z
	Subdominating process	2R	2A, 2R	2R	2R	2R
Fragmentation	Number of patches	stable	big increase	small decrease	big increase	small increase
	Number of patches > 3 ha	stable	big increase	fluctuation	small increase	stable
	Mean Patch Size	small increase	big de-crease	small increase	big de-crease	small decrease
	Mean Patch Size of the biggest 100 patches	small decrease	big de-crease	small increase	small increase	stable
Patch Form	PAR	stable	big increase	small decrease	big increase	small increase
	FD	stable	small increase	stable	small increase	small increase
	SI	small increase	small decrease	stable	stable	stable
Distances	NDD	stable	big de-crease	stable	small decrease	stable
	Std.Dev./NDD	big increase	big de-crease	fluctuation	big de-crease	small increase
	PROX	small increase	small increase	big increase	small decrease	small decrease
Dispersion	DIVISION	stable	big increase	small decrease	big de-crease	stable
	SPLIT	stable	big increase	small decrease	big de-crease	stable
	MESH	stable	big de-crease	small increase	big increase	stable

7.3. Landscape consequences of forest fragmentation and consolidation processes

The processes, which were outlined above, did not take place in an even manner over the entire study area. In particular, the rates of deforestations and forestations were differentiated, and the domination of the types of fragmentation changed. Consequently, forest cover on the habitats of the particular types of potential vegetation changed (Table 7.5), and the values of landscape metrics underwent changes.

Table 7.5. Codes and names of potential natural vegetation types, for which forest cover changes were analysed

Code	Name
12, 13	Pine forest (*Peucedano-Pinetum*, sarmatian and subboreal variants)
9a	Typical mixed pine-oak forest (*Querco-Pinetum typicum*)
6a	Dry oak-hornbeam forest (*Tilio-Carpinetum calamagrostietosum*)
6bc	Typical oak-hornbeam forest, poor and rich forms (*Tilio-Carpinetum typicum*)
6e	Moist oak-hornbeam forest (*Tilio-Carpinetum stachyetosum* and similar)
4a	Moist alder forest (*Fraxino-Alnetum*)
1abd	Boggy alder forest with red currant (*Ribeso-Alnetum*) and with Sphagnum (*Sphagno-Alnetum*), Boggy birch forest (*Thelypteris-Betula* community)
9c, 19	Moist mixed pine-oak forest (*Querco-Pinetum molinietosum*) and Moist mixed spruce-oak forest (*Querco-Piceetum*)
16	Moist pine forest (*Molinio-Pinetum*)
17ab, 18	Boggy pine forest, typical (*Vaccinio uliginosi-Pinetum typicum*) and with purple moor grass (*V.u.-P. molinietosum*), Boggy spruce forest (*Sphagno girgensohni-Piceetum*)

Remark: The detailed map of potential natural vegetation (see Chapter 4) distinguishes 21 vegetation types. Seventeen of them were complexed to the above units. The rest of them, covering extremely small areas, were neglected.

7.3.1. District of Parciaki

Diversification of the process of fragmentation and consolidation (Fig. 7.12A)

In the years 1800-1830 deforestations affected 3015 hectares, of which the singular wide subdivision (1RS) constituted 95%, while the second process in terms of importance – attrition of entire patches (1A) – accounted only for less than 4%. Forestations encompassed in this period the mere 169 hectares, and included only lateral accretion, first of all those with complication of the boundary (2ZB2), which accounted for 84% of change, while the remaining 16% were the lateral accretion without a change in the character of the boundary (2ZB0).

The years 1830-1885 marked the biggest deforestations on the area considered, amounting altogether to 7509 hectares. Wide subdivision dominated still, but, in distinction from the preceding period, these were the multiple subdivision (1RS2 – 49%). They were followed by three processes – lateral shrinkages with complication of the boundary (1ZB2), distal shrinkages (1ZK), and singular wide subdivision (1RS), which accounted for 9 to 13% of the entire area of deforestations. At the same time, during this period, the largest area was forested – altogether 4059 hectares. In this context the lateral accretion dominated with complication of the boundary (2ZB2) – 46%, other important processes being integration (2R) – 27% and creation of new patches (2A) – 20%.

In the period 1885-1928 mainly the decrements of the forest cover occurred, amounting to 5501 hectares, while the area forested increased by 785 hectares. The decrements were mainly due to wide multiple subdivision (1RS2) – 35%, and to lateral shrinkages with evening out of the boundary (1ZB1) – 27%. The increase of the forest cover took place mainly owing to the integration (2R) and the lateral accretion 2ZB0 and 2ZB1, accounting for 21% to 24% of the change.

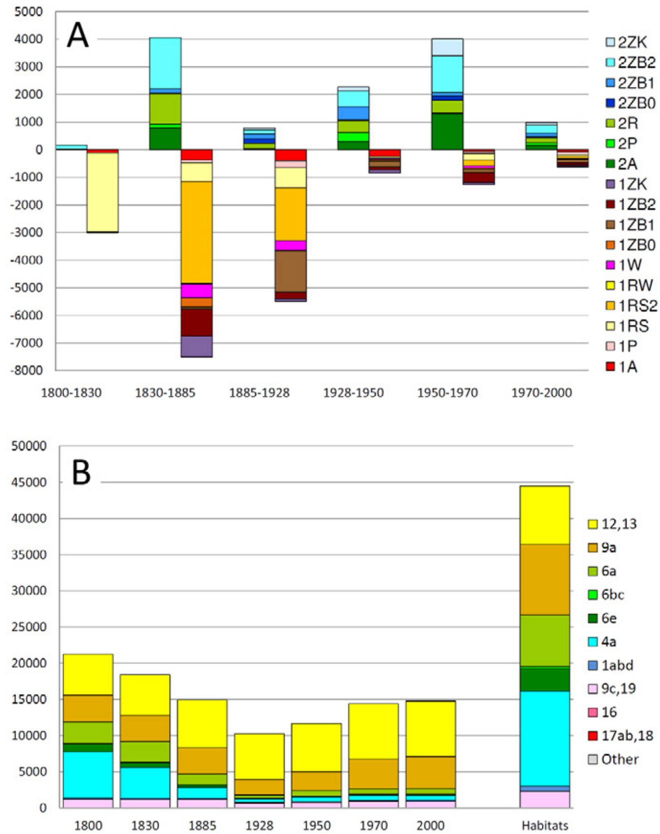

Fig. 7.12. Types of the forest surface decrements and increments (in hectares) (A); and the forest area on different habitats of the potential natural vegetation (B) on Parciaki region in years 1800-2000

The years 1928-1950 constitute the first of the three consecutive periods, during which forestations (2269 hectares in this case) dominated over the deforestations (843 hectares). Deforestations took place mainly due to attrition of entire patches (1A – 29%) and to the lateral shrinkage with the evening out of the boundary (1ZB1 – 26%). The extension of the forest area occurred primarily owing to the lateral accretion with complication of the boundary (2ZB2) – 25%, and with simplification of the boundary (2ZB1), as well as integration (2R) – 20% for each of the latter two.

The subsequent period, 1950-1970, was characterised by the deforestation over the area of 1260 hectares, with forestation affecting 4013 hectares. The deforestations were mainly the lateral shrinkages with complication of the boundary (1ZB2), encompassing 29% of the deforested area. They were followed by the wide singular subdivision (1RS) and wide multiple subdivision (1RS2) – respectively 18% and 16%. Forest cover increased primarily owing to lateral accretion with complication of the boundary (2ZB2) – 33%, and the creation of new patches (2A) – 32%.

The last period analysed, namely the years 1970-2000, featured the smallest scope of changes in forest area (624 hectares of deforestation and 988 hectares of forestation). The decrements were primarily due to the lateral shrinkages with evening out of the boundary (1ZB1), to perforation (1P) and to the lateral shrinkage with complication of the boundary (1ZB2) – 18%, 17% and 15%, respectively. The forestation processes were highly diversified – the lateral accretion with complication of the boundary (2ZB2) dominated (30%), while the contributions of all the other kinds of processes to the total forest cover increase (except for 2ZB0) were quite similar and were all contained in the interval 10-18%.

Changes of forest cover on habitats (Fig. 7.12B)

Changes in the forest cover did not affect in a similar degree all of the habitats. In the period 1800-1830 the biggest decrease of the forest area (2081 hectares) took place on the habitat of the floodplain deciduous forest (*Fraxino-Alnetum*), which was followed by the habitat of humid oak-hornbeam forests (388 hectares). This entailed the relative drop of forest cover on these habitats by, respectively, 16 and 13%. On the remaining habitats the changes – both absolute and in relative terms – were much lower.

The years 1830-1885 were characterised mainly by further deforestation on the floodplain deciduous forest habitat (2766 hectares), and on the habitat of the poor oak-hornbeam forest (*Tilio-Carpinetum calamagrostietosum*) – 1356 hectares, which brought the relative decrease of the forest cover on these habitats by, respectively, 21 and 19%. It should be emphasised here that in relative terms there has also been a significant decrease of the forest cover on the habitat of humid pine forest (*Molinio-Pinetum*) – by 16%, and of the different varieties of the oak-hornbeam forest – typical (16%) and humid (9%), even though the absolute magnitudes of deforestations on these habitats were not very high. New forests appeared mainly on the habitat of the typical pine forest (1017 hectares), bringing the increase of forest cover on this habitat by 13%.

During the subsequent period, i.e. the years 1885-1928, the deforestations took place mainly on the habitats of the typical mixed pine forest *Querco-Pinetum typicum* (1479 hectares), poor form of oak-hornbeam forest (1069 hectares) and the floodplain deciduous forest (957 hectares). To a lesser extent deforestations affected also humid mixed pine forests, fresh pine forests and humid oak-hornbeam forests (between 280 and 510 hectares). In relative terms the biggest decrease of forest cover was observed for the habitats of humid pine forests (30%), humid mixed pine forests (22%), as well as poor oak-hornbeam forest and typical mixed pine forest – 15% each of these two.

The period of 1928-1950 featured mainly the increments of forest area on the drier habitats of the poor oak-hornbeam forests, typical mixed pine forests and fresh pine forests (on the scale of 350-450 hectares), and on some habitats of the deciduous floodplain forests and the humid mixed pine forests (approximately 130 hectares each), but the percentage changes of the forest cover on the respective habitats were very limited and only in the case of the humid pine forest the change amounted to 10%.

In the years 1950-1970 absolute domination was observed of the forestations on the habitats of the mixed pine forests (1473 hectares) and of the fresh pine forests (1038 hectares), which brought the increase of forest cover on these habitats by, respectively, 15 and 13%.

The last period considered, 1970-2000, was characterised by small changes only, of which the most important ones were the forestations on the habitat of the mixed pine forests (361 hectares) and the deforestations on the habitat of the floodplain deciduous forests (101 hectares). Except for the habitat of the humid pine forest (which occupies, anyway, a very small area), the relative changes in the forest cover did not exceed 4% of the habitat area.

From today's perspective it can be stated that the changes in the distribution of forests, having taken place over the last 200 years, can be represented as forming two separate stages. The first of these corresponds to a systematic decrease of the forest area between the years 1800 and 1928. The second stage, lasting between 1928 and 2000, was characterised by a slow increase of the forested area, even though in the year 2000 the proportion of the forest cover was still lower than in 1800. From the point of view of the rates and directions of changes all of the habitats can be classified into three groups. The first of these groups contains only the habitat of the fresh pine forests, on which the forest cover systematically and quite smoothly increased from 70% in 1800 to more than 95% in 2000. The second group contains the habitats of the typical mixed pine forest and the humid mixed pine forest. For both these habitats the proportion of forest cover had been decreasing between the years 1800 and 1928, to then increase until 2000. Yet, in the case of the typical mixed pine forests the proportion of forest cover was higher in 2000 than in 1800, although it still did not reach even half of the habitat area. On the other hand, in the case of the humid mixed pine forest habitat, despite the fact that forest cover increased from 53% in 1928 to 93% in 2000, it was still lower than in 1800. The third group is composed of all the remaining habitats, on which the proportion of forest cover decreased over the entire period of 200 years, with the deforestation being most intensive in the case of floodplain deciduous forest and of all sub-associations of the oak-hornbeam forest.

Changes in the selected landscape metrics (Fig. 7.13)

The average magnitude of the forest patch was the biggest in the years 1800 and 1830, and it oscillated around 1000 hectares, then dropped by 1885 to approximately 280 hectares, and then remained at a similar level until 1950. Then, this value decreased to as little as 80 hectares by the year 1970, and the changes till the year 2000 were marginal.

It is worth paying attention to the fact that the values of other indicators of patch magnitude have been simultaneously changing. The magnitude of the biggest patch decreased slowly until 1885 from some 13,000 hectares to roughly 10,000 hectares, to then drop down to 5244 hectares by 1928. Later on, due to the consolidation processes and patch increase, the area of the biggest patch slowly increased until the year 2000, reaching 9300 hectares, which was still less than in the period 1800-1830. During the entire period analysed the standard deviation of the patch magnitude decreased smoothly from 2875 in the year 1800 to 1233 in the year 1885, and then to less than 700 in 1928. In the subsequent years the value of this indicator did not undergo more important changes.

The SI indicator displayed over the entire period analysed a weak downward tendency, with simultaneous increase of the maximum value and decrease of the minimum value.

These changes have not been taking place in an even manner. The average value of SI did not change in the years 1800-1885, remaining at the level of approximately 1.86. In the years 1928 and 1950 this value was above 1.7, while in the years 1970 and 2000 it was equal approximately 1.66.

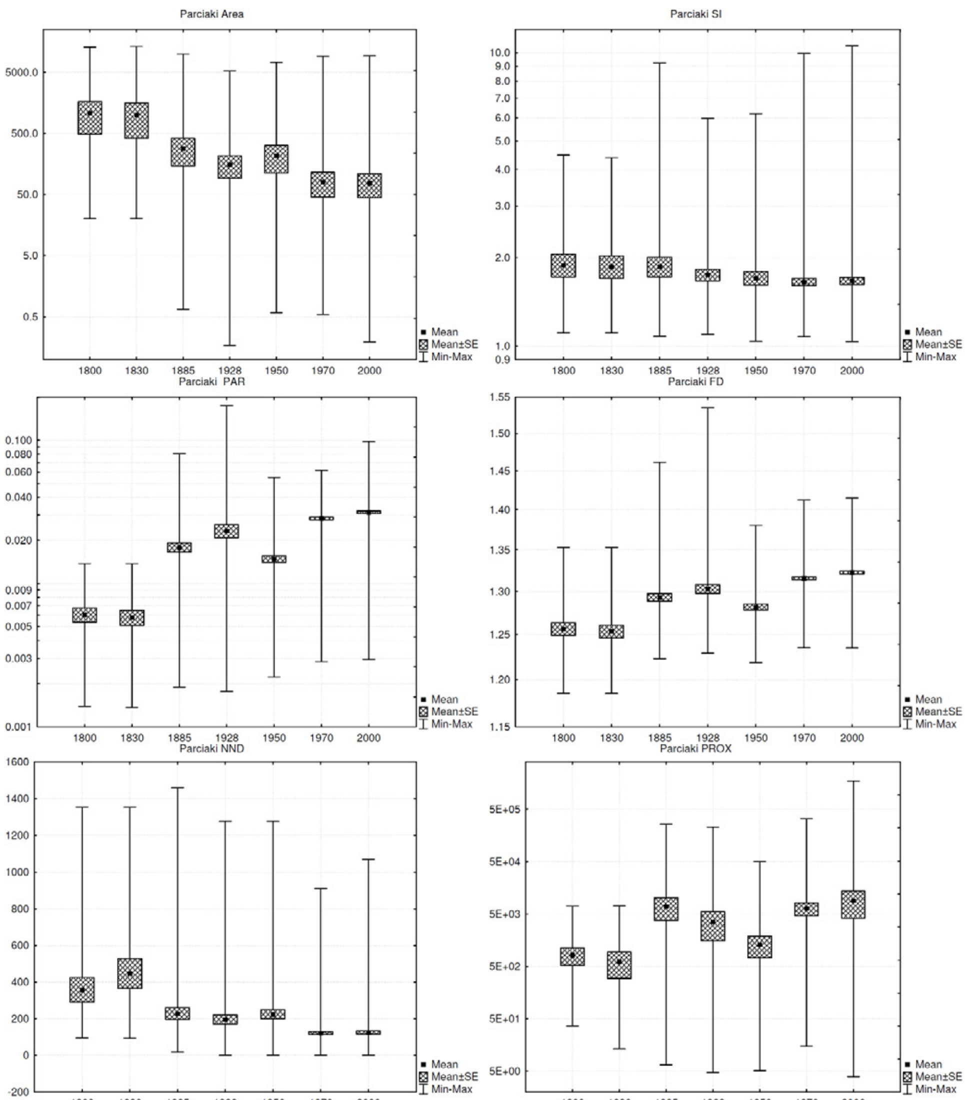

Fig. 7.13. Changes of the values of the chosen landscape metrics on Parciaki region in years 1800-2000

The values of the PAR indicator had a different course of changes over time. The lowest – and statistically insignificantly different – values were observed for the years 1800 and 1830 (0.006). Then, the value of PAR increased a lot, up to 0.018 in 1885, and slowly increased further until 1928 (to 0.023), to then drop by 1950 to 0.015, that is – the lowest level since 1885. The consecutive distinct increases occurred in 1970 (to 0.028) and yet in 2000 (to 0.031). It is also worth noting that in the entire period considered the minimum value of this indicator has been systematically and relatively uniformly increasing, while the maximum values were the lowest in 1800 and 1830, and the highest in 1928.

The values of the FD indicator had identical course over time to those of SI. The lowest, and statistically insignificantly different values were observed in the years 1800 and 1830 (approximately 1.26), then the value of FD increased to 1.29 by the year 1885, and yet increased slowly until 1928 (to 1.30), to then drop in the year 1950 to 1.28, that is – the level lower than in 1885. The subsequent distinct increase took place in the year 1970 (1.31), and it continued until 2000 to the value of 1.32 (the difference being insignificant).

Regarding the course of changes of the NND indicator, three separate periods can be distinguished, with the general downward trend. In the years 1800-1830 there was a limited, statistically insignificant increase from 357 to 447 m, followed by a significant decrease by the year 1885 down to 228 m, and then virtually lack of any changes until the year 1950. The value of NND dropped again significantly in 1970 to the value of 125 m. An identical course of changes characterised, as well, the minimum values, the median and the quartiles of the NND indicator, and only the maximum values, while displaying the general downward tendency, attained the highest value in 1885.

The PROX indicator featured a different course of variability. In the period 1800-1830 a limited and statistically insignificant decrease of its value took place, from 828 to 619, and then the value of the indicator increased significantly up to 7061. Between 1885 and 1950 a regular decrease has been taking place down to the value 1312. The last period was characterised by a sharp increase of the PROX value, from 6426 in 1970 up to 9012 in 2000.

7.3.2. District of Myszyniec

Diversification of the processes of fragmentation and consolidation (Fig. 7.14A)

In the years 1800-1830 the deforestations encompassed the surface of 946 hectares, while 639 hectares were forested anew – these values were the lowest among all the periods considered. The decrements of the forest cover were mainly due to lateral shrinkages without the change of the character of the boundary (1ZB0) – 59%, and to narrow subdivision (1RW) – 37%. The forestations were primarily occurring through lateral accretion with complication of the boundary (2ZB2) – 49%, and through creation of new patches (2A) – 35%.

During the period 1830-1885 close to 21,800 hectares of forest cover disappeared, while forestations encompassed 6386 hectares. These were the biggest changes over the entire analysed time interval of 200 years, entailing the biggest shifts in the area and distribution of forests. The deforestations were mainly wide multiple subdivision (1RS2) – 83%, while new forestations took mainly the form of lateral accretion with complication of the boundary (2ZB2) – 47%, and of integration (2R) – 31%.

The subsequent period, 1885-1928, was marked by the decrements of the forest area amounting to 4785 hectares, and the increments amounting to 1949 hectares. The decrements took place mainly due to lateral shrinkages with evening out of the boundary (1ZB1) – 50%, and due to the attrition of the entire patches (1A) – 18%. Forest areas increased owing to integration (2R) – 24%, and three categories of accretion: distal (2ZK), as well as lateral with simplification of the boundary (2ZB1) and with complication of the boundary (2ZB2), which accounted for, respectively, 19, 18 and 16% of the newly forested area.

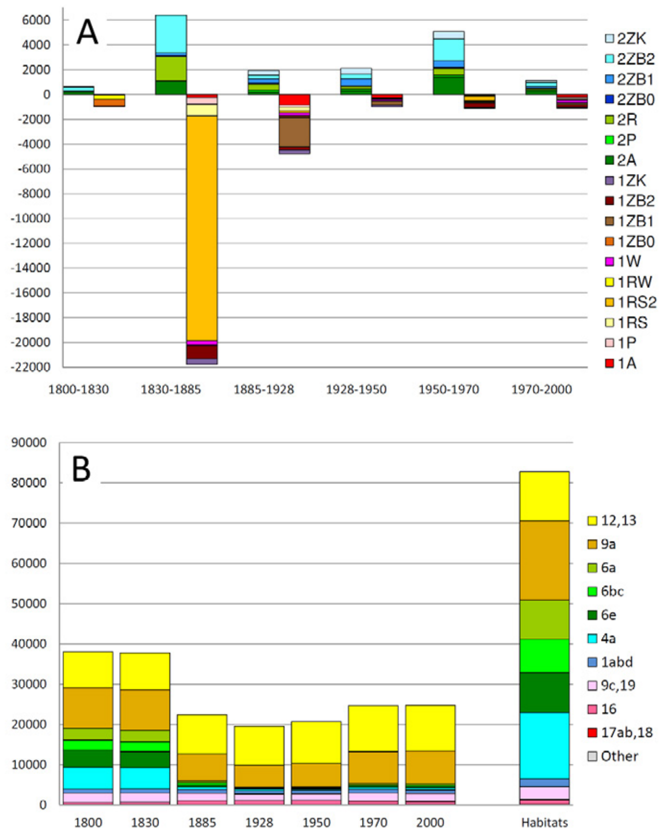

Fig. 7.14. Types of the forest surface decrements and increments (in hectares) (A); and the forest area on different habitats of the potential natural vegetation (B) on Myszyniec region in years 1800-2000

In contradistinction to the preceding periods, when the decrements of the forest area had been bigger than new forestations, in the years 1928-1950 the trend reversed for the first time. In this period the decrements affected only 969 hectares, while increments encompassed 2123 hectares. Forest cover shrank primarily due to the attrition of the entire patches (1A) – 28%, and to the lateral shrinkage with evening out of the boundary (1ZB1) – 26%. New forest surfaces appeared first of all owing to the lateral increase with evening out of the boundary (2ZB1) – 28%, which was followed by the lateral accretion with complication of the boundary (2ZB2) – 18%, and the creation of new patches (2A) – 15% of the total of new forest area.

In the period 1950-1970 the decrements to the forest cover encompassed 1107 hectares, while the increments – 5086 hectares. The decrease of the forest area occurred primarily due to wide multiple subdivision (1RS2) – 34%, and the lateral shrinkage with complication of the boundary (1ZB2) – 30%. The processes extending the forest cover were first of all the lateral accretion with complication of the boundary (2ZB2) – 35%, and the creation of new patches (2A) – 28%.

The years 1970-2000 were characterised by the very small net changes in the forest cover area, since decrements amounted to 1076 hectares, while increments to 1142 hectares. The decrease of the forest area was due in a similar degree to a range of spatial processes, including attrition of the entire patches (1A) – 21%, incisions (1W) – 19%, lateral shrinkages with complication of the boundary (1ZB2) – 17%, along with perforation (1P) and lateral shrinkage with evening out of the boundary (1ZB1) – both of the latter two accounting for less than 11%. Increase of the forest cover took place mainly through lateral accretion with complication of the boundary (2ZB2) – 30%, and owing to the creation of the new patches (2A) – 23%.

Changes of forest cover on the habitats (Fig. 7.14B)

In the years 1800-1830 changes in the forest cover on particular habitats were very limited and ranged from 130 hectares of decrements on the habitat of the floodplain deciduous forests to 195 hectares of increments on the habitat of the fresh pine forests. In relation to the areas of the particular habitats the changes in the forest cover were also small and ranged from 3% of decrease on the habitat of the humid oak-hornbeam forests to 2% of increase on the habitat of the fresh pine forests.

The subsequent period, that is – the years 1830-1885 – was characterised by the deforestations on the majority of habitats, with the biggest scale of deforestations affecting the habitat of the floodplain deciduous forests (4698 hectares), followed by the humid oak-hornbeam forests (3501 hectares), mixed pine forests (3414 hectares), poor oak-hornbeam forests (2398 hectares), and typical oak-hornbeam forest. In terms of proportions the forest cover dropped the most on the habitats of the swampy pine forest and the humid oak-hornbeam forest (by more than 30%), but the decrease was significant, as well, on the habitats of the floodplain deciduous forest and the two remaining forms of the oak-hornbeam forests (beyond 20% of the respective habitats). Somewhat lower, but also significant decreases of the relative forest cover – exceeding 10% – took place on the habitats of both forms (typical and humid) of the mixed pine forests.

The next period considered, 1885-1928, was similar to the preceding one, but the areas deforested on particular habitats were smaller. On the majority of habitats the deforestations were contained in the interval of 100-430 hectares, and only on the habitat of the fresh mixed pine forest it occurred on 1305 hectares. On no habitat did the decrease in relative terms exceed 10%, the biggest decrease having been observed on the habitats of the humid and fresh mixed pine forests (8 and 7%, respectively).

In the years 1928-1950 only small changes took place of the forest areas on particular habitats. The biggest forestations occurred on the habitat of the fresh pine forests (656 hectares) and the mixed pine forests (452 hectares), while the biggest deforestations, encompassing 106 hectares, concerned the floodplain deciduous forest habitat. Changes in relative forest cover were small and only on the habitat of the fresh pine forest they exceeded 5% of the habitat area.

Then, in the period of 1950-1970 deforestations of the habitats were minimal, while forestations dominated on the habitats of the mixed pine forest (2074 hectares) and the fresh pine forest (1971 hectares). In terms of percentages, despite a small absolute increase, the biggest relative increase took place on the habitat of the swampy pine forest (13%), which was followed by the humid mixed pine forest, typical mixed pine forest and fresh pine forest (11, 11 and 9%, respectively).

The last period considered, that is – the years 1970-2000, saw again small changes in the areas of forests on the particular habitats, with somewhat bigger percentage decreases occurring on the humid and wet habitats (swampy pine forests, humid pine forests, alder woods, as well as humid mixed pine forests), contained in the interval 1-6%. On the remaining habitats very low increases dominated, below 1% of the areas of the respective habitats.

It can be stated from the current perspective that the changes in the distribution of forests, which have taken place during the last 200 years, can be represented as forming two separate stages. The first of them was associated with the decrease of the forest areas between 1800 and 1928, with the most intensive decrease of forest cover in the period 1885-1928. The second stage, lasting from 1928 to 2000, was characterised by a slow increase of the forest areas, so that in the year 2000 the forest share was still well below that of 1800. Now, in terms of the rates and directions of changes in forest cover all the habitats can be divided up into three groups. The first group includes solely the habitat of the fresh pine forest, on which forest cover has been systematically and quite evenly increasing, from 73% in 1800 to more than 93% in 2000. The second group comprises the habitats of the typical mixed pine forest, humid mixed pine forest and alder woods. On these habitats forest cover had been decreasing between 1800 and 1928, to then increase until 2000, reaching the share values of 41, 62 and 44%, respectively. It ought to be noted, though, that these shares were still lower than in 1800. The third group encompasses all the habitats, on which forest shares have been in principle decreasing over the entire period of the last 200 years, although there have also been periods of small increases. In the cases of habitats of floodplain deciduous forest and all the sub-associations of the oak-hornbeam forest the biggest decreases of the forest shares took place in the first stage distinguished here (from more than 30% to less than 3% over the years 1800-1928).

Changes in the selected landscape metrics (Fig. 7.15)

The average magnitude of patches was the highest in the years 1800 and 1830, amounting to more than 2000 hectares. In the same period the maximum and minimum patch magnitudes were also the biggest. Until the year 1885 a significant decrease of all these characteristics took place, in particular – the average patch magnitude decreased to 97 hectares. The years 1885-1950 saw a limited and slow increase of the average patch magnitude, up to 157 hectares. By the year 1970 a decrease occurred again to 64 hectares, followed by further decrease until the year 2000 to 52 hectares, this latter decrease being, though, statistically insignificant. In 2000 the lowest minimum patch magnitude was recorded, as well. Yet, it should be emphasised that the decrease of the average patch magnitude resulted not only from the splitting of the bigger patches into the smaller ones, and the decrease of the bigger patches, but also from the creation of a high number of very small patches. This is expressed through the differentiation of the median of the patch magnitude. In the years 1800 and 1830 it was higher than 170 hectares, while in the years 1885-1950 it oscillated around 10 hectares, to drop down to less than 3 hectares in the years 1970-2000.

A division, similar to the one characterised before, into three periods, featuring different rates and directions of changes in the indicator values, can be also observed for other landscape metrics.

The value of SI was the highest in the years 1800 and 1830 (roughly 1.9). Until the year 1885 a significant decrease of SI took place, down to 1.7. In the period between 1885 and 1950 a slow and limited increase of the value of this indicator took place, up to the value of 1.8. By 1970 a drop took place again to the value of 1.6. In 2000 the value was i nsignificantly higher than in 1970.

The temporal variability of the PAR indicator was somewhat different. Between 1800 and 1830 there was a slight and insignificant increase from 0.005 to 0.006, followed by a significant increase until 1885 (to 0.021). Then, by 1928, a decrease to 0.016 took place, while in 1950 the value of PAR was only insignificantly different from that in 1928. There was, on the other hand, a significant increase of the value until 1970. Then, in the last period considered, there was only an insignificant increase, and in the year 2000 PAR was equal 0.034. It is worth mentioning that the minimum and maximum values of PAR have been changing in a similar manner, with the biggest increase of the maximum value having taken place in the period 1970-2000 (from 0.15 to 0.61).

An identical course of temporal changes to that of PAR was observed for the FD indicator. Thus, in the years 1800-1830 there was a slight and statistically insignificant increase, from 1.24 to 1.25, while a significant increase, up to 1.3, took place until 1885. In the subsequent period, until 1928, an insignificant decrease took place, and then in 1950 the value of FD was also insignificantly different from that in 1928. Then, by the year 1970 a significant increase took place up to the value of 1.32. In the last three decades considered the value of FD only insignificantly increased, up to 1.33. In the case of this indicator, like for the preceding one, the biggest increase of the maximum value took place in the period 1970-2000.

The average value of the NND indicator displays a general downward tendency, with bigger decreases having occurred in the periods 1830-1885 (from 380 m to 195 m) and 1950-1970 (from 284 m to 154 m). In the remaining periods changes have been distinctly smaller, and only in the years 1885-1950 there has been a slow, statistically significant increase. Let us add that the maximum value of NND changed in a much more irregular manner, with the highest value, namely 3094 m, observed in the year 1950.

Over the two centuries considered, the PROX indicator changed the least regularly of all the metrics analysed, preserving, though, the general upward tendency. The lowest values were observed in the years 1800 and 1830 (438 and 1025, respectively). Until the year 1885 a significant increase took place up to the value of 2959, followed by the decrease to 1127 in 1928, then to 1309 in 1950 (although the latter difference was not statistically significant). A very significant increase of the value of this indicator occurred between the years 1950 and 1970, up to the value of 5597. In the same period the standard deviation increased very distinctly, as well, along with the minimum and maximum values of PROX.

The values for the year 2000 (the average being equal 6350) did not differ statistically significantly from those for 1970.

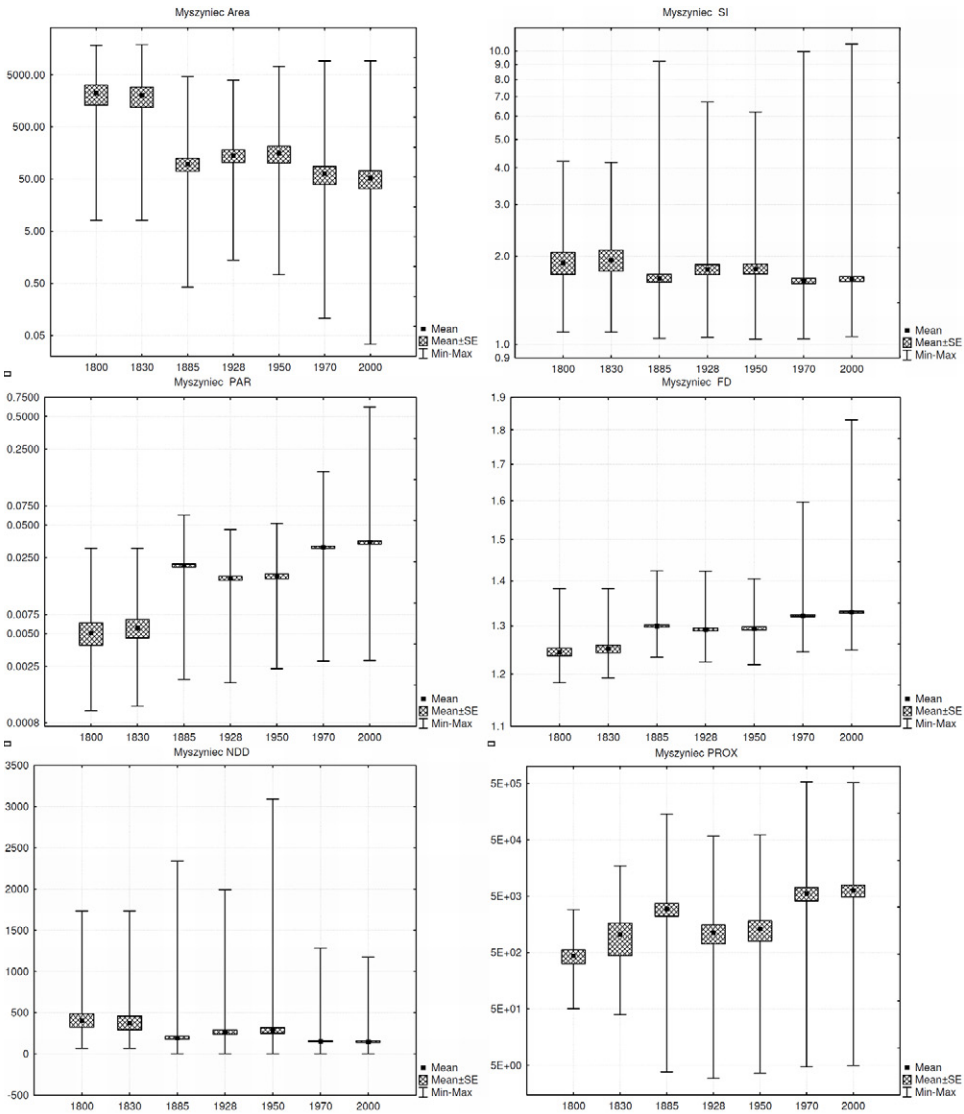

Fig. 7.15. Changes of the values of the chosen landscape metrics on Myszyniec region in years 1800-2000

7.3.3. District of Jedwabno

Differentiation of the fragmentation and consolidation processes (Fig. 7.16A)

In the years 1800-1830 the decrease of the forest cover amounted to 167 hectares, while the increase – to 639 hectares. The decrease was mainly due to the lateral shrinkages with evening out of the boundary (1ZB1) – 49%, and to the attrition of the entire patches (1A) – 32%. The increments of the forest area were primarily (72% of all the increments) taking place through lateral accretion without a change in the character of the boundary (2ZB0).

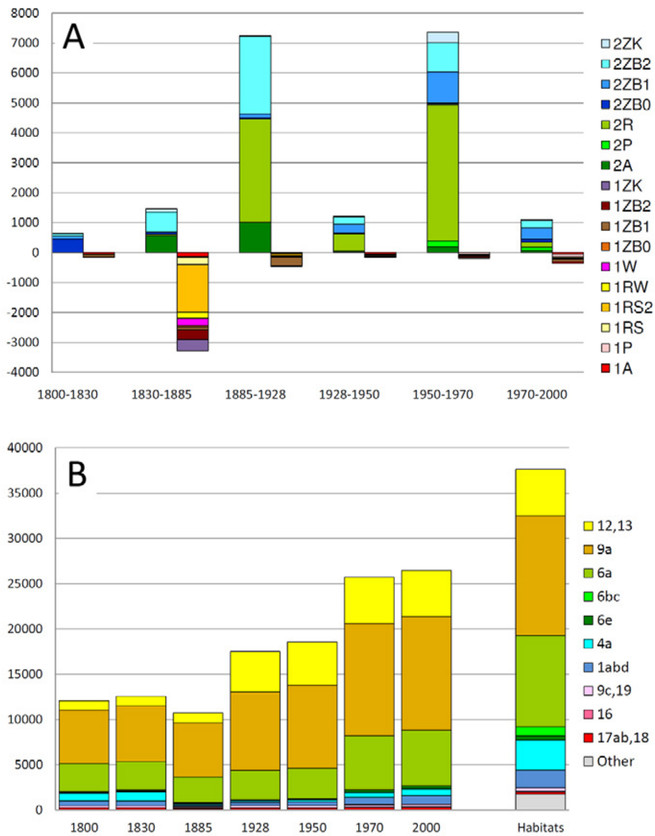

Fig. 7.16. Types of the forest surface decrements and increments (in hectares) (A); and the forest area on different habitats of the potential natural vegetation (B) on Jedwabno region in years 1800-2000

Between the years 1830 and 1885 the biggest decrements of the forest area took place, encompassing 3287 hectares. Forestations occurred over the area of 1462 hectares. This was the sole period, when deforestations were bigger than forestations. The decrements occurred mainly due to wide multiple subdivision (1RS2) – 48%, other processes playing much smaller roles. The increments of the forest area occurred primarily owing to the lateral accretion with complication of the boundary (2ZB2) – 46%, and to the creation of new patches (2A) – 39%.

The period of 1885-1928 saw the decrements encompassing 462 hectares and increments summing up to 7244 hectares. The decrements were essentially due to lateral shrinkages with evening out of the boundary (1ZB1) – 60%. They were followed by the wide multiple subdivision (1RS2) – 12%. The increments to the forest area took place first of all due to integration (2R) – 48%, and to lateral accretion with complication of the boundary (2ZB2) – 36%.

During the period 1928-1950 the decrements to the forest area occurred over 168 hectares, while accretion over 1207 hectares. The most important process causing the decrements to the forest area was attrition of entire patches (1A) – 30%, along with lateral shrinkages with evening out of the boundary (1ZB1) – 23%. Extension of the forest area took place mainly owing to the integration (2R) – 48%, as well as the lateral accretion with simplification of the boundary (2ZB1) and with complication of the boundary (2ZB2). The two latter processes occurred over, respectively, 25 and 19% of the entire area of new forestations.

The years 1950-1970 were characterised by very limited decrements to the forest area (189 hectares) and the biggest new forestations over the entire period of 200 years (7361 hectares). The decrements were in 30% due to perforation (1P), and, to a lesser degree, to lateral shrinkages with complication of the boundary (1ZB2) – 23%, as well as lateral shrinkages with evening out of the boundary (1ZB1) – 18%. The majority of the increments resulted from the same processes as in the preceding period – integration (2R) – 62%, lateral accretion with simplification of the boundary (2ZB1) and with complication of the boundary (2ZB2) – 14% and 13%, respectively.

The last period considered, 1970-2000, saw the decrements over 360 hectares and increments over 1111 hectares. The decrements took place owing to perforation (1P) – 26%, followed by three processes taking similar shares – lateral shrinkages with evening out of the boundary (1ZB1) and with complication of the boundary (1ZB2), as well as attrition of the entire patches (1A) – 18, 18 and 15%, respectively. The increments to the forest area occurred primarily due to the lateral accretion with simplification of the boundary (2ZB1) – 34%, and with complication of the boundary (2ZB2) – 22%.

Changes of forest cover on the habitats (Fig. 7.16B)

In the years 1800-1830 increase of forest area exceeding 100 hectares took place only on the habitats of the deciduous floodplain forest and the fresh mixed pine forest. In percentage terms the changes were little significant. Only in the case of the humid oak-hornbeam forest habitat did forest share increase by 12%, while in the cases of other habitats changes did not exceed 5%.

Between 1830 and 1885 decrements to the forest cover took place on the majority of habitats, with the decrease on the habitat of the deciduous floodplain forest amounting to 887 hectares, while on the habitats of the fresh mixed pine forest, the poor oak-hornbeam forest, and the alder woods the decrements were contained in the interval 200-350 hectares. Given the areas occupied by the respective habitats these limited absolute changes entailed quite distinct percentage changes. Forest shares on the habitats of the floodplain deciduous forest and humid oak-hornbeam forest dropped by more than 20%, while on the very humid and wet habitats (swampy pine forests, humid pine forests, humid mixed pine forests and alder woods) they decreased by more than 10%.

During the period 1885-1928 increases took place of the forest area on all the habitats, with the biggest increase observed on the habitats of the fresh pine forest (3375 hectares) and the fresh mixed pine forest (2672 hectares), this being equivalent to the relative increases by 20 and 66% of the habitat area, respectively. Relatively important increases of forest share, exceeding 17% (for, however, much smaller absolute areas) occurred, as well, on the wet and strongly humid habitats, i.e. those of the swampy pine forests and spruce woods on peat bogs, humid pine forests and humid mixed pine forests.

In the years 1928-1950 changes of the forest cover on particular habitats boiled down to very small increments, and only on the habitats of the poor oak-hornbeam forest, fresh mixed pine forest and fresh pine forest they were contained in the interval of 200-530 hectares. The relative changes in percentage terms did not exceed 5% on any habitat.

During the subsequent period, that is – in the years 1950-1970 – a very distinct increase of the forest cover took place on the habitats of the fresh mixed pine forest and the poor oak-hornbeam forest (3235 and 2567 hectares, respectively), which corresponded to the increase of the forest share by 25% of area of each of these forest types. On all the other habitats forest shares increased by more than 5%, although bigger absolute increases (between 300 and 500 hectares) took place only on the habitats of fresh pine forest, deciduous floodplain forest, and alder woods.

The period of 1970-2000, similarly as the three preceding periods, was also characterised by the increase of the forest cover on virtually all of the habitats, and only on the habitat of the fresh pine forests a marginal decrease took place (by 17 hectares). The increments mentioned were also small as to their areas. Only on the habitats of alder woods, floodplain deciduous woods, poor oak-hornbeam forest and fresh mixed pine forest these increments were contained in the interval 140-206 hectares, while on the remaining habitats they did not exceed 32 hectares. Consequently, relative changes in the forest cover were small, and only for the humid pine forest, alder woods, floodplain deciduous forest and humid oak-hornbeam forest these changes exceeded 5% of the respective habitat area.

It can be stated, taking the today's perspective, that the changes in the spatial distribution of forests, having taken place over the last 200 years, might be classified into two separate stages. The first of these stages consisted in the decrease of the forest cover between the years 1800 and 1885, with the changes in forest cover between 1800 and 1830 being minimal. The second stage, lasting from 1885 to 2000, was characterised by the general increase of the forest cover, with strong increases in the periods of 1885-1928 and 1950-1970, and definitely much slower increases in the periods of 1885-1928 and 1970-2000. Let us add that already in 1928 the overall forest share was higher than in 1800. In terms of the rate and the direction of changes in forest cover the habitats can be divided into two groups. The first one comprises the habitats of the fresh pine forest and the typical mixed pine forest, on which forest share has been systematically increasing from period to period, starting with, respectively, 20 and 45% in the year 1800, up to more than 99% and more than 95% in the year 2000. The second group of habitats includes the remaining habitats, on which a clear decrease of the forest share took place in the period 1830-1885 (quite often from more than 20% to less than 10%), followed by a slight increase in the years 1885-1928, and then a truly pronounced increase in the years 1950-1970. Except for the habitat of the deciduous floodplain woods, the remaining habitats from this group featured higher forest share in 2000 than in 1800.

Changes in the selected landscape metrics (Fig. 7.17)

The average magnitude of forest patches was the biggest in the years 1800 and 1830, when it amounted to 1130 and 1287 hectares, respectively. This value dropped to approximately 92 hectares by the year 1885, and has been increasing since then systematically, reaching 247 hectares in 1950, and 659 hectares in 1970. The increase between the years 1970 and 2000 amounted to only 41 hectares and was statistically insignificant. Other quantities, related to the magnitude of forest patches, changed also in an interesting manner. The area of the largest patch, at a similar level in the years 1800 and 1830 (a bit above 10,500 hectares), dropped down to 3971 hectares in 1885 and then has been systematically increasing, attaining the highest values in the years 1970 and 2000 (49,160 and 51,588 hectares, respectively). Yet, at the same time, during the entire period of 200 years the minimum area of the forest patch has been decreasing. The differentiation of the patch magnitude, expressed through standard deviation, was the lowest in 1885 (497), and has been consistently increasing since then, reaching the highest value in the year 2000 (5955).

A similarly dichotomous pattern characterised the changes in the values of the SI indicator. In the years 1800 and 1830 this value was the highest (1.77 and 1.87, respectively), and then a decrease took place by the year 1885, down to 1.42. Since that time the value of SI has been slightly increasing, through 1.49 in 1950 to 1.59 in 2000. The maximum value of SI was the lowest in 1885 (4.2) and since that time, again, it has been systematically increasing, with the increase being most pronounced in the period of 1885-1928 (up to 8.6), and the least pronounced in the years 1970-2000 (from 14.2 to 14.7).

Changes in values of PAR and FD took place according to the three-time-intervals pattern. In the case of PAR the lowest values were observed in the years 1800 and 1830 (respectively – 0.005 and 0.007). A significant increase took place until the year 1885, to the value of 0.023, followed by the decrease to the value of 0.020 in the years 1928 and 1950. Then, the years 1970 and 2000 were characterised by the highest value of PAR (0.028), statistically significantly different from those in the preceding periods.

The temporal course of the values of FD indicator was very similar to that of PAR. The lowest values were observed in the years 1800 and 1830 (respectively – 1.24 and 1.25), and they were followed by the increase until the year 1885 to the value of 1.28. In the consecutive periods, that is – in the years 1928 and 1950, a small and statistically insignificant decrease was observed to the value of 1.28. By the year 1970 the value of the FD indicator increased to 1.3, this value also appearing in the year 2000. It is worth emphasising that in the cases of both PAR and FD the maximum values were observed in 1970, and the values from the year 2000 are only slightly lower.

The temporal variability of the NND indicator appears to feature two periods of stable behaviour. The first of these encompasses the years 1800 and 1830. In this period the average values were the highest (619 m and 611 m, respectively, with the difference being statistically not significant). The maximum values and the standard deviations were also the highest then. Until the year 1885 a significant decrease took place down to the value of 186 m. During the subsequent periods, up till the year 2000, the average value of NND persisted at a similar level (in the interval between 123 and 159 m). The maximum values featured in this time period somewhat bigger oscillations, contained in the interval between 745 and 1080 m.

The PROX indicator displayed a very specific variability. It generally increased from the value of 1014 in the year 1800 to 114,971 in the year 2000. This relatively smooth increase was disturbed only in 1970, when the recorded average value of PROX was 6.7 million, and the maximum value was as high as 496 million.

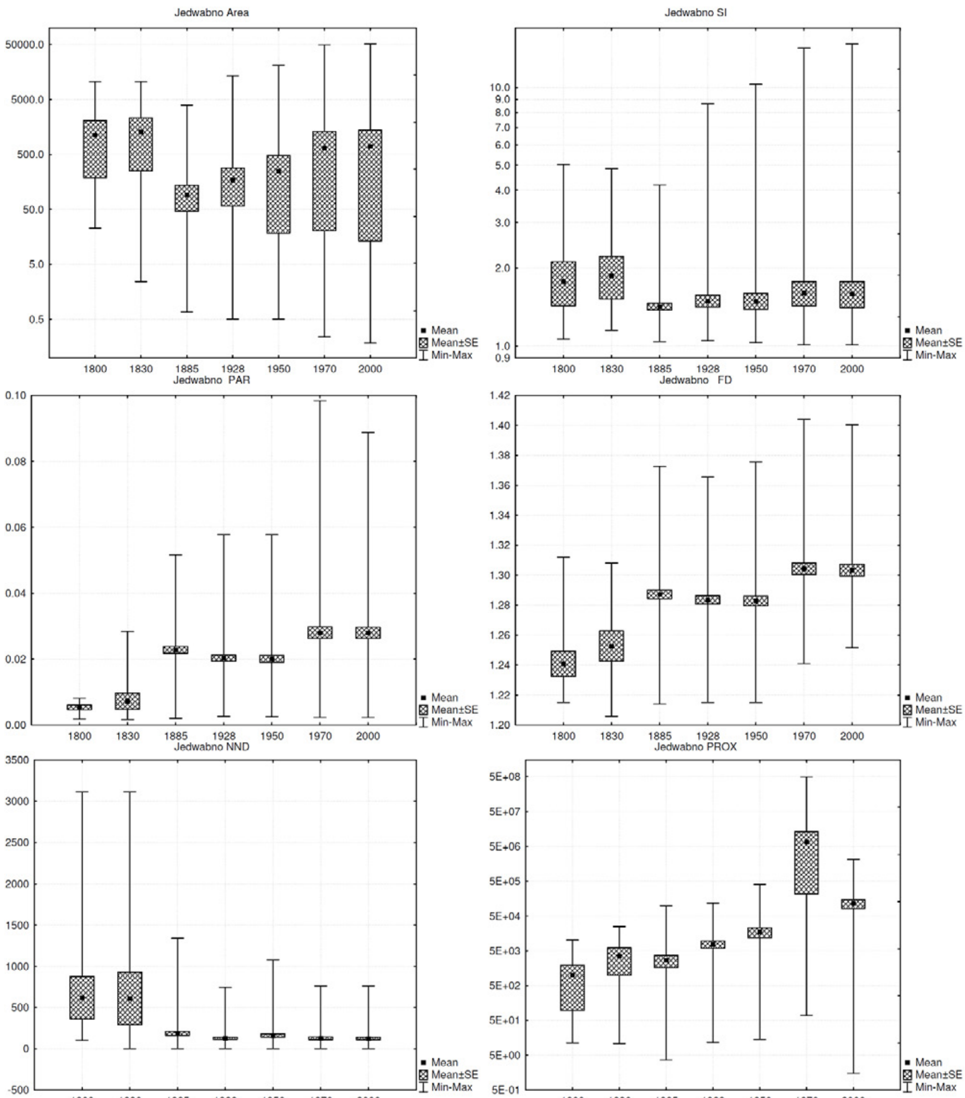

Fig. 7.17. Changes of the values of the chosen landscape metrics on Jedwabno region in years 1800-2000

7.3.4. District of Wielbark

The differentiation of the fragmentation and consolidation processes (Fig. 7.18A)
In the first period considered, i.e. in the years 1800-1830, like in all the subsequent periods, the increments of the forest cover were bigger than the decrements. The decrements amounted to 317 hectares, while the increments – to 386 hectares. The decrease of the forest cover took place solely owing to the attrition of the entire forest patches (1A) and to the distal shrinkage of the patches (1ZK), whose share in the general decrease of the forest cover amounted to, respectively, 69 and 31%. The increments of the forest area took place mainly due to consolidation (2R) – 48%, and to lateral increase without a change in the character of the boundary (2ZB0) – 29%.

Then, in the period 1830-1885 the biggest deforestations took place, encompassing 3121 hectares, but the increments to the forest cover were even bigger and amounted to 7209 hectares. The decrements occurred mainly owing to the wide multiple subdivision (1RS2) – 63%, followed by the attrition of the entire forest patches (1A) – 17%. Close to 42% of the increment to the forest area was due to the creation of the new patches (2A), with the consecutive 37% resulting from the lateral increments with complication of the boundary (2ZB2).

In the years 1885-1928 the decrements to the forest area affected 1428 hectares, with simultaneous forestation of 5534 hectares. The deforestations occurred mainly due to the lateral shrinkages of the patches with smoothing of the boundary (1ZB1) – 33%, while the roles of lateral shrinkages with complication of the boundary (1ZB2), perforation (1P) and attrition of the entire patches (1A) were distinctly smaller (15, 13 and 10%, respectively). The primary process, extending the forest area, which encompassed 51% of the total of accretion, was integration (2R), while other processes, of which the most important was lateral increment with complication of the boundary (2ZB2) – 18%, played a lesser role.

Between the years 1928 and 1950 the decrements encompassed 894 hectares, while new forest areas appeared on 1274 hectares. The decrements took place mainly owing to the lateral shrinkage with smoothing of the boundary (1ZB1) – 40% of area of all the decrements, and due to the attrition of the entire patches (1A) – 20%. Appearance of the new forest areas resulted from a variety of processes, of which the most important was the lateral increment with simplification of the boundary (2ZB1) – 39% of the area of all the increments, and integration (2R) – 30% of the new forested area.

The period from 1950 to 1970 was characterised by the smallest losses of the forest cover (only 285 hectares), while the total increase was the biggest over the entire time interval considered of 200 years, namely 8818 hectares. The decrements were primarily due to the lateral shrinkages with complication of the boundary (1ZB2) – 39% of the area of all the decrements, and to the lateral shrinkages with evening out of the boundary (1ZB1) – 21%. Forest area got extended primarily owing to integration (2R) and the lateral increments with complication of the boundary (2ZB2). The former process accounted for 51% of the total additional area forested, while the latter – for 16%.

In the years 1970-2000 the decrements of the forest area were small and amounted to 408 hectares. The increments were bigger, and they encompassed 1254 hectares.

The reason for the decrease of the forest area was, first of all, the lateral shrinkage with complication of the boundary (1ZB2) – 28%, followed by the lateral shrinkage with smoothing of the boundary (1ZB1) and perforation of the patches (1P), accounting for, respectively, 18 and 16% of the decrement area. The new forested surfaces appeared in 31% owing to the lateral increment with simplification of the boundary (2ZB1), to consolidation (2R), 23%, as well as lateral increments with complication of the boundary (2ZB2) – 20%.

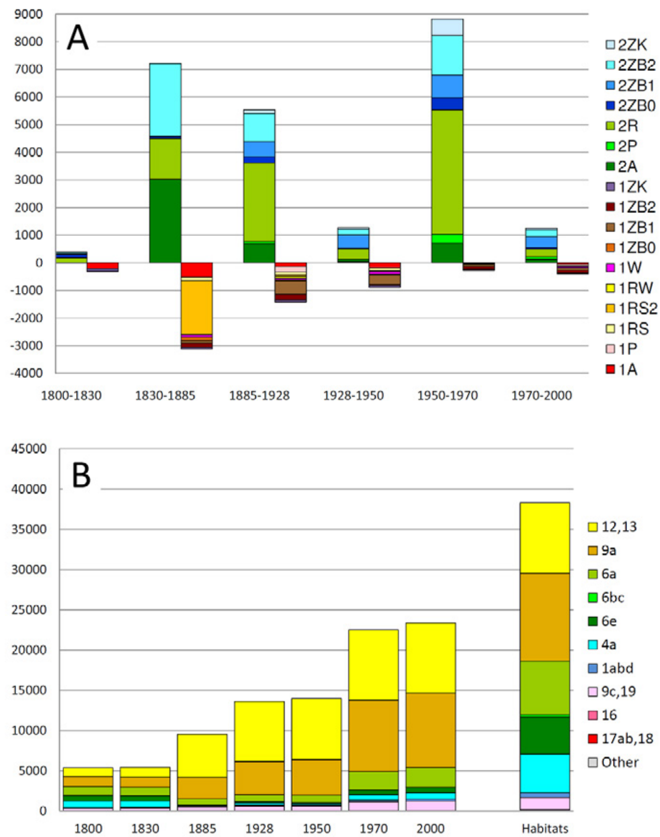

Fig. 7.18. Types of the forest surface decrements and increments (in hectares) (A); and the forest area on different habitats of the potential natural vegetation (B) on Wielbark region in years 1800-2000

Changes in forest cover on the habitats (Fig. 7.18B)

In the years 1800-1830 forest area decreased on the habitat of the deciduous floodplain woods and on the habitats of all the humid and wet sub-associations of the oak-hornbeam forest, with the decreases ranging from 5 to 66 hectares. On the remaining habitats the forested area slightly increased and only on the habitat of the fresh pine forest the increase exceeded 100 hectares. The respective changes were in relative terms quite limited and on no habitat did they exceed 2.1% of the habitat area.

The period between 1830 and 1885 was characterised by a clear increase of forest area on the habitats of the fresh pine forest and the fresh mixed pine forest (4128 and 1375 hectares, respectively), and by deforestations on the habitats of the deciduous floodplain forest, poor oak-hornbeam forest, and humid oak-hornbeam forest, all of them contained in the interval between 280 and 724 hectares. In the relative terms the share of forests increased on the habitat of the fresh pine forest by 47%, of the fresh mixed pine forest by 13%, and of the swampy pine forest and the spruce forest on peat bogs jointly by 21%. Bigger decreases occurred, on the other hand, only on the habitats of the deciduous floodplain deciduous forest and humid oak-hornbeam forest (15 and 11% of the habitat area, respectively).

During the years 1885-1928 small decreases of the forest cover took place on the habitats of the swampy pine forest and typical oak-hornbeam forest, along with differentiated, as to their scale, increases of forest areas on the remaining habitats. The biggest increments occurred on the habitats of the fresh pine forest and fresh mixed pine forest (2107 and 1507 hectares, respectively, which corresponded to the relative increases of 24 and 14%, respectively). Quite important relative increase, exceeding 11%, took also place on the alder woods habitat.

The period of 1928-1950 was characterised by small decreases of the forest areas on the habitats of humid pine forest, deciduous floodplain forest and the humid form of the oak-hornbeam forest, along with the increases on the remaining habitats, the increases exceeding 100 hectares only on the habitats of the fresh mixed pine forest and fresh pine forest. Consequently, changes in relative forest shares on particular habitats were very small, not exceeding 3% (except for the habitat of the swampy pine forest, where the decrease amounted to 84% of the total habitat area, but the total area of this habitat was below 12 hectares).

Between the years 1950 and 1970 forest cover increased on the areas of all the habitats. The highest increments were observed on the habitats of the fresh mixed pine forest, poor oak and hornbeam forest, and fresh pine forest (4453, 1389 and 1138 hectares, respectively). This brought the increase of relative forest cover on these habitats by, respectively, 41, 21 and 13%. Quite important relative increases of the forest cover – although for rather small total forest areas – exceeding 10% of the habitat area – were also observed on the habitats of the swampy pine forest, humid pine forest, humid mixed pine forest and alder woods.

During the last period considered, that is, 1970-2000, small increments to forest cover (not exceeding 350 hectares) occurred on almost all of the habitats. In the relative terms the biggest increase of forest share took place on the habitat of alder woods (11%), while on other habitats changes did not exceed 5%.

It can be concluded from the current perspective that the changes in the spatial distribution of forests, which have been taking place during the last 200 years, were accompanied by a constant, although uneven, increase of forest cover – namely the periods of strong increase of forest areas, i.e. 1830-1885, 1885-1928 and 1950-1970, existed along with periods of stabilisation or very slow increase, i.e. 1800-1830, 1928-1950 and 1970-2000. Regarding the rates and the directions of changes in the forest cover the habitats considered can be classified into three groups. The first of them includes the habitats of the swampy pine forest and of the spruce woods on peat bogs, as well as humid pine forest, on which the forest share over the entire period considered has been contained in the interval of 80-100%. The second group comprises the habitats of the fresh pine forest, typical mixed pine forest and humid mixed pine forest, on which forest share has been systematically increasing from, respectively, 13, 11 and 18% in 1800 to more than 99%, 84% and 76% in the year 2000. The third group contains the remaining habitats, on which forest cover had been decreasing between 1800 and 1885, to then start to increase, even though in the cases of the habitats of the deciduous floodplain forest and typical oak-hornbeam forest it is still lower than in the year 1800. In this third group the most pronounced increase of forest cover took place on the habitats of alder woods (from 8% in 1800 to 47% in 2000) and the poor oak-hornbeam forest (from 17% in 1800 to 37% in 2000).

Changes in the selected landscape metrics (Fig. 7.19)

The average magnitude of a patch was the highest in the years 1800 and 1830 (665 and 629 hectares, respectively). It decreased by 1885 to 78 hectares – the lowest value in the entire period considered of 200 years. Since that time the average magnitude of a patch has been increasing – to 133 hectares in 1928 and then to 385 hectares in 1950. Beginning with 1950 the changes in the patch magnitude have been limited (between 342 and 385 hectares) and statistically insignificant. Yet, there has been a clear increase of the maximum and minimum magnitudes of a patch, which attained in the year 2000, respectively, 51,588 hectares and 0.1 hectare.

The temporal course of values of the SI indicator was completely different. Generally speaking, during the 200 years these values did not undergo significant changes, fluctuating from period to period, and being all the time contained in the interval between 1.59 and 1.69. Behaviour of the maximum value of SI was yet different. It was the lowest in 1830 (4.44) and has been increasing systematically since then, up to 14.75 in the year 2000. The minimum value changed regularly, as well, decreasing from the value of 1.1 in 1830 to 1.0 in the year 2000.

Values of the PAR and FD metrics have been changing in quite a similar manner. In the case of PAR, the lowest values occurred in the years 1800 and 1830 (0.008 and 0.007, respectively). By the year 1885 there has been a distinct increase to 0.02, and then PAR has been decreasing over two consecutive periods, down to 0.015 in 1950. There was again a clear increase in 1970, up to 0.024, which was continued so that 0.03 was attained in 2000. In the years 1800-1970 the range of values between the minimum and maximum value of the PAR indicator has not changed much, with a slight increase of the maximum value from 0.02 to 0.05. It was only in the year 2000 when the maximum value sharply increased to the value of 0.23.

The lowest values of FD were observed in the years 1800 and 1830 (equal 1.25). Until the year 1885 a distinct increase took place to 1.29, and then during two periods the value decreased, down to 1.27 in 1950. The next distinct increase, to 1.3, took place by the year 1970, and then was continued up to the value of 1.31 in the year 2000. In the years 1800-1970 the range of values, from the minimum to maximum, of the FD indicator, has been undergoing small increase, related to a slight increase of the maximum value. It was only in the year 2000 that the maximum value increased in a more pronounced manner to 1.57.

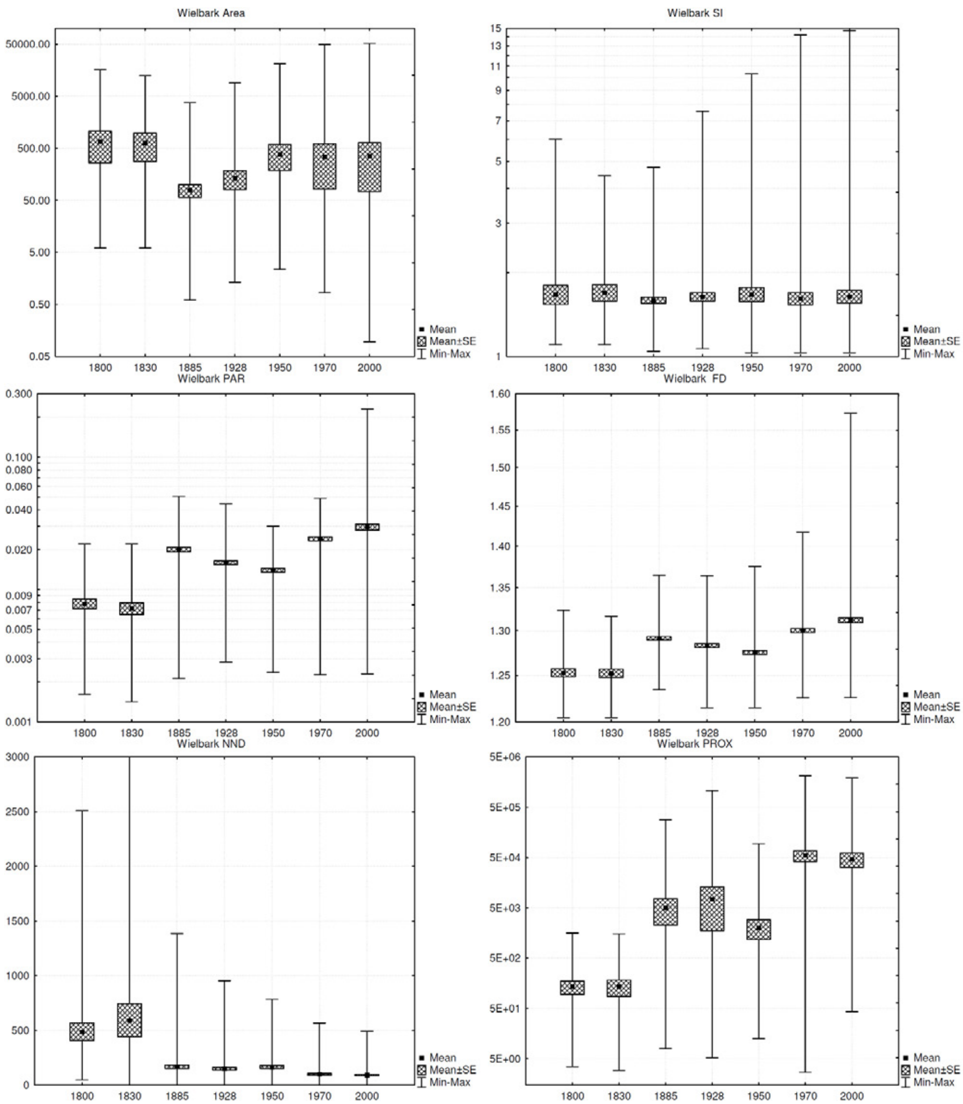

Fig. 7.19. Changes of the values of the chosen landscape metrics on Wielbark region in years 1800-2000

The temporal variability of the NND indicator displays a clear division into three intervals. The first one includes the years 1800 and 1830, when the value increased from 486 m to 592 m. Until the year 1885 a sharp decrease took place, down to 168 m, followed by small fluctuations, lasting until 1950. Then, another significant drop took place, down to 98 m, in 1970. A similar value (90 m) was also observed in the year 2000. Let us note that the maximum value of NND was the highest in 1830 (4869 m) and since that time it has been uniformly decreasing, through 954 m in 1928 to 491 m in 2000.

Changes in the values of the PROX indicator follow the three-stage pattern, as well, but with different characterisation than in the case of NND. In the years 1800 and 1830 the values of PROX were the lowest (at approximately 135). By the year 1885 this value increased to more than 4000, to then yet increase by 1928 to roughly 7000, and then to drop down to 2031 in 1950. Another sharp increase, to almost 55,000, that is – the highest value in the entire analysed period of two centuries – occurred in 1970. The value slightly decreased, to more than 46,000, by the year 2000. These latter time slices, i.e. 1970 and 2000, were also characterised by the highest maximum values, attaining as much as around 2 million. Let us yet add that the maximum values of PROX in the years 1800 and 1830 were lower than the average values in all the subsequent periods.

7.3.5. District of Szczytno

Differentiation of the fragmentation and consolidation processes (Fig. 7.20A)

In the period between 1800 and 1830 deforestation affected 909 hectares, while new forest surfaces appeared on 487 hectares. The primary cause for the decrements of the forest areas was distal shrinkage (1ZK), corresponding to 60% of the area of total decrements, along with the lateral shrinkages with smoothing of the boundary (1ZB1), as well as attrition of the entire patches (1A), the shares of the latter two processes amounting to 15% and 13%, respectively. The extensions of the forest areas took place owing to lateral increments without a change in the shape of the boundary (2ZB0) and lateral increments with simplification of the boundary (2ZB1), the share of these two processes in the new forestations being equal, respectively, to 67% and 33%.

During the period between 1830 and 1885 the biggest deforestations took place over the entire period of 200 years, amounting to 5274 hectares. The newly forested areas encompassed 1428 hectares. Two thirds of the whole area of deforestations resulted from the wide multiple subdivision (1RS2). The main processes, which led to the extensions of the forest cover, were consolidation (2R) – 45%, and creation of new patches (2A) – 25% of the new forest area.

In the years from 1885 to 1928 the decrements to forest area amounted to 1184 hectares, while new forestations – to 3032 hectares. The decrements were due in a similar degree to several processes, of which the most important were lateral shrinkage with smoothing of the boundary (1ZB1) – 27%, incisions (1W) – 25%, lateral shrinkage with complication of the boundary (1ZB2) – 16%, as well as attrition of the entire patches (1A) – 10% of the overall area of deforestations. The increments to the forest cover resulted also from a variety of processes, mainly from integration (2R) – 41%, lateral increment with complication of the boundary (2ZB2) – 24%, and creation of the new patches (2A) – 20% of the whole area of new forestations.

Between 1928 and 1950 the decrements to the forest cover were quite limited, amounting to only 256 hectares, while increments summed up to 810 hectares. A quarter of all the decrements were due to incisions (1W), followed as to significance by wide singular subdivision (1RS) – 21% of deforestations, while attrition of the entire patches (1A) and lateral shrinkages with smoothing of the boundary (1ZB1) caused 18% of deforestations each. The increments resulted mainly from the lateral increment with complication of the boundary (2ZB2) – 39%, integration (2R) – 28%, as well as lateral increment with simplification of the boundary (2ZB1) – 20% of the new forest area.

The period from 1950 to 1970 was characterised by the lowest losses to forest cover (164 hectares) and the biggest extensions of the forest area (5317 hectares) in the entire period analysed of 200 years. The primary process, resulting in the decrease of the forest area was lateral shrinkage with complication of the boundary (1ZB2) – 47% of all the decrements. The extensions to forest cover took place mainly through consolidation (2R) – 52%, and lateral increment with complication of the boundary (2ZB2) – 21% of the newly forested area.

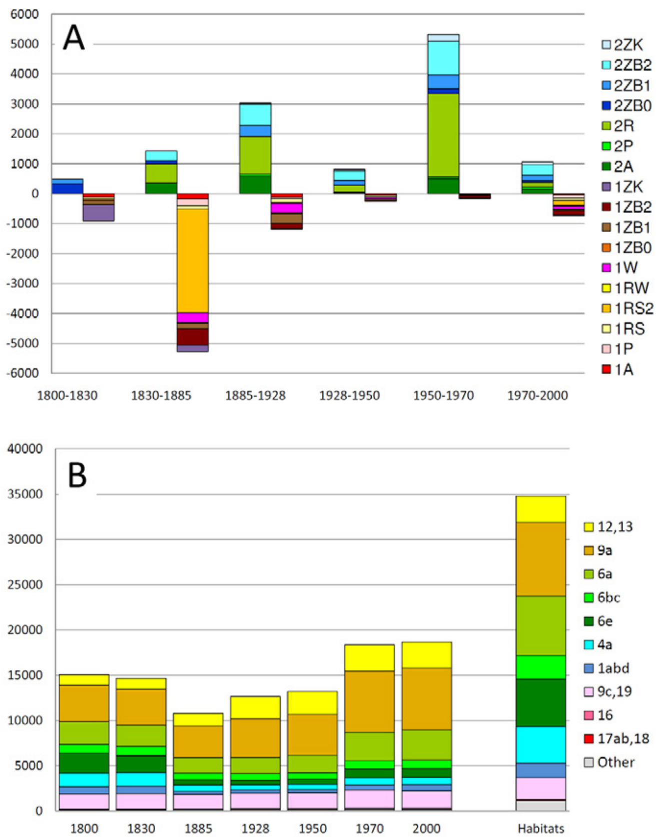

Fig. 7.20. Types of the forest surface decrements and increments (in hectares) (A); and the forest area on different habitats of the potential natural vegetation (B) on Szczytno region in years 1800-2000

In the last period considered, that is – 1970-2000 – the decrements summed up to 730 hectares, while increments to 1058 hectares. The decrements were due in a similar degree to several processes: wide multiple subdivision (1RS2) – 21% of all the deforestations, lateral shrinkage with complication of the boundary (1ZB2) – 19%, perforation (1P) – 16%, and incision (1W) – 14%. The increments resulted primarily from the lateral increment with complication of the boundary (2ZB2) – 34%, and lateral increment with simplification of the boundary (2ZB1) – 17%, as well as creation of new patches (2A) and integration (2R), the two latter processes corresponding to 15% of the new forest area.

Changes of forest cover on the habitats (Fig. 7.20B)

In the period 1800-1830 deforestations took place on the habitats of humid oak-hornbeam forest, poor oak-hornbeam forest and typical mixed pine forest (358, 136 and 81 hectares, respectively). Quite limited increases of forest area, not exceeding 60 hectares, occurred on the habitats of humid mixed pine forest, alder woods, typical oak-hornbeam forest, as well as fresh pine forest. Altogether, changes in forest area were not significant, and only on the habitat of humid oak-hornbeam forest the decrease amounted to 7% of forest area, while on all other habitats changes did not exceed 2% of the habitat area.

In the years 1830-1885 there was a clear domination of deforestations on the majority of habitats. The biggest deforestations took place on the habitats of the humid oak-hornbeam forest and the floodplain deciduous forest (1262 and 813 hectares, respectively). Smaller deforestations affected the habitats of the poor oak-hornbeam forest, typical mixed pine forest, humid mixed pine forest, alder woods, and typical oak-hornbeam forest (between 130 and 650 hectares). It was only on the habitat of the fresh pine forest that the forest area increased by 216 hectares. There was also a distinct change of forest shares on particular habitats. Increase by more than 7% of the habitat area concerned only fresh pine forest, while the biggest relative decreases occurred on the habitats of alder woods, humid oak-hornbeam forest and deciduous floodplain woods (31, 24 and 20% of area, respectively). The decreases were somewhat smaller, but still beyond 10%, on the habitats of the swampy pine forest, humid pine forest, and typical oak-hornbeam forest. On the remaining habitats the deforestations were smaller, yet still exceeding 5%.

The period from 1885 to 1928 saw, on the one hand, deforestations exceeding 100 hectares on the habitats of the deciduous floodplain forest and the humid oak-hornbeam forest, but, first of all, the increments to the forest cover on the habitats of the fresh pine forest (1033 hectares) and fresh mixed pine forest (800 hectares). On the remaining habitats the increments were much smaller, below 100 hectares. Altogether, forest share increased the most on the habitats of the humid pine forest, fresh pine forest, and swampy pine forest (by, respectively, 45, 35 and 29% of the habitat area). The decreases of forest shares, which occurred on only three habitats, were lower than 4%.

Between 1928 and 1950 small increases of the forest area took place on all the habitats, but only on the habitats of the poor oak-hornbeam forest and the typical mixed pine forest the increases exceeded 100 hectares, being lower than 80 hectares on all the other habitats. In effect of these increases, forest shares on particular habitats changed minimally, so that in no case the relative change exceeded 3.5% of the habitat area.

The period from 1950 to 1970 was also characterised by the forest area increase on all the habitats, and much bigger than in the preceding period, at that. An especially significant increase occurred on the habitats of the fresh mixed pine forest and the poor oak-hornbeam forest (2240 and 1207 hectares, respectively), while on the other habitats (except for the swampy pine forest and humid pine forest) the increases were contained in the interval of 150-450 hectares. These high increments of the forest areas resulted in the pronounced increases of forest shares on the particular habitats, the increases amounting to 28% on the habitat of the typical mixed pine forest, and to 13-18% on the habitats of the fresh pine forest, reed grass oak-hornbeam forest and humid mixed pine forest.

The consecutive period, that is, the years 1970-2000, was characterised by very limited changes in the forest covers on particular habitats, with the decrease of the forest cover on the habitat of the humid mixed pine forest by 111 hectares, and the increase on the habitats of the alder woods and poor oak-hornbeam forest – by 150 and 193 hectares, respectively. The biggest relative increase of the forest area took place on the alder woods habitat (by 9%), while changes on other habitats did not exceed 6%.

It can be stated from the current perspective that the changes in the distribution of forests, which took place over the last 200 years, could be perceived as forming two separate stages. The first of these stages consisted in the decrease of the forest area between the years 1800 and 1885, with the changes in forest cover in the period 1800-1830 being minimal. The second stage, lasting from 1885 to 2000, was characterised by a slow increase of the forest cover in the years 1885-1950, and a strong increase in the years 1950-1970, when the total forest share exceeded that from the year 1800. From the point of view of the rates and directions of changes in the forest cover the habitats can be classified into three groups. The first group consists of the habitat of the fresh pine forest only, on which forest cover has been increasing systematically from period to period, starting with 40% in 1800 and ending with 99% in 2000. The second group comprises the habitats of the swampy pine forest, humid pine forest, humid mixed pine forest, poor oak-hornbeam forest, and typical mixed pine forest, on which forest cover did decrease in the years 1830-1885, and then more or less uniformly increased until the year 2000, attaining values higher than in 1800. The third group encompasses the remaining habitats. On these other habitats a decrease of the forest cover also took place in the years 1830-1885, but then, in the years 1885-1950 forest cover has not changed much or even decreased further. Despite the increase of the forest cover on these habitats in the years 1950-2000, the terminal forest shares are still lower than in the year 1800.

Changes in the selected landscape metrics (Fig. 7.21)

In the period between 1800 and 1830 the average patch magnitude increased from 885 hectares to 1125 hectares, but then dropped down by the year 1885 to 115 hectares. In the consecutive periods, up till 1970, the average magnitude of a patch has been increasing – to 156 hectares in 1928, 338 hectares in in 1950, and 358 hectares in 1970. In the year 2000 the average surface of a patch was equal 271 hectares and was statistically insignificantly different from those in the two preceding periods. The maximum patch magnitude was the lowest in 1830 (3771 hectares) and since that time it has been systematically increasing, reaching 49,160 hectares in 1970, and yet 51,588 hectares in 2000. This last time instant observed was also characterised by the lowest minimum surface of a patch.

Two time intervals can be distinguished regarding the changes in the value of the SI indicator. The first of these intervals encompasses the years 1800 and 1830 and is characterised by the increase of the indicator value from 1.6 to 1.7. By the year 1885 this value decreased to 1.55, and since that time almost regularly increased, to 1.6 in 1928, 1.65 in 1950, and 1.68 in 2000. Attention ought to be paid to the fact that in this sequence of values no consecutive two are statistically significantly different, but the difference between the values of SI in 1885 and in 2000 is statistically significant.

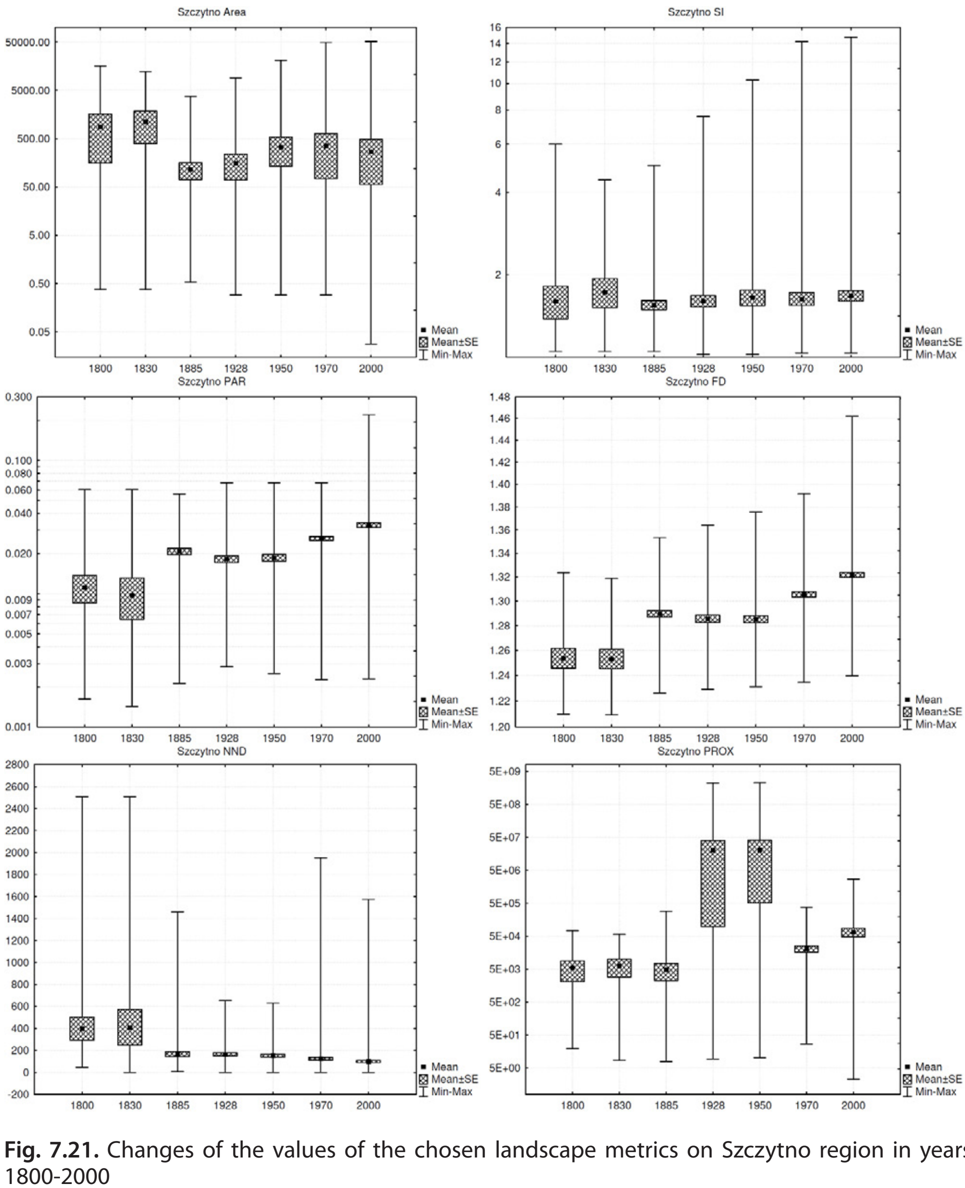

Fig. 7.21. Changes of the values of the chosen landscape metrics on Szczytno region in years 1800-2000

Another type of variability is represented by the PAR metric. Its values were the lowest in the years 1800 and 1830 (0.011 and 0.010, respectively). In 1885 a significant increase took place up to 0.021, followed by a decrease by 1928 (statistically significant), down to 0.018. Starting with this time instant, constant increase of PAR value has been observed, through 0.019 in 1950, 0.026 in 1970, to 0.033 in the year 2000. Let us also add that the maximum value of PAR changed in the years 1800-1970 only a little, being contained in the interval of values 0.06-0.07, while in 2000 it increased sharply to 0.22.

The scheme of temporal changes was in principle identical for the FD indicator. The average values were the lowest (equal to 1.25) in the years 1800 and 1830, and then increased to 1.29 in 1885. Until 1950 this average persisted at a similar level, and then increased in 1970 to 1.3, and in 2000 to 1.32. In distinction from the case of the PAR indicator, the maximum values of FD were the lowest in the years 1800 and 1830, and amounted to 1.21, to then increase in the consecutive periods, initially slowly, to 1.23 in 1885, 1950 and 1970, and thereafter faster, to 1.24 in the year 2000.

The highest values of the NND indicator were observed in the years 1800 and 1830 (397 m and 410 m, respectively). Then a decrease followed, to 166 m in 1885. Since that time further, very slow decrease of the NND value has been observed, to the level of 153 m in 1950 (the differences between the years 1885, 1928 and 1950 being statistically insignificant), and then to 123 m in 1970, and yet to 99 m in the year 2000. The maximum value of NND did not display such regularity. It was the highest (2507 m) in the years 1800 and 1830, to then drop to 1461 m by the year 1885, and to less than 653 m in the years 1928-1950. The two later periods were characterised by the maximum value of NND higher than 1573 metres.

Quite specific course over time was observed for the PROX indicator. The value of this indicator has been little variable in the period 1800-1885, being contained in the interval 5000-6400. Then, the years 1928 and 1950 were characterised by very high values of this indicator, exceeding 20 million. This value dropped to a bit more than 20,000 by the year 1970, and then rose again to almost 68,000 by the year 2000.

7.3.6. District of Spychowo

Differentiation of the fragmentation and consolidation processes (Fig. 7.22A)

During the period 1800-1830 deforestation affected 629 hectares, while new forest areas appeared on 707 hectares. More than half (51%) of the decrements in forest cover were due to the attrition of the entire patches (1A), while the remaining decrement processes were the lateral shrinkage with evening out of the boundary (1ZB2) and without a change in the character of the boundary (1ZB0), which contributed, respectively, 27 and 20% of the decrement area. The increments of the forest cover took place primarily owing to the lateral increment without a change in the character of the boundary (2ZB0) – 45%, and to integration (2R) – 26%, as well as lateral increment with simplification of the boundary (2ZB1) – 24% of the newly forested area.

During the period between 1830 and 1885 the biggest deforestations took place, encompassing 5766 hectares, while newly forested area amounted to 1808 hectares. This was the sole period, when decrements were bigger than increments. The decrements were mainly due to the wide multiple subdivision (1RS2) – 55% of the area of decrements, and single wide subdivision (1RS) – 17%. The majority of the new forestations arose owing to the lateral increment with complication of the boundary (2ZB2) – 53%, and to creation of the new patches (2A) – 32% of the newly forested area.

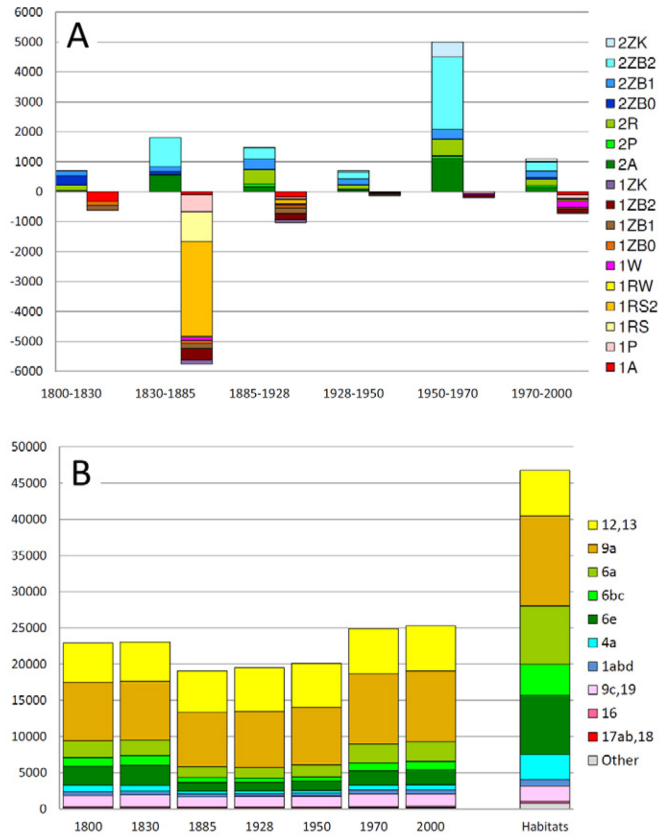

Fig. 7.22. Types of the forest surface decrements and increments (in hectares) (A); and the forest area on different habitats of the potential natural vegetation (B) on Spychowo region in years 1800-2000

From 1885 to 1928 1024 hectares of forest disappeared, while new forest surfaces appeared on 1483 hectares. The decrements to forest cover resulted from numerous different processes, none of which played a dominant role. The most important among them were the lateral shrinkage with complication of the boundary (1ZB2), lateral shrinkage with smoothing of the boundary (1ZB1), attrition of the entire patches (1A), as well as wide multiple subdivision (1RS2). These processes corresponded to, respectively, 20, 19, 18 and 14% of total decrement area. The extensions to the forest cover took place mainly owing to integration (2R) – 31%, as well as lateral increment with simplification (2ZB1) and with complication of the boundary (2ZB2) – 25% of the increments each.

The period of 1928-1950 was characterised by the lowest losses to the forest cover (139 hectares) over the entire time period considered. The increments were also very limited, amounting to 710 hectares only. The decrements occurred primarily due to the lateral shrinkage with evening out of the boundary (1ZB1) – 31%, lateral shrinkage without a change in the character of the boundary (1ZB0) – 15%, and the attrition of the entire patches (1A), as well as incisions (1W) – the latter two accounting for 14% each.

New forest areas appeared mainly owing to lateral increments with complication of the boundary (2ZB2) and with simplification of the boundary (2ZB1) – 31 and 29%, respectively, of the newly forested area.

From 1950 to 1970 the decrements affected 204 hectares formerly under forest, while the increments encompassed the biggest area during the whole period of 200 years – 4998 hectares in total. The decrements to the forest cover occurred mainly through lateral shrinkage with complication of the boundary (1ZB2) – 30%, as well as perforation (1P) and incisions (1W) – 27 and 21%, respectively, of the deforested area. The increments comprise mainly the lateral increments with complication of the boundary (1ZB2) – 49%, and creation of the new patches (2A) – 22% of the newly forested surfaces.

Finally, in the years 1970-2000 the decrements amounted to 720 hectares of forest, while increments encompassed 1101 hectares of the newly forested area. The causes of the decrements to the forest cover were mainly incisions (1W) – 28% of the area, along with lateral shrinkages with complication of the boundary (1ZB2) – 19%, and perforation (1P) – 17%. Forest cover extended primarily through lateral increment with complication of the boundary (2ZB2) – 28%, and with simplification of the boundary (2ZB1) – 20%, as well as integration (2R) – 20% and creation of new patches (2A) – 14% of the new forested surfaces.

Changes of forest cover on habitats (Fig. 7.22B)

In the period between 1800 and 1830 limited deforestations (40-155 hectares) took place on the habitats of deciduous floodplain woods, poor oak-hornbeam forest, and typical mixed pine forests. Forestations, on the scale of 50-160 hectares occurred on the habitats of the humid mixed pine forest, humid oak-hornbeam forest, typical oak-hornbeam forest, and fresh pine forest. All this did not change essentially the structure of forest cover on the habitats – on none of them the changes exceeded 4%.

The years 1830-1885 were characterised by the decrease of the forested areas on all the habitats except for that of the fresh pine forest. The biggest losses, in absolute terms, took place on the habitat of humid oak-hornbeam forest (1580 hectares), followed by those on the habitats of deciduous floodplain forest, typical and poor oak-hornbeam forest, as well as typical mixed pine forest (between 400 and 700 hectares). Forest surface increased only on the habitat of the fresh pine forest – by close to 300 hectares. The biggest decreases of the forest share (exceeding 10% of the habitat area) occurred on the habitats of humid pine forest, humid mixed pine forest, alder woods, deciduous floodplain woods, humid as well as typical oak-hornbeam forest.

Between 1885 and 1928 forest cover increased on several habitats, the increase being the biggest on the habitats of typical mixed pine forest and fresh pine forest (267 and 335 hectares, respectively), while there has been a limited decrease of the forest cover on the habitats of the typical and reed grass oak-hornbeam forests, not exceeding altogether 200 hectares. These limited changes have not entailed bigger shifts in the forest cover shares on the habitats, and it was only on the habitat of the fresh pine forest that the forest share increased by more than 5%.

The time interval between 1928 and 1950 was characterised by a very small increase of the forest cover on all the habitats, with exception of the swampy pine forest habitat, where approximately 2 hectares of forest disappeared, and the fresh pine forest habitat, where the loss amounted to 14 hectares. On the habitats of the poor oak-hornbeam forest and the typical mixed pine forest the increases amounted to 255 and 179 hectares, respectively, while on no other habitat did the increment exceed 55 hectares. These highly limited changes in forest cover brought only minimal changes in forest shares on the habitats, not exceeding 4%.

Then, from 1950 till 1970 there has been an increase of the forest cover on all the habitats, and the biggest one, amounting to 1951 hectares, occurred on the habitat of typical mixed pine forest. On all the other habitats (except for the habitats of the swampy and humid pine forests – where the changes did not exceed 20 hectares) the increase was contained in the interval between 180 and 900 hectares. The proportions of forests on habitats underwent distinct changes. It was only on the habitat of the fresh pine forest that the relative increase was lower than 5%, and was lower than 10% on the habitats of humid pine forest, deciduous floodplain woods, and humid oak and hornbeam woods. On all the other habitats, the forest shares increased by more than 10%.

The period from 1970 to 2000 was yet another period with very small changes. The decrements to the forest cover, not exceeding 50 hectares, took place only on the habitats of humid pine forest, humid mixed pine forest, and fresh pine forest. On all the remaining habitats forest cover increased, by 157 hectares on the habitat of the poor oak-hornbeam forest and by less than 80 hectares on all the other ones. There was no habitat, on which the change in forest share would exceed 3%.

It can be stated from the perspective of today that the changes in the distribution of forests, having taken place during the last 200 years, formed two separate stages. The first of these stages consisted in the decrease of forest cover between the years 1800 and 1885, with, however, the changes taking place between 1800 and 1830 being truly minimal. The second stage, which lasted from 1885 till 2000, was characterised by a very slow increase of forest cover in the period 1885-1950, and a strong increase in the years 1950-1970, when the forest share exceeded that of the year 1800. In terms of the rates and directions of changes in forest shares all the habitats can be classified into three groups. The first group includes only the habitat of the fresh pine forest, on which forest cover has been systematically increasing period to period, from 86% in 1800 to 99% in the year 2000. The second group comprises the habitats of the swampy and humid pine forests, as well as humid and typical mixed pine forest, on which forest share decreased in the period 1830-1885, and then increased more or less uniformly until the year 2000, attaining values higher than in 1800. The third group encompasses all the other habitats. On those habitats a decrease of the forest cover also took place in the years 1830-1885, but then, in the years 1885-1950 there have been no significant changes to the forest share, or even this share decreased. Further, despite the increase of the forest cover on these habitats in the years 1950-2000, the final values were lower or only slightly higher, compared to those of the year 1800.

Changes in the selected landscape metrics (Fig. 7.23)

The average surface of a patch increased from 2257 hectares in 1800 to 3320 hectares in 1830, to then decrease by the year 1885 to only 227 hectares. Since that time, until the year 2000, the changes of the average patch area were relatively small and statistically insignificant, although one could indicate a weak trend, first upward to 317 hectares in 1950, and then downward to 261 hectares in 2000. The maximum magnitude of a forest patch changed in a different manner – from around 19,000 hectares in the years 1800 and 1830, to the value of approximately 15,000 hectares in 1885, the latter value persisting roughly until as late as 1950, to then increase to more than 49,000 hectares in the years 1970 and 2000.

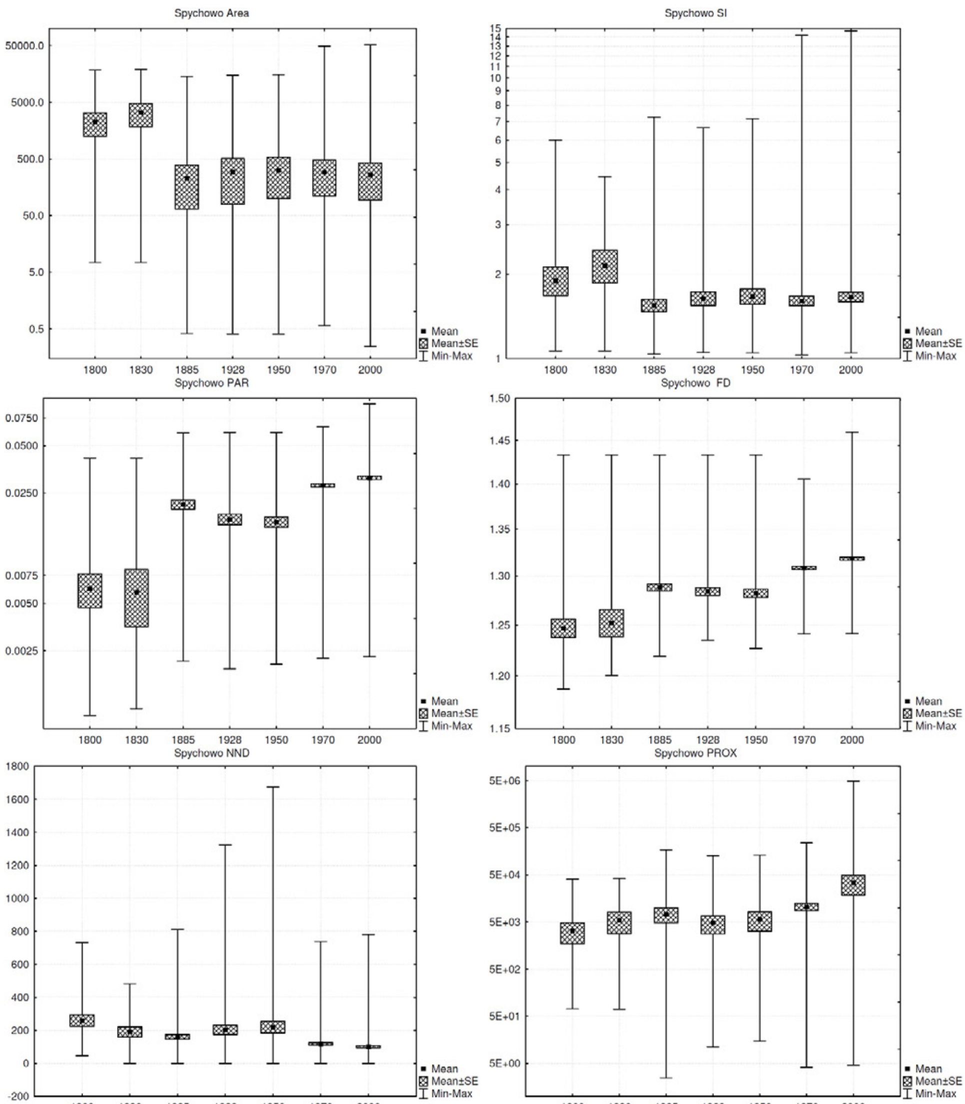

Fig. 7.23. Changes of the values of the chosen landscape metrics on Spychowo region in years 1800-2000

The average value of SI increased from 1.9 in the year 1800 to 2.1 in 1830, and then dropped to 1.5 in 1885. In the subsequent periods, up till the year 2000, a weak upward tendency has been observed, with small changes, and values being contained in the interval 1.61-1.67.

A distinct division into three different periods characterises the temporal variability of the PAR indicator. It was the lowest (0.006) in the years 1800 and 1830, to then increase to 0.021 by 1885, and next to decrease to 0.017 by 1928, and to 0.016 in 1950. There was a distinct increase between 1950 and 1970, to 0.028, continued up to 0.031, attained in the year 2000. A similar division into three periods concerns also the course of maximum values of PAR. The maximum was the lowest (0.04) in the years 1800 and 1830, and then between 1885 and 1950 its value was around 0.06. The last period considered, i.e. the years 1970 and 2000, featured the increase of the maximum value of PAR from 0.07 to 0.09.

The pattern of changes in time was much alike for the FD indicator. Its value was the lowest (around 1.25) in the years 1800 and 1830, then it increased to 1.29 in 1885, and afterwards decreased evenly to 1.28 in 1950. In the last period, i.e. in the years 1970 and 2000, the value of FD increased from 1.31 to 1.32. It is interesting to note that between the years 1800 and 1950 the maximum value of FD has not been changing, persisting at 1.43, and decreased only in 1970 to 1.41, to then increase again in the year 2000. The specific course of variability of the FD indicator in the district of Spychowo, as compared to other areas considered, is also associated with the most regular increase of the minimum value of this indicator, from 1.19 in 1800 to 1.24 in the year 2000.

Temporal variability of the NND indicator features also a characteristic course, with oscillations around a general downward tendency. Its value was the highest (259 m) in 1800, to gradually decrease down to 161 m in 1885, and then to increase to 219 m in 1950, and to gradually decrease again to 101 m in the year 2000. The maximum value of NND displayed a more irregular variability. It was the lowest (482 m) in the year 1830, and the highest (1674 m) in 1950.

The temporal course of the PROX indicator featured a slight and irregular upward tendency in the years 1800-1950, when it has been taking value from the interval 3250-5670 (the consecutive differences being statistically insignificant). A more pronounced increase, up to the value of 10,521, took place in the year 1970, followed by a further significant increase to 33,640 by the year 2000.

7.4. The similarities and the differences as to the course of processes on the areas considered

In the year 1800, that is – at the very beginning of the period analysed, the differentiation of regions with respect to the absolute forest area on the particular habitats was quite significant, but also inhomogeneous. Two separate parts could be easily distinguished: the less internally diversified north-western part (areas of Wielbark, Szczytno and Jedwabno), and the southern and eastern areas (Parciaki, Spychowo and Myszyniec), the respective areas being less mutually similar (Fig. 7.24A). Similarity between districts in terms of forest shares on particular habitats only partly corresponded to the similarity in terms of absolute forest cover areas on the habitats (Fig. 7.24B). The forest share structures were especially alike in the areas of Spychowo and Myszyniec, as well as in Szczytno and Jedwabno. It ought to be emphasised that each of the remaining areas (Wielbark, Parciaki) featured to such an extent specific forest share structures that similarity with any other area was lower than 10%. Concerning the similarity as to the magnitude, shape and mutual position of the forest patches, defined with the landscape metric values, there was a clear division into two parts of the area considered in the year 1800. The first of these two, situated in the east of the study area, encompassed Spychowo and Myszyniec, while the second one included the remaining subregions of the study area. It should be emphasised that within the framework of the second part, the areas of Wielbark and Szczytno featured higher mutual similarity (Fig. 7.24C).

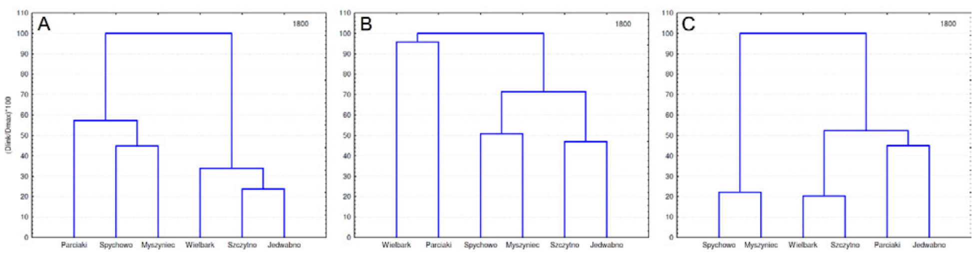

Fig. 7.24. Similarity between regions in 1800 based on: A – forest cover area (ha) on different habitats – raw data; B – percentage share of forest cover on different habitats – raw data; C – landscape metrics values (MPS, MaxArea, FD, SI, PAR, NND, PROX) – standardized data. Dendrograms constructed according to Ward's method with Euclidean distances

The changes in the spatial distribution of forests, which took place in the years 1800-1830, were brought about by the significant deforestations in the district of Parciaki, accompanied by very small (Myszyniec, Jedwabno) or small deforestations in the remaining districts, as well as the smallest areas of new forest over the entire period analysed of 200 years. In the district of Parciaki the most intensive deforestation (exceeding 10% of the respective habitats) affected the humid and fertile habitats, that is – those of the deciduous woods, *Fraxino-Alnetum*, and the humid form of the oak-hornbeam forest, *Tilio-Carpinetum stachyetosum*. The types of fragmentation and consolidation in the particular districts were also quite differentiated, which entailed changes in the values of some landscape metrics (Table 7.6). The dendrogram of similarity of the districts with respect to changes in terms of changes in forest cover on particular habitats indicates that, side by side with the quite obvious isolation of the district of Parciaki, the remaining districts were divided into two groups, the highest similarity as to the magnitude of changes in forest cover on the habitats being observed for three districts: Szczytno, Wielbark and Myszyniec (Fig. 7.25A). The similarity as to the surfaces affected by the particular categories of fragmentation and consolidation of the forest patches had a somewhat different character (Fig. 25B). Thus, apart from Parciaki, a specific structure of domination of these processes, different than in other districts, was characteristic for Myszyniec and Szczytno.

The changes, which took place in the years 1800-1830 as to the distribution and character of forests did not bring about strong changes in the similarity between the particular districts, neither as to the absolute areas of forests (Fig. 7.26A), nor as to the forest shares on particular habitats (Fig. 7.26B). There were also virtually no changes in the division into two areas, distinguished with respect to the values of landscape metrics (Fig. 7.26C).

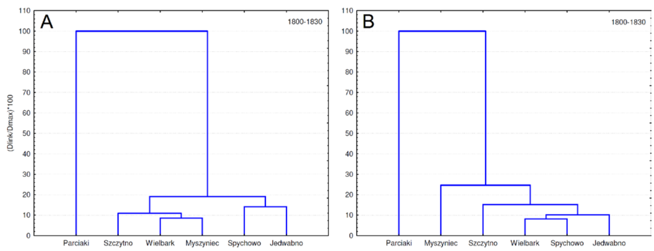

Fig. 7.25. Similarity between regions based on changes taking place in years 1800-1830: A – changes of forest cover area (ha) on different habitats – raw data; B – area of different categories of forest decrement and increment. Dendrograms constructed according to Ward's method with Euclidean distances

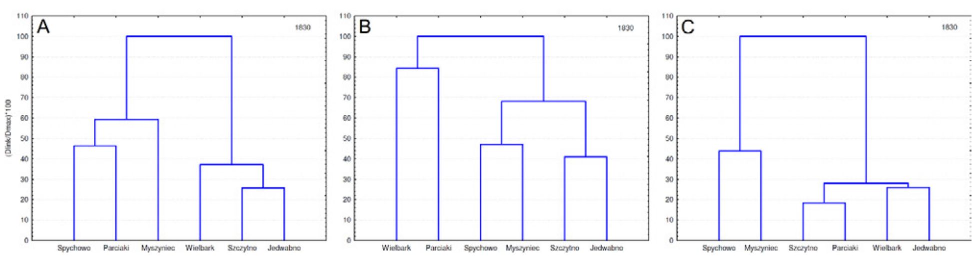

Fig. 7.26. Similarity between regions in 1830 based on: A – forest cover area (ha) on different habitats – raw data; B – percentage share of forest cover on different habitats – raw data; C – landscape metrics values (MPS, MaxArea, FD, SI, PAR, NND, PROX) – standardized data. Dendrograms constructed according to Ward's method with Euclidean distances

It should be emphasised, though, that in in 1830, contrary to 1800, the districts of Parciaki and Szczytno featured higher similarity within the framework of the second area.

The period between 1830 and 1885 was characterised by the maximum deforestations in all the districts, compared to all the other periods considered during the 200 years analysed. In absolute terms the biggest deforestations occurred in the district of Myszyniec, and they were 3 to 7 times bigger than in other districts. The deforestations were accompanied by the new forestations, which were the highest in relative terms in Myszyniec and Parciaki, quite significant in Wielbark, and moderate in other in the remaining districts (Table 7.6). In all the districts, the dominating deforestation process consisted in multiple wide subdivision, while the subdominating processes differed among districts. The forestation processes were more diversified, although most often the primary role was played by the lateral accretion with complication of the boundary. The deforestations affected humid and wet habitats, including the habitats of the deciduous floodplain woods *Fraxino-Alnetum*, alder woods *Ribeso-Alnetum*, humid mixed pine forest *Querco roboris-Pinetum molinietosum*, as well as various forms, in terms of soil fertility, of the oak-hornbeam forest. On the other hand, forest shares increased on the poorer habitats, including the habitat of the fresh pine forest – in Parciaki and Wielbark by more than 10% of habitat area, while in Myszyniec and Szczytno – by more than 5% (Table 7.6).

The analysis of the dendrogram from Fig. 7.27A indicates that the similarity of districts with respect to the forest area on the particular habitats in the years 1830-1885 changed gradually. Only Szczytno and Spychowo formed a compact group, which the district of Jedwabno approached, while Myszyniec and Wielbark displayed only a low degree of similarity to the remaining districts. The similarity with respect to the areas subject to different categories of decrement and increment of the forest patches featured quite akin characteristics (Fig. 7.27B). In particular, Szczytno and Spychowo formed a very compact group (just like in the case of similarity with respect to changes of forest cover on the habitats).

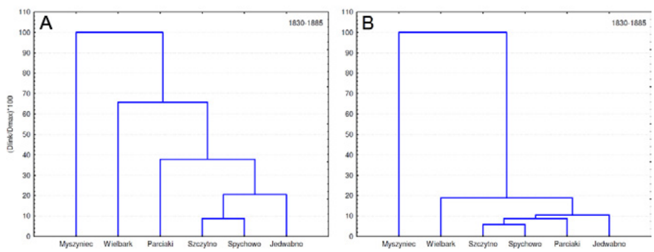

Fig. 7.27. Similarity between regions based on changes taking place in years 1830-1885: A – changes of forest cover area (ha) on different habitats – raw data; B – area of different categories of forest decrement and increment. Dendrograms constructed according to Ward's method with Euclidean distances

The processes, which took place in the years 1830-1885, changed the scheme of similarities between the districts. In place of two groups of districts, distinguished in 1830 for the forest covers on individual habitats, there were in 1885 three distinct groups: Szczytno and Jedwabno, Spychowo and Myszyniec, as well as Wielbark and Parciaki, with the difference between the second and third groups being smaller than between them and the first group (Fig. 28A). The similarity between the districts, defined for the forest shares on particular habitats, underwent smaller changes. Like in the preceding period, the groups of Spychowo and Myszyniec, as well as Szczytno and Jedwabno, were preserved, but the district of Parciaki became more similar to the first group, while the district of Wielbark – to the second one (see Fig. 7.28B). In view of the changes in all the landscape metrics in the period 1830-1885 (see Table 7.6), there has also been a distinct change in the similarities of districts with respect to magnitude, shape and mutual location of the forest patches. Only Wielbark and Szczytno were characterised by relatively high mutual similarity with this respect (Fig. 7.28C).

In the years 1885-1928 intensive deforestation continued in the districts of Parciaki and Myszyniec, while they were much more limited in other regions. The dominating decrement process was most often the lateral shrinkage with evening out of the boundary (except for Parciaki, where primarily wide multiple subdivision contributed to the deforestation). The new forestations had a different spatial distribution. They were very limited in Parciaki, medium-sized in Spychowo and quite large in other districts.

Table 7.6. Synthetic characteristics of the main processes in the course of forest changes in analysed regions

Processes and indices		Regions	Periods					
			1800-1830	1830-1885	1885-1928	1928-1950	1950-1970	1970-2000
Deforestation	Area	Parciaki	big	maximum	big	small	medium	minimum
		Myszyniec	minimum	maximum	big	small	medium	medium
		Jedwabno	minimum	maximum	small	small	small	small
		Wielbark	small	maximum	medium	small	minimum	small
		Szczytno	small	maximum	medium	small	minimum	small
		Spychowo	small	maximum	medium	minimum	small	small
	Dominating process	Parciaki	1RS	1RS2	1RS2	1A	1ZB2	1ZB1
		Myszyniec	1ZB0	1RS2	1ZB1	1A	1RS2	1A
		Jedwabno	1ZB1	1RS2	1ZB1	1A	1P	1P
		Wielbark	1A	1RS2	1ZB1	1ZB1	1ZB2	1ZB2
		Szczytno	1ZK	1RS2	1ZB1	1W	1ZB2	1RS2
		Spychowo	1A	1RS2	1ZB2	1ZB1	1ZB2	1W, 1ZB2
	Subdominating process	Parciaki	1A	1ZB2, 1ZK, 1RS	1ZB1	1ZB1	1RS, 1RS2	1P, 1ZB2
		Myszyniec	1RW	1ZB2	1A	1ZB1	1ZB2	1W, 1ZB2
		Jedwabno	1A	1ZK	1RS2	1ZB1	1ZB2	1ZB1, 1ZB2
		Wielbark	1ZK	1A	1ZB2	1A	1ZB1	1ZB1, 1P
		Szczytno	1ZB1, 1A	1ZB2	1W	1RS	1ZK	1ZB2, 1P
		Spychowo	1ZB1, 1ZB0	1RS	1ZB1, 1A	1ZB0	1P, 1W	1ZB2, 1P
Aforestation	Area	Parciaki	minimum	maximum	small	big	big	small
		Myszyniec	minimum	maximum	big	big	big	medium
		Jedwabno	minimum	medium	big	medium	maximum	medium
		Wielbark	minimum	big	big	medium	maximum	medium
		Szczytno	minimum	medium	big	small	maximum	medium
		Spychowo	minimum	medium	medium	small	maximum	medium
	Dominating process	Parciaki	2ZB2	2ZB2	2R	2ZB2	2ZB2	2ZB2
		Myszyniec	2ZB2	2ZB2	2R	2ZB1	2ZB2	2ZB2
		Jedwabno	2ZB0	2ZB2	2R	2R	2R	2ZB1
		Wielbark	2R	2A	2R	2R	2R	2ZB1
		Szczytno	2ZB0	2R	2R	2ZB2	2R	2ZB2
		Spychowo	2ZB0	2ZB2	2R	2ZB2	2ZB2	2ZB2
	Subdominating process	Parciaki	2ZB0	2R, 2A	2ZB0, 2ZB1	2ZB1, 2R	2A	2R
		Myszyniec	2A	2R	2ZK	2ZB2, 2A	2A	2A
		Jedwabno	2ZB1	2A	2ZB2	2ZB1	2ZB1	2ZB2
		Wielbark	2ZB0	2ZB2	2ZB2	2ZB2	2ZB2	2R, 2ZB2
		Szczytno	2ZB1	2A	2ZB2, 2A	2R	2ZB2	2ZB1
		Spychowo	2R, 2ZB1	2A	2ZB1, 2ZB2	2ZB1	2A	2ZB2
Forests on habitats	Decrease > 10% habitat area	Parciaki	4a, 6e	4a, 6a, 6bc	9c, 6a, 9a	-	-	-
		Myszyniec	-	9c, 4a, 6e, 6bc, 6a, 9a	-	-	-	-
		Jedwabno	-	9c, 19, 1abd, 4a, 6e	-	-	-	-
		Wielbark	-	4a, 6e	-	-	-	-
		Szczytno	-	1abd, 4a, 6e, 6bc	-	-	-	-
		Spychowo	-	9c, 19, 1abd, 4a, 6e, 6bc	-	-	-	-
	Decrease > 5% habitat area	Parciaki	-	6e	1abd, 4a, 6e	-	-	-
		Myszyniec	-	-	9c, 1abd, 6bc, 9a	-	-	-
		Jedwabno	-	-	-	-	-	-
		Wielbark	-	6bc	-	-	-	-
		Szczytno	6e	9c, 19, 6a, 9a	-	-	-	-
		Spychowo	-	6a	-	-	-	-
	Increase > 10% habitat area	Parciaki	-	12	-	-	9a, 12	-
		Myszyniec	-	-	-	-	9c, 9a	-
		Jedwabno	6e	-	9c, 19, 9a, 13	-	9c, 19, 1abd, 6e, 6a, 9a	-
		Wielbark	-	9a, 13	1abd, 9a, 13	-	9c, 19, 13, 1abd, 6a, 9a	1abd
		Szczytno	-	-	13	-	9c, 19, 6a, 9a, 13	-
		Spychowo	-	-	-	-	9c, 19, 1abd, 6bc, 6a, 9a	-
	Increase > 5% habitat area	Parciaki	-	-	-	9c	1abd	-
		Myszyniec	-	12	-	12	12	-
		Jedwabno	-	-	1abd	-	4a, 6bc, 13	1abd, 4a, 6e
		Wielbark	-	9c, 19	9c, 19	-	4a, 6e	-
		Szczytno	-	13	9a	-	1abd, 4a, 6e, 6bc	1abd
		Spychowo	-	-	13	-	4a, 6e	-
Total change of forest area		Parciaki	Decrease (6500 ha)					
		Myszyniec	Significant Decrease (13,300 ha)					
		Jedwabno	Significant Increase (14,400 ha)					
		Wielbark	Significant Increase (18,022 ha)					
		Szczytno	Increase (3616 ha)					
		Spychowo	Increase (2325 ha)					
Landscape metrics	Mean Patch Size	Parciaki	stable	decrease	stable		decrease	stable
		Myszyniec	stable	decrease	small increase	stable	decrease	stable
		Jedwabno	stable	decrease	small increase	small increase	increase	stable
		Wielbark	stable	decrease	small increase	increase	stable	
		Szczytno	small increase	decrease	small increase	increase	stable	
		Spychowo	increase	decrease	stable			
	SI	Parciaki	stable		small decrease	stable		
		Myszyniec	stable	decrease	small increase	stable	decrease	small increase
		Jedwabno	stable	decrease	small increase	stable	small increase	stable
		Wielbark	stable	small decrease	small increase	stable		
		Szczytno	small increase	decrease	small increase	small increase	small increase	small increase
		Spychowo	increase	decrease	small increase	stable		small increase
	PAR	Parciaki	stable	increase	increase	decrease	increase	small increase
		Myszyniec	stable	increase	decrease	small increase	increase	small increase
		Jedwabno	small increase	increase	decrease	stable	increase	stable
		Wielbark	small decrease	increase	decrease	decrease	increase	increase
		Szczytno	small decrease	increase	decrease	stable	increase	increase
		Spychowo	stable	increase	decrease	stable	increase	increase
	FD	Parciaki	stable	increase	increase	decrease	increase	small increase
		Myszyniec	small increase	increase	small decrease	stable	increase	small increase
		Jedwabno	increase	increase	small decrease	stable	increase	stable
		Wielbark	stable	increase	decrease	decrease	increase	increase
		Szczytno	stable	increase	decrease	decrease	increase	increase
		Spychowo	small increase	increase	decrease	stable	increase	increase
	NND	Parciaki	increase	decrease	stable		decrease	stable
		Myszyniec	stable	decrease	small increase	stable	decrease	stable
		Jedwabno	stable	decrease	small decrease	small increase	stable	
		Wielbark	increase	decrease	stable		decrease	stable
		Szczytno	stable	decrease	stable		decrease	stable
		Spychowo	decrease	small decrease	small increase	small increase	decrease	stable
	PROX	Parciaki	decrease	increase	decrease	decrease	increase	stable
		Myszyniec	increase	increase	decrease	stable	increase	stable
		Jedwabno	increase	increase	decrease	increase	increase	decrease
		Wielbark	stable	increase	small increase	decrease	increase	stable
		Szczytno	stable		increase	stable	decrease	increase
		Spychowo	small increase	small increase	decrease	small increase	increase	increase

Codes for (de)fragmentation processes – see Table 7.1, codes for potential vegetation types – see Table 7.5. Small area habitats (codes 16, 17ab, 18) omitted.

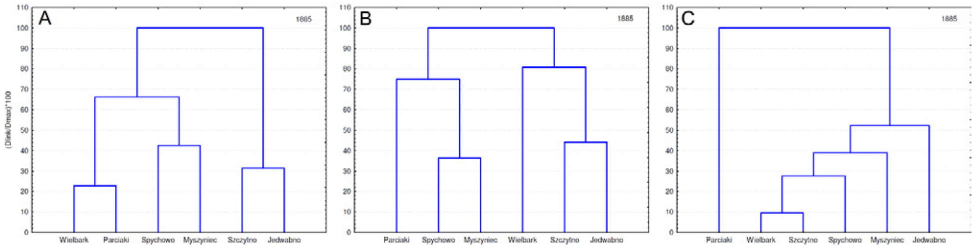

Fig. 7.28. Similarity between regions in 1885 based on: A – forest cover area (ha) on different habitats – raw data; B – percentage share of forest cover on different habitats – raw data; C – landscape metrics values (MPS, MaxArea, FD, SI, PAR, NND, PROX) – standardized data. Dendrograms constructed according to Ward's method with Euclidean distances

The dominating process in the increments to forest area was integration (Table 7.6). The differentiation of the processes of changes in the forest cover found its reflection in the dendrograms of similarities between districts. Both in terms of changes in the forest cover on particular habitats (Fig. 7.29A), and as to the areas subject to different spatial categories of forest area change (Fig. 7.29B), three groups of districts can be distinguished. The first of them comprised Wielbark and Jedwabno, the second – Szczytno and Spychowo, the third – Myszyniec and Parciaki.

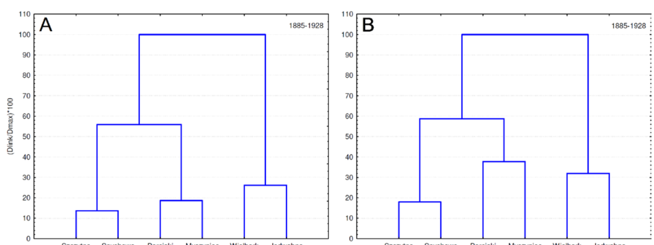

Fig. 7.29. Similarity between regions based on changes taking place in years 1885-1928: A – changes of forest cover area (ha) on different habitats – raw data; B – area of different categories of forest decrement and increment. Dendrograms constructed according to Ward's method with Euclidean distances

The transformations, which took place in the years 1885-1928 resulted in the similarities between districts in 1928 definitely different than in 1885. First of all, the group of Myszyniec and Spychowo, appearing frequently in the preceding periods, disappeared. Then, two separate groups emerged, corresponding, roughly, to the south-western and northern (or north-eastern) parts of the area. Regarding the similarity of the forest cover surfaces on the habitats, the south-western part encompassed the districts of Wielbark, Parciaki and Myszyniec (Fig. 7.30A), while in terms of forest shares on habitats it encompassed only Parciaki and Wielbark (Fig. 7.30B). The remaining districts made up the northern part. The similarities were, however, quite different, as regards the values of landscape metrics (Fig. 7.30C). In this respect the district of Szczytno was the least similar to all the other ones, these remaining districts being divided into two groups: the southern one (Parciaki and Myszyniec) and the northern one (Wielbark, Spychowo and Jedwabno).

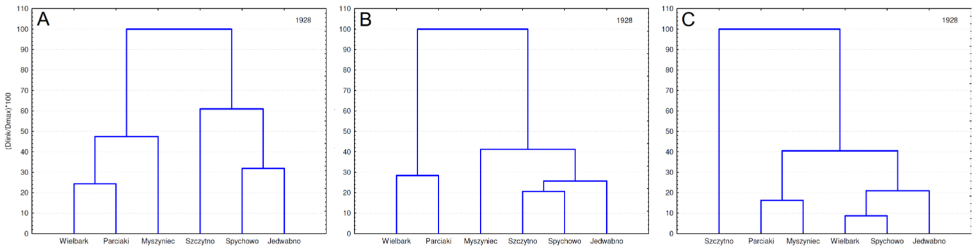

Fig. 7.30. Similarity between regions in 1928 based on: A – forest cover area (ha) on different habitats – raw data; B – percentage share of forest cover on different habitats – raw data; C – landscape metrics values (MPS, MaxArea, FD, SI, PAR, NND, PROX) – standardized data. Dendrograms constructed according to Ward's method with Euclidean distances

The subsequent period, from 1928 to 1950, featured very small decrements to forest area in all the districts. In terms of spatial processes, the decrements were mainly due in Parciaki, Myszyniec and Jedwabno to the attrition of the entire patches, followed by the lateral shrinkage with simplification of the boundaries. Lateral shrinkage was the dominating process in all the other districts. In the same period important forestations took place in Parciaki and Myszyniec, medium-sized ones in Jedwabno and Wielbark, and only quite limited in Szczytno and Spychowo. The changes in the forest area did not entail significant modifications in the forest shares on habitats. The forest cover shares increased by more than 5% only in Parciaki on the habitat of mixed pine forest *Querco-Pinetum typicum* and in Myszyniec on the habitat of the fresh pine forest *Peucedano-Pinetum*. Changes in the landscape metrics were differentiated, but it should be emphasised that despite quite important forest area increases in Parciaki and Myszyniec, numerous landscape metrics did not change their values in these districts (see Table 7.6). Under many aspects the processes, taking place in this period were a continuation of the previous processes. Hence, groups of districts, distinguished on the basis of similarity of changes of the forest area on the habitats in the years 1928-1950 were very much like the groups, distinguished on the basis of changes in forest cover on the habitats in the period 1885-1928. The sole significant difference consisted in fact that the previously well separated group, containing Wielbark and Jedwabno, ceased to exist, meaning that Wielbark became more similar in terms of changes in forest cover to Szczytno and Spychowo, while Jedwabno became more similar to Parciaki and Myszyniec (Fig. 7.31A). On the other hand, the division of regions into three groups, distinguished on the basis of areas subject to various types of spatial forest cover change processes, persisted, even though the interconnections between these groups changed (Fig. 7.31B).

The similarities between the districts with regard to the forest areas (Fig. 7.32A) and the forest shares (Fig. 7.32B) on the habitats were in 1950 almost identical to those from the year 1928. Division into the same groups persisted, and the values of similarity measures changed only slightly. The similarities with respect to the landscape metrics changed, however, in a bit more pronounced manner (Fig. 7.32C). The isolated position of Szczytno also persisted in 1950, while the differences among the remaining districts decreased, so that one, relatively extensive group of districts appeared, featuring similar differentiation of the average forest patch magnitude, shape indicators and distances between patches.

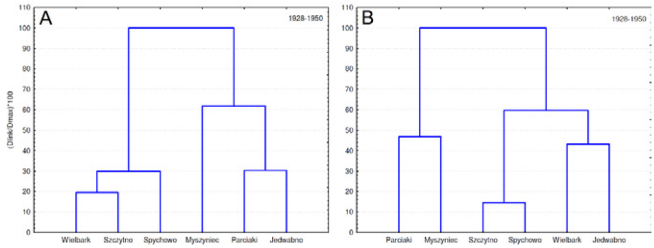

Fig. 7.31. Similarity between regions based on changes taking place in years 1928-1950: A – changes of forest cover area (ha) on different habitats – raw data; B – area of different categories of forest decrement and increment. Dendrograms constructed according to Ward's method with Euclidean distances

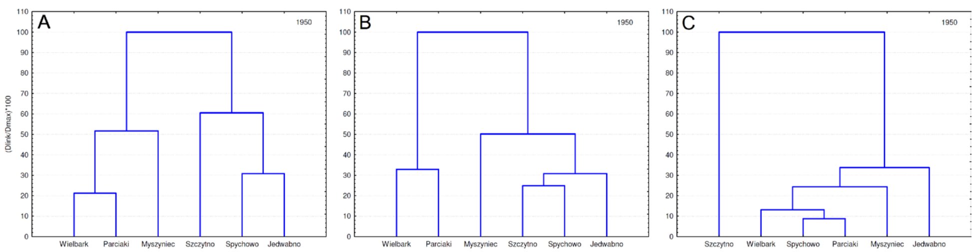

Fig. 7.32. Similarity between regions in 1950 based on: A – forest cover area (ha) on different habitats – raw data; B – percentage share of forest cover on different habitats – raw data; C – landscape metrics values (MPS, MaxArea, FD, SI, PAR, NND, PROX) – standardized data. Dendrograms constructed according to Ward's method with Euclidean distances

The consecutive period, that is – the years 1950-1970 – was marked by the medium-sized deforestations in the districts of Parciaki and Myszyniec, and small or very small deforestations in the remaining districts. The deforestations took place mainly through lateral shrinkage with complication of the boundary, and only in Myszyniec the dominating process consisted in wide multiple subdivision. On the other hand, very extensive new forest areas appeared during this period, the biggest over the entire span of 200 years in all the districts, except for Parciaki and Myszyniec. The main processes, which brought the increments of the forest area, were lateral increments with complication of the boundary and integration. In all districts the forest share on the habitat of the mixed pine forest *Querco-Pinetum typicum* increased by at least 10%, and in the majority of districts there was also an increase by at least 5-10% on the habitat of alder woods and on some other kinds of habitats (see Table 7.6).

Summing up, in terms of changes in the forest areas on the habitats in the period 1950-1970 the most similar were the districts of Szczytno and Spychowo, as well as those of Parciaki and Myszyniec. The third group consisted of Wielbark and Jedwabno, but their mutual similarity was lower (Fig. 7.33A). The similarities between the districts in terms of areas subject to particular processes of spatial change in forest cover had a different pattern. The districts of Spychowo and Szczytno, which were so similar in terms of changes in forest cover on the particular habitats displayed significant differences with respect to the (de)fragmentation processes, with Spychowo being more similar to the group of Parciaki and Myszyniec, while Szczytno was more similar to Wielbark and Jedwabno (Fig. 7.33B).

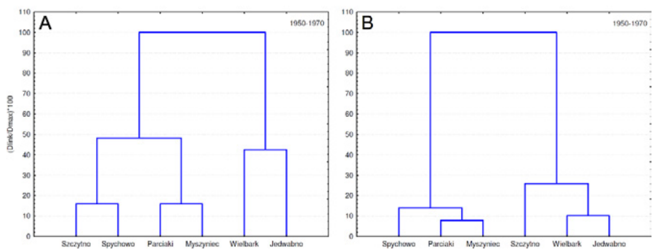

Fig. 7.33. Similarity between regions based on changes taking place in years 1950-1970: A – changes of forest cover area (ha) on different habitats – raw data; B – area of different categories of forest decrement and increment. Dendrograms constructed according to Ward's method with Euclidean distances

For a more complete characterisation let us add that the changes in values of the majority of landscape metrics were not unidirectional – depending upon the district there were decreases, periods of stability, or increases. Only values of PAR and FD increased in all the districts (Table 7.6).

Large changes, which took place in the distribution of forests in the years 1950-1970, caused that the mutual similarities between districts had a distinctly different pattern than in 1950. In particular, attention is attracted to the low similarity between districts as to the forest cover areas on individual habitats, so that only Wielbark and Spychowo formed quite a coherent group, while all the other districts displayed distinctly specific features (Fig. 7.34A). The situation was different concerning the similarities of forest shares on individual habitats. On the one hand, Parciaki and Myszyniec were characterised by pronounced differences, and on the other hand – the remaining (Masurian) districts were relatively mutually similar (Fig. 7.34B). Yet, Parciaki and Myszyniec were highly similar regarding the values of the landscape metrics, and, in the region of Masuria, Szczytno and Spychowo displayed similarity that was akin to the former (see Fig. 7.34C).

The last period analysed, that is – the years 1970-2000 – was characterised by small (or medium – in Myszyniec) deforestations, which were due in a similar degree to several processes, and by medium (or small – in Parciaki) forestations, which were primarily due to various kinds of lateral accretion (Table 7.6). The increase of the forest areas was reflected in a distinct manner through a change in forest shares only in the cases of the habitat of alder woods *Ribeso nigri-Alnetum* in the district of Wielbark (increase by more than 10% of the available habitat) and in the districts of Jedwabno and Szczytno (increase by more than 5%), as well as on the habitat of the floodplain deciduous forest *Fraxino-Alnetum* and the humid oak-hornbeam forest *Tilio-Carpinetum stachyetosum* (increase by more than 5% in Jedwabno). Mutual similarity between the districts with respect to changes in forest areas on particular habitats was not too high, but one can still distinguish three separate groups. The first of them includes Wielbark and Parciaki, the second – Spychowo and Myszyniec, and the third one – Szczytno and Jedwabno (Fig. 7.35A). Regarding the areas, on which various forms of spatial changes of forest patches took place, the setting of the districts was completely different. Most similar with this respect were Wielbark and Jedwabno, while the remaining districts formed the second group, in which higher similarity characterised Szczytno and Parciaki (Fig. 7.35B).

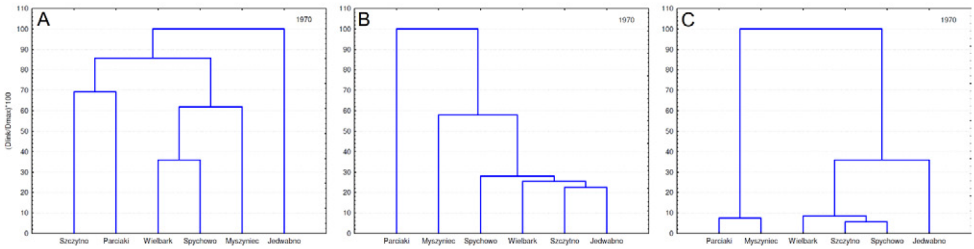

Fig. 7.34. Similarity between regions in 1970 based on: A – forest cover area (ha) on different habitats – raw data; B – percentage share of forest cover on different habitats – raw data; C – landscape metrics values (MPS, MaxArea, FD, SI, PAR, NND, PROX) – standardized data. Dendrograms constructed according to Ward's method with Euclidean distances

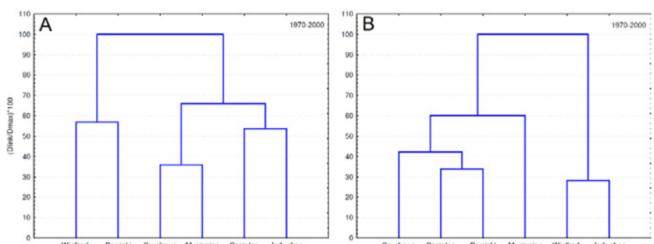

Fig. 7.35. Similarity between regions based on changes taking place in years 1970-2000: A – changes of forest cover area (ha) on different habitats – raw data; B – area of different categories of forest decrement and increment. Dendrograms constructed according to Ward's method with Euclidean distances

It is worth emphasising that from the point of view of the spatial structure of landscape, changes, which took place in the distribution of forests in the years 1970-2000 were not too high. This is reflected, for instance, through the lack of significant differences between the years 1970 and 2000 with respect to the values of such indicators as MPS and NDD, and that for all the districts. The least variable characteristics were observed for the district of Jedwabno, where only the PROX indicator did change (Table 7.6).

The similarities between districts in the year 2000 make very pronounced the differences between the southern, Kurpie, part, comprising districts of Parciaki and Myszyniec, and the northern, Masurian part, comprising the remaining districts. This is visible when we look at the forest areas on particular habitats (Fig. 7.36A), at the forest cover shares on habitats (Fig. 7.36B), and at the values of landscape metrics (Fig. 7.36C).

The analysis, here presented, which is based on the dendrograms of similarity (Figs. 7.24 to 7.36) and the general data, presented in Table 7.6, allows for grasping of the main directions of changes and development trends of the forest areas in the districts. First of all, it should be remembered that the initial state of the analysis, that is – the year 1800 – is also one of the states in the sequence of changes. This is well evidenced

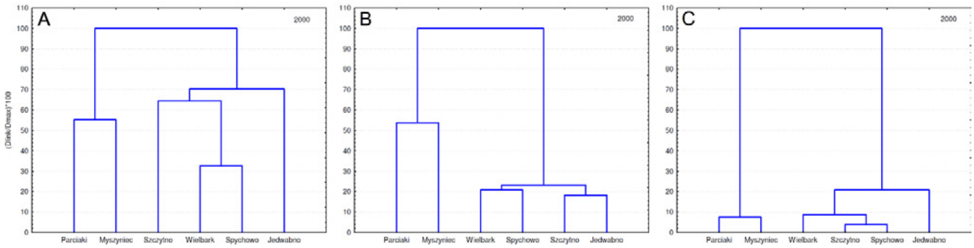

Fig. 7.36. Similarity between regions in 2000 based on: A – forest cover area (ha) on different habitats – raw data; B – percentage share of forest cover on different habitats – raw data; C – landscape metrics values (MPS, MaxArea, FD, SI, PAR, NND, PROX) – standardized data. Dendrograms constructed according to Ward's method with Euclidean distances

by the comparison of the so-called Suchodolec's map, showing the situation as of roughly 1740 in the Masurian part and partly also in the Kurpie part, with the state as of the year 1800. Already a superficial, not cartometric, analysis demonstrates that during the 60 years between 1740 and 1800 forest areas changed in all the districts, with the relatively large deforestations having taken place in Wielbark, Jedwabno and the northern part of Myszyniec (the part covered by the map), while the smallest changes occurred in Spychowo. Yet, if we neglect the earlier changes, the analysed time interval between 1800 and 2000 can be divided into two parts, the period between 1800 and 1928, and then between 1928 and 2000[3] (Fig. 7.37). This division is based on the key criterion of frequency of appearance of given districts on the dendrograms (Figs. 7.24 to -36) in common groups featuring high similarities, and on the auxiliary criterion of concordance of the directions and intensities of changes in the values of the landscape metrics. In the first period, i.e. in the years 1800-1928, based on the general similarity of the areas (in hectares) of the forest covers on the particular habitats, forest shares on these habitats, as well as magnitude, shape and mutual distances of forest patches in space, three big units can be distinguished, displaying similar types of landscape structures of forests. The first, most pronounced group, comprised Myszyniec and Spychowo, the second was composed of Wielbark and Parciaki, and the third – of Jedwabno and Szczytno. Attention ought to be paid to the fact that this division into units in terms of spatial structure of forests did not coincide with the division into Prussia (Masuria) and Polish Crown (Kurpie), i.e. with the political-economic division of the study area, and was, it seems, a reflection of an earlier existing (before 1800) differentiation in land use and in the settlement structure.

Simultaneously, in the same period of 1800-1928 the processes shaping the spatial structure of the forests took a different pattern – meaning the dominations as to deforestations and forestations with respect to areas and habitats, as well as the areas subject to different forms of spatial changes of forest patches. In process terms the division between the Kurpie part (Parciaki and Myszyniec) and the Masurian part was visible, in principle,

[3] The year 1928 was selected largely in nominal terms, since under a more detailed analysis also a transitory period could be distinguished, between 1885 and 1950, during which, gradually, an increasing number of structural characteristics were making Spychowo similar to Szczytno, and Myszyniec to Parciaki.

starting with the first time interval analysed, that is – 1800-1830 – although in the confines of Masuria only Spychowo and Szczytno featured high similarity, while similarity between Wielbark and Jadwabno was much lower.

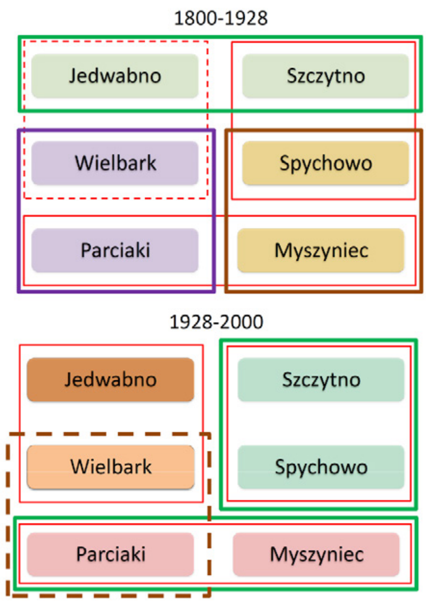

Fig. 7.37. Generalized pattern of similarity between regions in two periods. Thick colour lines – similarity based on the forest area (ha) and share (%) on habitats as well as similarity of values of chosen landscape metrics; thin red lines – similarity of the size of the deforested and afforested areas, as well as the similarity of the forest decrement/increment types

The domination of the particular processes in Kurpie and in Masuria brought about a change in the structural similarities between the districts. Since 1928 a clear division becomes visible between the southern part (i.e. in Kurpie, that is – the districts of Parciaki and Myszyniec), and the internally diversified Masurian part. In this Masurian part, the districts of Szczytno and Spychowo display far reaching similarity as to the geometric and habitat characteristics of the forest patches, while Jedwabno and Wielbark maintain differences all the time, with Wielbark being until as late as 1970 more similar in terms of some characteristics to Parciaki than to Jedwabno. These differences have not been evened out to the end, despite the fact that during the entire period between 1928 and 2000 the processes of changes in distribution and fragmentation of the forests were quite similar in Wielbark and Jedwabno.

7.5. The persistence and the changes in the districts

The detailed analyses of the states and the changes as to selected properties, characterising forest areas in the districts and in particular time periods, presented before, enable an assessment of the degree of stability of forest structure in landscape during the entire interval of 200 years (Table 7.7). In a synthetic rendition, i.e. taking the entire interval analysed as a whole, the smallest changes in the distribution of forests took place in Spychowo and Myszyniec, while the biggest ones – in Wielbark. The lowest shares of subdivision and integration (i.e. the processes most strongly transforming the spatial structure of forests) in the overall areas of deforestations and forestations were observed for Spychowo and Myszyniec, while the highest – for Parciaki. On the other hand, in terms of changes in the values of landscape metrics Parciaki was most stable, with the remaining districts being characterised by a distinctly higher variability.

Table 7.7. Simplified evaluation of forest changes and landscape stability, based on selected criteria

Processes	Regions	Periods						
		1800-1830	1830-1885	1885-1928	1928-1950	1950-1970	1970-2000	
Forest distribution changes (% of total unit area)	Parciaki	7.2	26.0	14.1	7.0	11.9	3.6	
	Myszyniec	1.9	34.0	8.1	3.7	7.5	2.7	< 5
	Jedwabno	2.1	12.6	20.5	3.7	20.1	3.9	5-10
	Wielbark	1.8	27.0	18.2	5.7	23.8	4.3	10-20
	Szczytno	4.0	19.3	12.1	3.1	15.8	5.1	> 20
	Spychowo	2.9	16.2	5.4	1.8	11.1	3.9	
Share of subdivision (1R) and Integration (2R) (% of forest changes area)	Parciaki	89.9	47.5	45.1	15.8	17.1	19.0	
	Myszyniec	22.4	74.8	14.1	10.6	15.5	9.8	< 10
	Jedwabno	0.5	43.7	46.0	41.8	60.4	13.6	10-25
	Wielbark	26.2	34.4	44.3	22.4	49.8	19.2	25-50
	Szczytno	4.2	63.0	33.5	25.8	51.1	23.2	> 50
	Spychowo	13.6	55.3	25.5	16.3	11.0	16.5	
Landscape metrics changes (sum of absolute values of standardized metrics: Number, MPS, MaxPatch, FD, PAR, SI, NND, PROX)	Parciaki	3.7	6.0	2.1	5.8	5.6	1.8	
	Myszyniec	2.2	12.4	6.6	2.7	7.7	1.9	< 2.5
	Jedwabno	2.8	12.0	3.9	3.7	7.2	4.0	2.5-5.0
	Wielbark	4.5	9.7	4.3	5.2	4.7	1.9	5.0-10.0
	Szczytno	4.9	7.9	7.7	3.8	8.0	1.8	> 10.0
	Spychowo	5.6	12.2	5.0	3.5	7.6	1.4	
Total stability classes	Parciaki	C	D	C	C	C	A	
	Myszyniec	A	D	C	B	C	A	A
	Jedwabno	A	D	D	B	D	B	B
	Wielbark	B	D	C	C	D	A	C
	Szczytno	A	D	D	B	D	B	D
	Spychowo	B	D	C	B	C	A	

Analysis of changes occurring in the particular time intervals indicates that in the years 1800-1830 the most stable was the forest cover in Myszyniec, Jedwabne and Szczytno, while the most pronounced changes took place on the area of Parciaki. The second period, that is – the years 1830-1885 – was marked by the strong transformations of the forest cover in all districts. In the subsequent period (the years 1885-1928) the process of transformation of forests in the landscape was continued, even though with a lower intensity, this intensity being the lowest in Parciaki and Myszyniec (that is – in the Kurpie part of the study area), while it was the highest in Jedwabne. The period between 1928 and 1950 was the period of a relative stabilisation of the forest structure in the landscape on the entire study area. During this period the distinctly highest structural stability was observed in Myszyniec and Spychowo, and the lowest – in Parciaki and Wielbark. In the years 1950-1970 a new increase of intensity of changes was observed, the most intensive changes taking place in Wielbark, Jedwabne and Szczytno. Then, the last period, that is – the years 1970-2000 – was characterised by the high structural stability of the forest cover in all districts, even higher than in the period 1800-1830, which also featured low variability of the structural characteristics (except for Parciaki).

The analysis of content of Table 7.7 indicates also that there is no district, for which two consecutive time periods can be found, featuring high stability with respect to all the properties analysed. It can be stated, on the other hand, that Parciaki was characterised by the longest – as compared to other districts – time interval of the continuing, intensive changes, these changes taking place between the years 1800 and 1970. Similarly dynamic changes in the spatial structure of forests occurred in the case of Wielbark, and that over a period not much shorter, namely between the years 1830 and 1970.

7.6. Habitat-related interdependencies of the processes of forest fragmentation and consolidation

Already a cursory analysis of the previously presented temporal variability of the forest covers on particular habitats, and the variability of the area shares as well as the role played by the individual categories of the spatial forest patch change processes suggests that these two variables are interrelated. The degree of association of these two variables can be determined with the Cramér's V test[4]. The results, presented in Table 7.8, indicate that except for the period 1830-1928, the categories of deforestations were more strongly linked with habitats than the categories of forestations. This means that at least some of the categories of deforestations were non-randomly concentrated on a limited number of habitats, conform to the economic preferences, dominating during a given period of time. It should be emphasised that in the case of deforestations the highest values of Cramér's V concern the periods 1830-1885 and 1950-1970, that is – both the period of a high stabilisation of the spatial structure of forests, and the period of strong transformations of this structure. Regarding the deforestations the strongest association with the types of habitats was observed in the time intervals 1830-1885 and 1950-1970,

[4] Cramér's V is a measure of association between two discrete (nominal) variables, and may be used with variables having two or more levels. It is a post-test to determine the strength of association after chi-square has determined significance. Cramér's V is calculated as: SQRT(chi^2/(n min(M-1; N-1)), where chi^2 is chi-square, n is the number of cases and M, N are the numbers of rows or columns in the table. Large V means that there is a tendency for particular categories of the first variable to be associated with particular categories of the second variable.

i.e. unambiguously in the periods of the deepest transformations of the spatial structure of landscape (compare with the data of Table 7.7).

Table 7.8. Results of Cramer's V test for association strength between aforestation/deforestation categories and types of habitats in different periods. In all cases association between variables is significant at $p < 0.0001$ (results of chi^2 test)

Years	Forest	
	decrease	increase
1800-1830	0.435	0.195
1830-1885	0.111	0.204
1885-1928	0.167	0.243
1928-1950	0.236	0.140
1950-1970	0.317	0.207
1970-2000	0.239	0.140

It is interesting that in consideration of the temporal succession in the case of types of forestations we deal all the time with the fluctuations of the V values, meaning that from period to period the categories of forestations had similar and not too high association with the habitats (various spatial categories of forestations on particular habitats occupied the areas close to the respective proportions of the overall areas of the habitats). On the other hand, in the case of the fragmentation types, leading to the decrease of forest cover on particular habitats, in the years 1830-1970 the values of Cramér's V had an increasing character, meaning that the individual categories of fragmentation would appear increasingly selectively on only definite types of habitats.

In the general perspective, the influence is also observed, exerted by the total areas of forestations / deforestations on the values of Cramér's V (Fig. 7.38).

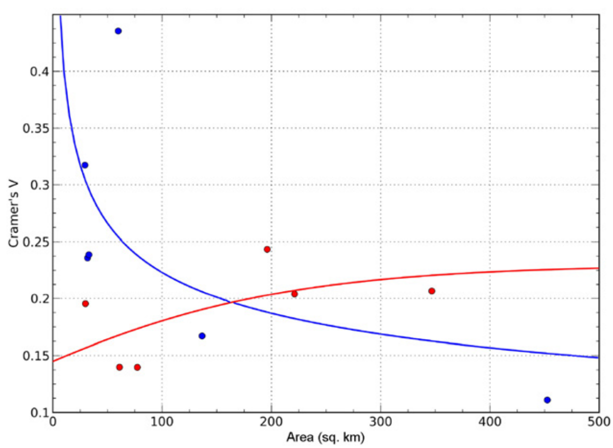

Fig. 7.38. The relationship between the total deforested (blue) and afforested (red) area and the value of Cramer's V statistics

For the small overall area of deforestations high values of the V statistic are observed, falling along with the increase of the total deforested area. This means that limited deforestations are rather linked with the modification and adjustment of the spatial structure to local needs, with the primary role played by only some categories of decrement, concentrated, in addition, on a small number of habitats. When the overall deforested area increases, the processes dominate, leading in effect to the revolutionary changes in the landscape structure, and the diverse types of decrement appear in a non-selective manner on a significant number of habitats. The interrelations are entirely different for the forestations. For the small overall areas the values of V statistic are very low, and they go up with the increase of the overall area of the new forests. This means, on the one hand, that small new forest surfaces would arise spontaneously on numerous different habitats, and on the other hand – that the large-scale planned forestations, to be carried out through patch integration or accretion, were consciously concentrated on selected groups of habitats.

Values in the table are calculated as 100×(observed-expected)/expected. Observed and expected values were taken from the contingency tables for Cramer's V Test of Independence. Colours denote direction and level of differences between expected and observed values of spatial extend of processes on habitats. Small area habitats (codes 16, 17ab, 18) omitted.

The data, which are put together in Table 7.9, make possible a more detailed identification of the association between particular categories of decrement/increment and types of habitats. In a general view, the strongest ties with the habitats is displayed by the attrition and creation of the new patches, somewhat weaker – by the subdivision and integration, while the weakest – by the shrinkage and accretion.

Over the entire analysed period of 200 years the attrition of entire patches was less important than other processes of decrement on the habitats of the fresh pine forest. A similar interrelation, though less pronounced, held also for the habitats of the humid mixed pine forests. On the other hand, significantly more extensive attrition of patches took also place on the oak-hornbeam forest habitats, with, in the case of the typical oak-hornbeam forests a weak reversal of the interrelation taking place in the years 1830-1885, and in the case of humid oak-hornbeam forests – in the years 1800-1830. For the remaining habitats the proportions changed in time, frequently from period to period, although for the alder woods one could indicate the time interval between the years 1885 and 1970 as the period, when the attrition of the entire patches were lower than the proportional mean value. For the creation of the new patches the interrelations were in general outline similar. This means that on the pine forest habitats the area of the newly appearing patches was disproportionately small compared to other processes, leading to the increase of forest cover in the years 1885-2000, although it had been distinctly higher in the years 1800-1830. In the cases of the typical and humid oak-and-hornbeam forests and of the deciduous floodplain forests the interrelations were opposite. In the years 1885-2000 the newly appearing patches occupied a bigger area, and in the years 1800-1830 a smaller area than it would have resulted from the percentage shares of the particular processes.

The interrelations took a different pattern for the case of patch subdivision and integration. First of all, there were periods, during which no connections existed between these

Table 7.9. Positive and negative preferences of main groups of forest decrement/increment processes to habitats of potential natural vegetation

Habitats	Years						Years					
	1800-1830	1830-1885	1885-1928	1928-1950	1950-1970	1970-2000	1800-1830	1830-1885	1885-1928	1928-1950	1950-1970	1970-2000
	Attrition (1A)						Creation (2A)					
12, 13	-94.8	18.8	-30.7	-60.1	-75.8	-85.8	89.6	-8.1	-61.9	-51.3	-52.7	-87.0
9a	78.2	-42.1	1.8	9.3	-70.8	-3.8	51.2	22.9	18.5	-0.1	-21.4	-16.3
6a	102.3	50.4	21.8	66.8	90.6	2.1	-94.5	5.0	143.5	9.7	-11.2	-11.3
6bc	138.7	-57.7	79.2	116.4	224.3	69.0	-77.1	40.6	49.0	218.3	159.7	93.2
6e	-44.0	4.6	58.6	106.5	-6.0	9.3	-35.9	36.4	211.2	86.2	104.1	56.9
4a	-44.3	31.0	-12.1	14.7	70.3	26.1	-83.9	-3.2	127.5	70.2	131.9	41.4
1abd	180.9	-17.3	-68.1	-85.0	-59.0	134.6	-18.6	-56.2	-0.1	-30.3	33.6	-30.5
9c, 19	-9.6	-67.0	-61.7	-56.2	9.5	-88.2	79.3	-56.1	34.8	35.8	-28.9	-60.6
	Subdivision – all types (1R)						Integration (2R)					
12, 13	5.6	-5.8	-26.9	7.6	6.3	-33.0	60.7	40.4	25.0	14.8	-32.7	57.0
9a	-41.4	-1.1	5.4	-28.1	-32.8	-27.9	1.4	-32.1	-0.2	2.2	10.2	-14.9
6a	-40.2	-11.6	26.1	6.5	2.3	-20.7	-73.3	-75.4	-52.8	28.1	30.0	-0.1
6bc	-99.2	11.9	-60.4	12.9	-42.7	6.5	49.9	-71.3	-83.4	-36.0	-52.8	-12.8
6e	-42.4	9.3	-59.6	-4.1	-46.9	-10.4	16.5	-40.2	-90.7	-71.7	-35.0	14.0
4a	55.8	1.5	43.9	-12.4	-3.8	22.6	-49.2	-20.4	-70.1	-56.5	-31.5	11.9
1abd	-62.9	-9.3	-43.6	50.5	9.9	51.1	-83.6	4.4	-32.1	-54.4	-16.4	9.7
9c, 19	16.6	-4.7	9.6	81.6	-41.3	93.9	-73.8	66.4	-37.9	-26.1	-12.7	-22.3
	Shrinkage – all types (1Z)						Accretion – all types (2Z)					
12, 13	34.9	21.1	18.9	23.1	2.1	32.5	-17.8	-14.8	-5.8	2.3	44.1	4.0
9a	37.1	12.6	-2.9	1.0	22.1	9.8	-5.0	1.8	-6.0	-0.8	-1.6	7.6
6a	23.6	39.6	-16.7	-28.2	-7.7	6.0	20.3	33.8	8.1	-12.4	-21.2	2.5
6bc	111.8	-39.6	11.4	-49.4	6.2	-19.7	-0.5	10.2	71.6	-20.1	-7.9	-17.2
6e	96.6	-40.0	15.4	-42.5	24.9	0.9	0.8	-2.5	25.6	14.4	-4.6	-16.3
4a	-78.8	-12.0	-17.8	-3.8	-3.1	-13.9	15.5	11.9	31.7	11.0	-16.5	-12.3
1abd	26.8	42.4	34.5	25.8	-0.9	-50.7	14.7	31.9	33.8	25.9	2.7	4.1
9c, 19	-25.2	32.4	8.4	8.8	20.8	-7.2	4.0	1.6	28.4	4.5	19.9	19.3

processes and the definite types of habitats, or such connections were very weak. For the subdivision, this happened in the years 1830-1885, 1885-1928 and 1950-1970. At the same time, these were the periods, when the strongest changes were taking place in the spatial structure of landscape.

In the case of integration processes, a weak connection with the types of habitats was characteristic for the years 1950-2000. We should emphasise here the specific character of the period 1800-1830, when the subdivision encompassed, compared to other processes, significantly smaller surfaces on the habitats of the mixed pine forest, alder woods and all forms of the oak-hornbeam forest, while the surfaces corresponding to the habitat of the deciduous floodplain woods were altogether significantly bigger. It is also interesting that in the periods 1928-1950 and 1970-2000, that is – in the periods of limited changes in the spatial structure, subdivision was dominating and encompassed relatively big areas on the habitats of alder woods and the humid mixed pine forest.

During the majority of the analysed period the integration processes had a non-selective character, without a distinct affinity to definite types of habitats. Only for the poor oak-hornbeam forest and the floodplain deciduous forest it is possible to indicate the years 1800-1950, and for the typical and humid oak-and-hornbeam forest the years 1830-1950, as the longer time intervals, during which consolidation processes encompassed disproportionately small surfaces.

The shrinkage and accretion occurred on all the habitats analysed, without a clear correlation with any of them. It was only in the years 1800-1830 that the shrinkage was linked with the habitats of the typical and humid oak-hornbeam forests, while they were relatively rare on the habitat of the deciduous floodplain woods. Then, in the years 1928-1950 the shrinkage on the habitats of the typical and humid oak-hornbeam forests was more limited than this would result from the area shares of all the categories of decrement. In the case of accretion the interdependences were even weaker. Only in the years 1885-1928 the accretion was significantly higher on the habitat of the typical oak-hornbeam forests, and in the years 1950-1970 they were higher on the habitat of the fresh pine forest.

7.7. Summary and conclusions

1. This elaboration presents the analysis of the forest cover changes in the rarely applied perspective of fragmentation and consolidation of the forest patches (decrement/increment types). From this perspective forests constitute patches, and all the other forms of land cover are the part of landscape matrix. In this context, the typology of changes in the size and shape of patches was extended and made more detailed, with distinction of the following categories: (a) among the decrements: attrition, perforation, narrow subdivision (split), singular wide subdivision, multiple wide subdivision (dissipation), distal shrinkage, lateral shrinkage without a change in the shape of the boundary, lateral shrinkage with complication of the boundary, lateral shrinkage with evening out of the boundary, as well as incision, and (b) among the increments: creation, filling, integration, distal accretion, lateral accretion without a change in the shape of the boundary, lateral accretion with complication of the boundary, and lateral accretion with evening out (smoothing) of the boundary.
2. For the study area treated as a whole we can distinguish three separate periods of relative stabilisation or slow changes: the years 1800-1830, 1885-1950 and 1970-2000, along with two periods of fast changes of revolutionary character: the years 1830-1885 and 1950-1970. Each of these periods was characterised by different nature of the processes of decrement and increment of the forests, as well as different directions of changes in the values of landscape metrics.
3. The detailed analysis of changes in the six areas, roughly corresponding to forest management districts (Wielbark, Jedwabno, Szczytno, Spychowo, Parciaki and Myszyniec) indicates that the years 1800-1830 were characterised generally by limited changes

(high stability) in all the districts except for Parciaki, where intensive processes were taking place, transforming the spatial structure of landscape. During the years 1830-1885 strong transformation of forests took place in all the districts. Then, in the period 1885-1928 the transformation mentioned came to an end, and smaller changes were occurring, having rather the character of modification of shapes of particular patches. The years 1928-1950 mark a subsequent period of relative stabilisation of the forest structure in the landscape over the entire area considered. Between 1950 and 1970 the changes intensified again and intensive transformation took place of the structural characteristics of forests in the landscape. The last period analysed, 1970-2000, was characterised by high structural stability of the forest cover in all districts.

4. In the years 1800-1885 subdivision dominated over the shrinkage by the factor of 2 to 3, while in the later periods this ratio was exactly to the opposite. Regarding forestations, the accretion has always been at least two times bigger than the integration, with the lateral accretion accompanied by the complication of the boundary being most important during the majority of periods. Creation of the new patches was a relatively important process in the periods of strong transformation of the landscape.
5. During the analysed period of 200 years the similarity between districts with respect to the spatial structure of forests (that is – magnitude, in hectares, of the forest cover on particular habitats, forest shares in % on these habitats, and the magnitudes, shapes, as well as distances of forest patches in space) changed many times over. The changes of similarities between districts were, on the other hand, much smaller, with regard to the processes shaping the alterations in the structure (i.e. the absolute changes in forest area, changes of forest shares on particular habitats, as well as areas subject to various kinds of categories of decrement and increment of the patches).
6. From the point of view of the similarity of structures and processes, the analysed period of 200 years can be divided into two sub-periods. The first of them encompassed the years 1800-1928, and the second – the years 1928-2000. In the first sub-period, we can distinguish three larger units, featuring similar type of landscape structure of forests. The first, most pronounced group comprised Myszyniec and Spychowo. The second was composed of Wielbark and Parciaki, while the last one – of Jedwabno and Szczytno. Attention ought to be paid to the fact that this division into units with respect to the spatial structure of forests did not coincide with the then political-economic division of the area and was, it seems, the consequence of the differences existing earlier (i.e. dating from before 1800) as to the land use and settlement structure. In the second period, namely starting with 1928, there was an increasingly distinct division into the southern part (Kurpie – Parciaki and Myszyniec), and the internally diversified northern, Masurian part, in which Szczytno and Spychowo displayed far reaching similarity in terms of geometrical and habitat characteristics of the forest patches, while Jedwabno and Wielbark were less mutually similar, with Wielbark being until as late as 1970 more similar to Parciaki than to Jedwabno with respect to some characteristics.
7. Regarding the similarities of the processes of deforestation/forestation, the division into the Kurpie part (Parciaki and Myszyniec) and the Masurian part has been visible, in principle, since the very first period analysed (1800-1830), although in Masuria

only Spychowo and Szczytno displayed frequently quite important similarities, while similarities between Wielbark and Jedwabno were much lower.

8. In a synthetic rendition, for all the periods together, relatively the smallest changes in distribution and landscape characteristics of forests were observed in Spychowo and Myszyniec, while the biggest – in Wielbark, with Wielbark (and Parciaki) being characterised by the longest periods – compared to other districts – of continuous intensive changes, these changes occurring in the years 1800-1970 (1830-1970 for Parciaki).
9. The categories of decrement/increment of forest cover display statistically significant, even though weak, correlations with the potential vegetation habitat types. The relatively strongest connections were observed for the years 1830-1885 and then in 1950-1970, that is – during the periods of the most pronounced transformations of the spatial structure of landscape. Besides, the categories of forest decrement were more strongly linked to definite habitats than the categories of forest increment.
10. Considering the groups of categories of spatial change, the strongest ties with habitats were displayed by the attrition and creation of the patches, somewhat weaker – by the subdivision and integration, while the weakest – by the shrinkage and accretion.
11. During the major part of the period analysed of 200 years the attrition of entire patches and the creation of the new ones were significantly less pronounced than the other processes of spatial change on the habitats of fresh pine forest and the humid mixed pine forest, while they were significantly more important on the oak-hornbeam forest habitats.
12. Compared to attrition and creation of patches, the subdivision and integration, as well as shrinkage and accretion have had for most of the analysed period the non-selective character, without distinct connections to definite types of habitats.

Generalising the results summarised above, we can state that:

- the spatial structure of forests did not change in a regularly unidirectional manner, but was characterised by changes of periodical nature, with the particular time intervals differing as to both directions and rates of changes;
- while the general pattern of changes for the entire study area has been preserved, individual districts featured definite specificity, expressed, for instance, through asynchronous character and different intensity of the processes taking place, changes in similarities between districts, and domination of different categories of decrement and increment of forest patches;
- in the southern (Kurpie) part, for most of the period analysed of 200 years, different processes dominated, changing the structure of forest cover, than in the northern, Masurian part; in effect of these processes, the initial structural division into three spatial units, having the East-West orientation, was replaced by the division into two groups of units, of which the first corresponds to the southern (Kurpie) districts, and the second – to the internally diversified set of Masurian districts;
- there exist weak, but statistically significant interrelations between the summary magnitude of deforestations (and, respectively, forestations), and the areas subject to the individual categories of decrement and increment of the forest patches; at the same time, the particular categories of the spatial change in forest cover displayed, at least in some periods of time, statistically significant ties with respect to definite

types of the potential vegetation habitats; the consequence of the changes in the surfaces and distribution of forests consisted in the changes of values of landscape metrics, concerning, for instance, the shapes of patches and the distances between them.

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8. THE HISTORY OF HUMAN IMPACT ON FORESTS OF THE MASURIA-KURPIE BORDERLAND

Joanna Plit, Ryszard Wojciech Pawlicki

8.1. An outline of climate changes from the early Middle Ages until today

The deployment of the settlement system and the stages of development of the region ought to be regarded against the background of time-wise variability of the climatic conditions in Central Europe, since changing conditions were either advantageous for the settlement process, while conditioning the manner, in which the area developed, or they simply hampered any further development. The characterisation here provided was elaborated on the basis of data from the literature (Lorenc, 2000; Maruszczak, 1999; Przybylak et al., 2010).

The period of the early Middle Ages, that is – the years 600-800 AD – was relatively warm and dry (compared to the contemporary conditions). The successive centuries, from 900 to 1100, were characterised by warming of climate with simultaneous increase of precipitation. Climate took on the maritime features. In the 13th century the warm period still persisted, but precipitation distinctly decreased, which resulted in a significant lowering of the groundwater level. The surfaces of lakes and swamps in the region probably distinctly shrank. Then, in the period between 1350 and 1500 significant fluctuations of climate are observed, associated with a distinct drop of average temperatures. The sequences of dry years were intertwined with very humid years, which brought bad crops, as well as numerous floods. Sequences of years with severe, frosty winters and cool summers appeared alternately with warm periods. This is also documented by the chronicler Jan Długosz in his Annals of the Kingdom. The years 1500-1550, on the other hand, were warm and crops were good.

After 1550, climate entered the period of cooling, called "Little Ice Age". The lowest average temperatures in Poland were registered in the second half of the 17th century. Precipitation also decreased, however, with reduced evaporation this resulted in rising of groundwater level and frequent floods. Climate was becoming more continental. In the first half of the 18th century climate somewhat warmed, but then, at the second half of that century cooled down again. Low temperatures in the 19th century and increased precipitation caused catastrophic crops (e.g. potato blight brought about hunger at the beginning and in the middle of the 19th century), and floods (mainly resulting from spring ice jams on the rivers). During the "Little Ice Age" the analysed area underwent permanent flooding, lakes increased their surfaces, wet areas became swampy. All this forced the inhabitants to opening up river outflows and to draining the wetlands and swampy areas. Since the half of the 19th century climate has been gradually warming up. The process of increase of average temperatures intensified at the turn of the 21st century (after Maruszczak, 1999; Lorenc, 2000).

8.2. The history of settling and development of the southern part of East Prussia

8.2.1. Changes in population density

The southern part of the Great Masurian Lakes and the Outwash of Pisz were inhabited between the 1st century BC and the 7th century AD by the western-Baltic tribe of Galindae, being a part of the ethnic-language group referred to as Prusses. This particular tribe was mentioned already by Ptolemy (about 100-178 AD) in work "Geographia" (Ptolemaei, 1843). The presence of Prusses in this area at that early period is demonstrated by the numerous archaeological findings, dated between 1st century BC and 4th century AD, and especially by the concentration of necropolises within the Lake region of Mrągowo and in the Great Masurian Lakes. At the basis of archaeological sources it can be concluded that the settlement process of Galindae was interrupted, or significantly limited, in the 5th century. Probably owing to the fact that they joined the great migration of the Goths towards the Black Sea steppes and then to the south and the west of Europe during the "Great Wandering of the Peoples". A small part of Galindae returned to Prussia, bringing with them a different culture, as documented by the archaeological findings from the 6th century, in which original ornaments and different shapes have been found. The western part of the area in question was populated by another Pruss tribe – the Sasinis. They settled more fertile lands, and put them to farming use (Okulicz-Kozaryn, 1997).

Location of the archaeological excavations demonstrates that the settlements of Prusses on the study area concentrated in the northern and north-western parts. Single sites have also been documented in the Forest of Pisz. The ancient Pruss population cultivated land, the seeds of wheat and barley have been found in the excavations; they raised animals (cattle, horses, sheep and pigs), and hunted (bones of roe-deer, beaver, boar and deer have been identified). The warming of climate and significant precipitation were conducive to the advance of the settling process. Yet, the invasions of the Baltic Jaćwing from the east in the 11th and 12th centuries, and retaliatory and pacifying military expeditions of the rulers of Poland – Kazimierz Odnowiciel and Bolesław Krzywousty from the South-West into the lands of Galindae and Sasini brought depopulation of these areas and secondary forestation of the abandoned fields and pastures. Thus, in the 14th century the chronicler of the Teutonic Knights, Peter Duisburg, author of "Chronicorn terrae Prussiae" (1326) noted on the area of the Forest of Galindae only few inhabitants originating from the ancient Pruss tribes (Piotr z Dusburga, 2004).

The Polish prince Konrad of Masovia issued on April 23rd, 1228, the document, which opened the way to the establishment of the property for the "Order of the Hospital of Our Lady of the German House in Jerusalem", active since 1190 in Palestine, that is – for the so-called Teutonic Knights. The purpose was to convert the heathen Prusses and to defend the boundary of Poland against the invasions of the belligerent tribes. The Knights quickly organised their administration on the Pruss lands, and turned it into an independent state, existing formally in the years 1228-1525, and displaying a strong expansion towards the neighbouring lands. The conquest of Pruss lands took place in years 1230-1283. Since the 14th century the Knights conducted a broad colonisation activity on the former lands of Galindae and Sasini. Initially, migration of the German-speaking population was directed to the area of today's Nidzica and Szczytno, mainly in the years 1350-1380. This German-speaking population came from the north-west along several migration routes. They settled primarily within the fringes of the Forest of Galindae, forming, defensive strongholds and building castles as the far-reaching outposts to the south and east (in Nidzica, Wielbark, Szczytno, Olsztynek, Szestno and Pisz). In the second half of the 14th century the flow of the German-speaking migrants weakened and colonisation of the region continued with the Slavonic population from the Land of Chełmno and with the Prusses, as well as Pomesanians (who underwent Polonisation relatively fast), and populations from the Polish Duchy of Masovia. Thus, the essential direction of migrations changed – the newcomers originated from the South and South-West.

During the 14th century significant changes took place in the organisation of villages. Side by side with the old type of villages, founded according to the local Pruss law, the settling and the new, regular division of the land was introduced according to the Magdeburg law, or to its Chełmno variant. In effect of the reform the gradual liquidation took place of the earlier division of land into the dispersed fields or patches, the compact pieces were introduced, measured in "łans" (1 "łan" = 16.8 hectares). In the just established larger villages peasants were assigned the share of two "łans" (33.6 hectares), and the village marshal obtained between three and six "łans" (50 to 100 hectares). The land ownership structure in the region was dominated by the large properties of the Order, the Bishops and the monasteries, with areas between 800 and 15,000 "łans" (i.e. 5440-252,000 hectares), followed by the relatively small properties of the knights, between 4 and 20 "łans" that is – 67 to 336 hectares (Białuński, 1996, 1999, 2001, 2002; Labuda, 1969).

The settlement action within the Teutonic-Masovian borderland intensified after the delimitation of the boundary in 1422, but analysed in detail fragment of border was estabilished in 1343 in Bratian. Numerous colonists from Masovia came in, moving upstream the rivers Pisa, Rozoga, Orzyc and Omulew. These settlers included an important share of small gentry from Masovia, who, when settling, got bigger farms and the privilege of direct succession, but were obliged to serve in the army. The second group was constituted by the peasants. The villages were founded "on raw trunk", meaning forest locations, where forest had to be felled and the clearings were first used for cultivation. These newcomers settled and developed first of all the former lands of Sasini, as well as unused lands around the castles of Olsztyn, Pisz, Ryn, Szczytno and Szestno.

The subsequent development of the settlement system took place after the secularisation of the Order in 1525. The process of settling of the area is illustrated on the map (Fig. 8.1), showing the dates of foundation of particular localities. Within the forest areas, belonging to the ruler (the Elector), of the now lay state, especially within the Forest of Pisz, ruthless and wasteful exploitation was carried out, with mass felling, production of tar, birch tar, potash, charcoal, etc. Vast empty spaces arose, to which new colonists

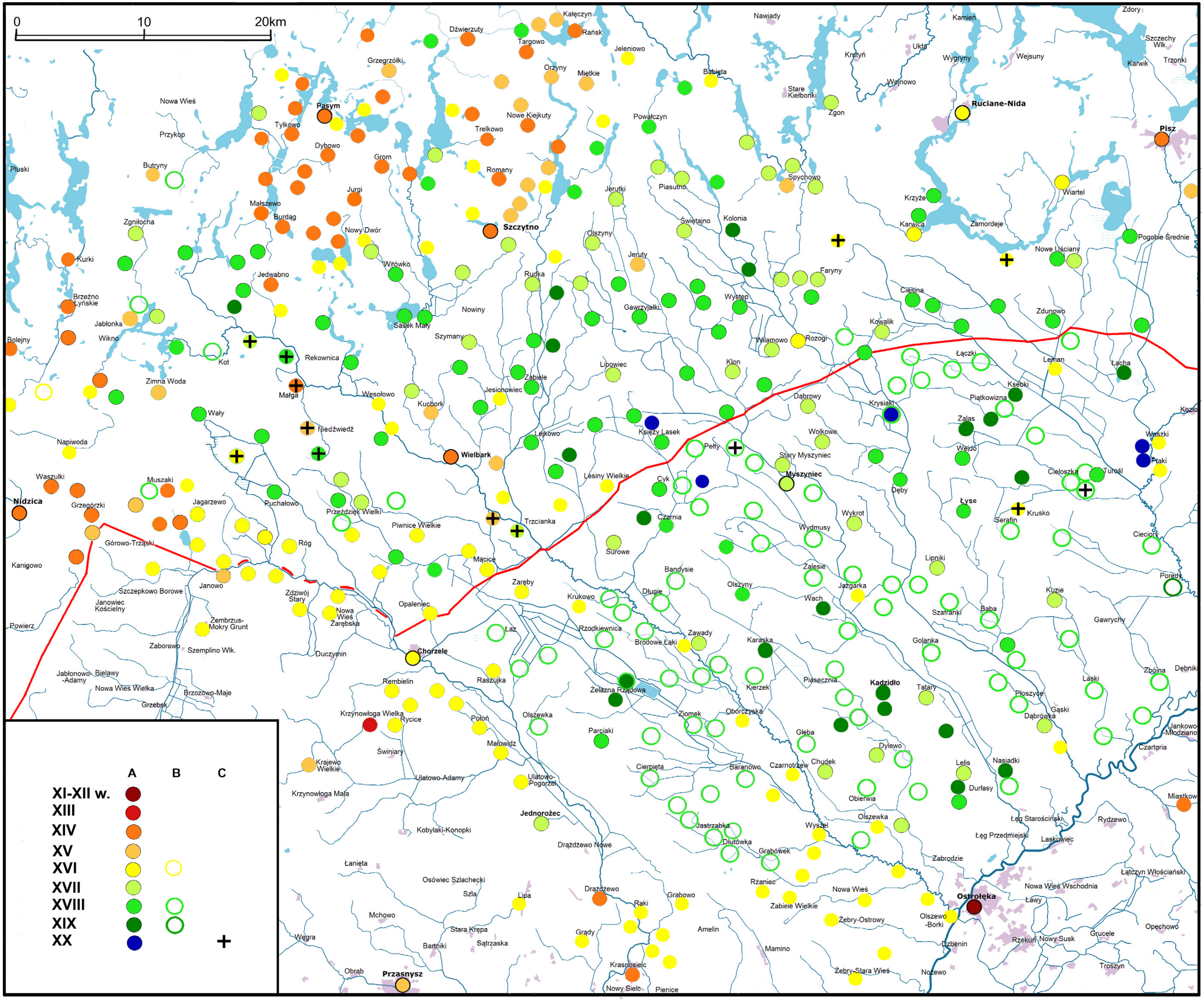

Fig. 8.1. Time of place establishing. A – according to the archive materials, B – according to the old maps, C – places not existing so far

were directed. In the framework of the so-called "box settlement"[1], which covered the area from Nidzica to the Pisa river and Śniardwy lake, in the years 1645-1722 in the county of Szczytno on the area of 747 "włókas" (roughly equivalent to "łan") 45 new settlements were established, while in the county of Pisz, in the years 1679-1749 – 42 villages were established. These localities were generally settled by local population (internal settlement) and bore Polish names (Chojnacki, 1984; Maciejewska, 1995). Thereby the area of cultivation was increased, however it had no influence on population growth. New settlements were estabilished on the poorest forest areas. Development of "box-settlement" had an impact on settlement network density. Many new small settlements were created around lakes and wetlands (Guttzeit, 1964; Maciejewska, 1995).

In the 18th century in Prussia the new wave of migration of the German population was directed mainly to towns in connection with the expansion of industry. After 1700, due to the enormous increase in taxes imposed on the population, mass flight of peasants to Poland from the bordering areas took place. Despite the depopulation of the region in the effect of numerous natural disasters, the royal Prussian decree of 1724, confirmed in 1739, forbade to populate the abandoned farms in Masuria by the migrants from Poland and Lithuania.

In the 18th century the population of Prussia was dominated by free peasants, having hereditary ownership rights. They had easement rights to pasture livestock in forests and on meadows, and the right to catch fish. The royal peasants constituted the second group in terms of their number. They paid the rent charges and were obliged to 60 days of service work per year – mainly in forests. It was forbidden in Prussia to leave the village (attachment to the land) and there were restrictive laws, forbidding import of cereals, flour, salt, spirits, tobacco, animals, meat and hides, and even wood, from Poland.

In 1799 the edict was issued on abolition of serfdom and soccage in royal domains. Yet, soccage was transformed into very high rents, and, at the same time, the easement privileges were taken away, along with the right to free pasturing of cattle in forests. This so-called enfranchisement reform brought about the bankruptcy and sale of numerous farms, which were largely taken over by the settlers from Germany. In the large feudal properties the enfranchisement was effectively hampered and ultimately took place only after the "Spring of the Peoples" in 1848. The royal attempts of introducing agrarian production reform – passage from the three-field system to crop rotation and consolidation of land plots – undertaken in the 18th century, did not succeed in view of the enormous resistance from the inhabitants. There was only a gradual enrichment of the choice of cultivated plants, with, perhaps, most important being the spread of potato growing (Chojnacki, 1984).

For the 19th century we dispose already of the relatively precise data on the population and nationality structures. For the counties of Szczytno[2] and Nidzica these data, taken from the German sources, have been analysed and presented by Leyding (1962) and Martuszewski (1976), Table 8.1.

[1] The "box settlement" process took place on the ducal grounds, with the peasants paying the rent charges directly to the "box", i.e. the treasure, of the ruler. This happened as the reaction of the Elector to the laws, promulgated by the Prussian States (the parliament).

[2] The data concern the county in the administrative boundaries as of the year 1955, almost identical with the contemporary one, i.e. as of 1999.

One easily notices that the population number inhabiting the study area has doubled or tripled during roughly 80 years (between 1818 and 1890). The inhabitants spoke mainly Polish. In view of the high share of the population of Poles among the inhabitants, this entire area was included in the territories subject to national plebiscite after World War I, according to the stipulations of the Treaty of Versailles in 1919. The plebiscite took place in the very disadvantageous international situation for Poland, during the Polish-Soviet war. Regarding the area in question, the results of the plebiscite have shown that almost everywhere people preferred to belong to Germany (East Prussia).

As to the county of Nidzica, Polish population resided mainly in its eastern and southern parts. In the middle of the 19th century Poles accounted for 99% of the population in the parishes of Jedwabno, Małga and Muszaki, and 100% in the parish of Łyna. The intensive Germanisation action, conducted since the 1880s in the schools, offices and in the military brought quite visible effects. Yet, the dramatic increase in the share of Germans, shown for the year 1925, indicates that the national census was falsified in this respect or at least manipulated, as performed under the vigilance of the gendarmerie. It should be noted that predominant part of this population did not fully demonstrate Polish national identity in the second part of the 19th century and the first half of the 20th century. The term "Poles" should not be treated in the sense of purely national, but more in the sense of language, culture and origin (Belzyt, 2013). In the next years the process of "statistical" Germanisation advanced very quickly. In the census from the year 1939 all inhabitants were arbitrarily considered Germans.

Table 8.1. Changes in population and nationality structure in Szczytno (germ. Ortelsburg) and Nidzica (germ. Neidenburg) districts

Year	Population in Szczytno district			Population in Nidzica district		
	total	Poles	Germans	total	Poles	Germans
1818	32,123			20,701		
1825	38,038	34,928	3,100	25,363		
1837	41,886	37,679	4,207	26,712*		
1846	48,408	42,827	5,581	31,981	21,542	10,439
1861	54,699	48,097	6,602	41,551**	33,557**	7,994**
1890	69,477	54,887	14,590	48,157	36,809	11,348
1910	68,774	49,384	19,390	49,628		
1925	70,902	21,982	48,920	38,599***		
1939	73,442		73,442	39,000		39,000
1960	55,200	55,200		32,100	32,100	
2009	69,286	69,286		33,444	33,444	

* 1835
** 1864
*** The area of the district was reduced on Versailes treaty.

Buildings in the villages and small towns in East Prussia were largely constructed of brick or were half-timbered, and virtually all roofs were covered with tiles, only few houses were tin-roofed. The change of construction materials to more solid ones was forced by the fire protection regulations from the beginning of the 19th century, forbidding the use of inflammable materials in newly constructed buildings and stipulating a sparser distribution of buildings in villages. Densely overbuilt towns, mainly with two- and three-storey buildings, had quite distinct historical centres (with the ruins of castles of Teutonic Knights). They were provided with water supply systems – the urban landscape was dominated by water towers, side by side with church towers and representative buildings of public administration and schools.

World War I entered this area already in first weeks of fighting, starting of entering the First Russian army on August 17, 1914 (Army "Niemen" attacked from the east) under the command of general Paweł Rennenkampf on East Prussia and attack of the Second Russian army on August 21 (Army "Narew" attacked from the south) under the command of general Aleksander Samsonow, advancing on the Eighth German army commanded by general Friedrich von Prittwitz soon replaced by general Paul von Hindenburg. Heavy fighting took place in the region, referred to afterwards by the Germans as the battle of Tannenberg (presently Stębark), ending with complete a complete deafeat of Russians commanded by general Samsonow. In German tradition this battle is treated as a revenge for the battle of Grunwald (in German historiography called the fires battle of Tannenberg). One is reminded of these events by war cemeteries.

During World War II destruction was brought into this area only by the Soviet offensive of January 1945, and by the moving line of fighting, but even more so – by that, what happened after the fighting moved westwards. The Soviet military were conducting the retaliatory action, burning, destroying and devastating the buildings and the infrastructure. Destruction of the villages, but especially of towns, was enormous. At the end of war a large part of the population, particularly German population, fled from the Red Army to Germany, a part of them were resettled already after the war conform to decisions of the conference in Potsdam (most of them were descendants of settlers from Poland).

The desolate land was settled by people coming from various directions, mainly from the neighbouring areas of Masovia, but also by Poles resettled from the east, i.e. from the former Polish territories, having been incorporated by the Soviet Union as a result of the war, primarily from the region of Vilno, as well as Poles and Ukrainians resettled from the south-eastern Poland as a part of the "Wisła" resettlement action. The process of emigration of the native population, speaking Polish dialect, frequently of Evangelical denomination, from Masuria to Germany, was also quite intensive just after the war, then slowed down, but thereafter again intensified in at least two waves (late 1950s and 1970s), so that virtually all of them left. Given the almost complete exchange of population it should be noted that locations of towns and villages virtually did not change. Yet, some of the abandoned settlements were not populated again, a part of land was forested, and a part was left as wasteland (Sakson, 1990, 1998).

Very important changes took place in the vicinity of Małga, after 1949, when the military authorities of People's Republic of Poland decided to estabilish a military training ground between road Nidzica-Wielbark on the south, Omulew river on the east and north and villages Wały and Muszaki on the west. For this reason villages, which survived the war in January 1945: Małga, Dębowiec Mały, Dębowiec Duży, Piec, Retkowo, Kanwezy, Sadek, Puchałowo and Ulesie were demolished. This area, which in 1939 was inhibited by 2299 people, as a result of events from 1945 and creation of military training ground was totally desolated (see Fig. 8.1). In 1993 the military facility was liquidated. On the part of this area the nature reserve "Małga" was created.

The settlement and development processes in the study area were very significantly influenced by the calamities. Epidemics among people and livestock, bad crops leading to hunger, wars and army marches, fires and floods, caused, for definite periods, a reversal of the settlement process, depopulation, and, consequently, the succession of the vegetation and the return of the forests (Leyding, 1962). Civilian population was affected by numerous elementary disasters, with the most dramatic effects being caused by the following events:

- In 1529 the plague decimated the entire Ducal Prussia; in the years 1539, 1549 and 1580 it seriously affected the population of counties of Szczytno, Działdowo, Nidzica and Giżycko.
- In the years 1600-1601 bad crops in Ducal Prussia caused hunger, leading to death of many inhabitants.
- The invasion of Tartars, allied with Poles, in revenge for the attitude of the Prussian Elector during the Polish-Swedish war in 1656, ravaged southern Prussia. Some 23,000 persons were killed, and 34,000 persons were taken prisoners, villages were burned down, even fruit trees were cut down in the orchards.
- In the years 1693 and also in the years 1708-1711, the plague, having come to Prussia from Poland, brought about great population losses in the entire region. Around 1/3 of the population of Ducal Prussia died – that is, 200,000-250,000 people, mainly in the eastern and southern parts, as well as in towns. In the ducal domains 2220 farms emptied.
- In the years 1714-1720 and 1726-1727 livestock diseases and catastrophic crops took place. The abandoned areas were colonised again only in 1750. Villages were settled then in the communes of Dźwierzuty, Szczytno, Rumy, Botowie, Rudziska, Jeleniowiec, Miętkie, Romany, Trelkowe, Grom, Krzywonogie and Lipowiec.
- Napoleon's wars brought acute losses to the region in the years 1806-1812 (robberies, taxation, contributions etc.). Hunger and diseases (especially cholera) decimated population (Chojnacki, 1984).
- During World War I population was displaced from the border-adjacent areas. Evacuation of the population, together with their belongings, to Germany, was organised.

Enormous losses took place during and just after World War II, especially due to forced evacuation of civilian by order of Gauleiter and the last *Oberpräsident* of East Prussia – Erich Koch and the Soviet offensive, flight and deportations of the local population, treated altogether as Germans.

8.2.2. Agriculture

The common way of cultivation in the 14th century was the three-field system. The crops raised were: wheat, rye, oats, buckwheat, millet, linen, peas, broad beans and small-seeded broad beans, tare, hemp, colza and turnip. It was quite common to sow a mixture of wheat and rye (this habit persisted in the counties of Pisz and Szczytno yet until the 20th century).

As late as up till the middle of the 18th century wooden farming tools were used (plough, harrow, lister), which implied shallow ploughing. Farming economy was little effective, concentrating on cereal production, with animal husbandry playing a small role (peasant pastured cattle mainly in the forests). In the 17th century one seed sown brought, on the average, 3.3 new seeds, and 5 at most. After the harvest the stubble was pastured and then burned out (Wieczerzak, 1968).

During the 19th century in Central Europe cultivation of potatoes and beetroots (sugar beets and mangels) became common. Already in the middle of the 19th century potatoes became the primary food crop in the villages. New crops forced a revision of management system, tree-field system was improving.

Prussian king Frederick II attempted an agricultural reform in the region, intending to replace the three-field system by the four-field one, and to intensify livestock raising by extending the feedstuff base (through introduction of new crops, like hops, lupine, clover). He promoted modernisation of farming through replacement of wooden farming tools with iron tools, and through introduction of new technological solutions (mowers, threshers, etc.). In the years 1729-1730 a mass action was undertaken in the region of planting fruit trees in orchards and along roads. Attempts of land consolidation, introduction of land rents for peasants and abolition of soccage were also made, but the general resistance from the inhabitants was very strong and the introduction of innovations progressed very slowly.

Since 1870 the three-field system was replaced by the four-field system, giving up fallowing, a part of meadows and unused land was included in the arable land, plots were being consolidated, and fields were delimited again. After the crop rotation system had been introduced, one of the crops introduced was clover, pastured directly in the fields, with the ground being fertilised by the excrements of the pastured cattle. During the 19th century in East Prussia horse raising (mainly for the army), as well as cattle, sheep and goat raising developed in the region on a bigger scale.

The law of 1799, mentioned already before, which was actually being implemented since 1808, liquidated the right to pasture in the forests. Due to the appropriation reform an average area of peasant farm in the entire Masuria amounted to 21.2 hectares. Let us add that large farms, having 100 and more hectares constituted 40% of all farms, while those with less than 5 hectares – only 5%. At the end of the 19th century large farms constituted 32% of their total number, the share of the medium-sized ones increased, while the share of the small ones remained similar. Crop yields distinctly increased (Table 8.2).

Table 8.2. The crop yields in East Prussia [dt ha^{-1}]

	1878	1888	1904
Wheat	9.7	10.1	17.6
Barley	9.7	8.6	17.3
Rye	8.5	8.9	16.0
Oats	8.0	8.2	16.6
Potato	54.8	68.2	131.8

For climatic reasons (relatively short growing season, early autumn frost), the sugar beets were cultivated in Masuria only on limited surfaces, but the yields achieved were high. Likewise, yields of the fodder crops in the region were high (Stępiński, 2000ab).

Manure was applied to the fields in East Prussia in the 17th century on average every eight years, in the 18th century – every five years, and in the second half of the 19th century – already every three years. Lime, meadow or lake chalk were scattered as mineral fertilisers. Application of humus on meadows and pastures was also customary, especially on the sandy habitats, where soils were poor and dry. Application of this type of fertiliser enriched the soils with the nutrient substances and entailed an increase in water capacity. At the end of the 19th century the use of mineral fertilisers – especially based on nitrogen – increased considerably.

Southern Masuria had advantageous natural conditions for the development of livestock economy. In the habitats of alluvial forests, in terrain depressions, after forests had been felled, conditions would arise appropriate for the development of meadows and pastures, while numerous water flows and lakes secured water supply. In the multiple-species deciduous and mixed forests it was possible to pasture not only cattle (used to World War I), but also pigs (abandoned after 1820).

Since the period of the Teutonic Knights, horses were raised in the region in relatively high numbers, mainly in the vast domains of the Order. Cattle and sheep were raised in limited numbers. Pigs were mainly raised on peasant farms. A very important role in feeding of pigs in winter was played by acorns, collected in forests. Peasants would buy out the right to gather acorns or had it guaranteed in the framework of easements.

In the 17th and 18th centuries animal raising was limited by the shortage of feedstuffs in winter and numerous animal diseases (the biggest epidemics taking place in the years 1714-1720). An important limitation was also constituted by wars and army marches, which decimated herds.

The numbers of livestock in East Prussia in the 17th and 18th centuries might be extrapolated on the basis of data from the second half of the 19th century, taking appropriately lower levels. The respective approximate numbers would thus be: for cattle – 650,000 (raised mainly in Natangia), for sheep – 1,800,000 (mainly in Upper Prussia), for horses – 350,000 (mainly in southern and western provinces), for pigs – 200,000 to 250,000 (with quite even spatial distribution) (Wieczerzak, 1968).

In the second half of the 19th century East Prussia was the area of developing and transforming livestock husbandry. The traditional forms of husbandry were being abandoned, consisting in grazing animals in woods and on pastures, and keeping over winter a small number of animals, necessary for reproduction. When the amount of available feedstuffs increased, owing to the introduction of fodder crops and potatoes into the crop structure, and the increase in cereal yields, the actual development of livestock economy became possible.

Forest litter was also exploited. After the easements had been liquidated and as forest entry was increasingly limited, litter exploitation slowly disappeared, but in some places persisted yet until World War I. Forest administration has been putting limits to the illegal exploitation of litter. Elements of the litter (leaves and needles, heather, bilberry, dry grasses and swards, mosses and ferns, as well as twigs), were used in cattle stables and pig sties (Broda, 1965; Kozłowski, 1846).

Since the first half of the 19th century a decrease in the number of sheep on the entire territory of East Prussia was noted. This decrease got yet more significant in the second half century (in the years 1866-1907). It was commonly held that weather conditions in Masuria (low temperatures, high precipitation) make sheep husbandry difficult. Thus, cattle were often replacing sheep. And the number of cattle doubled in the same period. The main breed of cattle was the Prussian black-and-white, but Dutch and Frisian breeds were also being introduced. The sanitary state was improved and the cattle tuberculosis was fought. Sheep and cattle raising was mainly the specialisation of large farms, particularly so in the north and in the west of the province, that is – outside of the study area.

Horse keeping continued in large state stables, but this activity expanded also to smaller farms, including the peasant-owned ones. Horses were pastured on acid, less fertile meadows, in greater numbers within the southern and south-western parts of East Prussia, along the boundary with Masovia. There was no dominant horse stable in the study area. Since the main purchaser of horses was the army, no draught nor cold-blooded breeds were raised.

During the 19th century a gradual increase in the number of pigs took place. Breeding was dispersed across the entire area of East Prussia, with peasants playing the most

Table 8.3. Changes of numbers of livestock in Szczytno (germ. Ortelsburg) and Pisz (germ. Johannisburg) district

District	Year	Horses	Cattle	Goats/sheep	Pigs
Szczytno	1936	14,863	40,387	1,796	45,528
	1946	2,469	1,805	1,600	880
	1955	8,380	19,958	12,445	22,479
	1960	8,610	21,665	8,897	25,466
	2002	1,904	31,863	436	17,693
Pisz	1936	11,930	27,935	3,440	3,094
	1946	2,007	2,414	2,941	753
	1960	6,100	18,200	8,900	22,500
	2002	1,116	23,798	393	9,508

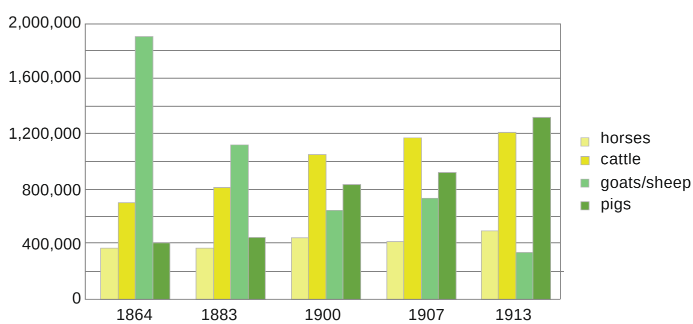

Fig. 8.2. Changes in numbers of livestock in East Prussia

important role as producers. Starting with the year 1880 a fast increase in goat numbers took place (6200 in 1864, 5500 in 1882, 28,200 in 1907). This was associated with the overpopulation of countryside and progressing pauperisation of numerous peasant farms (Stępiński, 2000ab).

Detailed data concerning the numbers of livestock in particular years are presented in Tables 8.3 and in Fig. 8.2. They can be compared with the data of Kurpie (Table 8.4) and of Polish Kingdom (Fig. 8.5).

8.2.3. Forest economy

The Forest of Galindae, called also the Great Forest, grew over the entire study area in its Masurian part until the end of 14th century. It was composed of coniferous and mixed pine-spruce-oak woods, with pronounced shares of hornbeam, maple, lime, birch, elm, and ash, as well as alder. This composition of tree stands persisted until the middle of the 17th century (conform to the descriptions of the "Jańsbork Forest" from 1576 and 1663). Due to the settling process and the development of land for farming, the reach of the great forest gradually shrank, especially from the north-western direction (Mager, 1960).

In the 16th century the great forests occupied more than 60% of the area, covering a broad belt along the boundary with the Kingdom of Poland, the eastern part of the region being almost entirely covered by woodlands. The settled and agriculturally used area was situated along on both sides of river Orzyc, between the localities of Chorzele and Nidzica (German: Neidenburg), on Nida river. The partly deforested areas were also: the valley of Omulew, the lands around Szczytno (then Ortelsburg in German and Zittna in Polish), Wielbark (German: Willenberg) and Pasym (German: Passenheim).

In the southern part of Masurian Lakeland and on Masurian Plain forests were intensively exploited – in many places iron peat bog ores were dug out and lime kilns were located by lakes. Informations about occurrence and use of iron peat bog in the southern part of East Prussia can be find in the works of German and also Polish researchers (Bock, 1782; Kozłowski, 1978; Mager, 1960; Ratajczak & Skoczylas, 1999; Zweck, 1900). Wood was used as a construction material and as fuel, in production of tar, ash, potash, charcoal, as well as a material for craft production. Ironworks existed since the 15th century, based on local extraction of iron peat bog ore (along a broad belt from Nidzica to Pisz), with deciduous tree charcoal used for smelting. After either ore or wood had been fully exploited in one place, production moved to another. Forests were also pastured, litter was collected, fruits, mushrooms etc. were gathered, and, of course, there was hunting and poaching. After trees had been felled and snags removed (used as raw material in potash production), clearings were burned out and cultivated for several years (mainly under cereals and buckwheat), until soil became barren. These fields were then abandoned for more than ten years, and either Scots pine was sown or they were left to natural succession of forest re-establishment. When the habitats regenerated, farming would return. More fertile habitats of deciduous forests were selected for this agricultural use. Such an economy caused lowering of the tree stand age, decreased soil fertility, as well as expanded coniferous tree species. Burning out of clearings initiated numerous forest fires, especially of pine forest fragments. This wasteful exploitation of woodlands caused that already in the 16th-17th centuries the Great Forest lost the character of primeval forest. The descriptions of the forest complex Johannisburgerheide (nowadays corresponding to the Forest of Pisz) from the 19th century speak of domination of mixed pine-and-spruce tree stands, with admixture of oak, and, on swampy areas – alder. Spruce took over more fertile habitats and wetter ones. The area share of deciduous species (hornbeam, lime, ash, maple, and aspen) was estimated at around 5%.

In the 18th century in Prussia changes were initiated as to the administration, economy and financing in the Prussian state, involving increase in effectiveness and profitability, separation of ownership, mechanisation of production, liquidation of harmful activities or privileges. These changes encompassed also forest management. In 1739 one of the items of the reform, concerning forests, forbade the use of the name Great Forest, since such an entity no longer existed. The action of forest development was started in 1755 with the measurement of forest complexes, as well as the identification and separation of state and private property. This work was then continued over the entire 19th century. Forest complexes were divided into districts, superior forest precincts and smaller precincts (the district of Johannisburger woods, having the area of 55,890 hectares, was divided into seven precincts). In the effect of the reform the forest area decreased, but it became also more compact. In the 19th century parcelling of the private forests was allowed, and their area was quickly diminishing. Forests were cut across by the road grid, vistas were established, and wetlands were drained.

In 1780 there were twelve wood distilleries, eight tar workshops, five charcoal workshops, four lime kilns and eight brickyards in the area of the Great Forest. All these plants were liquidated in the 19th century. At that time there still existed the ironworks in Małga, Sadek, Rustów, Stachy, Kucbork, Rudki, Kłoń, Rozogi, Karwica, Spychowo, Jesionowiec, Babięty and Wiartel, but they were closing their activity. At the turn of the 18th and 19th century the intensification of iron peat bog exploration took place in this region. The greatest perspectives to find raw material was around Wiartel and Nidzkie lakes. On the other hand, in Spaliny and Turośl exploitation of iron peat-bog ore began again. In Wądołek on Rybnica iron working plant was established, which was supplied with ore from local sources, in particular – from Spaliny and Turośl. Charcoal was used for smelting. Iron production was carried out in the years 1801-1899. The average daily yield was 1.9 tons (Maciejewska, 1970; Pawlicki, 1997).

Although beekeeping in the forests was among the traditional occupations of Prusses, it was liquidated in East Prussia in the years 1795-1807, with the same regulation prohibiting forest production of ash and potash.

Forest felling economy was conducted in the 19th century. Coniferous stands of 60-70 years of age were cut. The clearings were cleaned and coniferous trees were sown (less frequently planted). Wastelands and empty spaces were afforested, windfalls were liquidated and forest was re-established on their areas, sandy fields and dunes were immobilised and afforested, as well (thus, for instance, in the 1830s some 1837 hectares of poor soils were afforested in the vicinity of the villages Wały, Rekownica, and Ruda-Małga). Owing to this kind of management, single-age and single-species tree monocultures quickly appeared. Business profitability of forest cultivation increased, but ecological diversity was lost, habitats were degraded, resistance of ecosystems to invasions of pests in forests decreased (serious threats to forests came from pine beauty moth, nun moth, but also fires and strong winds). This way of managing forests lasted until the 1880s (the sole change consisting in increasing the cutting age of stands).

Detailed information was collected for the area of Forest of Pisz. Powerful hurricanes, which affected the region in the years 1833, 1839, 1867 and 1888 caused enormous losses, especially in the spruce stands. Numerous forest fires occurred also in this forest complex, the biggest ones in 1834 and during World War I (in the area of Szeroki Bór). Mass insect pest invasions occurred in the years 1866 and 1912-1914, while in 1923 and in 1927 pine beauty moth destroyed close to 9000 hectares of forest (Maciejewska, 1970).

At the beginning of the 20th century forest management in the Forest of Pisz was rationalised, with the entire woodland complex being transformed into forest hunting grounds for the state officials, and the cutting age raised to 140 years.

At the end of the 19th century investors turned their attention to the huge potential of unused forest resources in the southern part of East Prussia. One of them was Richard Anders (1856-1934), who at the age 26 began in Spychowo his own bussines, a leading company offering wiping the log and lumber trade. Around 1900 he took over a small sawmill in Ruciane belonging to E. Lehmann. Previously he bought a large plot of forest. He built a new large hall equipped with vertical steam-engine driven sawing machine produced in Sweden. Sawmill was being expanded until 1930s and belonged to the most modern in Germany. It was supplied with wood raw material coming from Pisz Forest floated to the plant directly by the system of Masurian lakes connected by canals. In 1887 he bought a forest in Szczytno and extensive parcel of the Evangelical parish. Soon he built first plants: a sawmill, a woodyard and a mill. Eventually he bought another parcels adjacent to railroad tracks, creating the largest investment in the town – the factory of strips and woodworking (Leistenfabrik), numbering a dozen production and storage facilities, with its own railway siding.

In the 1930s, the Anders family was already the owner of the wood industry group, the core of which was the "Richard Anders GmbH Niedersee/Ostpreussen" company well known throughout Germany and in neighboring countries. It included the following plants: a sawmill in Colony, a mill and carpenters and wood processing factories in Szczytno, a sawmill in Szymany and two sawmills in the Ostróda district – including one in Stare Jabłonki (Guttzeit, 1964; Meyhöfer, 1967). The plywood factory in Pisz belonging to Carl Haase was also an important plant in the region.

8.3. The history of settling and development of Northern Masovia – Green Kurpie

8.3.1. Population changes

This area has been populated since the Palaeolithic period, and from the Neolithic period the isolated findings include those from the times of cultures of spherical amphorae and of funnel-neck beakers. There are more numerous findings from the Bronze Age, and especially from the Trzciniec and Lusitanian cultures (discovered near to Chorzele and Piastów). Then, the sites of the Western-Baltic tumuli culture, and from the Roman period, dated between 1st century BC and 6th century AD (cemeteries and settlements), belonging to the culture of Przeworsk, were identified, in particular, near Leman, Kadzidło, Ołdak and Chorzele, along with a sequence of sites on river Orzyc, while the monuments originating from the culture of Wielbark were found near to the village of Leman. These cultures did not coincide, which is confirmed by the archaeological excavations concentrated along Narew and Orzyc rivers (Majka, 1984).

Between the 6th and 13th centuries this part of Masovia was virtually uninhabited and covered with forests. The vast forest complex, extending between river Narew and the boundary with Prussia, formed a whole with the Great Forest (the Forest of Galindae). The forest on the Masovian side was to a high extent swampy. Yet at the beginning of the 20th century Miklaszewski (1928) estimated that swampy areas accounted for 20% of the forest area, with the biggest peat-bog Karaska.

It was customary to speak of two parts of this forest, namely the Mazuch Forest, situated in the basin of Orzyc river and the right-hand part of the basin of Omulew river, and the Zagajnica Forest, situated between rivers Omulew and Pisa (Tyszkiewicz, 2003)[3]. Both these forest complexes and the extensive wet meadows belonged to the Princes of Masovia and constituted their hunting grounds. The renewed settlement process advanced from the south, from the valley of Narew river. Thus, in the 12th century the fortified localities of Różan, Ostrołęka and Nowogród were established, Krzynowłoga was founded in the 13th century, Drążdżewo and Krasnosielec in the 14th century, while Janów in the 15th century. After Masovia had been completely integrated with the Kingdom of Poland in 1525, the Forests became the royal domain.

According to the Historical Atlas of Poland (*Atlas Historyczny,* 1973), the entire Masovian part of the study area belonged in the second half of the 16th century to the royal domains. The villages owned and/or populated by the nobility in the nearest vicinity were located on the right bank of Orzyc, upstream of Chorzele. Yet in the 16th century this area was almost completely unpopulated, with no roads, rivers playing the role of transport routes in forests. The area has been in its majority covered still by forests. Villages appeared at the fringes of woodlands, and were inhabited by wood-distillers, beekeepers, hunters and fishermen. Inside the forests single huts were sparsely located (of the lumberjacks, wood-distillers, tar-makers, beekeepers or hunters), which did not form persistent settlements, though. There were also villages, whose inhabitants were the guardsmen of the forest complexes, situated around the "Great Forest" (Kolno, Nowogród, Ostrołęka, Przasnysz), which then transformed into urban centres. In the 16th century population density within the study area ranged between 0 and 5 persons per square kilometre, but in the neighbouring county of Kolno it was at around 20-25 persons, and in the county of Przasnysz – at 10-15 (Damrosz, 1962).

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[3] The division of vast forest areas into particular forest complexes, existing in the 16th-17th centuries, differs among particular authors. Thus, *Atlas Historyczny* (1973) distinguishes Zagajnica, Forest of Różan, and Mazuch Forest; Niedziałkowska (1981) splits up Zagajnica into Zagajnica of Łomża, Zagajnica of Nowogród, and Zagajnica of Ostrołęka, the latter also referred to as Skwa or Szkwa Forest. Likewise, the name of Różan Forest functions there, as well. Miklaszewski (1928) suggests a somewhat different division into forest complexes: *The Forest of Kurpie is a relic of the ancient Masovian forests. The compact complex of the Narew Forest was composed of the forests of Nowogród, Szkwa, Myszyniec and Ostrów. These woodlands joined in the west the Forest of Ostrołęka, in the east – the Lithuanian forests, in the south – the Forest of Białowieża, and in the north – the Prussian forests, among which – the Forest of Jańsbork (of Pisz)*.

Since the 16th century numerous settlements of iron ore diggers and ironworkers, along with ironworks, were located on the rivers. Location of the plants was associated with three factors – the appearance of a bog iron stone, the neighbourhood of a river, which made it possible to install a water wheel, and the vicinity of a deciduous forest, supplying wood for iron smelting. The charcoal for ironworks was produced on place. With this respect the so-called "black forest", meaning the deciduous woods with high share of alder and hornbeam in the stands (and also oak, lime, ash or maple), was especially attractive since it provided wood, from which highly energetic charcoal was produced. The iron ore settlements would be established on the basis of a personal privilege from the king (most often with hereditary rights), and they employed many people in production. Iron smelting would persist in one location for several decades. As plants were located in fertile habitats and involved quite a number of local residents, all of these settlements, after the ore was fully exploited or the local forest completely felled, gave rise to villages.

In the 15th century the ironworks existed in the forest, located in the following settlements of iron ore diggers on Omulew: Brodowe Łąki, Ruda Omulew (now: Grabowo), Przystań, Wyszel, Oborczysko and Czarnotrzew (Fig. 8.3).

In the 17th century, an ironwork existed in the village of Lelis, which was closed down for a lack of wood used to produce charcoal for smelting. At that time iron was also smelted in the village of Chudek. In 1605 there were, as well, iron ore plants in the village of Lemany. Based on the privilege of 1639 an ironwork plant was established in the village of Olszówka on Omulew, with ores being transported from the neighbouring villages of the nobility. The functioning of these ironworks is confirmed by a privilege of 1697. In 1718 the privilege of ore digging in Czarnotrzew was renewed (according to the documents from the royal domains – Piaścik, 1939).

Ash production played quite an important role on the territory of Kurpie in the 17th century. The settlements formed by persons employed were quite big (even up to 300 inhabitants, as noted by the Rev. Kościesza-Załuski in 1650, an envoy of the Jesuit mission in Myszyniec (Heymanowski, 1970). According to the inventory of the Łomża county of 1636, the wood-distillers and tar producers, using for their production mainly snags, but also the resinous trees (like pines), contributed to a significant devastation of forests. The primitive production of tar was carried out in the region on a significant scale. A considerable technological progress took place in the 17th century, when tar furnaces were introduced (Heymanowski, 1970).

Inside the forest complexes the most ancient settlers resided – beekeepers, tar-makers, hunters. They did not form compact settlements, but lived separately in dispersion. They would cultivate small fields and meadows. According to the inventory of the royal domains of 1616, the forest was inhabited by 84 beekeepers and 10 tar-makers (AGAD, ASK, Dz. XLVI 150), their settlements being very small (3-4 "włókas", i.e. 50-70 hectares). During the Swedish wars (in the middle of the 17th century) a big wave of population inflow to the forest was noted – the refugees, mainly from Masovia and from Ducal Prussia, seeking safe asylum. These newcomers would cut trees and develop clearings for farming. New, spontaneously developing villages emerged on completely raw grounds, but also the existing villages were being extended. Thus, the forest was settled again only in the 17th and 18th centuries. The stages of settlement process are shown

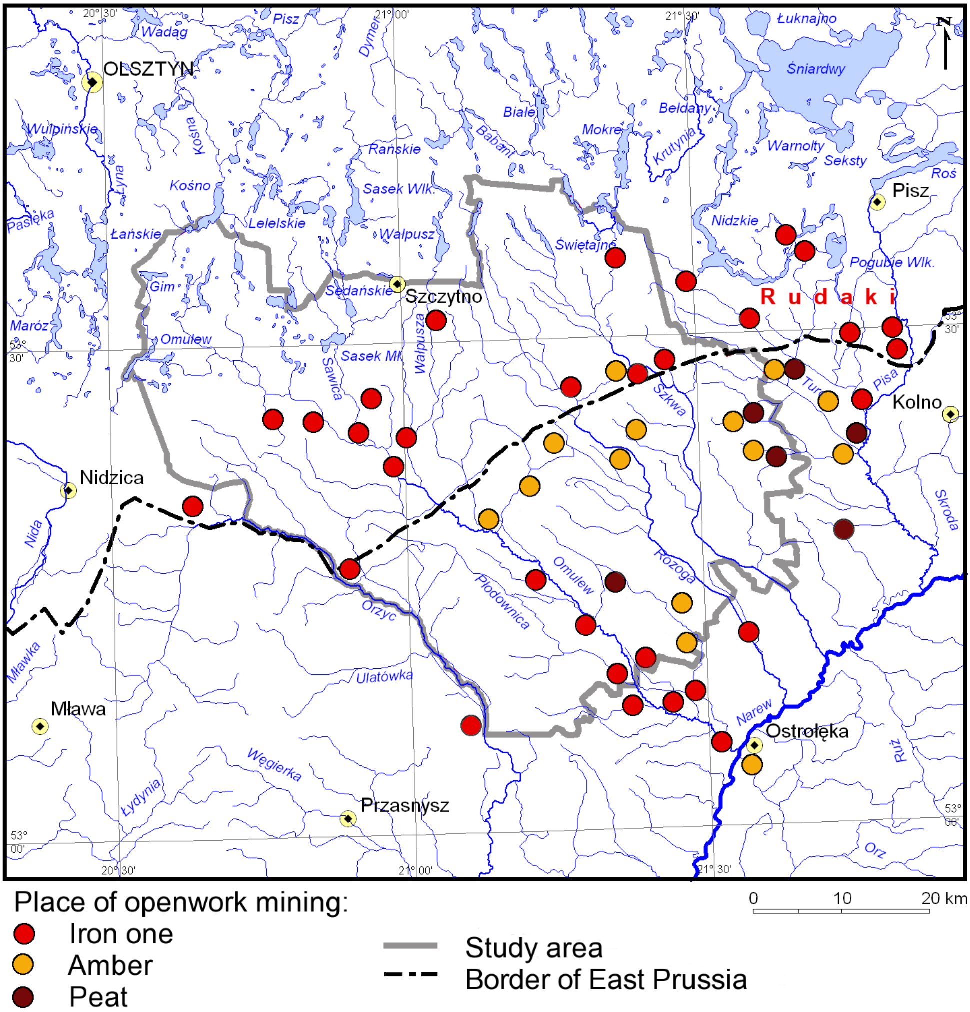

Fig. 8.3. Places of openwork mining

in Fig. 8.1. A Jesuit mission was erected in Myszyniec, intended to counter the spread of Protestantism onto the Polish territory.

The villages of Kurpie region bore very acute losses during wars, army marches, but also due to taxes and service works for the county authorities in Łomża and Ostrołęka. In 1750 the villages in the Zagajewska Forest in the county of Ostrołęka were charged with rents rather than soccage, but regarding the remaining ones, the system was changed only in the middle of the 19th century. It is estimated that in 1765 the forest was inhabited by approximately 5000 persons (Kazimierski, 1984).

After the partion of Republic of Poland, in the years 1796-1806 the territory of northern Masovia was incorporated into Prussia and called New East Prussia (German: Neuostpreußen). The occupants conducted a predatory exploitation of forests. As the lower stretch of Vistula and Bug rivers, as well as almost entire course of Narew were at that time in one country, the authorities aimed to re-establish the navigation and river transport of wood and of agricultural products down to the haven of Gdańsk. For this purpose all the structures that hampered the water flow on the tributaries of Narew were being destroyed (mills, fulleries, ironworks and sawmills). The regulation works on Narew and Orzyc were also undertaken, consisting in the shortening of river courses (cutting across the river meanders) and the acceleration of water outflow.

Then, during the Napoleon's wars the region of Kurpie was incorporated into the Warsaw Duchy, and as a result of findings of the Congress of Vienna in 1815 have been incorporated into the Kingdom of Poland, which in the years 1815-1832 was combined personal union with the Russian Empire and later until 1918 was part of this empire. Both during the Napoleon's wars and the Polish uprisings – the November Uprising (1830-1832) and the January Uprising (1863-1864) – heavy fighting took place in the area of Kurpie. As a result of the military operations and the stationing of armies the region was destroyed and economically devastated. Repressions of the tsarist authorities after the January Uprising, led to the loss of urban rights in 1870 by Chorzele, Janowo and Myszyniec (Fig. 8.4).

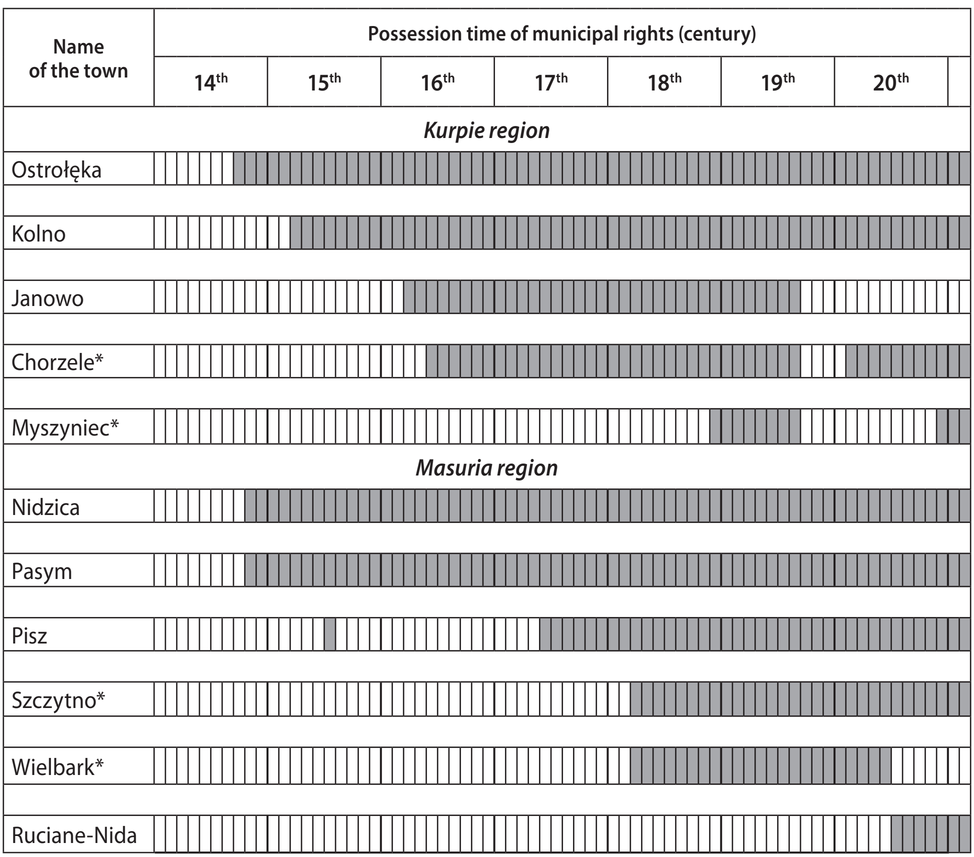

Fig. 8.4. Changes in the urban network in Masuria-Kurpie region

* – towns located in the study area.

In the Russian Empire forests (former royal or monastic) became the property of the tsar, the authorities limiting forest felling and turning of clearings into meadows and fields. In 1835 the inhabitants of Kurpie had beekeeping in the forest forbidden. Several reasons are provided in the literature, explaining the decline of forest beekeeping and the transfer of bees to artifitial hives: limitation to the forest entry, liquidation of the customary protection of huge trees, in which bee families could live, and which were fit for felling.

In the Russian Empire the agrarian reform, which abolished villein service and gave peasants a farming land, was introduced through the enfranchisement law of 1864 (its actual implementation in the region continued yet in the 1890s). The Kurpie region proper, though, was inhabited by free royal peasants, who paid rents since centuries. The enfranchisement reform of 1864 did not bring "forest people" a lot of good. It must be emphasised that the farm economy in Kurpie was based on the simultaneous use of forest resources and land cultivation. This reform made them farmers only. Forest apiculture and hunting were totally forbidden. The gathering of fuel wood in forest was limited, and free felling was liquidated. In the place of the easement privileges they obtained the right to use the "dropouts" and "pieces" (felling clearings and other free spaces in forest).

Peasants were settled in the confiscated estates, previously being courtly lands. The estates were parcelled, and a couple of new villages were established, having a regular shape and a geometric design of land divisions. The register of the localities was put in order, and several villages, having developed illegally on the forest clearings, were given proper rights (e.g. Wach, Krysiaki, Pupkowizna). Consolidation of the land plots was also carried out in some villages, but this process was very slow.

After the enfranchisement, the number of settlements decreased. This was most probably brought about by the inclusion of hamlets into the bigger villages, or by the joining of settlements (Sokolewicz, 1964).

At the turn of the 20th century the countryside in Kurpie was overpopulated, poor soils not being able of feeding the inhabitants. Poverty forced common job-related emigration of women – mainly seasonally to fieldwork in East Prussia, and the young – for a longer time, to Prussia and to America. After World War I migratory flows went to various parts of Poland, mainly to towns. Numerous groups of inhabitants of Kurpie settled the so-called Regained Lands, formerly belonging to Germany, mainly the neighbouring regions of Warmia and Masuria.

Over the centuries, there have been cases of population decimation by natural disasters, and to a lesser extent by disease, as the settlements were scattered, but very much by the famine of 1881 (drought, hail and fires). Hunger reigned also during World War I and immediately after it – in the years 1915-1917 and 1920.

The population of Kurpie was forced in during the World War I to abandon their homes and to move, along with their belongings, deep into Russia. This was the classical Russian strategy of leaving barren ground to the enemy, when retreating. Many villages were burned down, most of the livestock was confiscated for the army. After the war the inhabitants came back, but they had to start over, building homes and farms, bringing fields to cultivation. Livestock was re-established slowly. During the reconstruction the village patterns were often modified, like the division of land (and that is why old plans are often in disagreement with the current situation). The modifications consisted in a looser configuration of structures, wider and straighter roads, and establishment of central squares. Yet, the villages were still wooden, and straw or shingle roofed.

Makulski (1964) distinguishes the following three periods in the development of the region of Zagajnica Forest:

1. Until the 17th century a moderate exploitation of forest resources and natural deposits is taking place. There are dispersed apiaries, ironworks, mills, tar plants, and sawmills, forests are penetrated by hunters, fishermen and shepherds. Their dispersed and temporary settlements reach deeply into forest complexes along river valleys. The farmer settlements moved slowly from the south and south-west, forming most often the deforested belts. One should also note the migrations of settlers from the north, resulting in the appearance of Protestants in the villages, with reaction constituted by the establishment of a Jesuit mission in Myszyniec (with headquarters in Łomża). This period ends with the Thirty-Year War and the surging demand for agricultural products.
2. Pressure is exerted towards the agricultural use of land. The forest-livestock-farming economy dominates in the region. There is a considerable share of apiculture. This stage lasts until the end of the 18th century.
3. Between the middle of the 19th century and 1945 a change takes place in the ownership relations (passage from feudalism to capitalism), limitation of the rights of the native population regarding the use of forest. New tools and machines are introduced in agriculture, and the range of crops is broadened. The livestock-and-farming economy dominates. Forests have been measured and subject to systematic management.
4. After World War II slow modernisation of agriculture takes place, along with the development of infrastructure. The region specialises in livestock raising, especially of dairy cattle, and the livestock numbers generally increased (Makulski, 1964).

World War II lasted in this region from 1939 to 1948 and turmoil associated with with this war lasted to 1948, and locally until 1950. After the Germans marched in, the area was incorporated into the Reich, and a part of population was resettled to the so-called General Governorship (Generalgouvernement), while another part was transported to forced labour.

The German Nazis carried out the complete extermination of the Jewish population, inhabiting in significant numbers the small towns of the region. Jewish population increased in the townships in a spectacular way in the 19th century. For instance in 1820, out of 1203 inhabitants of Chorzele, Jews accounted for 32.5%, in 1857 – out of 1930 inhabitants there were 49.2% of Jews, in 1860, when there were 2032 inhabitants – 55.1% of them were Jews, and then in 1905, when some 4000 persons lived in Chorzele, Jews accounted for 57%. Although after World War I the population number decreased (in 1931 this number was at 3032, and in 1939 at 3800), the share of the Jewish population on the eve of World War II was also about half. This population did not survive the war. The last groups of Jews left the township on December 8th, 1941, transported to Maków, from where they were taken to the German extermination camps (Spector & Wigoder, 2001).

The inhabitants of Kurpie organised armed resistance against the German occupants. Guerilla detachments fought against the Nazis, and afterwards – against the communist authorities. The agrarian reform encountered in the areas of the Kurpie Forest a clearly negative attitude, and the establishment of large cooperative farms as well as state farms faced resistance and boycott. Ultimately, only few such farms were established – mainly on land, where improvement undertakings (primarily draining) were freshly done. Family farms continued to dominate the agrarian structure (Kazimierski, 1984).

8.3.2. Agriculture

The region of Kurpie features, in general, quite adverse habitat conditions, with poor soils, sandy within the dunes, and wet and swampy in the lows. Farming developments were first done in the most fertile habitats, stretching along the river valleys. In the forests, the alternating farming dominated – after a couple of years of agricultural use the land would be abandoned and became fallow, overgrowing gradually with forest. New fields were established on freshly felled clearings. Farming would return to the previously abandoned location after some period of time, usually more than ten years.

In the 18th century (...) *arable land was established either on better, drier meadows, or, again, by cutting forest. Initially, buckwheat or rye were sown only on the freshly cleared forest land, or within the spaces, where branches were burned out and bushes as well as smaller trees cut down. After a couple of years, when soil would become clearly less fertile, cultivation was transferred to a new place and farming would start over* (Chętnik, 1927b). The three-field system was commonly used. The primary crops were cereals. The yields were very low yet in the 19th century. It is estimated that one seed produced only 2-4 seeds. When free tree cutting was allowed, farms were extended at the expense of forest areas. This, however, was forbidden in the 19th century. Since the time the land was measured, farms could be extended by developing wastelands or common grounds (communal meadows, pastures or forests belonging to village).

Stable manure was applied as fertiliser every few years, since, owing to the grazing of livestock in forests, not much dung would accumulate in stables or pigsties. On the mounds the pig manure was applied, as it would maintain well humidity, while in the wet lows – horse manure. Forest litter was also used to soil fertilization. Buildings for keeping livestock were strewn with moss, needles, straw and hay from sedge meadows (not fit for animal feeding) – forest litter was used as fertiliser in the fields.

Modernisation of agriculture progressed very slowly. Cultivation of potatoes was introduced at the beginning of the 19th century, and potato became quickly a main nutritional crop on poorer farms. In that period 1/3 of the cultivated area was sown with rye, the second most important cereal being millet. Other crops grown were wheat, oats (less frequently barley), peas, linen and hemp, buckwheat, lupine and bird's foot. Yields were still low. Farming was focused on subsistence, and, in fact, production hardly sufficed for the needs of the inhabitants. Fish caught in many rivers accounted for quite a large share in the diet of the inhabitants of Kurpie.

Yet in the 1880s wooden tools were used for cultivation. Iron plough ultimately replaced the wooden one in the 1920s, while a scythe was increasingly used to harvest from half of the 19th century. Crop rotation was introduced at the beginning of the 20th century (Sokolewicz, 1964).

Starting with 1881 the tsarist officials would perform the consolidation of land plots, the dispersed ones were turned into compact areas, while common village pastures were divided up into individual parts. The process of reforming the ownership and land use structure was very slow, though. The consolidation work continued after World War I in sovereign Poland. It started again, together with the regulation of property rights, in 1925, and then taken up anew after World War II, to be finished in the 1950s.

Yet, it was until the 1970s that some forms of joint use of meadows, pastures and forests persisted in Kurpie (both within one village and between the neighbouring villages and hamlets), see Biernacka (1962). Cultivation of land was very highly taxed in the tsarist period, due to the tendency to classify soils as fertile. This made farming highly unprofitable. It was only in the independent Poland that in 1924 a commission, sent to the region by the Director of the Treasury Department, verified and changed the still applied classification of soil quality and associated tax rates. Soil classification in the forest part went considerably down, e.g. class II was generally changed to class IV (in a six-grade classification), see Chętnik (1927b). The three-field system with fallows disappeared from the region as late as in the inter-war period. The mechanization of basic farm works progressed slowly (treadmill, thresher), mineral fertilisers and seed selection were introduced. The Nazi occupation of 1939-1945 forced an increase in agricultural yields, due to the implementation of compulsory supplies for the army.

The agrarian reform, which was carried out in the socialist People's Poland, did not bring essential changes, the family farms were left – although they were partly consolidated. Most farmers did not receive any additional land for cultivation, because the farms' size was usually over standard in the region with very weak soils. Few cooperative and state farms were established on the freshly drained fallow lands, mainly oriented at livestock husbandry. The area structure of family farms in the county of Ostrołęka in 1958 was dominated by farms considered relatively big for Polish conditions. Thus, among them, the farms of 5-7 hectares accounted for 17.6% of the total number, farms of 7-10 hectares – 29%, farms of 10-14 hectares – 27.4%, and those of 14-20 hectares – 17% (*Województwo Warszawskie w liczbach,* 1959). At that time arable lands accounted for 29.8%, meadows 12.7%, pastures 14.7%, and forests 26.6%, while fallow lands even 16%. The main crop was rye (40.9% of the sown area), followed by potatoes (29.8%), oats (8.3%), and wheat (4.4%). Yields slowly increased, but were still low, in 1958 the rye yield per hectare was roughly 1.3 ton, and that of potatoes – 14 tons (*Województwo Warszawskie w liczbach,* 1959).

Beside land cultivation in this region, breeding also played an important role. The forest of Zagajnica is cut across by the valleys, filled with peat bogs, in which numerous rivers and smaller streams flow. Wide valleys and boggy bowls constitute very good places for grasslands. The use of the meadows inside the Green Forest (another name of Zagajnica) was an ancient custom. The inventories of the years 1576 and 1616 confirm the official grants in the framework of beekeeping rights (forest meadows, beekeeper meadows). Beekeepers possessed meadows in forest yet before they settled there, and paid a low tax on that account. They were also entitled to turn those meadows into arable fields. The biggest number of beekeeper meadows was located along Narew and Pisa rivers (Biernacka, 1962).

Before the enfranchisement reform of the year 1864, mass grazing was carried out in the forest. For this purpose the swampy areas around natural lakes, floodplains, peat bogs and swamps were used. The in-forest meadows were often established by the population in an active manner. Piaścik (1939) claims that pastoral activities were among the most ancient ones in this area. Forest administration would define grazing areas, but poor protection of forests allowed for any use of forest resources. Cattle and sheep could be grazed in the forest, also for a small fee. Grazing of pigs in the woodlands was not very common, due to the domination of pine forests, and it functioned still in the 1830s. Grazing of cattle and sheep in the forests was much more common and lasted until World War I. It diminished owing to afforestration of clearings and wastelands in the forest, and due to the reconstruction of stands, but also because the feeding capacities of farms themselves increased as a result of intensification of agriculture and introduction of new crops into cultivation (Broda, 1965).

Grazing in forest was also carried out by those farmers who would not pay the respective tax (the so-called "horn tax"). Horses were also illegaly grazed in forest during the night. This way of using forest resources lasted between spring and autumn, as long as it was possible. Grazing of horses in forests has been yet noted in 1955. Cattle, horses, sheep, as well as pigs, grazed on pastures and fallows, in forest, and in fields after the harvest time. Animals were grazing together on community pastures. The village pastoral guard was also organised during grazing in forests.

The numbers of livestock kept are very hard to estimate. By extrapolating the data for the neighbouring region it can be estimated that farms of 1 "włóka" area, i.e. of roughly 16.8 hectares, would keep between ten and twenty cattle, one pair of horses, more than ten, less frequently several dozen sheep, and a couple of pigs (Chełchowski, 1888). Even the landless farmers often owned some cattle grazed on the community pastures. The number of livestock kept was most probably constrained by the capacity of feeding animals during winter.

The amount of hay collected in the region was quite low, because grass were cut with a sickle, the scythe having been introduced to a common use in the 19th century. Branches of deciduous trees and bushes, as well as cereals and straw were also used for animal feeding. The custom of feeding sheep with branches and twigs of deciduous trees persisted yet until the middle of the 19th century, while the habit of cutting down young trees for this purpose was supported by foresters. After potato had been introduced into cultivation in the 19th century, it quickly became the basic feedstuff for pigs. Since that time the share of pigs among animals raised has been increasing.

During the period of the 19th century partition of Poland an important role was played by breeding geese, mainly for smuggling into Prussia. Although there are no statistics on this subject, it is known from the interviews that in the villages close to the Prussian border enormous flocks of geese were breeding, to be then smuggled in mass over the border to Prussia.

The reliable quantitative data on the animal husbandry are provided up till the end of the 19th century. Data were gathered for the counties and also estimates were provided for the provinces and the entire country (Fig. 8.5, Table 8.4).

During the inter-war period a fast increase in the livestock numbers took place. It was already in 1921 that the number of livestock (except for sheep) exceeded the level from before the war. The agricultural census allowed also for having data on individual villages. Niedziałkowska (1981) put together these data as of 1921 for selected villages in Kurpie. Attention is especially attracted by the high number of cattle raised (Table 8.5).

Land improvement undertaking in the inter-war period contributed to the increase and enhancement of quality of agricultural land, and especially of meadows. Hay production increased threefold, and its quality improved. Alas, land improvement introduced was only aimed at drainage (like in many similar cases), causing drying of the ground, with accelerated outflow of water. After a couple of years this would result in a distinct decrease in hay production, due to excess drying of the soil and rotting of the peat bogs. New breeds of animals were introduced. During World War II Germans took care of the livestock husbandry, provided animals of better varieties.

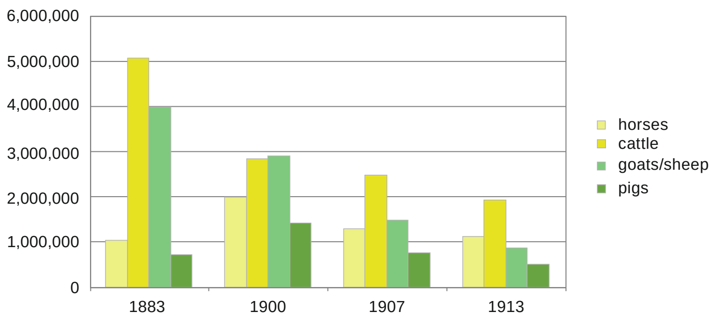

Fig. 8.5. Changes in numbers of livestock in Kingdom of Poland

Table 8.4. Changes in numbers of livestock in Kolno and Ostrołęka district

District	Year	Horses	Cattle	Goats/sheep	Pigs
Kolno	1907	15,086	25,313	22,539	3,030
	1921	14,537	27,272	8,669	12,254
	1945				
	1960	15,600	33,700	16,900	51,800
	2002	896	50,297	213	80,082
Ostrołęka	1907	13,182	28,346	16,285	3,431
	1921	12,524	31,610	3,901	13,487
	1945	9,416	9,820	1,620	2,578
	1960	15,860	42,000	16,000	56,600
	2002	3,840	95,114	481	42,796

Table 8.5. Inhabitants and numbers of livestock in some Kurpie's communes in 1921 year

Community	Inhabitants	Horses	Cattle	Pigs	Sheep
Dylewo	6,426	1,238	3,543	1,133	302
Myszyniec	7,671	1,203	3,343	710	125
Nasadki	5,162	970	2,358	531	279
Wach	8,102	1,198	4,793	971	584

The land improvement action was continued after the war. Before these undertakings the meadows in the region of Kurpie were mowed once a year and produced 1 to 2 tons of hay per hectare, while after land improvement they were mowed twice a year and produced 4-6 tons of hay of better quality (Biernacka, 1962). At the same time, the area of pastures and wastelands, where animals could be grazed freely, was shrinking. Forest grazing, treated negatively during the inter-war period, disappeared almost entirely after the war. As tractors became more common, horse breeding diminished. Pig raising, on the other hand, increased significantly. Nowadays, the region specialises in the dairy cattle production.

8.3.3. Forest management (including beekeeping, amber and peat exploitation)

Although economy of the royal forest was oriented mainly at apiculture and big game hunting, that is – the activities that destroy forests to a minimal degree, the descriptions of the forest complex from the 16th-18th centuries imply quite serious destruction of the stands, and even the devastation of habitats. At that time already young stands dominated, mainly of Scots pine and birch. Clearings, felled areas, and wastelands constituted a significant share in forest areas. There were many places, where after the trees had been cut, loose sands appeared and started to move. Production and transport of wood and of potash in the region was not also very intensive and did not play a significant role. However, the mass production of charcoal for ironworks caused stands' devastation, due to cutting off hardwood deciduous trees (Table 8.6).

Table 8.6. Different contemporary and past means of utilizing the forests in Masuria-Kurpie region between 13th and 19th century

Kind of activity	Aim of activity							
	gathering amber/ peat and bog ore	gathering of food	gathering of fodder	collection of building wood	gathering of fuelwood	production of pitch, charcoal, ash	land for agriculture	fertilizing of fields
Cutting trees			[light]	[medium]	[medium]	[medium]	[dark]	
Pulling stumps							[dark]	
Grubbing up snags							[light]	[light]
Burning/cleaning forest							[medium]	[medium]
Raking litter			[light]					[dark]
Gathering brushwood					[medium]			
Stripping bark				[light]				
Foraging			[medium]					
Keeping bees		[dark]						
Huntuing and poaching		[medium]						
Picking herbs/mushrooms/fruits		[light]						
Opencast mining	[medium]				[light]			

Grayscale intensity corresponding with process intensity.

The first limitations to the forest "entry" were issued in the years 1765-1780 by the royal undersecretary of the Treasury, A. Tyzenhauz. In order to improve the property supervision and to limit the excessive exploitation of forests he divided up the complexes into "quarters" and "guards".

After the third partition of Poland in 1795, the Prussian occupants conducted careless and wasteful exploitation of resources, and especially – mass felling and exportation of wood. Yet, it was exactly the Prussian authorities that started putting in order forest management in the Forest of Kurpie. Woodlands became the property of the state. Forest management was organised in three tiers: forest districts, sub-districts and (game-keeping) precincts. In the perspective of consolidation of forest areas, fields and meadows, as well as dispersed settlements inside the woodlands were liquidated. The inhabitants were relocated, and they were offered land at the border of forest complexes or along the wider vistas (sometimes establishing thereby new settlements). The freedom of felling meant for gaining new agricultural land was limited. The consecutive administrations continued the work on the reform of forest management and forest economy. The actual work on forest development went on for 50 years, during which forest complexes were consolidated, Scots pine was planted on empty spaces, clearings and felled areas. Tree stands were gradually transformed in the direction of a single-age monoculture of Scots pine. Since most of forests grew in the pine forest habitats, planting of this species was conform to the habitat potential.

Russians, who took over this area after the downfall of the Warsaw Duchy (1815), took away some of beekeeper's meadows and rented them out. A part of them were afforested. In 1816 the tsarist authorities confiscated the arms of the "Kurpie shooters", the armed formation, established to serve in the Polish army at the end of the 18th century, and forbade hunting (Tyszkiewicz, 1976). In 1835 Russian authorities removed from the forest dispersed settlements (Sokolewicz, 1964). In the years 1840-1850 forests were measured, state forests were separated from the private ones, and an attempt was made of shortening (straightening) of the property boundaries. In effect, the so-called "forest rests" came into beeing, which could have been informally cultivated by landless peasants to make a living. This practice was common in Forest of Kurpie, and for this reason the possibility of cultivating "rests" on the rights of the lease was introduced by authorities, what usually was not socially approved. Many of the former clearings, which had been used for farming, were included in the forest area. This all was the reason for many conflicts with the local population. The relocated population was transferred to sawmills or to the neighbouring villages, in which the land used was increased by adding the "rests". In 1853 the ultimate separation of the governmental property from the peasant property took place. Meadows over Pisa and Szkwa were taken away form the inhabitants of Kurpie (Sokolewicz, 1964).

As mentioned already, due to the reckless exploitation of forest, in many places fields of loose sands were activated. They constituted a threat to the villages and the agricultural land, but also for the neighbouring woodlands. In the years 1839-1852 the action of stabilisation and afforestation of moving dunes was carried out. Afforestation of "peasant wastelands" was conducted, in particular, near to the villages of Wydmusy, Chudek, Gleba, Lelis, Obiernia, Kadzidło, Brzozówka, Płoszczyce, Grale, and Golonka, as well as Kurpiowskie (a village situated in the lower course of rivers Szkwa, to the south of the study area).

During World War I the forest was exploited very intensively for wood. Chętnik (1927b) wrote that in 1916 Germans transported from the forests of Morgowniki, Dobry Las, Suchy Borek and Gawrychy altogether 9200 pieces of building wood, and in 1917 from the pine forests of the villages of Pianki, Gąski, Tabory, Parzychy and Gawrychy – as many as 62,000 trunks of big and healthy trees. Forests were most devastated in the vicinity of Nowogród. In order to facilitate transportation of wood from the forest, Germans modernised the road from Myszyniec to Ostrołęka and built narrow-gauge railway lines from Myszyniec to Łomża through Dęby-Łyse, Zbójna, Nowogród and from Dęby to Kolno. Chętnik (1927b) estimates that more than 25% of the forest area was destroyed, mainly the old stands of 100-125 years. The remnants of the ancient forest were preserved in the district of Czarnia. Immediately after World War I local inhabitants of Kurpie also contributed to destruction – they had to reconstruct the burned farmyards and the destroyed villages. Enormous moorlands or sandy swards with big junipers and few birches are documented through numerous photographs from the area of Kurpie Forest, and became the symbol of cultural landscape of the region.

The people of Kurpie reaped a broad variety of uses from the forest, with virtually unlimited exploitation lasting almost until the 20th century. Initially, when the population density was low, the forest would regenerate, but starting from the 17th century, when the population number quickly increased, gradual degradation of forest and wetland habitats and ecosystems followed.

It was possible, for a low fee, to gather faggots in the forest (the so-called "groving right") – while the fees, collected by forest district officers, were often lowered or periodically annulled, in view, for instance, of the calamities (like in 1831). In the winter, the inhabitants (and particularly the royal peasants) could gather on some days of the week the branches lying on the ground[4].

A document dated for the year 1843 (sanctioning, in fact, the common custom) allowed for gathering of litter, moss, and falling leaves and needles in forests, except for young stands not exceeding 30 years. Litter was collected every three years outside the growing season (Chętnik, 1927b). The custom persisted until World War I (Broda, 1965).

Apiculture used to be an important branch of the forest economy in the Forest of Kurpie. Population of the Kurpie Forest specialised in production of honey and wax. The beekeepers had a free entry to the forest, had their own rights, and were allowed to proceed with a limited felling around their homesteads (to establish a field and a meadow). They were taxed in kind (honey, wax, hay) or in money. The inventory documents from the 16th century reported the presence of 84 beekeepers. King Sigismund III Vasa guaranteed through special legal acts the privileged position of the beekeepers in Zagajnica forest, while limiting the rents and the levies they had to pay. The beekeepers were not the owners of trees inhabited by bees (usually 60 per beekeeper), but only their tenants.

Bees were kept in natural tree hollows and artificially hollowed trunks of different tree species (limes, oaks, pines). The dominant apicultural tree in the region was Scots pine. After the bears were exterminated in the region in the 18th century (one of the last bears in the region, called "beekeeper", lived near Wyszków), the height of holes meant

[4] In the study area, both royal and serf peasants lived.

for bees were lowered from 3-4 metres to even only 1.5-1 metres above the ground. Single trees have been preserved until now, in which bees were kept in the holes at different heights. The beekeeping trees were subject to legal protection and could not be cut. Starting with the 17th century the number of bee families kept in the Kurpie Forest quickly decreased. The process of decline in forest apiculture was correlated with the settling of the woodlands.

The privileges of beekeepers were liquidated when Poland lost independence at the turn of the 19th century. In the Prussian partition, to which the study area initially belonged, the royal forests were taken over by the Prussian state, and the right of beekeepers to use of a piece of forest was abolished. The beekeeping trees were systematically cut down – until the year 1799 altogether 4000 such trees were cut down, and only 621, containing bee nests, were left, and until the year 1806 further 1200 such trees were felled. At the same time, drilling of new bee holes in the trees was forbidden in view of the protection of stands (Biernacka, 1962; Chętnik, 1913).

The Russian tsarist authorities ultimately liquidated the forest apiculture in the years 1835-1840, turning the beekeepers into peasants. Since the middle of the 19th century farmers in Kurpie bred their bees in their farmyard apiaries.

Clusters of amber, occurring in Kurpie in the Quaternary sediments with glacial and fluvioglacial genesis, were formed by redeposition of Tertiary deposits in the Ice Age (from about 1,700,000 to about 10,000 years ago). Local amber belongs to a Baltic variety (*Succinit*) and it is varied in terms of accumulation forms and color varieties. Amber is found in the region to the north of Narew river (mainly within the Kurpie Plain). There were also many locations where concentrations of amber existed in the secondary deposits in the river alluvia and in the bottoms of peat-bog bowls, taking the shapes of belts, lenses, and oval clusters (Kozłowski, 1846).

The lack of detailed research does not allow to determine when exactly people started extracting amber. Amber was often accidentally found, eg. during plowing, digging ditches and wells (at a depth of 2-4 metres) and during clay pits and gravel pits exploitation. These findings have led over time to the regular search of this material. Amber was exploited by opencast digging since the 17th century, up till the 1870s. In the digging places the oval craters were left after the exploitation. An especially extensive amber digging field stretches from the boundary of East Prussia close to the village of Pełty, through Myszyniec and Ostrołęka, forming a belt of roughly 42 km of length and 24 km of width. At the beginning of the 19th century 30 amber mines functioned. The centres of extraction were the villages of Dylewo, Kadzidło, Czarnia, Myszyniec, Łyse and Zalas (Chętnik, 1927a). Yields were quite significant, the amber diggers traded pots of thick amber grains. Plants processing amber were located in Myszyniec and Ostrołęka. In the 20th century digging of amber was forbidden in view of forest devastation.

Extraction of peat dates from the 19th century, and intensified after the valleys of Omulew, Szkwa, Pisa and also their tributaries had been drained in the half of the 20th century. Locations of peat-bog exploitation were situated close to the villages of Leman, Ptaki, Zalas, and Łyse (the peat-bogs around the lake Krusko). The biggest yields are obtained from the deposits situated between the villages Karaska, Kieszek and Piaseczno, as well as Gawrychy and Popiołki (Fig. 8.3). Ponds formed in the exploited peat-bog craters.

8.4. Political boundary between Prussia and Masovia – its course, persistence and perception in the landscape

Formation of the boundary between lands of ancient Pruss tribes and lands of Slavonic peoples was more complicated process than recently assumed in the literature. It did not run along the natural barriers of orographic or hydrographic (large rivers or extensive swamps) character. The borderland areas were not too fertile and poorly settled. That is why this borderland remained for a long period a virtually uninhabited belt of hardly penetrable forests. There are several places in the forests on the border of Masovia, where the relics of the early medieval earthworks have been identified (fortifications dated for 11th-13th centuries). These structures were built by the Masovians. Some sections of mentioned shafts were marked on the maps in scale 1:50 000 created by S. Suchodolec (mapped in the years 1683-1712 – see Kowalczyk, 2003).

The reach of Masovian settlement has been established on the basis of written and material sources (cemeteries, settlements, villages and treasures), toponomastic and cartographic sources (Kowalczyk, 2003; Kowalczyk-Heyman, 2013). In the second half of the 13th century colonization of voids and forests flourished also at the junction of developing state of the Teutonic Knights and the independent Masovia. Then, there have been long disputes between the Teutonic Order and the Masovian Duchy as to the detailed course of the boundary. Until about 1320 there was a need for the boundary demarcation (Sieradzan, 1996). The process of delimitation was delayed, because it was in the interest of the local population of Kurpie and of the few remaining descendants of the Prussian tribes of Galindae and Sasini not to establish a precise boundary, since this facilitated free movement and exploitation of forest resources within a broader border-adjacent belt of land.

An approximate description of the course of the boundary is provided in the documents of the Grand Master of the Order, Luther of Braunschweig (1331-1335). Its course was made sufficiently precise by the Grand Master of the Order Ludolf König von Wattzau and the Masovian Prince Ziemowit III in the framework of the peace agreement signed in November 8, 1343 in Bratian. From today's perspective the course of the agreed boundary line was not very precise. There were long sections (10-70 km) between border points resulted from strong afforestation and swamping of the border area. These difficult natural conditions caused probably that the agreed borderline did not arouse disputes (Sieradzan, 1996). The ultimate detailed delimitation took place after the treaty of Melno in 1422. The Teutonic Order built for defensive purposes several castles in the border-adjacent zone (in Nidzica, Olsztynek, Szczytno, Wielbark and Pisz), as well as a system of defensive fortifications.

The borderland zone, within which the boundary between Masovia and Prussia was determined, belongs among the most persistent in the history of Poland (Plit, 2006). It ran along roughly the same line for more than 600 years (not the entire length), and for most of this time this was the boundary between two states, only after World War II it became the boundary between two Polish provinces. The two most recent administrative divisions – which tended to wash away the cultural identity of the regions – would shift over individual segments the traditional territorial division, incorporating particular villages either to the (former) province of Ostrołęka, or to the province of Masovia.

The course of the ancient boundary is emphasised by the different patterns of field checkerboard, corresponding to different ownership division on the two sides of border. Land belongs not only to different farmers, but also to different villages, while the wall mentioned makes the impression of the no-man's-land. The ancient boundary functions until today in the minds of inhabitants, who can still indicate very precisely its course, and, when describing the location of particular objects, use such expressions as: "meadow beyond the border", "tree growing on the border", etc. Notwithstanding the fact that for almost 70 years now the boundary has only the inner administrative character and is not being maintained as a formal border, neither protected nor fortified, it is still well perceived on many segments in the cultural landscape. There are numerous locations along the ancient border, where trenches dating from World War II can still be seen. Their forms are clearly different from that of the older structures. The trenches zigzag very distinctly, and the forms are sharper, much less eroded.

On both sides of the border the boundaries of large estates (of the 18th and 19th centuries) were sometimes distinguished by the lines of big boulders, less frequently by the piles of stones. A part of these stones were broken into smaller fragments, and in some cases border walls were constructed with those pieces of stone. It occurred on some occasions that the large boulders were brought over several kilometres from the moraine areas to the area of outwash, like, for instance, in the village of Warmiak.

The Ducal Forests (thereafter the Royal and Imperial forests) in East Prussia were often surrounded by a wall and a ditch, similarly as this was done along the state border.

8.5. Type of villages

On the territory of the former East Prussia there exists a clear division of the village types between the medieval settlements of Prusses and that established by the Teutonic Order – and the later ones. More or less up to the boundary between Nidzica and Kętrzyn the oval and circular villages prevail, having arisen until the 15th century. To the east of this line various street villages dominate (Kiełczewska-Zaleska, 1951).

The villages that were established later on (according to the law of Chełmno or to the law of Magdeburg), were carefully planned along a wide road. They were characterised by the compact, regular pattern of farmyards in two rows. Family houses were situated with the gable towards the road, and there was a belt of gardens and orchards just behind the proper farmyards. Gates were often erected at the extremes of village, limiting the access to structures. The fief-based (with "łan" units) setting of fields was preserved in many places, with some modifications introduced in the 19th century during the land regulation and after World War II. This kind of street villages, which is encountered in southern Masuria and in Kurpie, is being associated with the settling of the population originating from Masovia. The examples of street villages in Masuria are: Jeruty, Klon, Lipowiec, Leszczyny, Rumy, and Wały. The counterpart examples in Kurpie are: Brzozowy Kąt, Cięk, Cyki, Dąbrowy, Surowe, and Wołkowe. The villages of Wyk and Świnia in Masuria are of an oval type. In the case of the villages of Duglasy and Rzędówka a transformation took place from the spontaneously developing unordered villages – classified by Szulc (2002) as "forest colonies" – to the row-type villages, following land consolidation and ownership regulation (Piaścik, 1939).

Within forest areas new settlements, the "colonies", had a loose spatial pattern of the hamlet type, with a block-like pattern of fields. The biggest number of such settlements was established in the Forest of Kurpie in the second half of the 17th century and until the end of the 18th century (Szulc, 1995). On the other hand, the same author, Szulc (2002) quotes from the area here considered only one example of a village plan – for the village of Nasadki in the municipality of Lelis, which this author classifies as a row village.

8.6. Land improvement works

Human interventions into the hydrography of the region are recorded in chronicles and in inventory documents. Mills, ironworks and sawmills were constructed on river flows, along with other plants, taking advantage of the energy of flowing water. In order to accelerate the flow, water was dammed and thus reservoirs were established (upper ponds). The Henneberg map documents several such reservoirs on the rivers Orzyc, Omulew, and upper Wałpusza. Then, the maps of Suchodolec, Schrötter, and Textor show numerous mills, iron-mills and sawmills in the entire study area. Another kind of human intervention was to clear the river channels for navigation, meaning timber floating. The riverbeds were cleared of obstacles and their course was shortened – the meanders were dug through, and the windings straightened, the outflow was accelerated by deepening the mouth segments, canals were dug across the watersheds to connect basins. One of the undertakings of this sort was the extension of the Łyna river waterway by connecting the small lakes to the south of Łańskie Lake and construction of a Nidzki Canal in Ruciane.

The drainage of swamps and wetlands to the south-east of Wielbark in the basin of Wałpusza river was carried out in the years 1769-1794. Two villages were established on the dried-out ground – Łatana Wielka and Łatana Mała, and also Lejkowo, Olędry, Ostrowy, Zapadki and Borki Wielbarskie. Wetlands were drained within the middle stretch of Orzyc, between the villages of Wały, Wichrowiec, and Róg. Draining canals were dug near to Chorzele, Szczytno, Jetuty, and Macice. Analogous undertakings carried out in the southern part did not bring expected effects due to a low slope of the rivers Orzyc, Omulew, Rozoga and Szkwa.

Under the Prussian partition (1772-1807), regulation of Narew river was started, along with the removal of dams at mills and fishponds, meant to facilitate floating.

Land improvement activities were generally undertaken on the southern part of East Prussia at the beginning of the 19th century. Proper drainage started after 1880. In the years 1869-1900 effective drainage was applied to approximately 14,000 hectares in the northern part of the Szczytno county. Besides, the Dymer Land Improvement Board, active since 1873, drained a number of shallow lakes – Dymer, Kołoj, Czarne, Płociczno, Gisielskie, and Szczepankowskie, as well as numerous swamps and peat-bogs. Until 1886 (this date being determined by the time of charting of sheets of the map *Karte des Deutschen Reiches*, which were the basis for the inventory of land improvement works) the canals would cut across the swampy areas in the eastern part of the analysed fragment of East Prussia, and the channels of small rivers were straightened up there (to the south and east of Szczytno). The new investment activities would be associated with previously established grid of canals, extending them and complementing connections. Yet, the precise, dense land improvement work of this kind was effected only in the valley of Rozoga near to the village of Występ. During the next 20 years the grid was made denser, forming along the border compact areas with fully regulated water conditions. In the same period land improvement was also developed in the basin of Orzyc and of upper Omulew. A vast reservoir close to Małga was emptied and the valley was subject to land improvement, with draining of wetlands around Wielbark, which were transformed into mowed meadows. Before and during World War II Omulew and its tributaries – Czarka and Wałpusza – were regulated, the water level was brought down and the meadows of Wielbark were drained.

In Kurpie the drainage works have started later on. For the purpose of draining in the years 1854-1862, the government of the Polish Kingdom commissioned the digging of the Serafin and Turośl canals. The outflow was carried away to Pisa river. They dried out the swamps to the north of Krusko Lake close to the village of Serafin and significantly diminished the area of overgrowing lake, and liquidated or limited a number of smaller bogs in the municipality of Turośl (Chętnik, 1913). The surface of this lake was reported to be 900 "morgas" – i.e. roughly 500 hectares, but already the map of 1886 registered remnants of the lake in the southern part of the bowl.

Drainage, performed near to the village of Wach, caused that in 1930 the level of water went down significantly and a part of meadows and pastures was turned into arable fields, what is clearly visible on the compared map series.

In the years 1934-1939 land improvement works were carried out in the valleys of Rozoga and Szkwa. During the regulation work river beds were straightened up and water flow was accelerated, which did set in motion the progressing process of down-cutting erosion. The land improvement undertakings were unilateral and brought about only drying out, and not the true-to-life regulation, which could depend upon the weather conditions. Consequently, water level dropped by 2-3 metres, the soils were excessively dried out, and the moorsh forming process of peat soils was set in motion.

The land improvement undertakings in the Green Forest after 1945 encompassed the valleys of the rivers Płodownica, Piasecznica, Trybówka, Rozoga, Szkwa and Turośl. These undertakings were meant to bring the complete regulation of the hydrographic network. Conform to the prerequisites of the project, the area would be irrigated during droughts with water from Masuria. River valleys and boggy depressions were cut across with canals. The swampy area of Szeroka Biel having the surface area of 10,000 hectares was also drained. In the course of these works a system of weirs, sluices, gates and dams was simultaneously executed, making it possible to limit the outflow of water during drought. Since 1958 land improvement works concentrated on the valley of Omulew and the tributaries of this river, but the costly projects were not carried out to the end. Then, during the 1960s land improvement works in the valley of Rozoga were finished. Most of the undertakings aiming at denser network of canals and drainage had been terminated yet until the 1960s. The system though, worked badly. It served, actually, mostly, if not only, drainage. The respective authorities saw the causes of the failure of land improvement projects in low farming culture in the region (Kutrzeba-Pojnarowa, 1962, 1964).

8.7. Summary

Chronology of events on both sides of the boundary

Period (years)	The Prussian part (including the fragment of the Forest of Pisz)	The Masovian part (including the fragment of the Forest of Kurpie)
1000-1200	Poorly populated area, subject to the influence of the Pruss tribes	Area poorly populated by the Slavs, belonging to the Duchy of Masovia
1228	The Teutonic Order is brought in so as to conquest and Christianise the Prusses; the Order starts the process of settling and developing the region	
1343 1422	Delimitation of the analysed section of the border Ultimate delimitation of the boundary between the two states	
1525-1600	Secularisation of the Order and its state. The Duke of Prussia is the vassal of Polish king. Conversion to Protestantism.	Incorporation of Masovia into the Kingdom of Poland. Settling and economic development of the region.
The 17th and the beginning of the 18th centuries	Wars ravage the region, numerous diseases decimate the population.	The Swedish wars and the northern war destroy the region. The region is again settled and developed
18th century	Frederick Wilhelm I and II expand the absolute monarchy, reform agriculture, army and administration. Forest economy reform since 1739, land improvement undertakings in many regions. Ground rent of peasants in 1795.	In 1795 – incorporation of the region into the Prussian partition. Prussian king starts the reform of forest economy, continued over the 50 years to follow
19th century	Destructions during the Napoleon's wars, cholera epidemics; 1810 – abolition of serfdom; 1808-1848 – enfranchisement of peasants. Economic development, introduction of potato, white beet and forage plants to cultivation, industrialisation, development of infrastructure, land improvement	Destructions during the Napoleon's wars; 1807-1815 – independent Duchy of Warsaw; 1815-1830 – the so-called Polish Kingdom, autonomous province of the Russian Empire; after 1830 – elimination of partial autonomy. Introduction of potato, land improvement; 1864-1890 – abolition of soccage and serfdom, enfranchisement of peasants
1914-1920	World War I; plebiscite among the inhabitants, who opted for the inclusion in Germany	World War I. Relocations of the borderland population. Regaining of independence by Poland. Reconstruction of the villages.
1939-1945	World War II. War damages. Forced evacuation of the civilian population at the turn of 1944/1945, escape and resettlement of the inhabitants. Incorporation of the southern part of East Prussia to Poland. Looting and influx of "wild settlers" and then planned colonization of the region. Change of the socio-demographic and nationalistic relations, reconstruction, development of the destroyed land, significant afforestation.	World War II. Eviction and extermination of the Jewish population. War damages. Reconstruction, development of the area. Resettlement of the population on the former territories of East Prussia. Continuation of land improvement. Construction and modernization of technical infrastructure.

It can be concluded from the above summary of events that the development of the neighbouring areas took a similar course, but with a distinct delay in time. The part of the study area belonging to East Prussia was settled by about 100-200 years earlier.

The reforms of economy and the modernisation of agriculture, forestry and industrialisation were introduced by some 50 years earlier and covered more areas of life. Of very high importance was the timing of enfranchisement of peasants, and the principles of introduction of this reform. In the East Prussia preference was assigned to large, profitable farms, while in the Russian part land was partitioned into small plots among peasants and left the right of land division among heirs. The consequence was not only the lower agricultural production, but also dispersed settlement pattern. Only potato, as the feedstuff and nutritional crop, became common at almost the same time. The basic farming activity on both sides of the border was livestock husbandry.

The dominat share of the population of Polish nationality in the entire study area since the late Middle Ages until today implies that the ways of using land and exploiting the forest have been in the past very similar, if not identical, on both sides of the border. The differences resulted from the different structure of the neighbouring areas development and especially asynchronous in development of neighboring regions. The agrarian and forest reforms were carried out earlier and were more profound in East Prussia – and the intensification of economic activities occurred faster there.

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9. PRESSURE FROM WILD UNGULATES UPON THE FORESTS OF THE MASURIA-KURPIE BORDERLAND

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9.1. Scope of the research

The preceding chapters contained the analysis of the range, the processes and the conditioning of the natural and human-induced changes in the spatial distribution of forest areas. These analyses, though, did not, in principle, treat the assessments concerning the functioning of the forests here considered as ecosystems. One of the elements that might at least in an indirect and approximate manner help in the functional assessment of forests is constituted by the animal world, and especially by the large herbivore mammals, generally associated with forests, referred to as ungulates. The respective species can be treated as the general indicators of functioning of ecosystems, both in terms of trophic linkages with other components of fauna, and through the pressure exerted (by the intake of plants as nutrition) on the plant species composition, production of plant biomass, as well as the renewal processes of the undergrowth and the tree stands.

Five species of ungulates exist nowadays on the area considered, four of them being native: elk (*Alces alces*), red deer (*Cervus elaphus*), roe deer (*Capreolus capreolus*) and wild boar (*Sus scrofa*). One – fallow deer (*Dama dama*) is an introduced species. In older, but already historical, times, there were further three species that existed on the area in question, namely: European bison or wisent (*Bison bonasus*), nowadays encountered only in few forest complexes of Central Europe, as well as auroch (*Bos primigenius*) and wild forest horse (*Equus ferus ferus*) – the latter two altogether extinct by now.

The numbers of game animals (being the basis for determining the scale of pressure exerted on forest associations) depend upon a number of factors, of which the most important are: the presence of appropriately convenient habitats, also conveniently distributed across space (that is – the composition and the configuration of landscape), and the external factors increasing or limiting the population numbers, including economic use of the forest (timber-wise and non-timber-wise), livestock husbandry, hunting (and poaching), and the impact from predators. The action of these factors on particular species has been and continues to be differentiated in time and space. Precise determination of the role, played by the particular factors in the shaping of the numbers of ungulates would require, though, having reliable data on the numbers of animals of individual species within the well-defined spatial units and at definite time slices. Yet, in view of the quality of the available data such a complete analysis is not possible. That is why the investigations, which are reported in this chapter, have a limited character, and they concern:

– detailed analysis of the temporal and spatial differentiation of the magnitudes of ungulate populations, and the pressure exerted by them on the forests in the years 1993-2009 in division into the spatial units, corresponding to forest districts;
– determination of the influence, exerted by the habitat differentiation of the forests and the spatial structure of landscape on the intensity of pressure coming from the game animals;
– determination of the similarity between the forest districts regarding the pressure exerted by the game animals;
– retrospective assessment of the changes in the density of ungulates during the period starting in 1948.

In spatial terms the scope of the investigation encompasses the areas of six forest districts in their current boundaries: Jedwabno, Szczytno, Spychowo, Wielbark, Parciaki and Myszyniec, with a slight modification, consisting in the omission of a part of the forest district of Parciaki, situated to the west of Orzyc river, and addition of the fragments of Korpele forest district, situated to the south of the roads Jedwabno-Szczytno and Szczytno-Rozogi (see Fig. 7.1). The basic data on the forest districts, subject to the comparative investigations, are presented in Table 9.1.

Table 9.1. Area of forest districts

Forest District	Area of district [km^2]	Area of forest [km^2]	Woodiness [%]
Jedwabno	370.6	264.6	71.4
Spychowo	470.1	245.1	52.1
Szczytno	331.1	176.7	53.4
Wielbark	381.6	233.5	61.2
Korpele (fragment)	46.2	22.0	47.7
Total Masuria	1,599.6	941.9	58.9
Myszyniec	797.3	242.0	30.3
Parciaki	718.0	189.3	26.4
Parciaki (evaluated part)	446.8	148.0	33.1
Total Kurpie	1,244.1	389.9	31.3

In this report from investigations, the numbers of animals are turned into densities with respect to the areas of the entire respective units, while in the analysis of the pressure, exerted by the ungulates on forests, the densities are determined with respect to the forest areas as of the year 2000 (see Chapters 5 and 6). For some specific purposes the densities with respect to forest cover follow the development of this cover over time.

The source materials used in the analysis can be divided into two essential groups:
– data and reports, concerning the magnitudes of the populations of ungulates in spatial units (forest districts and other ones);
– results from the analysis of landscapes and the distribution of forests (landscape composition and configuration metrics), and of the types of habitats (the potential natural vegetation), related to the assumed spatial units (forest districts).

Materials from the first group include, first of all, the unpublished statistical data, concerning the numbers of animals in successive years of the period 1993-2009 in the six forest districts considered, obtained from the Regional State Forest Board in Olsztyn.

The second group of materials was constituted by the data on the distribution of forests in the space of the forest districts investigated (see Chapter 7), with due consideration of the differentiation of the potential vegetation (see Chapter 4).

9.2. Temporal and spatial differentiation of the magnitudes of ungulate populations in the years 1994-2010

The data set on the numbers of ungulate animal species over the area in question during the 17 years considered, for which we dispose of the reliable and unified statistical data from the Regional State Forest Board in Olsztyn, is shown in Table 9.2. This data set constitutes the basis for the analysis of differences between the forest districts and between the regions as to the state of the animal world (Figs. 9.1 through 9.6).

Red deer (*Cervus elaphus*)

Red deer is a big animal, featuring high mobility, in principle sedentary, but capable of quite distant wanderings, especially during the mating season. The wanderings may entail movements among the forest districts, particularly so in the places, where there are no bigger gaps between the forest complexes. The numbers of the red deer population are shown in Fig. 9.1. Visible are the very important differences in the levels of density of this species – from around 0.1 animals km^{-2} in the case of Myszyniec forest district in the 1990s, up to 1.9 animals km^{-2} for the forest district of Jedwabno in the years 2005-2009. The ratio of the extreme values of animal density in the forest districts (Myszyniec 2002 to Jedwabno 2007) is equal 1:28. The analysis of the diagram presented and of the table allow for making the following observations:

- the density curves shown for the forest districts can be distinctly classified into three groups, encompassing: 1 – forest district of Jedwabno, 2 – the three other forest districts from Masuria, 3 – two forest districts from Kurpie;
- the forest district of Jedwabno features a distinctly higher density of the deer population, with an increase in the years 2000, compared to the 1990s, by approximately 50%, the higher density persisting until today; such a state is achieved for the density of the population at about 1.9 animals km^{-2} over the entire area of the forest district, and regarding the very forest area – 2.6 animals km^{-2};
- in the group of the three remaining forest districts from Masuria one (Spychowo) features changes that can be interpreted as fluctuations or temporary limitation to the population at the beginning of the years 2000, while the two remaining forest districts display – along with definite fluctuations – a more or less visible increase of the number of red deer;
- the forest districts from Masuria, when treated together, show an unequivocal upward trend, which is approximately linear, from roughly 0.7 to 1.2 animals km^{-2} of the area, with the average for the entire respective surface being equal 0.96, and for the forest area – 1.62 per 1 km^2, which may indicate that the state of saturation of the environment has not been reached yet;

Table 9.2. Basic data of ungulates mammals abundance on study area during the years 1994-2010

Species	Forest district	Number of specimens during the years (state from 15th of March)																	
		1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	average
Red deer	Jedwabno	510	438	471	444	570	540	515	517	548	623	685	684	700	704	700	690	695	590.24
	Spychowo	457	364	339	468	384	492	433	360	358	312	327	320	320	335	335	385	455	379.06
	Szczytno	197	213	203	195	222	293	276	246	219	252	249	247	236	275	306	314	345	252.24
	Wielbark	196	167	168	150	115	218	325	269	276	317	369	316	320	342	345	384	421	276.35
	Korpele*	25	27	25	24	28	37	35	31	27	32	31	31	30	34	38	39	43	31.53
	Total Masuria	**1,385**	**1,209**	**1,206**	**1,281**	**1,319**	**1,580**	**1,584**	**1,423**	**1,428**	**1,536**	**1,661**	**1,598**	**1,606**	**1,690**	**1,724**	**1,812**	**1,959**	**1,529.41**
	Number of specimens km^{-2} of territory	0.9	0.8	0.8	0.8	0.8	1.0	1.0	0.9	0.9	1.0	1.0	1.0	1.0	1.1	1.1	1.1	1.2	0.96
	Number of specimens km^{-2} of forest	1.5	1.3	1.3	1.4	1.4	1.7	1.7	1.5	1.5	1.6	1.8	1.7	1.7	1.8	1.8	1.9	2.1	1.62
	Myszyniec	55	57	70	64	65	66	57	56	54	59	83	70	84	125	132	144	126	80.41
	Parciaki	76	136	102	93	103	127	123	121	147	96	150	145	123	123	172	204	232	133.71
	Parciaki**	59	106	80	73	81	99	96	95	115	75	117	113	96	96	135	160	181	104.56
	Total Kurpie	**114**	**163**	**150**	**137**	**146**	**165**	**153**	**151**	**169**	**134**	**200**	**183**	**180**	**221**	**267**	**304**	**307**	**184.97**
	Number of specimens km^{-2} of territory	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.2	0.2	0.2	0.2	0.15
	Number of specimens km^{-2} of forest	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.5	0.5	0.5	0.6	0.7	0.8	0.8	0.47
Roe deer	Jedwabno	490	393	482	399	534	550	565	565	555	644	725	805	790	810	810	790	790	629.24
	Spychowo	1,038	815	684	1,393	1,440	1,564	1,443	1,360	1,252	1,136	1,554	1,340	1,340	1,124	1,297	1,324	1,375	1,263.47
	Szczytno	458	468	442	417	451	701	662	653	699	1,030	880	842	694	629	659	713	786	657.88
	Wielbark	650	531	561	437	449	643	762	646	663	695	685	707	608	674	615	714	735	633.82
	Korpele*	57	59	55	52	56	88	83	82	87	129	110	105	87	79	82	89	98	82.24
	Total Masuria	**2,693**	**2,266**	**2,224**	**2,698**	**2,930**	**3,546**	**3,515**	**3,306**	**3,256**	**3,634**	**3,954**	**3,799**	**3,519**	**3,316**	**3,463**	**3,630**	**3,784**	**3,266.65**
	Number of specimens km^{-2} of territory	1.7	1.4	1.4	1.7	1.8	2.2	2.2	2.1	2.0	2.3	2.5	2.4	2.2	2.1	2.2	2.3	2.4	2.04
	Number of specimens km^{-2} of forest	2.9	2.4	2.4	2.9	3.1	3.8	3.7	3.5	3.5	3.9	4.2	4.0	3.7	3.5	3.7	3.9	4.0	3.47
	Myszyniec	1,003	743	751	667	677	726	997	1,017	908	876	834	730	708	816	900	958	966	839.82
	Parciaki	657	650	628	554	545	536	541	549	556	461	543	530	505	540	547	589	718	567.59
	Parciaki**	514	508	491	433	426	419	423	429	435	361	425	414	395	422	428	461	561	443.85
	Total Kurpie	**1,517**	**1,251**	**1,242**	**1,100**	**1,103**	**1,145**	**1,420**	**1,446**	**1,343**	**1,237**	**1,259**	**1,144**	**1,103**	**1,238**	**1,328**	**1,419**	**1,527**	**1,283.68**
	Number of specimens km^{-2} of territory	1.2	1.0	1.0	0.9	0.9	0.9	1.1	1.2	1.1	1.0	1.0	0.9	0.9	1.0	1.1	1.1	1.2	1.03
	Number of specimens km^{-2} of forest	3.9	3.2	3.2	2.8	2.8	2.9	3.6	3.7	3.4	3.2	3.2	2.9	2.8	3.2	3.4	3.6	3.9	3.29
Elk	Jedwabno	3	6	3	1	0	0	0	0	0	3	3	11	15	20	20	27	27	8.18
	Spychowo	25	13	9	0	0	0	0	0	0	0	0	0	0	4	4	6	21	4.82
	Szczytno	13	13	3	4	3	0	0	0	0	0	0	0	0	2	5	14	13	4.12
	Wielbark	7	17	14	7	3	0	0	0	0	0	0	4	4	7	9	9	5	5.06
	Korpele*	2	2	0	1	0	0	0	0	0	0	0	0	0	0	1	2	2	0.51
	Total Masuria	**50**	**51**	**29**	**13**	**6**	**0**	**0**	**0**	**0**	**3**	**3**	**15**	**19**	**33**	**39**	**58**	**68**	**22.69**
	Number of specimens km^{-2} of territory	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.01
	Number of specimens km^{-2} of forest	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.02
	Myszyniec	39	28	35	26	29	29	25	32	34	36	60	53	65	76	75	91	62	46.76
	Parciaki	19	2	2	2	4	3	0	0	0	0	0	0	0	6	7	12	3	3.53
	Parciaki**	15	2	2	2	3	2	0	0	0	0	0	0	0	5	5	9	2	2.76
	Total Kurpie	**54**	**30**	**37**	**28**	**32**	**31**	**25**	**32**	**34**	**36**	**60**	**53**	**65**	**81**	**80**	**100**	**64**	**49.52**
	Number of specimens km^{-2} of territory	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.04
	Number of specimens km^{-2} of forest	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.2	0.2	0.2	0.3	0.2	0.13
Fallow deer	Jedwabno	65	65	62	98	68	59	47	32	30	30	28	26	30	34	30	30	30	44.96
	Spychowo	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
	Szczytno	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
	Wielbark	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
	Korpele*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
	Total Masuria	**65**	**65**	**62**	**98**	**68**	**59**	**47**	**32**	**30**	**30**	**28**	**26**	**30**	**34**	**30**	**30**	**30**	**44.96**
	Number of specimens km^{-2} of territory	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.03
	Number of specimens km^{-2} of forest	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.05
	Myszyniec	0	0	0	0	7	5	7	7	9	9	0	0	0	0	0	0	0	2.59
	Parciaki	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
	Parciaki**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.00
	Total Kurpie	**0**	**0**	**0**	**0**	**7**	**5**	**7**	**7**	**9**	**9**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**2.59**
	Number of specimens km^{-2} of territory	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
	Number of specimens km^{-2} of forest	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.01
Wild boar	Jedwabno	207	210	215	243	205	178	201	201	255	275	310	240	240	220	215	270	300	234.41
	Spychowo	161	117	126	152	118	114	142	184	107	243	288	200	200	200	202	219	301	180.82
	Szczytno	159	148	123	107	115	132	147	138	147	194	235	194	157	189	215	248	283	172.41
	Wielbark	162	185	147	155	124	210	206	256	236	268	330	295	261	281	278	213	266	227.82
	Korpele*	20	19	15	13	14	17	18	17	18	24	29	24	20	24	27	31	35	21.55
	Total Masuria	**709**	**679**	**626**	**670**	**576**	**651**	**714**	**796**	**763**	**1,004**	**1,192**	**953**	**878**	**914**	**937**	**981**	**1,185**	**837.02**
	Number of specimens km^{-2} of territory	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.6	0.7	0.6	0.5	0.6	0.6	0.6	0.7	0.52
	Number of specimens km^{-2} of forest	0.8	0.7	0.7	0.7	0.6	0.7	0.8	0.8	0.8	1.1	1.3	1.0	0.9	1.0	1.0	1.0	1.3	0.89
	Myszyniec	102	89	76	79	77	80	121	129	128	130	166	176	182	201	247	298	370	155.94
	Parciaki	109	102	112	92	82	95	113	114	132	130	142	133	131	140	163	206	360	138.59
	Parciaki**	85	80	88	72	64	74	88	89	103	102	111	104	102	109	127	161	282	108.38
	Total Kurpie	**187**	**169**	**164**	**151**	**141**	**154**	**209**	**218**	**231**	**232**	**277**	**280**	**284**	**310**	**374**	**459**	**652**	**264.32**
	Number of specimens km^{-2} of territory	0.2	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.4	0.5	0.21
	Number of specimens km^{-2} of forest	0.5	0.4	0.4	0.4	0.4	0.4	0.5	0.6	0.6	0.6	0.7	0.7	0.7	0.8	1.0	1.2	1.7	0.68
Total deer family (Red deer × 1 + Roe deer × 0.2 + Elk × 3.33 + Fallow deer × 0.5)	Jedwabno	650	569	608	576	711	680	652	646	674	777	854	895	923	950	944	953	958	765.79
	Spychowo	748	570	506	747	672	805	722	632	608	539	638	588	588	573	608	670	800	647.82
	Szczytno	332	350	301	292	322	433	408	377	359	458	425	415	375	407	454	503	545	397.52
	Wielbark	349	330	327	261	215	347	477	398	409	456	506	471	455	500	498	557	585	419.96
	Korpele*	41	44	38	36	40	54	51	47	45	57	53	52	47	51	57	63	68	49.69
	Total Masuria	**2,121**	**1,863**	**1,780**	**1,912**	**1,960**	**2,318**	**2,310**	**2,100**	**2,095**	**2,287**	**2,476**	**2,421**	**2,388**	**2,481**	**2,561**	**2,746**	**2,956**	**2,280.78**
	Number of specimens km^{-2} of territory	1.3	1.2	1.1	1.2	1.2	1.4	1.4	1.3	1.3	1.4	1.5	1.5	1.5	1.6	1.6	1.7	1.8	1.43
	Number of specimens km^{-2} of forest	2.3	2.0	1.9	2.0	2.1	2.5	2.5	2.2	2.2	2.4	2.6	2.6	2.5	2.6	2.7	2.9	3.1	2.42
	Myszyniec	385	299	337	284	300	310	343	369	353	359	450	392	442	541	562	639	526	405.40
	Parciaki	271	273	234	210	225	244	231	231	258	188	259	251	224	251	305	362	386	258.98
	Parciaki**	212	213	183	165	176	191	181	180	202	147	202	196	175	196	238	283	302	202.52
	Total Kurpie	**597**	**512**	**520**	**449**	**477**	**501**	**524**	**550**	**555**	**506**	**652**	**589**	**617**	**738**	**800**	**922**	**827**	**607.92**
	Number of specimens km^{-2} of territory	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.6	0.6	0.7	0.7	0.49
	Number of specimens km^{-2} of forest	1.5	1.3	1.3	1.2	1.2	1.3	1.3	1.4	1.4	1.3	1.7	1.5	1.6	1.9	2.1	2.4	2.1	1.56

* Korpele Forest district – evaluated part of Forest district; as 0.125 of Szczytno Forest district; based on ratio of forest districts area.

** Parciaki Forest district – evaluated only part; as 0.782 of Forest district.

- the two forest districts from Kurpie, both when treated separately and jointly, show a slow increase of the red deer population during the period analysed, from roughly 0.1 to 0.25 animals km^{-2}, with the average for the entire area equal 0.15, and for the forest cover – 0.47 animals km^{-2};
- the difference of densities of the red deer populations in Kurpie and Masuria is very pronounced; with respect to the entire areas of the forest districts considered the ratio is, on the average, 1:6.75, but it must be noted that this proportion has improved over the recent years, and has been equal 1:4.8 during the last two years; if we refer not to entire forest district areas, but to forest cover itself, this proportion gets even less striking – on the average 1:3.6, and during the last two years – 1:2.55.

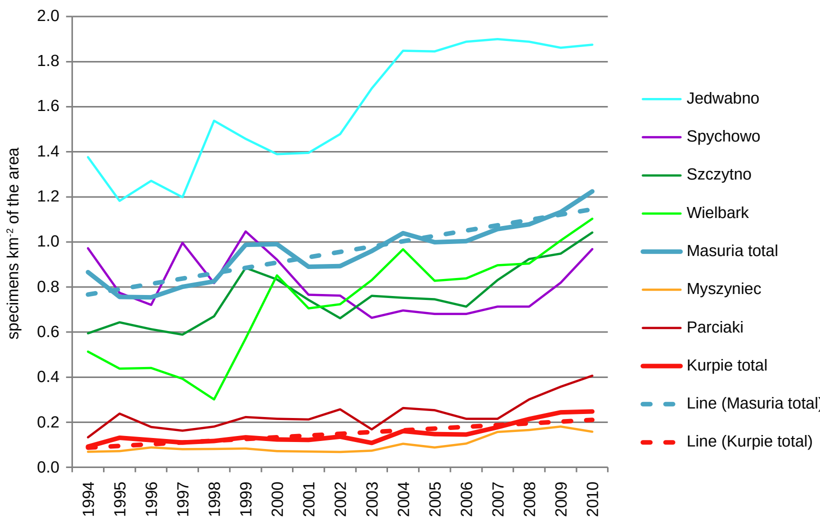

Fig. 9.1. Red deer density (specimens km^{-2} of the Forest districts) in Masuria and Kurpie during the years 1994-2010. Masuria total: y = 0.0237x + 0.7432; R^2 = 0.8147. Kurpie total: y = 0.0077x + 0.0792; R^2 = 0.7066

Roe deer (*Capreolus capreolus*)

Roe deer is the smallest of the ungulates. It is characterised by distinct territorialism and the movements of the animals both during a day and during a year are quite limited as to the distances. The home range of individuals almost always are fully contained within the confines of such spatial units as forest districts. The densities of the roe deer population in the forest districts considered and in the regions, related to the entire areas, are shown in Fig. 9.2. The following observations can be forwarded on the basis of the data provided:

- the curves, which illustrate the changes in the roe deer numbers within the forest districts, show distinct differentiation into: 1 – the group of forest districts from Masuria, displaying high internal diversity as to the course of changes in roe deer density, this diversity can be referred to as asynchronous character of changes, while the average values remain quite similar; and 2 – the group of forest districts from Kurpie, displaying higher similarity, but also not a fully synchronous character of changes;

- the numbers of roe deer within Kurpie remain during the period considered quite stable, and the slight differences that appear give the basis for supposing the appearance of fluctuations with the cycle of some 8-10 years, which, however, cannot be confirmed in view of a too short time series; the average density is at about 1 animals km^{-2} for the entire area, but 3.3 animals km^{-2} when considered for forest cover only;
- the numbers of roe deer in the Masurian part display high variability over time and among the particular forest districts; in general terms, an increase is observed over the period considered from roughly 1.6 to 2.4 animals km^{-2} for the entire area; the average value for the period analysed is at about 2 animals km^{-2} of the entire area, or up to 3.5 animals km^{-2} for the proper forest area;
- the proportion of the numbers of roe deer between Kurpie and Masuria – in terms of density for the entire respective areas – is approximately equal 1:2, which would imply a much lower density in the Kurpie part, but when we consider the density within the proper forest area, this proportion becomes 1:1, meaning that there are no differences with this respect.

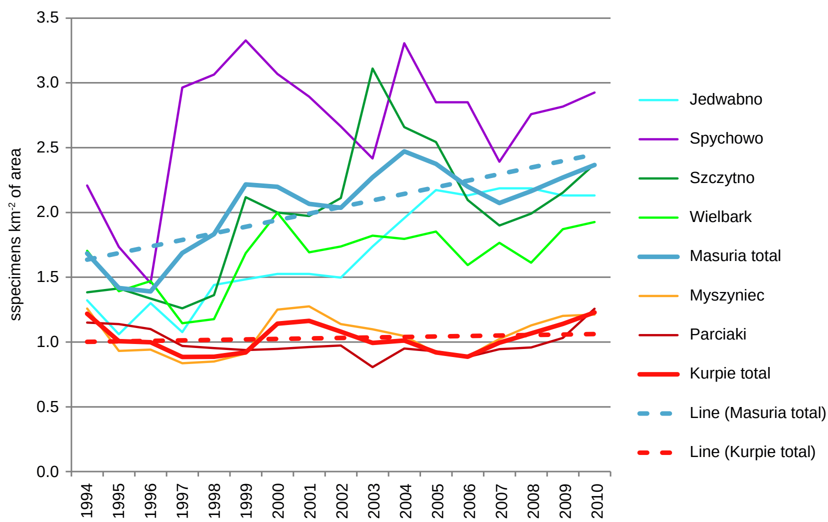

Fig. 9.2. Roe deer density (specimens km^{-2} of the Forest districts) in Masuria and Kurpie during the years 1994-2010. Masuria total: $y = 0.0508x + 1.5854$; $R^2 = 0.6125$. Kurpie total: $y = 0.0038x + 0.9977$; $R^2 = 0.0277$

Elk (*Alces alces*)

Elk is the biggest ungulate living nowadays on the territory here considered. The analysis of the differences in numbers of animals between the forest districts is insofar difficult as the species displays high mobility, moving for significant distances, and thus is hard to register adequately, while, at the same time, it is a relatively easy game, so that the elk population is highly vulnerable to excess exploitation on the national or regional scale. The overall elk population has been highly unstable in time on the territory considered during the period analysed, and it was also differentiated as to the numbers among the forest districts (Fig. 9.3). The time period here analysed coincides with the years of excess hunting exploitation of elk in the 1990s, the period of the collapse in the elk population in Poland as a whole, and then the period of increase of the elk population after the moratorium had been introduced on shooting the elk, which is still in force, even though it could now be annulled.

Quite different in terms of qualities of the elk population from all the other forest districts considered is the forest district of Myszyniec. This forest district includes, namely, a large peat bog "Karaska", which has been for decades very popular among elk. That is why the data from Myszyniec have been decidedly higher than from the majority of other forest districts, especially so in the period of the breakdown of the elk population at the turn of the 21st century. During that period the numbers of elk, registered in five forest districts dropped to zero, and it was only in Myszyniec that the existence of approximately 30 animals was reported.

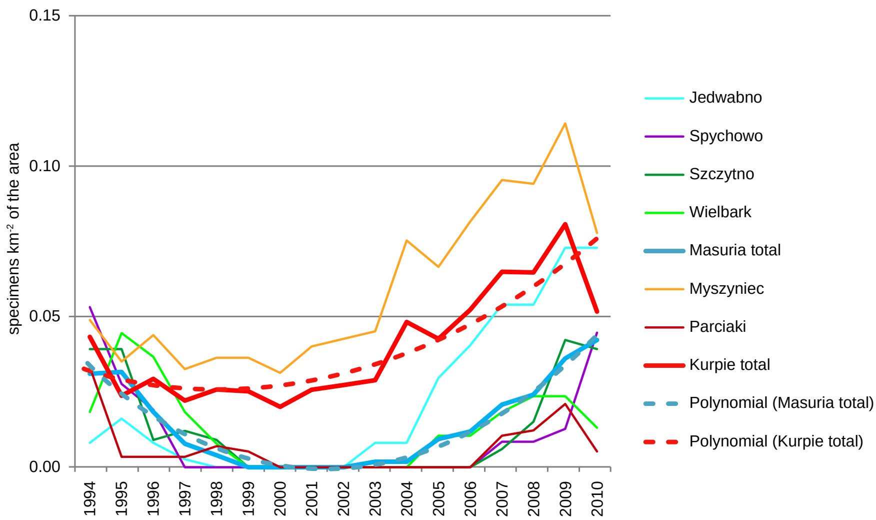

Fig. 9.3. Elk density (specimens km^{-2} of the Forest districts) in Masuria and Kurpie during the years 1994-2010. Masuria total: $y = 0.0006x^2 + 0.0105x + 0.0433$; $R^2 = 0.9678$. Kurpie total: $y = 0.0003x^2 + 0.0036x + 0.0353$; $R^2 = 0.7534$

In the years of increase and decrease of the numbers of elk population data from all the forest districts display a similar tendency, which demonstrates that we deal, in fact, with just one population. During the periods of increase the numbers of elk are relatively higher, compared to other forest districts (except for Myszyniec), in the forest district of Jedwabno.

In the northern part of the territory investigated, treated as a whole (i.e. in Masuria), the numbers of elk ranged from 0 (in the years 1999-2002) to 68 in 2010, which amounts to the maximum density of 0.014 per 1 km^2 for the entire area, or 0.024 per 1 km^2 of the proper forest areas. On the other hand, in the southern part (Kurpie) the number of elk ranged from 25 (in 2000) to 108 (2009), this being equivalent to densities ranging from

0.02 to 0.08 per 1 km^2 for the entire area, or 0.06 to 0.26 per 1 km^2 for the forest cover. Compared to the previously considered species these densities are indeed lower, but it should be kept in mind that elk is a large animal, and its role is also more pronounced.

Fallow deer (*Dama dama*)

Fallow deer was introduced on the area investigated for game purposes. Its constant presence was registered only in the forest district of Jedwabno, and, within a more limited temporal extent (years 1998-2003), in the forest district of Myszyniec (Fig. 9.4). The density of this species was in the forest district of Jedwabno relatively higher in the 1990s – roughly 0.18 per 1 km^2 of the entire area (0.25 per 1 km^2 of forest area), to then decrease in the years following 2000 by more or less half – down to 0.08 per 1 km^2 of the entire area (0.11 per 1 km^2 of forest area). The significance of this species is, therefore, local, and it does not play any serious role on the scale of the regions.

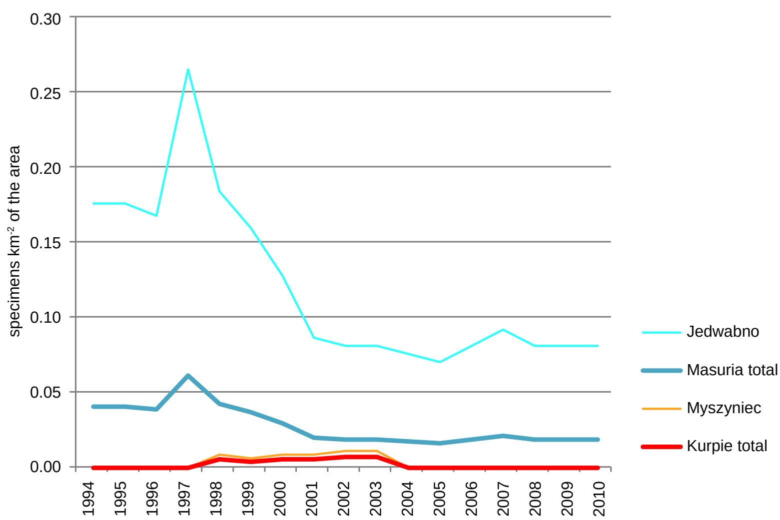

Fig. 9.4. Fallow deer density (specimens km^{-2} of the Forest districts) in Masuria (only Jedwabno) and Kurpie (only Myszyniec) during the years 1994-2010

Cervidae jointly

For the comparative purposes use is often made of the so-called "number of the Cervidae", meaning the formula aiming at presentation of the joint role of the four here considered species of the Cervidae. This is done by calculating the weighted sum of the numbers of animals from these species, with one red deer = 0.3 of a elk = 2 fallow deers = 5 roe deers. The results, obtained with the use of this formula for the analysed six forest districts are shown in Fig. 9.5. Based on these data, the following observations can be forwarded:

- there is a distinctly lower density of the Cervidae in the forest districts, situated in Kurpie, than in those from Masuria; the respective ratio for the densities within the entire areas is 1:2.9, while in the case of the forest area only it is 1:1.5;

– for both regions considered an upward trend can be observed over the considered period of 17 years, although this trend is doubtful for one of the forest districts in Masuria;
– of particularly interesting is the course of the curve showing the number of the Cervidae in the forest district of Jedwabno, where, after a period of lower numbers at the end of the 20th century, there was a clear increase, followed by a stabilisation; this kind of a curve often describes the effect of equilibration of a population due to balancing out of the growth processes with the resistance of the environment;
– within the region of Kurpie longer stabilisation was replaced by a slow increase in the initial years of the 21st century, and the character of the respective curves might suggest that the growth processes have not terminated yet.

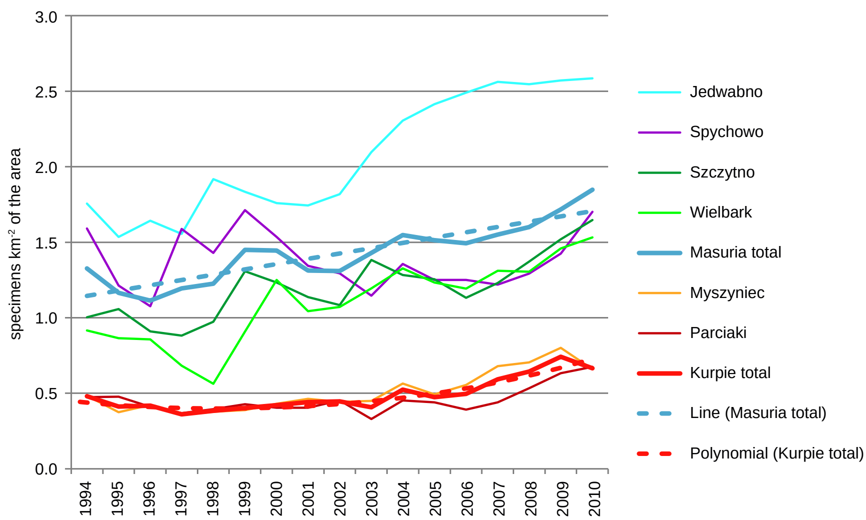

Fig. 9.5. Deer family density in livestock units – total Deer family = Red deer × 1 + Roe deer × 0.2 + Elk × 3.33 + Fallow deer × 0.5 (specimens km^{-2} of the Forest district) in Masuria and Kurpie during the years 1994-2010. Masuria total: $y = 0.0351x + 1.1097$; $R^2 = 0.7956$. Kurpie total: $y = 0.0024x^2 + 0.0266x + 0.4711$; $R^2 = 0.8907$

Wild boar (*Sus scrofa*)

Wild boar is an animal featuring limited mobility, higher than for the roe deer, but lower than for the red deer, and, of course, much lower than that of the elk. For a vast majority of cases it can be assumed that the home range of an individual is confined within a forest district. The numbers of wild boar for the forest districts within the area considered are shown in Fig. 9.6. Upon the analysis of these diagrams one can forward the following observations:

– the dynamics of changes in the population of wild boar in Masuria and Kurpie differs, while it is quite similar when we consider forest districts within the same region; this difference motivates to suppose a certain isolation of the two regions with this respect and the existence of some barriers to the spread of wild boar;

– significant fluctuations of the numbers of wild boar can be observed on the area of Masuria, these fluctuations being partly synchronous; this is particularly visible for the high numbers registered in the years 2004 and 2010; in general terms, one can discern quite distinct upward trend;
– on the territory of Kurpie the changes observed have had during the major part of the period analysed quite mild character, initially a slight decrease, and then an increase, and only in the recent years (2008-2010) the increase took on a more rapid course;
– proportion of the densities of wild boar in Kurpie and Masuria is equal 1:2.5 when the entire areas are accounted for, and 1:1.3 when proper forest areas are considered.

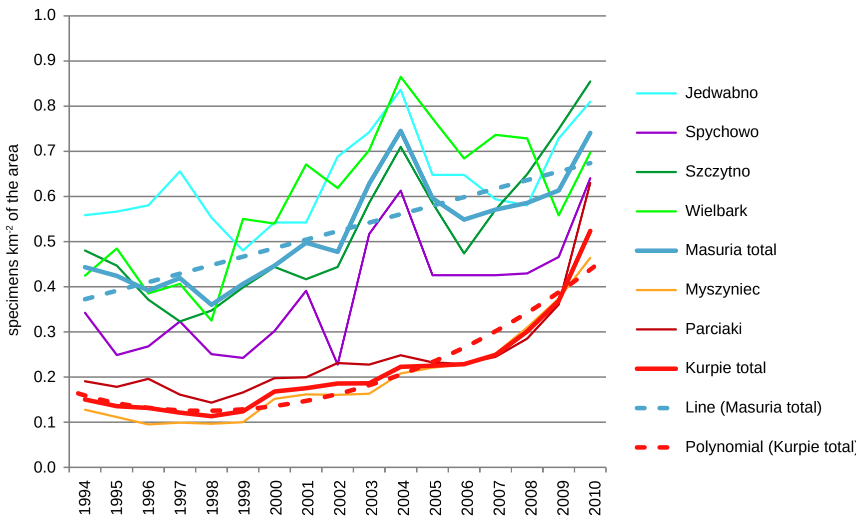

Fig. 9.6. Wild boar density (specimens km^{-2} of the Forest district) in Masuria and Kurpie during the years 1994-2010. Masuria total: y = 0.0188x + 0.3539; R^2 = 0.6538. Kurpie total: y = 0.0021x^2 + 0.0209x + 0.1764; R^2 = 0.9049

9.3. The pressure from the ungulates on forest biocoenoses

The degree of pressure, exerted by the ungulates on forests was determined on the basis of population numbers and the daily norms of nutritional requirements of the species feeding on fresh biomass (Table 9.3). The magnitude of the pressure thus calculated and its species structure was analysed with respective diagrams (Figs. 9.7, 9.8). The pressure, which is exerted by the ungulates on forest biocoenoses results primarily from the uptake of plant nutrition, meaning an action, oftentimes of a selective character, on plants, including the tree species forming the natural or human-planted tree stands. This pressure may take on frequently a very special nature, focusing on, for instance, the younger forms of the tree species, which leads to consequences well beyond the sheer quantity of the feedstuff consumed.

When analysing the proportions of the pressure that is exerted on the environment by the particular ungulate species within the territory investigated (Fig. 9.7), we can conclude as to the following relationships:

Table 9.3. Daily demand of ungulates on plant biomass

Species	Literature data relating to amount of daily consumed fresh plant biomass [kg]	Value accepted to calculation [kg day^{-1}]
Red deer	stag: 16-17 – according to Haber (1961); 22 – according to Bogdaszewski (unwritten); hind: 12.3 – according to Bobek et al. (1992); about 16 – according to Bogdaszewski (unwritten); 12-14 – according to Giżejewski (unwritten); calf: 10.2 – according to Bogdaszewski (unwritten).	17.24 – on the basis of Bogdaszewski, making an assumption of calfs 20%, stags and hinds 40% share in.
Roe deer	3.0 – according to Kałuziński & Bresiński (1976); 3.0 – according to Pielowski (1999); 4.5 – according to http://www.myslistwo.com/sarna.php	3.5 – on the basis of data next to; in accordance with proportion to red deer (1:0.2)
Elk	40 – according to Heptner et al. (1966); 70 – according to Bogdaszewski (unwritten); 35-40 – according to Giżejewski (unwritten).	57.0 – in accordance with proportion to red deer (1:3.333)
Fallow deer	20 – according to Bogdaszewski and Demiaszkiewicz (unwritten); 8-10 – according to Giżejewski (unwritten).	9.0 – in accordance with proportion to red deer (1:0.5)
Wild boar	wild boar 1 year old: 1.4; wild boar 2 years old: 2.1; wild boar 4 years old: 3.6 – according to Genov (1981ab).	2.5 – on the basis of data next to; making an assumption of share: one years old wild boar 50%, 2 years old 30% and older 20%. [Attention: relatively small quantity of food intake by wild boar comparing with deer family is probably resulting from food variety.]
European bison	40-60 – according to https://en.wikipedia.org/wiki/European_bison; 30 – according to Bozik (2008)	No analysed, because of absence of species on investigated area currently.

- three forest districts from the region of Masuria: Szczytno, Spychowo and Wielbark, display a highly similar species structure of the pressure; in each of them the biggest pressure comes from the red deer (50-60%); the share of roe deer is equal roughly 1/3, of the wild boar approximately 4-7%, and of elk – 2-4%, while fallow deer takes no share in the pressure;
- the forest district of Parciaki, located in Kurpie, but in the direct neighbourhood of the forest district of Wielbark;
- the forest district of Jedwabno features a distinctly different structure of the pressure, in which the domination of the red deer is highly pronounced (almost ¾ of the entire pressure comes from this species); there is also, in the case of this district, a small, but significant share of the fallow deer, practically absent in other forest districts;
- then, the structure of the pressure is quite different from that of the other districts in the forest district of Myszyniec, located in Kurpie; there, the share of the roe deer is the highest (close to 40%), which is similar to the situation in the neighbouring districts of Parciaki (to the West) and Spychowo (to the North); the share of the red deer is relatively low (below 20%), while the share of elk is exceptionally high (above 1/3), this being the main difference with respect to all other forest districts;
- as we compare the forest districts from Masuria with those from Kurpie, we can state that in Masuria two species are decisive: red deer and roe deer, accounting jointly for 90% of the pressure, in the rough proportion of 2:1; in Kurpie, on the other hand,

side by side with roe deer (40%), similar shares (25-29%) are taken by the red deer and elk;

- the compared structures of the pressure in particular forest districts are well correlated with the spatial setting of the districts, that is – the neighbouring forest districts are to some degree similar; against the background of this general regularity the district of Myszyniec stands out, its similarity to the district of Spychowo, neighbouring upon it from the North, being exceptionally small; it can be supposed that there exists a distinct barrier, separating these districts as to the movement of the ungulates, especially the larger ones, displaying higher mobility, that is – elk and red deer.

By analysing the intensity of the pressure, exerted upon the forests by the ungulate animals in particular forest districts (Fig. 9.8), one can derive conclusions on a number of similarities and differences between them:

- the highest pressure on forests is observed in the case of the forest district of Jedwabno; the average value of the joint pressure from the ungulates per 1 km^2 of the forest is the highest there (more than 19 t km^{-2} yr^{-1}), with the course of changes between 1994 and 2010 being the most regular; in the first part of the period considered (until 2002) the magnitude of the pressure was estimated at approximately 15-17 t km^{-2} yr^{-1}, to then distinctly increase above 20 tons; the main component of this general pressure is the pressure coming from the red deer population; in the last years of the period analysed (2005-2010) the increase of the overall pressure has been due to the increase of the pressure from elk, and, at the same time, a certain levelling off of the pressure can be observed, as if it has been attaining a state of equilibrium at about the level of 24 tons;
- lower values of the pressure, but its relatively similar course over time, have been observed for the forest districts, neighbouring upon Jedwabno, namely in Szczytno (to the East) and in Wielbark (to the South-East); in both these forest districts an increase of pressure is visible in the period analysed, with the average value equal approximately 15 tons and the maximum value equal 22 tons in the case of Szczytno, while in the case of Wielbark the average pressure is at about 12 tons, and the maximum is at 17 t km^{-2} yr^{-1}; in the cases of both these districts the character of the curves seems to suggest that the increase of pressure has not terminated yet;
- significant changes are observed for the forest district of Spychowo, the course of these changes implying fluctuations having the maxima of roughly 20 tons and the minima of roughly 15 t km^{-2} yr^{-1}; the dynamics of these changes, similarly as in the cases of other forest districts in Masuria, depended most of all upon the shifts in the population numbers of red deer and, to a much lesser degree, of elk;
- the values of pressure in Parciaki, located in Kurpie, are distinctly lower than for the forest districts from Masuria – only a bit more than a half of the average pressure calculated for the Masurian forest districts; during the major part of the period analysed the level of pressure there was stable at around 8-10 t km^{-2} yr^{-1}, and only at the end of this period an increase of pressure took part, mainly owing to the increase of the number of red deer, and to a lesser degree of elk;
- the values of pressure in Myszyniec, are similar to those in Parciaki (both these districts being located in Kurpie), but the species structure of this pressure is clearly

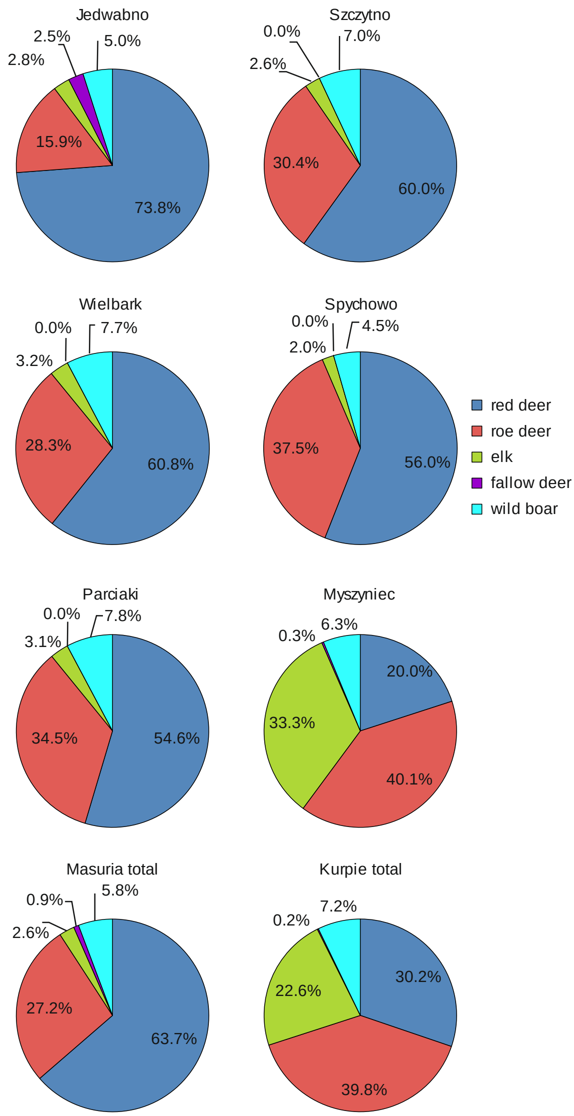

Fig. 9.7. Impact of ungulates species in Forest distrcts during the years 1993-2009

different; here, as well, an increase in the magnitude of pressure has been observed at the end of the period analysed, but it resulted to a higher degree from the increase of the number of elk than of the red deer.

The analysis of the changes in the pressure, exerted by the ungulates on forests in the six forest districts considered (Fig. 9.9), leads to formulation of the following regularities:

– forests in the districts located in Masuria are generally subject to bigger pressure from the ungulates than forests in Kurpie, with the forest district of Wielbark, directly neighbouring upon Kurpie, displaying an intermediate characteristic;

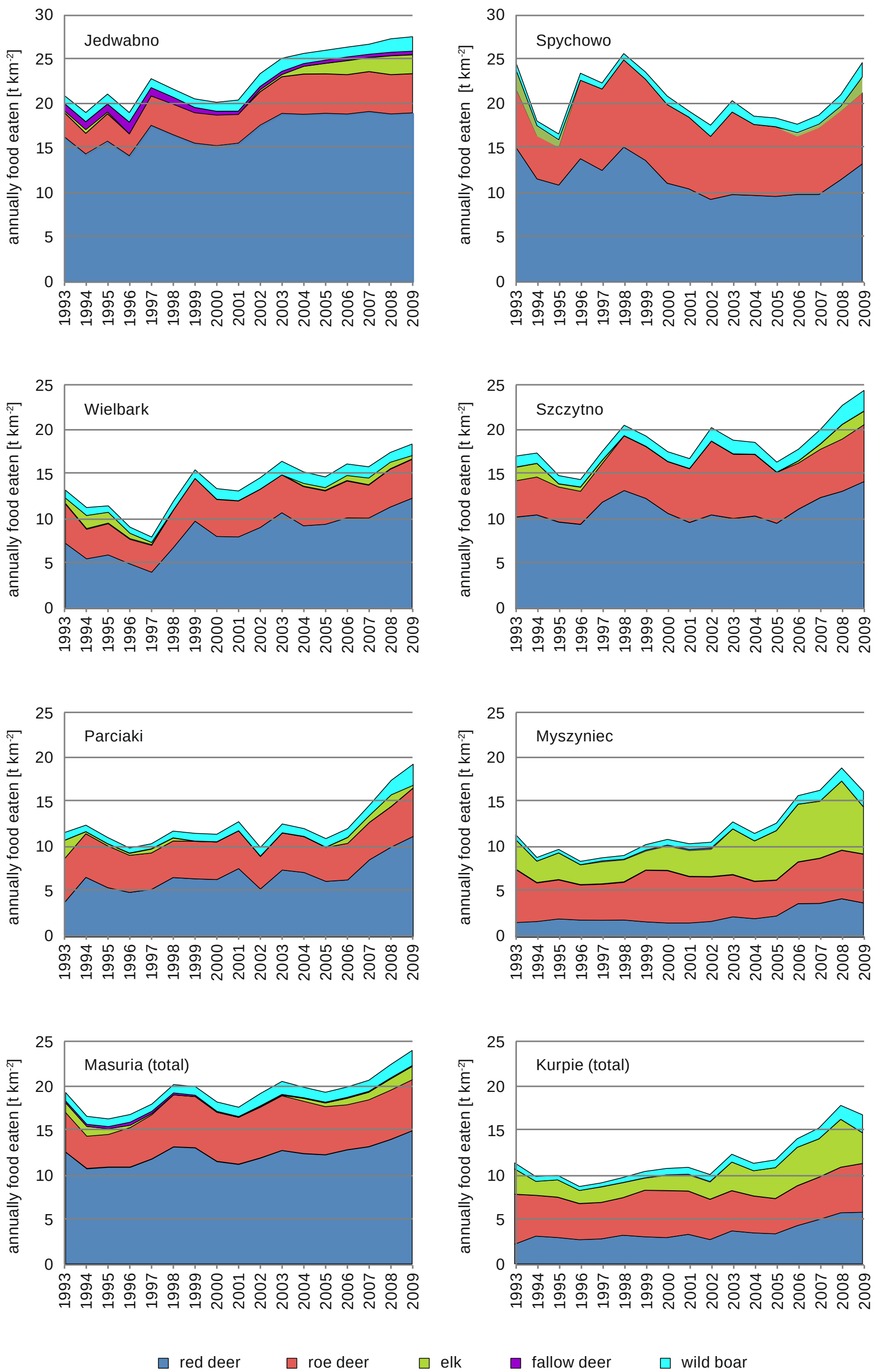

Fig. 9.8. Species structure and changes of ungulate impact in analysed Forest districts during the years 1993-2009

– both in the case of the Masurian part, as a whole, and in Kurpie, an unambiguous and strong tendency of increase of the pressure is observed over the period considered;
– extrapolation of the trends to date suggests that the limiting value of the pressure in Masuria might be roughly 24 tons, and in Kurpie – between 15 and 18 t km^{-2} yr^{-1} of fresh biomass consumed by the ungulates.

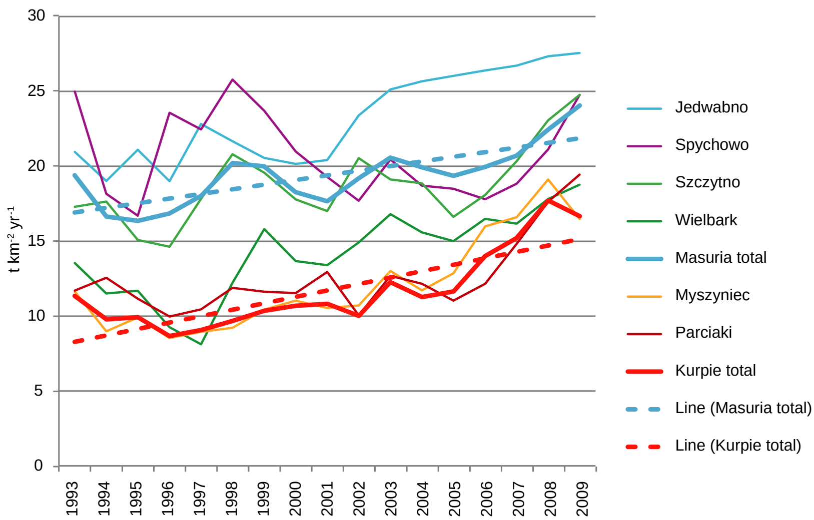

Fig. 9.9. Intensity of ungulates consumption of fresh plant biomass (t km^{-2} yr^{-1} of forest) in Forest districts and in Masuria and Kurpie total. Masuria total: $y = 0.3093x + 16.615$; $R^2 = 0.597$. Kurpie total: $y = 0.4283x + 7.8617$; $R^2 = 0.6644$

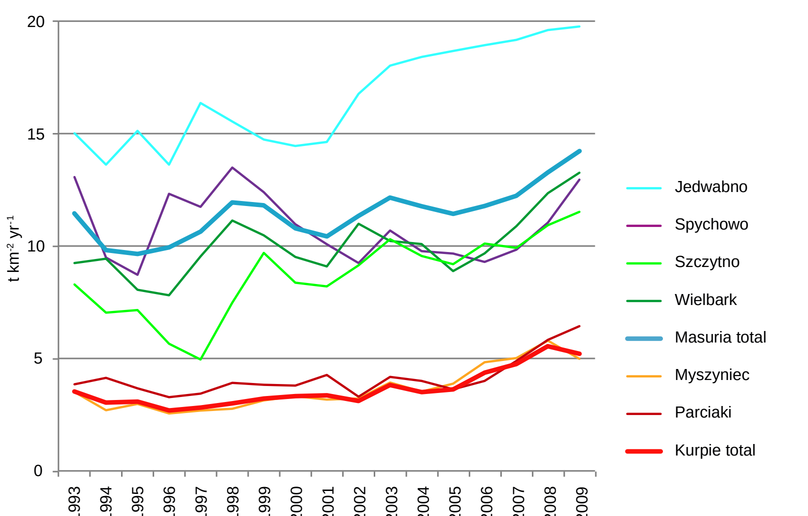

Fig. 9.10. Ungulates consumption of fresh plant biomass of whole study area of Masuria and Kurpie (t km^{-2} yr^{-1} of study area)

The pressure from the ungulates can also be related to the entire area of the forest district, whether or not it is covered by forests. The results of the respective analysis are shown in Fig. 9.10. The values, which are shown in this diagram, make very visible – more so than in Fig. 9.9 – the differences between Masuria and Kurpie, resulting from the bigger share of forest cover in Masuria.

9.4. Similarity of the areas in terms of pressure from the game animals

Detailed analyses of the temporal and spatial differentiation of pressure from the game animals in particular forest districts make it possible to determine the general similarity between the particular regions (forest districts) in terms of the state and the dynamics of pressure. For this purpose, the variables were used, for each forest district, expressing the pressure (i.e. as before, tons of fresh biomass consumed during a year per 1 km^2 of forest) from each animal species in each consecutive year over the period from 1994 to 2010 (thus, altogether 17 years x 5 species = 85 values per forest district). Besides, additional variables were adopted, expressing the change of pressure from year to year in absolute values. The dendrograms of similarity, shown in Fig. 9.11, were obtained for the Euclidean distance and for clustering with Ward method.

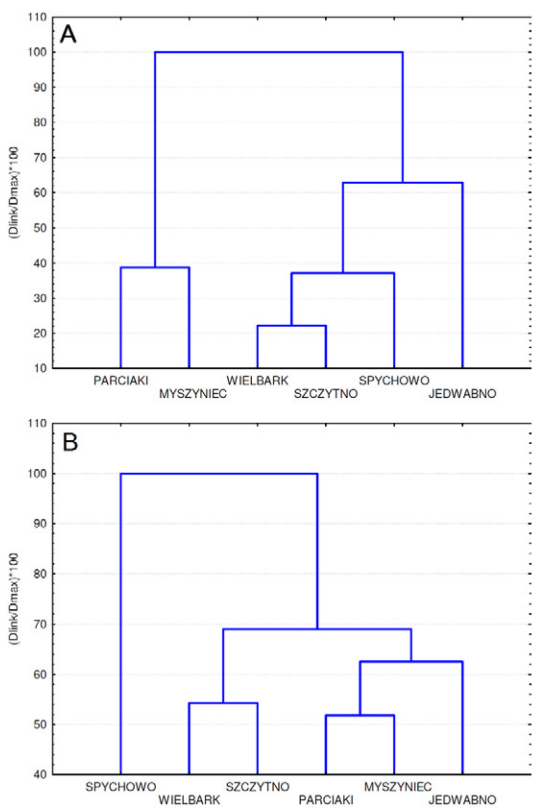

Fig. 9.11. Tree diagram of regions similarity based on impact values (A) and impact changes values (B)

The pattern of the dendrogram obtained for the similarity between the forest districts based on the values of pressure for the entire time series 1994-2010 (Fig. 9.11A) is almost identical with the one, obtained for the similarity between the forest districts in terms of area (in hectares) covered by forests on particular habitats in the year 2000 (see Fig. 7.36A). In both cases division is observed into two groups. The first consists of the Kurpie districts (Myszyniec and Parciaki), while the second – of the Masurian districts considered. In the latter group a further subdivision can be distinguished – with the district of Jedwabno in the first subgroup and the remaining Masurian three districts (Wielbark, Szczytno and Spychowo) in the second subgroup. Mutual similarities of forest districts in the latter subgroup are at the same order of magnitude as the similarity between Myszyniec and Parciaki.

The image is, however, different, when we take as criterion of similarity the changes of pressure from year to year (Fig. 9.11B). In this perspective, Spychowo forms a separate, relatively isolated group. The remaining forest districts are divided into two less separated groups, with Wielbark and Szczytno forming the first of them, and Parciaki, Myszyniec and Jedwabno – the second one. Thus, with this respect there is no division into the Masurian and Kurpie parts, which is so distinct in the case of the dendrogram based on values of pressure. At the same time, the image here commented upon demonstrates that the changes in the population numbers of the particular species, and hence also the magnitude of the pressure, do not result in a direct manner from the surfaces of forests on individual habitats. Further, this result can also provide evidence for the conclusion, drawn upon the basis of observation of the annual numbers of individual species, that in some of the forest districts one deals currently with the period of stabilisation of the animal numbers (associated, perhaps, with the saturation of the habitat), while in other districts there is still a relatively pronounced increase of the population numbers.

9.5. The influence of the habitat diversity of the forests and spatial structure of landscape on the pressure exerted by the game animals

9.5.1. Introduction

The purpose of analyses, reported in the present sub-chapter is to determine: (a) the interdependence between the pressure from particular species of the game animals and the habitat structure of the forest; (b) the interdependence between the pressure from the game animals and the characteristics of the spatial configuration of forest patches in landscape. The analysis was performed only for red deer, roe deer, elk and wild boar, with exclusion of fallow deer, in view of the low numbers of these animals and much stronger (as compared to the other species) anthropogenic control over this population. The input materials for the analyses were constituted by the map of distribution of forests corresponding to the situation as of the year 2000 (see Chapter 5), with consideration of the differentiation of the potential vegetation (see Chapter 4). Given the important fluctuations of the numbers in the individual species populations from year to year (see the changes shown in Figs. 9.1, 9.2, 9.3 and 9.6), the level of pressure was represented by the average from the years 1997-2003. At the same time, taking into account the directional changes of animal numbers (which can also be seen in the figures mentioned), indicating, most

Table 9.4. Codes and names of variables used in analyses

Variable group	Variable code	Variable name
Landscape metrics*	L_plat	number of forest patches
	area_mean	mean area of forest patch (ha)
	area_median	median area of forest patch (ha)
	area_max	maximal area of forest patch (ha)
	area_std	standard deviation of the area of forest patches
	FD_mean	mean fractal dimension of forest patch
	FD_median	median area of forest patch (ha)
	FD_max	maximal fractal dimension of forest patch
	FD_std	standard deviation of fractal dimension of forest patch
	SI_mean	mean shape index of forest patch
	SI_median	median shape index of forest patch
	SI_max	maximal shape index of forest patch
	SI_std	standard deviation of shape index of forest patch
	NND_mean	mean nearest neighbour distance from forest patch to forest patch
	NND_median	median nearest neighbour distance from forest patch to forest patch
	NND_max	maximal nearest neighbour distance from forest patch to forest patch
	NND_std	standard deviation of nearest neighbour distance from forest patch to forest patch
	PROX_mean	mean proximity index
	PROX_median	median proximity index
	PROX_max	maximal proximity index
	PROX_std	standard deviation of proximity index
Potential vegetation	las1abd	forests on *Ribeso-Alnetum* habitat (% of total forest area)
	las4a	forests on *Fraxino-Alnetum* habitat (% of total forest area)
	las6a	forests on *Tilio-Carpinetum calamagrostietosum* habitat (% of total forest area)
	las6bc	forests on *Tilio-Carpinetum typicum* habitat (% of total forest area)
	las6e	forests on *Tilio-Carpinetum stachyetosum* habitat (% of total forest area)
	las9a	forests on *Querco-Pinetum typicum* habitat (% of total forest area)
	las9c,19	forests on *Querco-Pinetum molinietosum* and *Querco-Piceetum* habitats (% of total forest area)
	las12,13	forests on *Peucedano-Pinetum* habitat (% of total forest area)
	las16	forests on *Molinio-Pinetum* habitat (% of total forest area)
	las17ab,18	forests on *Vaccinio uliginosi-Pinetum* and *Sphagno-Piceetum* habitats (% of total forest area)
	nielas1abd	non-forest vegetation on *Ribeso-Alnetum* habitat (% of total non-forest area)
	nielas4a	non-forest vegetation on *Fraxino-Alnetum* habitat (% of total non-forest area)
	nielas6a	non-forest vegetation on *Tilio-Carpinetum calamagrostietosum* habitat (% of total non-forest area)
	nielas6bc	non-forest vegetation on *Tilio-Carpinetum typicum* habitat (% of total non-forest area)
	nielas6e	non-forest vegetation on *Tilio-Carpinetum stachyetosum* habitat (% of total non-forest area)
	nielas9a	non-forest vegetation on *Querco-Pinetum typicum* habitat (% of total non-forest area)
	nielas9c,19	non-forest vegetation on *Querco-Pinetum molinietosum* and *Querco-Piceetum* habitats (% of total non-forest area)
	nielas12,13	non-forest vegetation on *Peucedano-Pinetum* habitat (% of total non-forest area)
	nielas16	non-forest vegetation on *Molinio-Pinetum* habitat (% of total non-forest area)
	nielas17ab,18	non-forest vegetation on *Vaccinio uliginosi-Pinetum* and *Sphagno-Piceetum* habitats (% of total non-forest area)
Animal impact	jelenie_sr06_10	mean red deer impact in years 2006-2010 (t km^{-2} yr^{-1})
	jelenie_sr97_03	mean red deer impact in years 1997-2003 (t km^{-2} yr^{-1})
	sarny_sr06_10	mean roe-deer impact in years 2006-2010 (t km^{-2} yr^{-1})
	sarny_sr97_03	mean roe-deer impact in years 1997-2003 (t km^{-2} yr^{-1})
	łosie_sr06_10	mean moose impact in years 2006-2010 (t km^{-2} yr^{-1})
	łosie_sr97_03	mean moose impact in years 1997-2003 (t km^{-2} yr^{-1})
	dziki_sr06_10	mean boar impact in years 2006-2010 (t km^{-2} yr^{-1})
	dziki_sr97_03	mean boar impact in years 1997-2003 (t km^{-2} yr^{-1})

* – detailed formulas and ways of calculation are described in McGarigal (2002).

probably, the tendency towards the attainment of the equilibrium state (concordance of the population number with the habitat capacity), the average from the years 2006-2010 was additionally adopted for the analyses, as corresponding to a different degree of saturation of the habitats with the respective species. The spatial structure of the forest patches was determined on the basis of the assumed landscape metrics. Their list is provided in Table 9.4.

9.5.2. Associations between the composition and configuration of landscape and the pressure from the game animals

The interdependences between, on the one hand, composition and configuration of landscape, and, on the other hand, the pressure from the game animals, were determined with the use of the correlation analysis for the variables considered, see Table 9.5. The analysis of the data contained in the table suggests that each of the species is characterised by specific interrelations.

Table 9.5. Pearson's product-moment correlations (coefficients statistically significant at p = 0.05 are marked)

	dziki_ sr97_03	**jelenie_ sr06_10**	**jelenie_ sr97_03**	**łosie_ sr06_10**	**łosie_ sr97_03**	**sarny_ sr06_10**	**sarny_ sr97_03**
FD_mean	-0.799	-0.911	-0.793	0.510	0.653	0.293	0.425
FD_median	-0.789	-0.935	-0.814	0.402	0.562	0.265	0.416
PROX_median	0.559	0.842	0.669	-0.076	-0.275	-0.402	-0.588
PROX_mean	0.810	0.868	0.654	-0.232	-0.387	-0.468	-0.625
nielas6a	0.735	0.888	0.785	-0.476	-0.623	-0.260	-0.394
SI_median	-0.845	-0.916	-0.798	0.624	0.752	0.311	0.436
L_plat	-0.935	-0.929	-0.818	0.708	0.815	0.263	0.383
area_std	0.857	0.974	0.898	-0.436	-0.586	-0.091	-0.253
nielas9a	-0.860	-0.946	-0.908	0.545	0.671	-0.018	0.143
nielas12,13	-0.898	-0.839	-0.843	0.675	0.744	-0.115	-0.014
SI_std	0.811	0.991	0.918	-0.465	-0.627	-0.112	-0.285
las6a	0.785	0.963	0.906	-0.465	-0.618	-0.047	-0.234
las9a	0.717	0.927	0.860	-0.243	-0.416	-0.056	-0.229
area_mean	0.778	0.969	0.855	-0.332	-0.508	-0.212	-0.388
area_max	0.817	0.803	0.849	-0.579	-0.652	0.254	0.148
SI_max	0.815	0.798	0.846	-0.581	-0.652	0.258	0.154
las12,13	-0.597	-0.784	-0.865	0.354	0.469	-0.378	-0.209
FD_max	-0.520	-0.650	-0.699	0.876	0.933	-0.041	0.056
nielas16	-0.712	-0.547	-0.514	0.958	0.950	0.169	0.189
las16	-0.722	-0.594	-0.572	0.967	0.972	0.139	0.171
las6bc	-0.059	0.073	0.349	-0.152	-0.135	0.852	0.797
las6e	0.058	0.057	0.364	-0.420	-0.356	0.879	0.884

The frequency of appearance and hence also the pressure from the roe deer increases with the share of forests on the habitat of *Tilio-Carpinetum typicum* and *Tilio-Carpinetum stachyetosum* (Fig. 9.12). There are no direct nor indirect interdependences, on the other hand, between the pressure and the magnitude and spatial structure of the forest patches. Moreover, additional analyses imply that the share of forests on the habitat of typical and moist oak-hornbeam forests is not significantly correlated with any of the remaining variables, taken for analysis.

The numbers of, and hence the pressure from the population of elk is positively correlated with the variable FD_max (meaning that the more irregular are the shapes of the forest patches, the higher the pressure from elk), and with the share of forest on the habitat

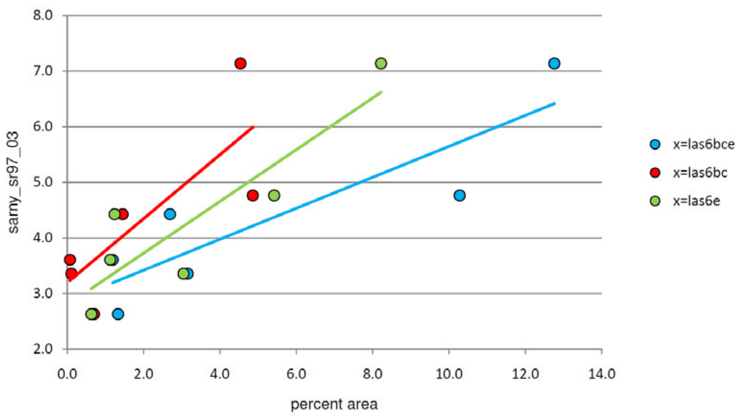

Fig. 9.12. Relationship between the impact of roe-deer and the percentage cover of forests on *Tilio-Carpinetum typicum* (6bc) and *Tilio-Carpinetum stachyetosum* (6e) habitats. For X = las6bc Y = 0.575x+3.195, R^2 = 0.636; for X = las6e Y = 0.465x+2.793, R^2 = 0.782; for X = las6bce Y = 0.278x+2.836, R^2 = 0.775

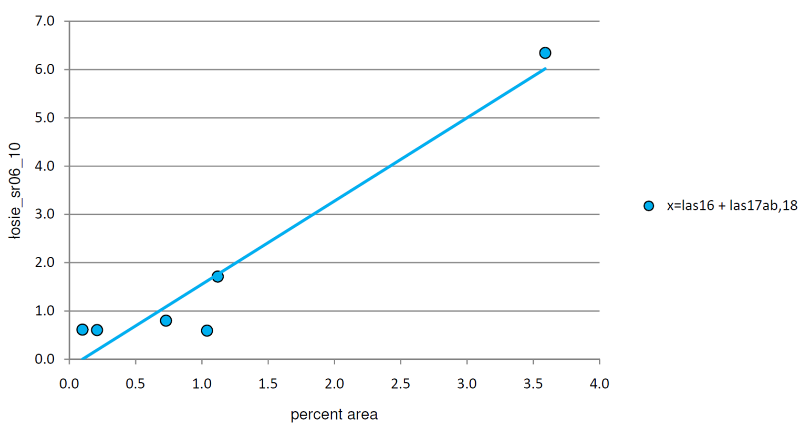

Fig. 9.13. Relationship between the impact of moose and the percentage cover of forests on *Molinio-Pinetum*, *Vaccinio uliginosi-Pinetum* and *Sphagno-Piceetum* habitats. Y = 1.723x-0.171, R^2 = 0.93

of *Molinio-Pinetum* as well as the share of the non-forest vegetation on the very same habitat. Simultaneously, considering the frequent spatial neighbourhood of forests on the habitat of *Molinio-Pinetum* with swampy pine forests and spruce woods on peat-bogs, it turns out that a similar level of correlation concerns the association between the pressure from elk and the joint area of these habitats (Fig. 9.13). A more distinct dependence appears, though, only when the share of these forest types exceeds jointly one percent of the forest area. There is, on the other hand, no direct association with other indicators of forest types and of the magnitude and spatial structure of patches (moreover, the share of these forests is not significantly correlated with any of the remaining variables, taken for analysis, either).

The density and the resulting pressure from the wild boar displays a positive correlation with the standard deviation of the size of patches (that is – the higher the differentiation of the sizes of forest patches, the bigger the pressure from the wild boar), and a negative correlation with the number of patches (Fig. 9.14) as well as the median of the shape index (meaning that the bigger the fragmentation of the forest surface and the more irregular the shapes of the patches the lower the pressure from the wild boar). Besides, a negative correlation is observed with the share of the non-forest vegetation on the habitats of the typical mixed pine forest and fresh pine forest (this being insofar understandable that wild boar acquires a part of feedstuff from outside of the forest, while the non-forest associations on these particular habitats are relatively the poorest in nutritional terms). It also can be concluded on the basis of the results quoted that wild boar is not strongly attached to one definite type of forest, more important than the typological differentiation being the size structure of the forest areas.

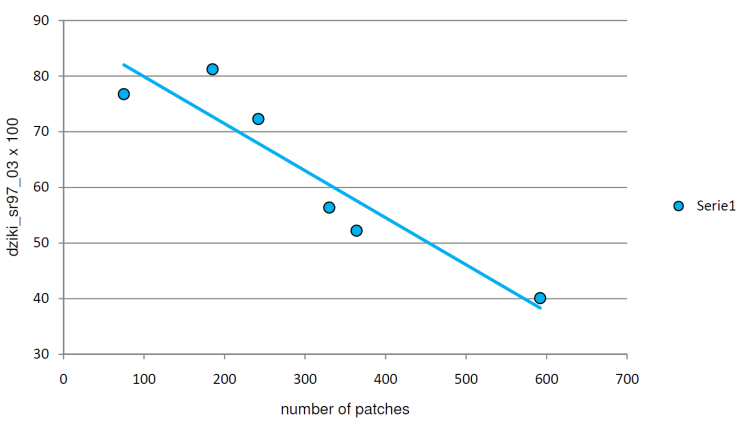

Fig. 9.14. Relationship between the impact of wild boar and the number of forest patches. $Y = -0.084x+88.35$, $R^2 = 0.87$

Contrary to the previously considered species, the density of and the pressure from red deer population demonstrates a distinct association not only with the shares of definite forest habitats, but also with the spatial structure of landscape. In particular, positive correlation of the pressure from the red deer is registered with such landscape metrics as PROX_median, area_mean, area_std, SI_std. This amounts to stating that the pressure from the red deer is higher for the forest patches bigger on the average, but at the same time more diversified as to their magnitude, with relatively irregular shapes, located mutually close by. Positive correlation with the pressure from the red deer is also observed for the area shares of forests on the habitats of *Tilio-Carpinetum calamagrostietosum* and *Querco roboris-Pinetum typicum* (Fig. 9.15). Besides, negative correlation is observed with the share of non-forest vegetation on the habitats of the typical mixed pine forest and fresh pine forest. In this context, attention ought to be paid to the fact that the variables mentioned above are not fully independent, as displaying relatively high and statistically significant mutual correlation.

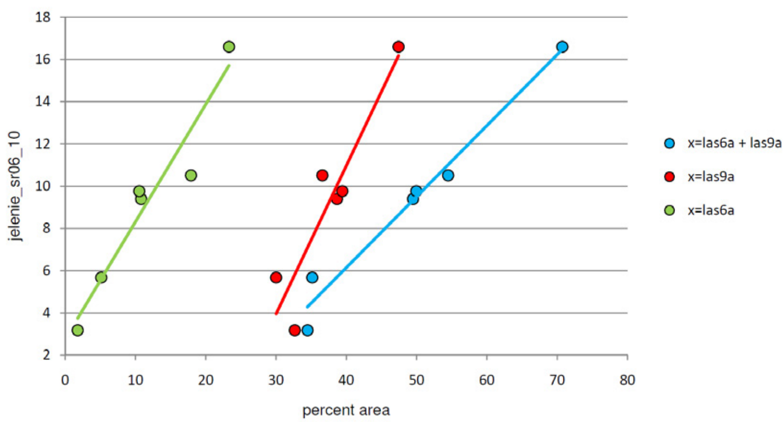

Fig. 9.15. Relationship between the impact of red deer and the percentage cover of forests on *Tilio-Carpinetum calamagrostietosum* (6a) and *Querco roboris-Pinetum* (9a) habitats. For X = las6a Y = 0.555x+2.752, R^2 = 0.927; for X = las9a Y = 0.701x-17.1, R^2 = 0.858; for X = las6a+las9a Y = 0.336x-7.301, R^2 = 0.972

A complement to the analysis of correlation, making it possible to account for the simultaneous influence of a number of variables, is provided by the principal component analysis (PCA). So, Fig. 9.16 shows the distribution of particular variables and objects (regions) on the plane defined by two first components, while Table 9.6 contains factor-variable correlations (factor loadings).

The analysis of Table 9.6 suggests that only three first factors play a role in the ordering of the variables and jointly explain more than 83% of total variability.

Thus, **Factor 1** corresponds to the landscape characterised by a low number of patches, with domination of large patches and a low numbers of small patches. At the same time, these patches are quite regular in their shape and are situated close by, filling the space to a high extent. In terms of habitats this landscape features high shares of the habitats of *Tilio-Carpinetum calamagrostietosum* and *Querco roboris-Pinetum* in the forests, as well as a high share of the oak-hornbeam forest habitats and a low share of the pine forests and mixed pine habitats on the non-forested surfaces. The closest to the so defined model pattern is the area of Jedwabno forest district, while Myszyniec is the farthest away. Parciaki display similar relative position to that of Myszyniec, while intermediate positions are taken by Spychowo, Wielbark and Szczytno.

Tabela 9.6. Factor-variable correlations (factor loadings). Most important relations are marked

	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
SI_std	0.995	-0.065	0.021	-0.058	-0.054
area_std	0.985	-0.136	0.041	-0.018	0.094
area_mean	0.984	0.032	0.141	-0.107	-0.010
las9a	0.942	-0.159	0.250	-0.155	0.029
las6a	0.942	-0.021	0.020	0.332	-0.039
nielas6a	0.910	0.053	-0.076	-0.380	-0.135
PROX_mean	0.892	0.326	0.127	0.180	0.225
PROX_median	0.859	0.343	0.335	-0.120	-0.135
area_median	0.820	0.229	-0.100	-0.471	0.208
nielas12,13	-0.838	0.380	0.284	-0.151	-0.224
nielas9a	-0.932	0.168	0.081	-0.298	-0.090
SI_median	-0.934	-0.110	0.245	0.222	0.073
L_plat	-0.938	-0.058	0.337	-0.004	-0.052
FD_mean	-0.942	-0.070	0.112	0.306	0.043
FD_median	-0.960	-0.047	-0.037	0.272	0.026
las6e	-0.001	-0.920	-0.266	0.277	-0.076
NND_mean	0.014	-0.893	-0.197	-0.334	-0.226
NND_std	0.039	-0.873	-0.255	-0.400	-0.105
nielas4a	-0.406	0.833	-0.314	-0.201	-0.049
NND_max	0.066	-0.822	-0.314	-0.468	0.046
nielas6e	-0.242	-0.792	-0.307	0.160	0.440
las6bc	-0.008	-0.727	0.053	0.676	-0.110
NND_median	0.193	-0.726	0.126	-0.645	0.054
nielas6bc	-0.154	-0.625	0.672	0.332	-0.153
nielas16	-0.531	-0.082	0.826	-0.155	0.077
las4a	0.051	0.301	-0.823	0.469	-0.096
las16	-0.577	-0.047	0.799	-0.108	0.123
las17ab,18	0.463	-0.042	0.793	0.376	-0.114
las1abd	0.227	-0.080	0.768	0.594	0.002
nielas9c,19	-0.574	0.379	-0.683	0.239	-0.054
nielas17ab,18	0.705	0.161	0.626	0.111	-0.269
las9c,19	-0.664	-0.295	-0.108	0.630	0.250
FD_std	-0.150	0.161	0.323	-0.548	0.739
PROX_std	0.716	0.369	-0.086	0.473	0.345
SI_mean	-0.818	-0.256	-0.227	0.440	0.142
PROX_max	0.503	0.549	-0.362	0.397	0.396
nielas1abd	0.808	0.343	0.315	0.355	-0.068
area_max	0.798	-0.525	-0.164	0.118	0.214
SI_max	0.798	-0.525	-0.164	0.118	0.214
FD_max	-0.601	-0.037	0.586	-0.202	0.503
las12,13	-0.741	0.430	-0.128	-0.499	-0.012
Cumulative % of variance	47.82	67.63	83.08	95.39	100.00

Factor 2 characterises the landscape, in which the spatial structure of patches is not important, provided the patches are situated close one to another at similar distances, while, simultaneously, there is a low share of the oak-hornbeam forest habitats within the forests and a high share of the floodplain deciduous forest habitats on the non-forest areas. This characterisation is most similar to that of Parciaki, with Spychowo being the farthest away. The remaining areas feature the intermediate characteristics.

Factor 3 corresponds to the landscape, in which the spatial structure of patches is completely insignificant, with the distinguishing feature being constituted by the high share of the wet and swampy habitats (*Ribeso-Alnetum, Molinio-Pinetum, Vaccinio uliginosi-Pinetum, Sphagno girgensohnii-Piceetum*), and a low share of the habitats of the floodplain deciduous woods *Fraxino-Alnetum* within the forests, with the simultaneous high

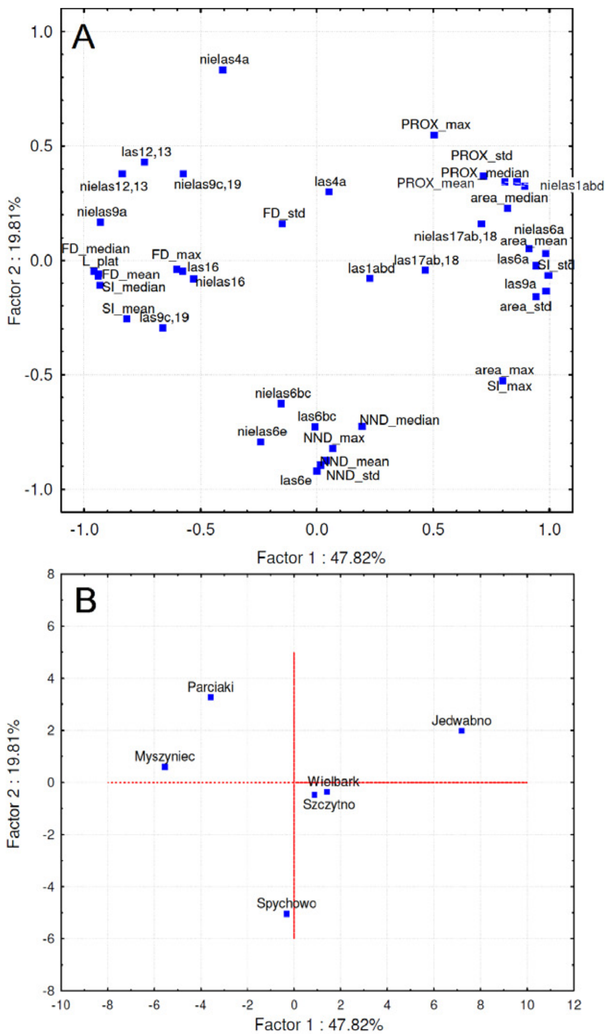

Fig. 9.16. Projection of the variables (A) and regions (B) on the factor-plane

share of the habitats of *Molinio-Pinetum, Vaccinio uliginosi-Pinetum, Sphagno girgensohnii-Piceetum* and *Tilio-Carpinetum typicum* on the non-forest surfaces. The closest to the thus defined model pattern is the forest district of Myszyniec, while the farthest – the one of Parciaki.

Determination of the correlation between the pressure from the particular animal species and the factors established through application of the PCA (Table 9.7) implies – in a broader manner than the correlation with the individual variables – the optimum type of landscape for the particular species.

Table 9.7. Correlations between animal impacts and Factors derived from PCA. Values significant at p = 0.05 are marked

	Factor_1	Factor_2	Factor_3
dziki_sr97_03	0.848	0.012	-0.348
jelenie_sr06_10	0.994	-0.034	-0.006
jelenie_sr97_03	0.896	-0.325	-0.028
sarny_sr06_10	-0.176	-0.872	0.087
sarny_sr97_03	-0.346	-0.874	-0.018
łosie_sr06_10	-0.471	0.175	0.843

In such a perspective we observe a significant correlation between, on the one hand, Factor 1, and, on the other, the pressure from the wild boar (Fig. 9.17) and from the red deer (Fig. 9.18). There is a significant correlation between Factor 2 and the pressure exerted by the roe deer (Fig. 9.19), as well as between Factor 3 and the pressure exerted by the elk (Fig. 9.20).

It is worth noting that in all these four cases the associations have, actually, the nonlinear character, and for wild boar, roe deer and red deer the changes of pressure are slower

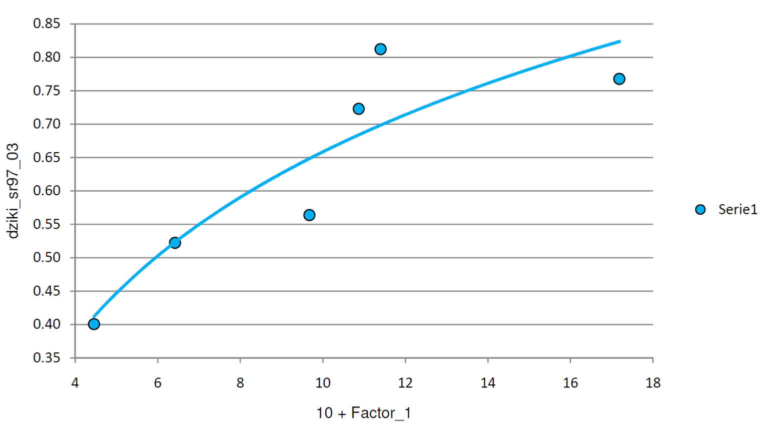

Fig. 9.17. Relationship between the impact of wild boar and Factor 1 derived from PCA. X = 10+Factor_1; Y = 0.305ln(x) – 0.043; R^2 = 0.807

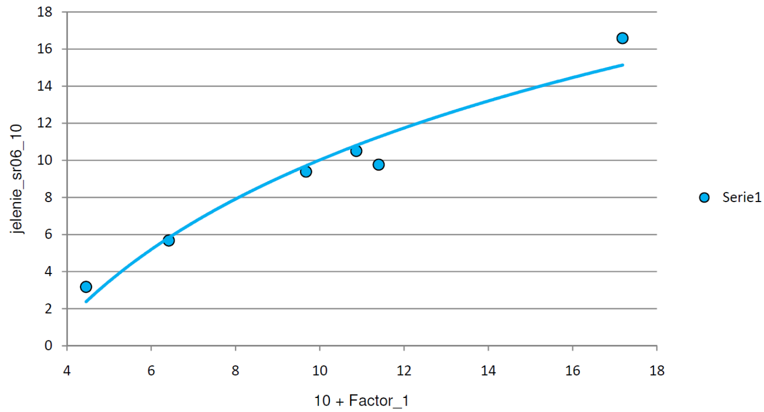

Fig. 9.18. Relationship between the impact of red deer and Factor 1 derived from PCA. X = 10+Factor_1; Y = 9.451ln(x) – 11.74; $R^2 = 0.95$

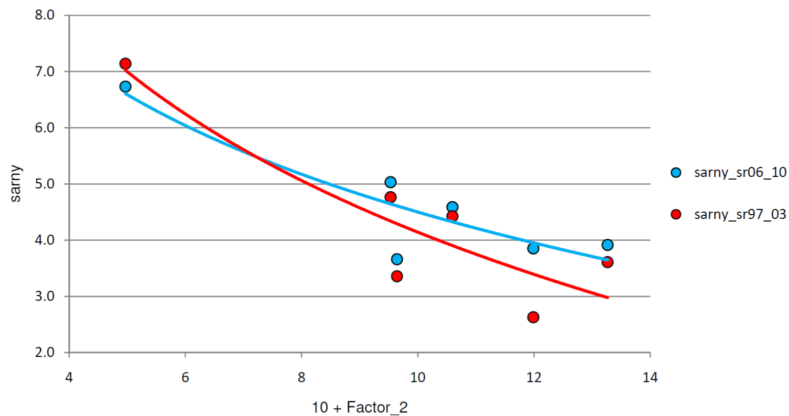

Fig. 9.19. Relationship between the impact of roe-deer and Factor 2 derived from PCA. X = 10+Factor_2; Y1 = sarny_sr06_10; Y2 = sarny_sr97_03; Y1 = -3.01ln(x) + 11.44; $R^2 = 0.816$; Y2 = -4.11ln(x) + 13.62; $R^2 = 0.813$

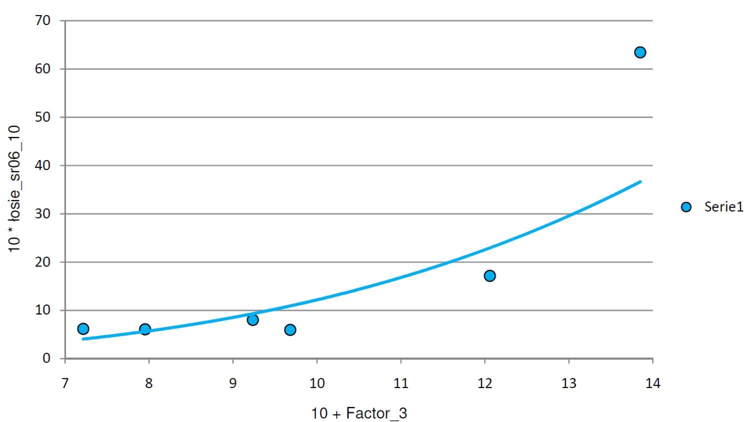

Fig. 9.20. Relationship between the impact of elk and Factor 3 derived from PCA. X = 10+Factor_3; Y = 10×łosie_sr06_10; $Y = 0.005x^{3.385}$

for the higher values of the independent variable, while for elk the slowest changes take place when the independent variable takes on the low values.

It should additionally be emphasised that there is a significant correlation between Factor 1 and the summary pressure from all of the Cervidae (including fallow deer) and from all of the ungulates together.

9.6. The states of the populations of ungulates within the borderland of Masuria and Kurpie after the World War II in retrospection

The data on the population numbers (densities) of the ungulates on the territory analysed, concerning the years 1993-2009 allow for the analysis concerning a short time interval. These data show the relatively important changes in the numbers of animals from year to year, attaining the increments of almost 90 percent in the case of the red deer (Wielbark forest district, years 1997-1998), or more than 100 percent in the case of the roe deer (Spychowo, years 1995-1996), as well as more than 120 percent for the wild boar (Spychowo, years 2001-2002), see Table 9.2. The question therefore arises whether these shifts, taking place over the 17 years, even if they display during this period some directional changes, are just short-lived fluctuation episodes, or do they constitute a fragment of the longer in time, directional processes of changes in the numbers of populations of the particular species. In order to answer this question, assessment was made of the numbers of ungulates beginning from the year 1948, with the help of all the available materials, of differentiated character and quality. Adoption of this period for analysis resulted not only from the availability of data, but also from the fact that over this entire period a relatively uniform manner of managing the forest was maintained, and there were no significant (in comparison with the earlier periods) catastrophic phenomena, such as wars, fast mass deforestations, or depopulations.

In this assessment use was made of three kinds of data:

- Series 1: data from the inventories or estimates carried out in the forest districts considered and in the units that could be quite unambiguously identified with the present-day forest districts, that is – in the former divisions into the forest districts (quite an important part of this data set, but not the entirety, is constituted by the previously analysed data from the years 1993-2009); these data have, by their very nature, the basic character;
- Series 2: archival data (statistical yearbooks, archives of the state forest board in Olsztyn), and published reports (Fafiński, 1968), on the numbers of animals of particular species over larger administrative units (like provinces or units of forest administration), originating from the archival accounts and statistical yearbooks; these data were then referred to the area considered (Masuria and Kurpie separately) on the basis of proportions according to the total area or the forest area, sometimes with additional consideration of the information on the actual proportions of the numbers of animals in a given species between the study area and the respective administrative unit; these data constitute a reliable complement to the Series 1 data, assuming that the ratios of the numbers of animals in particular species between the study area and the administrative units are correct and have not been changing too significantly during the period in question;

– Series 3: values of the probable numbers of animals, calculated on the basis of data from the statistical yearbooks and the archive of the state forest board in Olsztyn, concerning the wild animal yields in large administrative units; these data, again, were referred to the study area with consideration of the identified proportions between the population numbers and the yield (this issue is discussed at length in Chapter 10); the data from this category are the least reliable, for the game yields are influenced not only by the animal population magnitudes, but also by a number of other significant factors; yet, these data were also used, because for some earlier periods they might constitute the sole source of information on the numbers of animals.

The data collected in the context of this estimation of the ungulate population numbers in the two basic regions of the study area are shown in Fig. 9.21. Attention ought to be paid to the fact that the data refer to the time periods of different lengths; then, for two species (elk and fallow deer) it was possible to put together the data only for the area of Masuria, and the values of density in numbers of animals km^{-2} differ very much between the regions and the species. Despite these reservations an attempt was made of modelling the changes in density on the basis of the collected data, treated jointly, without distinction of the series, described above. For this purpose the following analyses were performed (see Figs. 9.22 through 9.29):

– the first one was the smoothed average line, obtained using the "smoothing spline" method, which was determined with the PAST software (Hammer et al., 2001);
– the second was the regression model based on the sum of sinusoids, also obtained with the help of the PAST software (Table 9.8);

Table 9.8. Parameters for sum-of-sinusoids regression models. Each sinusoid is given by $y = a\cos[2\pi(x\text{-}x0)](T\text{-}p)^{-1}$, x0 is the first (smallest) x value

Region	Species	Constant	sinusoid 1			sinusoid 2			sinusoid 3			R^2
			amplitude (a)	phase (p)	period (T)	amplitude (a)	phase (p)	period (T)	amplitude (a)	phase (p)	period (T)	
Masuria	red deer	0.76120	0.5820	-1.7400	61.00	0.3830	-2.80	24.00	0.0588	2.180	12.00	0.79574
	roe deer	1.47300	1.1900	-1.6300	61.00	0.6910	-2.11	22.50	0.3100	-2.880	11.40	0.79274
	fallow deer	0.01213	0.0149	-0.8230	61.00	0.0107	-1.29	27.00	0.0115	-2.210	17.00	0.86129
	elk	0.02512	0.3050	-0.0974	28.80	0.3120	-2.30	61.00	0.3060	3.040	28.51	0.98268
	wild boar	0.42530	2.6800	-0.8480	61.00	2.5800	2.39	59.31	0.0469	-2.870	16.45	0.86302
Kurpie	roe deer	1.34400	23.0000	-0.3950	42.00	23.1000	2.82	41.24	0.2650	-2.710	13.27	0.91594
	wild boar	0.25210	13.3000	0.1710	18.15	62.9000	-2.74	17.59	49.9000	0.457	17.46	0.91045

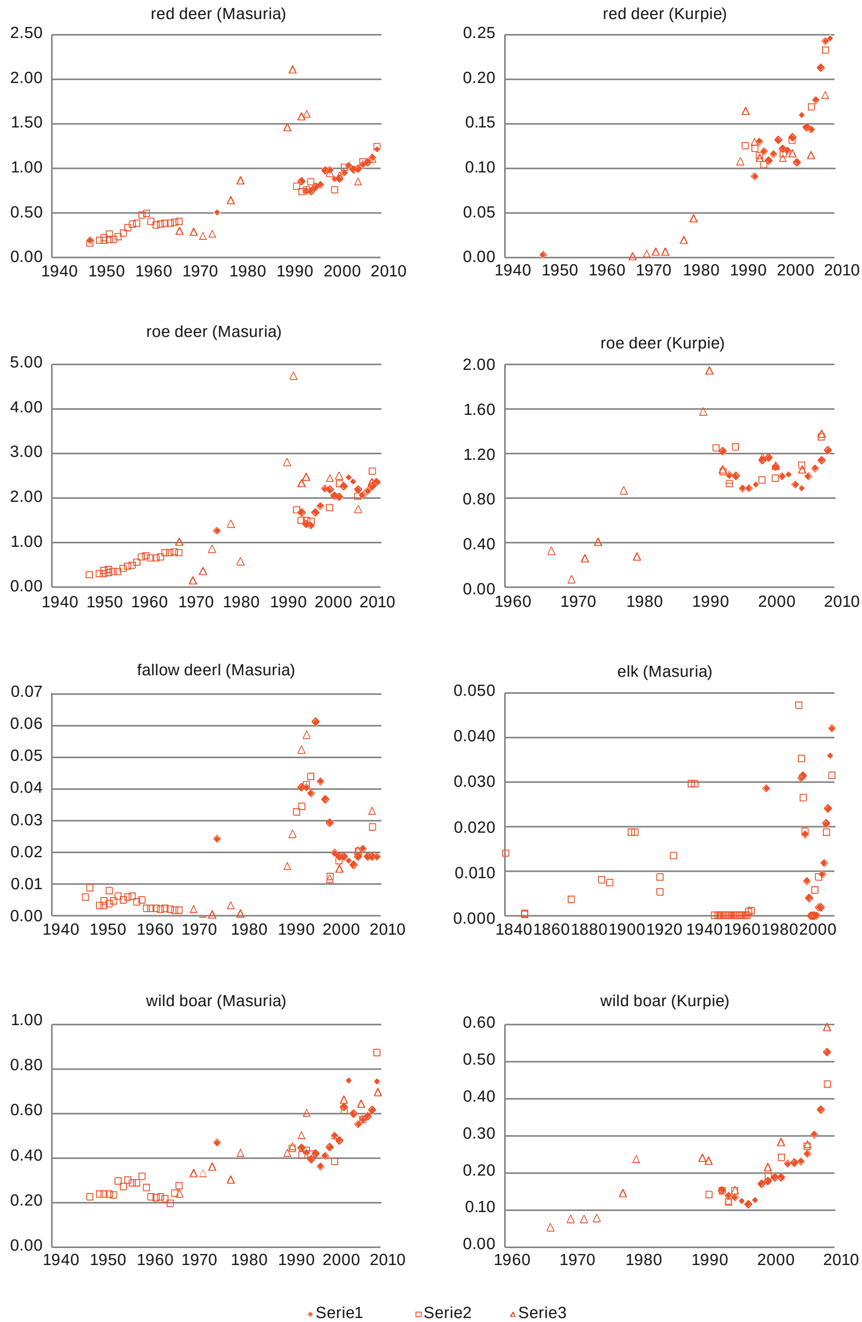

Fig. 9.21. Summary of the data of ungulates density in historical period (specimens km^{-2} of the study area)

– the third was the trend pattern (shown on the bottom figures), in all cases curvilinear; the trend function, shown in the text was selected from among those generated by the CurveExpert application, which were statistically significant and describing adequately the behaviour of the variables; the criteria of choice of the function encompassed the minimum value of the AIC criterion, the possibly simple arithmetic form, and the variability of the function that could be interpreted in terms of knowledge of natural phenomena (Table 9.9).

Table 9.9. Parameters for functions of trend

Region	Species	Function	Parameters			R^2
			a	b	c	
Masuria	red deer	$a(x-b)^c$	0.0302000	-5.3700	0.8644	0.6558
	roe deer	$a(x-b)^c$	0.0317000	-4.3147	1.0381	0.7053
	fallow deer	$ax(b+x)^{-1}$	0.1443000	233.5160	-	0.4246
	wild boar	$1(a+bx)^{-1}$	4.5650000	-0.0503	-	0.8299
Kurpie	red deer	ax^b	0.0000114	2.3734	-	0.8224
	roe deer	$a[1+(xb^{-1})^c]^{-1}$	1.1169000	29.5050	-8.1245	0.6952
	wild boar	$1(a+bx)^{-1}$	24.1345000	-0.3552	-	0.7948

Red deer

Within the northern part of the study area (i.e. in Masuria) the reconstruction of the red deer population numbers can be carried out since, more or less, the end of the World War II. Three sources of data were at disposal, concerning the information on the numbers of red deer (Series 1) within the area of Masuria. Goetz (1948) provided the data on the number of red deer for the area of the state forest board of Olsztyn (this area corresponding approximately to the province of Olsztyn as of the same time), as well as the data, from which approximate numbers can be derived for the territories of the contemporary forest districts[1]. For the year 1975 one could find in the archive of the state forest board in Olsztyn the data on the number of red deer for the four Masurian forest districts that are of interest here (within their confines as of now). Then, for the years 1993-2009 we disposed already of the detailed data for the forest districts, as commented upon before. The results of the analysis of these data, together with the quantities, calculated on the basis of population numbers or on yields, for the administrative units in Masuria, are shown in Fig. 9.22. The image obtained presents a very clear increase of the red deer population over the 60 years. With respect to the entire area the density of the red deer increased from roughly 0.20 to 1.20 per km^2, that is – more or less six times over. The curves shown do not allow for the unambiguous suggestions as to whether the stabilisation level has been already attained, or the population still has a room for a significant growth. The smoothed averaged

[1] The report by Goetz gives the number of red deer for the whole administrative area corresponding to the board in Olsztyn, along with a map, on which the respective forest districts are characterised by the signs, corresponding to the magnitude classes of the red deer population. By putting together this information it was possible to estimate in quantitative terms the red deer populations in the particular former forest districts, and then in the new, contemporary ones.

line, obtained with the "smoothing spline" method and the regression model based on the superposed sinusoids provide the image that is known for the changes of density of a population, whose growth exceeded the capacity of the respective environment and now the process of adaptation to this capacity takes place, as seen through damped oscillations. This might be an interpretation of a theoretician. A practitioner could have indicated that the changes occurring in the later part of the period might be associated

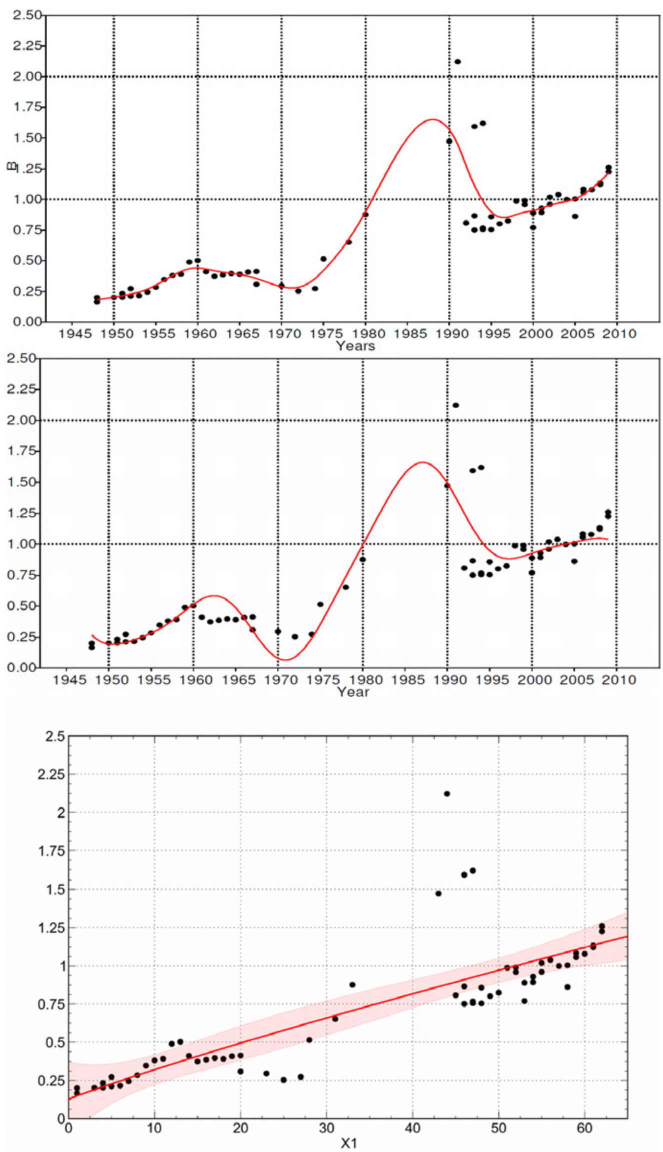

Fig. 9.22. Red deer density changes in Masurian districts. A – smoothing spline interpolation, B – sinusoidal model, C – trend line, X = 1 denotes 1948 year. Functions' parameters – Table 9.8 and 9.9

with the pressure from hunting exploitation or from the change in the pressure from predators (wolves). The image of the trend line, however, would imply that the growth process has not terminated yet. It is possible that the reasoning here presented is influenced by the fact that some data used for analysis, namely the data on yield, display a different dynamics than the data on animal numbers (see Fig. 9.21). Thus, one can see low hunting yields at the turn of the 1970s, maintained for purposes of re-establishment of the population, and very high yields from the beginning of the 1990s, associated with the reduction of the animal numbers in the special rearing centres.

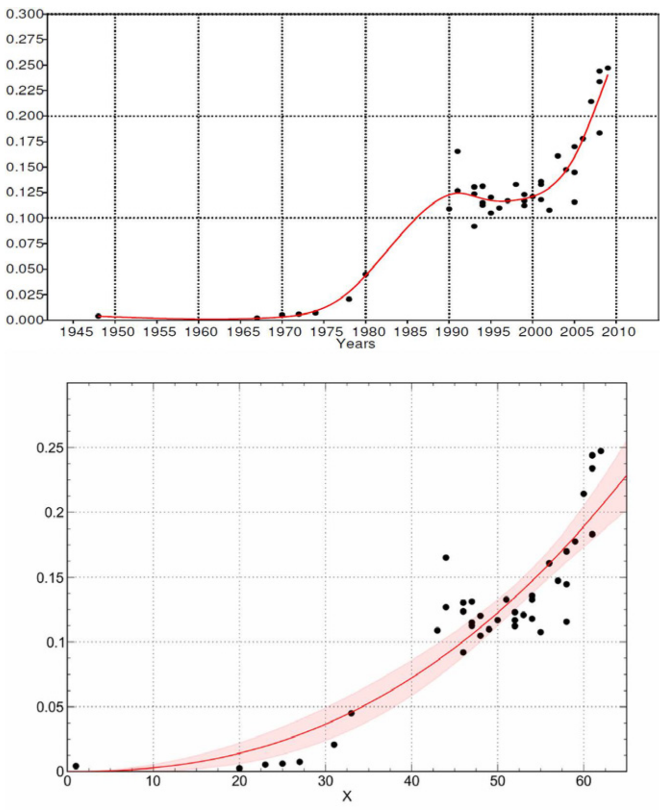

Fig. 9.23. Red deer density changes in Kurpie districts. A – smoothing spline interpolation, B – trend line, X = 1 denotes 1948 year. Function's parameters – Table 9.9

Changes in the numbers of red deer within Kurpie are shown in Fig. 9.23. In this case one can also go back with reconstruction of respective numbers to the year 1948. The very same source, Goetz (1948), indicates that in 1948, within the Kurpie part of the study region, only in the forest district of Parciaki there were up to five red deer[2]. Definitely, the

[2] It might have occurred that – in fact – there was no red deer within the area of interest here, regarding Kurpie, for it cannot be excluded that these few animals clustered in this part of the forest district of Parciaki, which is not included in the study.

density of these animals was negligible. The further indirect data allow for assuming that it was only in the 1970s, and, on a bigger scale – in the 1980s – that red deer appeared for good on this area, and since that time the number of these animals has been increasing, although the increase was not uniform at all. Thus, after the increase in the 1980s there followed stabilisation in the 1990s, and a significant increase again in the initial years of the 21st century. The shape of the curves suggests that the state of natural stabilisation of the density of this specie is still far away. This conclusion is confirmed by the fact that the density at the end of the period here considered relative to the forest area in Kurpie was at around 1/3 of the counterpart density in Masuria. This difference partly results from the lower fertility of the habitats in Kurpie, but partly also certainly from the not fully terminated process of settling of the respective areas in Kurpie by the red deer.

Roe deer

The estimated numbers of roe deer in Masuria since 1948 are shown in Fig. 9.24. In this case, for the beginning of the period, we dispose only of the indirect data, yet they form a coherent whole with the contemporary ones. On this basis we can conclude that there has been a distinct increase in the numbers of these animals in Masuria, from approximately 0.30 to 2.40 animals km^{-2}, meaning the increase by the factor of eight – that is, even more pronounced than for the red deer. The course of the curves suggests that since the year 1990 we deal with short-cycle fluctuations, which would correspond to the general saturation at the level of 2.2 animals km^{-2} of the area. The retrospective study of the changes in the numbers of roe deer within the Kurpie part of the study area could be performed starting only with the year 1967, and for the beginning of this period the respective estimate is based only on the hunting quota and actual game yields, this being, though, quite a misleading premise (Fig. 9.25). For this reason, the values of the trend, calculated for the years 1945-1965, close to zero, should be considered doubtful – most probably, the numbers were low, but definitely not that low[3]. Notwithstanding these reservations, it appears to be probable that the roe deer population increased during the period considered perhaps by the factor between three and six. Apparently, the density of this species within Kurpie also attained a kind of stabilisation at the level of 1-1.2 animals km^{-2} of the area, with distinct short-cycle fluctuations. The comparison of the stabilisation levels in Masuria and Kurpie shows a distinctly higher density in Masuria, when the density is related to the entire area, while the densities related to the proper forest cover are very similar (approximately 4.8-4.9 animals km^{-2} of forest), and this density in Kurpie is even slightly higher. Roe deer is the species, which is relatively the least associated with the forests from among the ungulate species here considered, and so the assessment of the density for the entire area and for the forest cover is definitely justified.

[3] One of the present authors (JMM) knows the tales of the old age inhabitants of Kurpie, dealing with hunting on the respective areas. One of such stories (told by Franciszek Fonk from the village of Dynak) started with the words: *Imagine, Gentlemen, that one day a roe deer was spotted in the woods*…, after which a description followed of a collective hunting with dogs, ending with successful shooting of the animal by one of the local hunters. This story suggests the very scarce appearance of the game animals, even those most common, like roe deer.

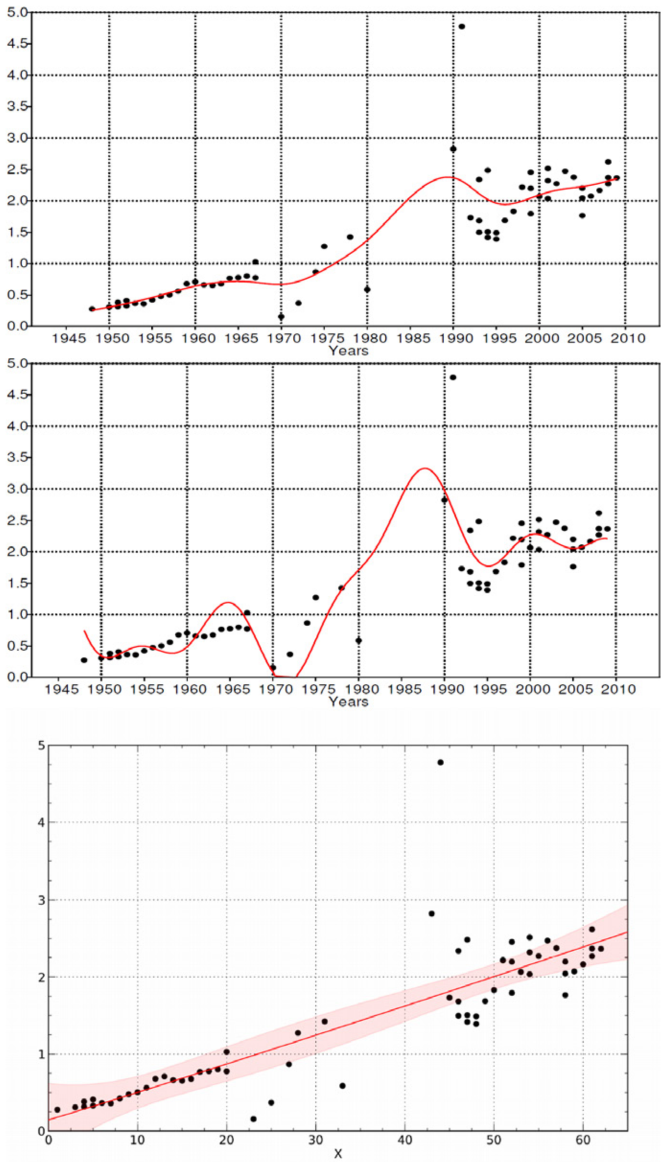

Fig. 9.24. Roe deer density changes in Masurian districts. A – smoothing spline interpolation, B – sinusoidal model, C – trend line, X = 1 denotes 1948 year. Functions' parameters – Table 9.8 and 9.9

Fallow deer

Changes in the number of fallow deer within the Masurian territory considered here, since 1948, are shown in Fig. 9.26. One can observe low numbers of animals from this species until as late as the 1990s, then a significant increase, followed by a drop, and again a stabilisation after the year 2000. This appears to be the consequence of the changes in organisation of hunting activities, which took place over the area in question at the turn

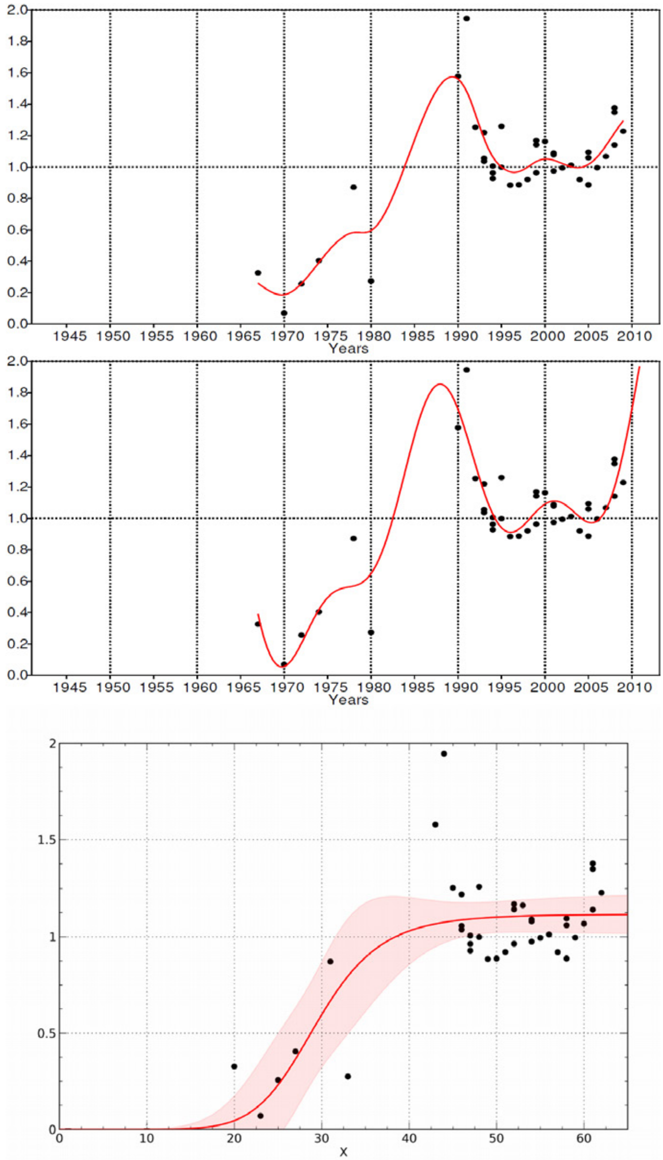

Fig. 9.25. Roe deer density changes in Kurpie districts. A – smoothing spline interpolation, B – sinusoidal model, C – trend line, X = 1 denotes 1948 year. Functions' parameters – Table 9.8 and 9.9

of the 1990s. One should also consider the fact that in practice, the presence of this species is mainly limited to just one forest district. The species has not been registered, either, in Kurpie, except for one very short episode (see previous comments). Generally speaking, fallow deer has marginal importance against the background of the ungulates as such, both in terms of the exerted pressure on the forests and in terms of hunting yields.

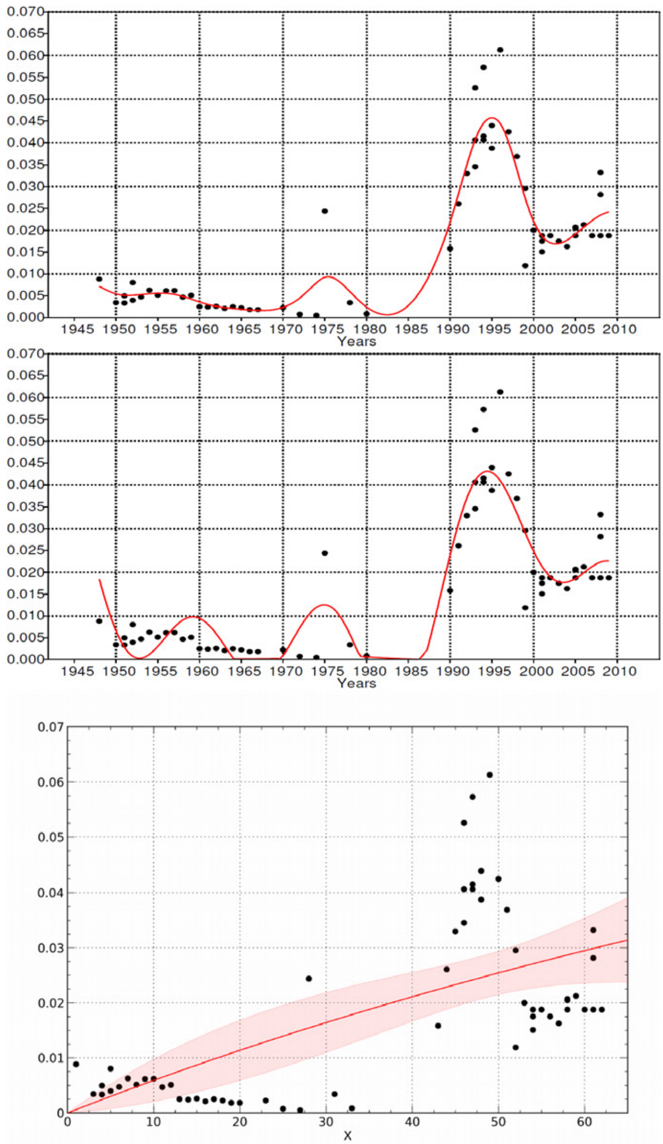

Fig. 9.26. Fallow deer density changes in Masurian districts. A – smoothing spline interpolation, B – sinusoidal model, C – trend line, X = 1 denotes 1948 year. Functions' parameters – Table 9.8 and 9.9

Elk

The reconstruction of the changes in the numbers of elk on the Masurian territory here analysed could be performed with a definite level of reliability since 1840 (see Fig. 9.21), owing to the data on the numbers of elk in the German East Prussia (Tryk, 2005). These

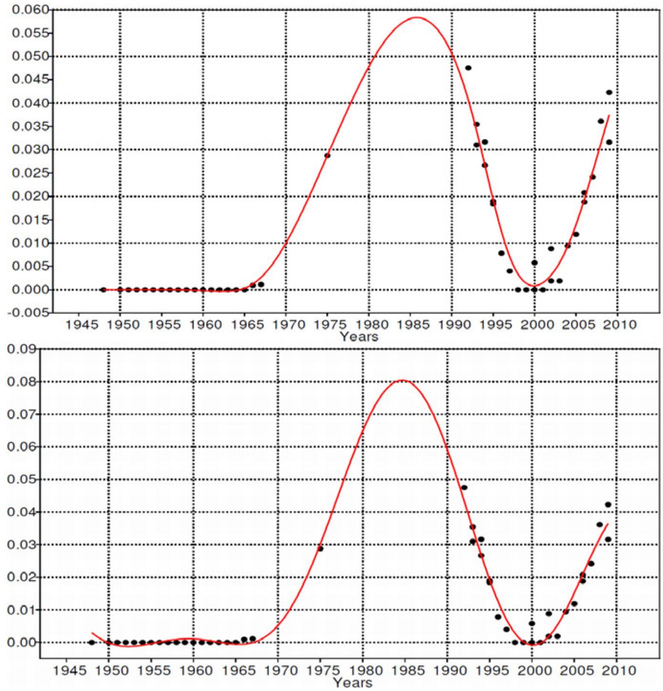

Fig. 9.27. Elk density changes in Masurian districts. A – smoothing spline interpolation, B – sinusoidal model. Function's parameters – Table 9.8

data were transformed to correspond to the study area based on per area indicators[4] and complemented with those for the post-war period (Fig. 9.27). Thus, it appears that the density of elk, quite high in 1840, dropped very much by the middle of the 19th century, to then systematically increase. There was a complete collapse of the elk population during the World War II, the effects of this collapse lasting more or less until the 1960s. Then, there was an abrupt increase of densities, with a maximum around the year 1985, followed by a drop to zero at around the year 2000, and again an increase at the end of the first decade of the 21st century – commented upon already before in the consideration of the changes in animal numbers in the period 1993-2009. Lack of appropriate data did not allow for the reconstruction of the retrospective data on numbers of elk in Kurpie. The figures shown here indicate the very high vulnerability of this species to the hunting exploitation, the numbers of elk shifting in the ranges not encountered for other species of the Cervidae.

[4] Transformation of the data available for a large region to much smaller units, like in this case, are charged with potential error due to potential differences in local densities, resulting in a given total number. This is particularly important in the case of elk, since this animal displayed high variations in numbers and in reach, and, on the top of this, it is a highly mobile species, moving over significant distances.

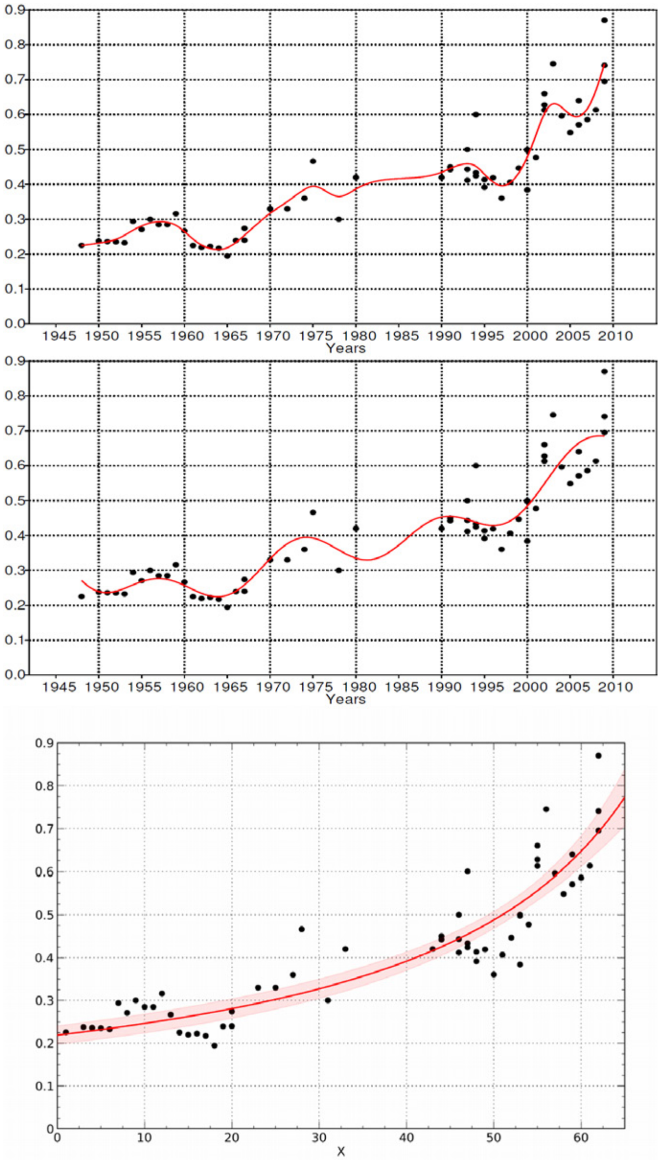

Fig. 9.28. Wild boar density changes in Masurian districts. A – smoothing spline interpolation, B – sinusoidal model, C – trend line, X = 1 denotes 1948 year. Functions' parameters – Table 9.8 and 9. 9

Wild boar

By tracing the changes in the densities of wild boar within the Masurian part of the study area since 1948 (Fig. 9.28) one can conclude that – the fluctuations, characterising this species, put apart – there is a clear increase of the densities from roughly 0.2 just after the war to 0.6-0.7 per km^2 of the area, that is – the increase by the factor of three. The course

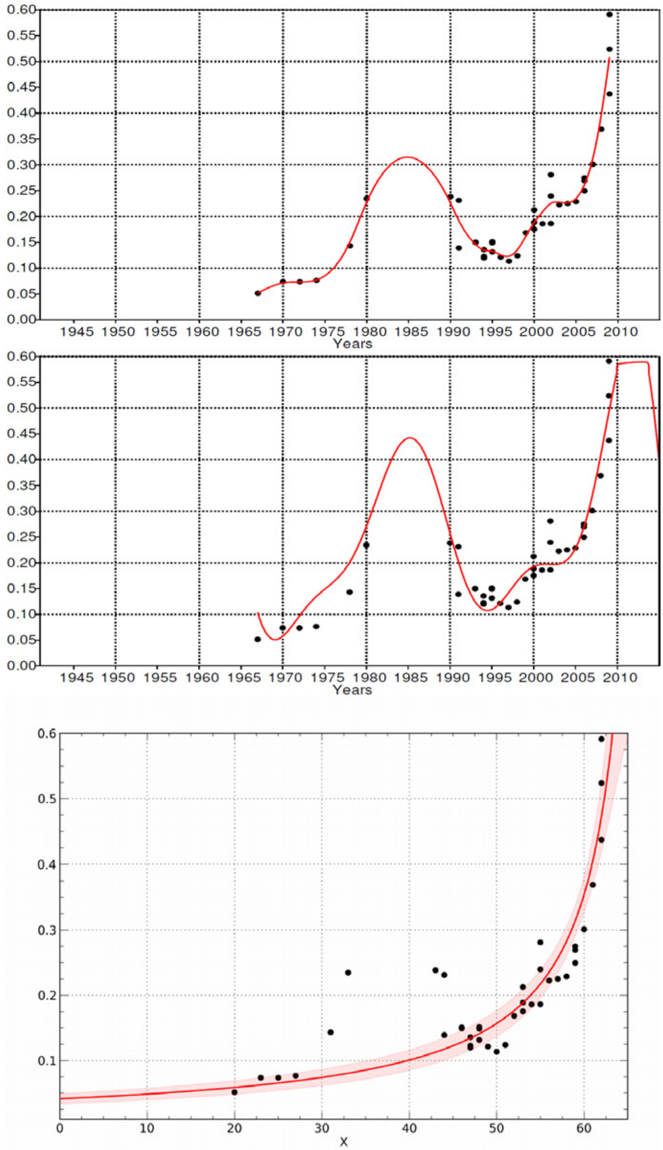

Fig. 9.29. Wild boar density changes in Kurpie districts. A – smoothing spline interpolation, B – sinusoidal model, C – trend line, X = 1 denotes 1948 year. Functions' parameters – Table 9.8 and 9.9

of the respective curves implies the possibility of a further increase in the population numbers.

Within Kurpie (Fig. 9.29) one also observes, since 1967, a distinct increase of the number of wild boar. Although the data are not very certain, it seems that the increase might have been by the factor of 4 or even 5. Significant fluctuations can be observed, but the essential impression is that of the sharp increase during the last years. The density of this species within Kurpie has certainly not reached the level of saturation of the environment, although the sinusoidal model (based, however, on a short time series of data) envisages the possibility of a sharp collapse of the population numbers.

By comparing the changes in the densities of the species here considered within the study area after the World War II, one can reach the following general conclusions:

- there has been a highly pronounced growth of the red deer population in Masuria, approaching the stabilisation level, and a delayed in time, and starting from zero, strong growth in Kurpie, still far from stabilisation;
- the population of roe deer increased both in Masuria and in Kurpie and attained the levels close to the stable ones;
- the population of wild boar increased – in the presence of numerous fluctuations – both in Masuria and in Kurpie, though the respective densities are well below the saturation of the environment;
- the changes in the numbers of fallow deer, observed in some of the forest districts in Masuria, do not provide the basis for indicating unambiguous directional tendencies;
- the changes in the elk populations display very strong fluctuations.

It is highly interesting that the fluctuations in the population numbers of red deer, roe deer and wild boar are quite synchronous, with a local minimum of these numbers at around the year 1995. This short-lived drop of the population numbers is observed in almost all of the data sets considered (see Fig. 9.21).

9.7. Estimated changes of pressure from the ungulates during the 60 years considered

Based on the data presented above, concerning the densities of the particular species of the ungulates in the regions of Masuria and Kurpie, estimation was carried out for seven time slices spaced by 10-year periods, using the course of the functions describing the temporal changes in the three series of data gathered. Then the plant mass was calculated – as before – consumed by the respective animals, related to the forest cover area, with due account for the changes in the forest cover (increase of forest shares) having taken place in both regions (Figs. 9.30 and 9.31). This quantity is treated as the measure for the pressure exerted by the ungulates on the ecosystems. Thus, Fig. 9.30 shows the data obtained in this manner with the help of application of the "smoothing spline" procedure for the calculation of the population densities, while Fig. 9.31 shows the data in terms of the trend line. It should be noted that the data concerning the pressure from roe deer and wild boar in Kurpie may be underestimated, and also that the data concerning the pressure from elk in Kurpie have lower likelihood than the other ones.

The data here reported allow for forwarding the following statements:

- the pressure from the feeding of the ungulates, exerted on forest ecosystems displays high variability over time; against the background of the general direction of changes the periods of increase and decrease of pressure are visible (Fig. 9.30); in the case of Masuria there is a particularly well pronounced peak of the number of red deer, documented there for the year 1990, which is followed by a drop (year 2000), and then

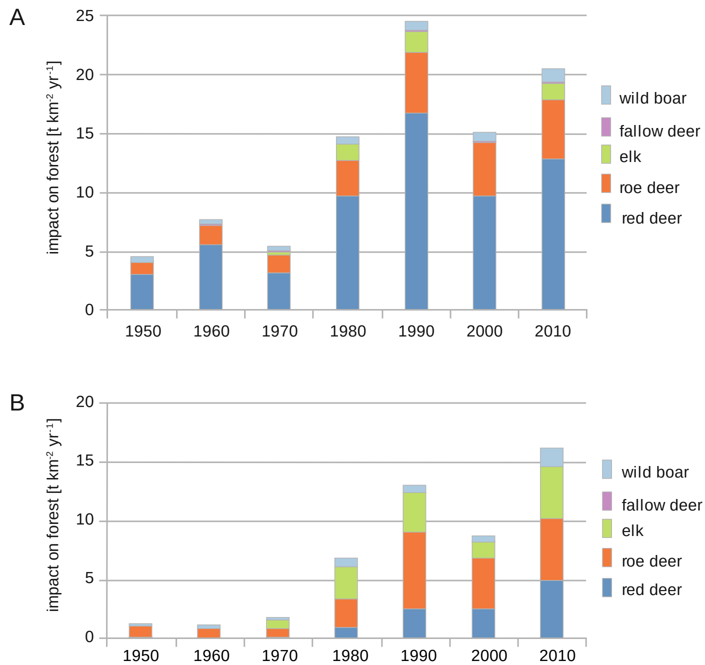

Fig. 9.30. Ungulates impact on forest in selected years. Estimated on the basis – density of species smoothing spline interpolation method. Changes of afforestation were taken into account. A – Masurian districts, B – Kurpie districts

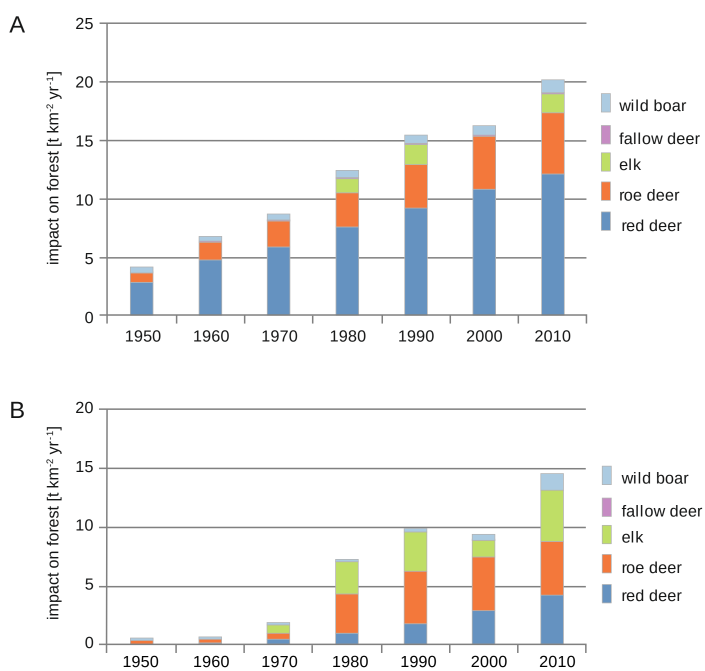

Fig. 9.31. Ungulates impact on forest in selected years. Estimated on the basis – density of species trend line method. Changes of afforestation were taken into account. A – Masurian districts, B – Kurpie districts

an increase again at the end of the period; these changes resulted most probably from two causes: variable policies of the state forest management concerning the population numbers of red deer in the forests (various hunting quota) and the renewal of the population of wolves, starting with some time instant, within the area considered[5]; the significant changes in the pressure, especially in Kurpie, result from the variable numbers of elk, this being also the consequence of the planning of hunting intensity for this animal by the state forest managers;

- in general terms, the pressure from the ungulates on forest ecosystems (see Fig. 9.31) systematically increases since the World War II in both regions; in the case of Masuria the increase is fourfold, in the case of Kurpie – more than seven times over, and perhaps even ten times;
- the maximum pressure from the ungulate feeding on the area considered, which might constitute the reference for the comparisons of the historical situations, took place in Masuria at the beginning of the 1990s – approximately 25 t km^{-2} yr^{-1} (somewhat lower at around the year 2010 – 21 tons), and in Kurpie – at the end of the period analysed (year 2010) – approximately 16 t km^{-2} yr^{-1};
- the biggest share in the increase of the pressure falls on red deer, as this species systematically, although unevenly over time, has been increasing in numbers, and, to a lesser degree – on elk (mainly in Kurpie), the latter species displaying significant fluctuations as to the population numbers;
- the level of pressure from the ungulates is definitely lower in Kurpie than in Masuria, which is the consequence, in particular, of the lower nutritional richness of the forests in Kurpie; yet, a tendency towards evening out of the pressure can be observed, since the increase of pressure was bigger in Kurpie than in Masuria.

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[5] Changes in the magnitudes of populations, calculated for the purpose of this study on the basis of the data for provinces, are also visible in their specific aspects on the local scale. Thus, for instance, in one of the hunting quarters in the forest district of Szczytno the total quota of red deer shooting for the season 1990/91 was 56, and for 1991/92 even 70, while for the season 2000/2001 it was only 17, and for 2013/14 it equals 33.

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10. HUNTING EXPLOITATION OF THE UNGULATES, NOW AND IN THE PAST – A FACTOR IMPACTING ECOSYSTEM SERVICES

Jan Marek Matuszkiewicz, Bożenna Grabińska

10.1. Introduction

The role of ungulates in the landscape can be considered in two perspectives: biocoenotic, that we dealt with in Chapter 9, and economic. Concerning the latter, the role of ungulates can be analysed in different ways – on the one hand in terms of the bag number for consumption and other purposes, and, on the other hand – as a factor limiting the effects of forest economy and agriculture (damages inflicted in forests and fields). Here, we deal uniquely with the analysis of quantitative yield of game animals within the study area, as an element of forest use for human purposes. In this analysis we refer to the data on bag number in the estimation of the population numbers. This is important for this research, since for the previous periods are usually no data, even estimates on the numbers of animals, while there is data on the hunting yields that can be used to estimate the density of the corresponding population in the past.

10.2. Bag number of the ungulates in the study area in the years 1993-2008

The magnitudes of yields of the four ungulate species during 16 hunting seasons on the territory of six forest districts (with modifications as to respective areas as mentioned in Chapter 9) are provided in Table 10.1. The data originate (like in Chapter 9) from the archive of the Olsztyn Regional District of State Forest. The data shown do not contain the elk bag numbers, since the archival sources that we made use of did not provide them, and since the year 2001 the moratorium on elk hunting has been in force. The bag number of fallow deer are so low that their analysis is of no significance. For these reasons, the yields of only three species were considered – of red deer, roe deer and wild boar. The bag numbers were analysed from two angles: the number of animals per area unit (of the entire area or of forest area), and proportions between the yields and the population size of a given species. Analyses were performed for two regions within the study area – Masuria and Kurpie.

Table 10.1. Bag number of game (specimens) in hunting year (from the 1st of April to the 31st of March of the next year) in the study area

Species	Forest districts	Number of the gained animals (in specimens) in the hunting year																
		1993/1994	1994/1995	1995/1996	1996/1997	1997/1998	1998/1999	1999/2000	2000/2001	2001/2002	2002/2003	2003/2004	2004/2005	2005/2006	2006/2007	2007/2008	2008/2009	average
Red deer	Jedwabno	232	217	254	197	223	204	183	164	139	153	146	142	127	117	138	136	173.3
	Spychowo	185	118	115	98	141	134	135	98	68	67	75	80	74	66	66	85	100.3
	Szczytno	125	113	96	97	155	110	99	76	73	61	50	63	47	55	63	79	85.1
	Wielbark	111	60	81	54	54	55	61	50	38	36	50	47	50	57	52	62	57.4
	Korpele*	16	14	12	12	19	14	12	10	9	8	6	8	6	7	8	10	10.6
	Total in Masuria	**669**	**522**	**558**	**458**	**592**	**517**	**490**	**398**	**327**	**325**	**327**	**340**	**304**	**302**	**327**	**372**	**426.7**
	Specimens km^{-2} of the area	0.4	0.3	0.3	0.3	0.4	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3
	Specimens km^{-2} of forests	0.7	0.6	0.6	0.5	0.6	0.5	0.5	0.4	0.3	0.3	0.3	0.4	0.3	0.3	0.3	0.4	0.5
	Myszyniec	14	17	15	16	14	14	15	10	13	15	10	16	13	30	22	33	16.7
	Parciaki	18	29	38	33	30	40	41	41	45	41	36	34	32	37	43	45	36.4
	Parciaki**	14	23	30	26	23	31	32	32	35	32	28	27	25	29	34	35	28.5
	Total in Kurpie	**28**	**40**	**45**	**42**	**37**	**45**	**47**	**42**	**48**	**47**	**38**	**43**	**38**	**59**	**56**	**68**	**45.2**
	Specimens km^{-2} of the area	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0
	Specimens km^{-2} of forests	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.2	0.1
Roe deer	Jedwabno	110	121	216	155	216	232	211	219	168	188	182	184	180	152	172	176	180.1
	Spychowo	343	171	203	413	435	438	424	465	403	309	317	263	228	196	213	227	315.5
	Szczytno	155	179	151	142	218	220	214	220	202	180	183	175	148	136	141	152	176.0
	Wielbark	229	110	114	98	144	175	166	161	110	129	130	140	113	120	88	93	132.5
	Korpele*	19	22	19	18	27	28	27	28	25	23	23	22	19	17	18	19	22.0
	Total in Masuria	**856**	**603**	**703**	**826**	**1,040**	**1,093**	**1,042**	**1,093**	**908**	**829**	**835**	**784**	**688**	**621**	**632**	**667**	**826.1**
	Specimens km^{-2} of the area	0.5	0.4	0.4	0.5	0.7	0.7	0.7	0.7	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.5
	Specimens km^{-2} of forests	0.9	0.6	0.7	0.9	1.1	1.2	1.1	1.2	1.0	0.9	0.9	0.8	0.7	0.7	0.7	0.7	0.9
	Myszyniec	184	106	105	107	119	102	134	131	103	95	77	82	67	89	76	94	104.4
	Parciaki	99	101	91	88	85	98	113	104	98	111	99	90	82	93	102	114	98.0
	Parciaki**	77	79	71	69	66	77	88	81	77	87	77	70	64	73	80	89	76.6
	Total in Kurpie	**261**	**185**	**176**	**176**	**185**	**179**	**222**	**212**	**180**	**182**	**154**	**152**	**131**	**162**	**156**	**183**	**181.1**
	Specimens km^{-2} of the area	0.2	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	Specimens km^{-2} of forests	0.7	0.5	0.5	0.5	0.5	0.5	0.6	0.5	0.5	0.5	0.4	0.4	0.3	0.4	0.4	0.5	0.5
Fallow deer	Jedwabno	0	9	14	8	10	5	0	3	0	0	3	0	0	0	0	3	3.4
	Spychowo	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
	Szczytno	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
	Wielbark	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
	Korpele*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
	Total in Masuria	**0**	**9**	**14**	**8**	**10**	**5**	**0**	**3**	**0**	**0**	**3**	**0**	**0**	**0**	**0**	**3**	**3.4**
	Specimens km^{-2} of the area	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Specimens km^{-2} of forests	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Myszyniec	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
	Parciaki	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
	Parciaki**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
	Total in Kurpie	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0.0**
	Specimens km^{-2} of the area	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Specimens km^{-2} of forests	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wild boar	Jedwabno	66	119	149	95	112	119	108	118	143	196	155	119	109	137	154	231	133.1
	Spychowo	81	35	71	82	89	106	102	97	107	131	75	72	87	80	102	177	93.4
	Szczytno	115	103	76	75	104	128	105	99	94	135	91	90	87	88	138	226	109.6
	Wielbark	91	69	58	35	47	63	58	74	67	91	95	59	71	77	72	99	70.4
	Korpele*	14	13	10	9	13	16	13	12	12	17	11	11	11	11	17	28	13.7
	Total in Masuria	**367**	**339**	**364**	**296**	**365**	**432**	**386**	**400**	**423**	**570**	**427**	**351**	**365**	**393**	**483**	**751**	**420.2**
	Specimens km^{-2} of the area	0.2	0.2	0.2	0.2	0.2	0.3	0.2	0.3	0.3	0.4	0.3	0.2	0.2	0.2	0.3	0.5	0.3
	Specimens km^{-2} of forests	0.4	0.4	0.4	0.3	0.4	0.5	0.4	0.4	0.4	0.6	0.5	0.4	0.4	0.4	0.5	0.8	0.4
	Myszyniec	62	31	40	30	22	45	59	58	56	63	61	65	52	72	107	128	59.4
	Parciaki	95	67	44	33	48	86	90	82	103	98	88	66	92	83	104	181	85.0
	Parciaki**	74	52	34	26	38	67	70	64	81	77	69	52	72	65	81	142	66.5
	Total in Kurpie	**136**	**83**	**74**	**56**	**60**	**112**	**129**	**122**	**137**	**140**	**130**	**107**	**124**	**137**	**188**	**270**	**125.3**
	Specimens km^{-2} of the area	0.1	0.1	0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.1
	Specimens km^{-2} of forests	0.3	0.2	0.2	0.1	0.2	0.3	0.3	0.3	0.4	0.4	0.3	0.3	0.3	0.4	0.5	0.7	0.3

* Forest district Korpele – only part of the district included, evaluated as 0.125 of the Szczytno forest district (calculation based on the area ratio).
** Forest district Parciaki – included only 0.782 of the total area of the forest distirict.

10.2.1. Bag number of red deer

In the years 1993-2008 in the Masurian part of the study area on average 426.7 red deers were hunted per year (this number including stags, hinds and calves), the number being equivalent to 0.27 of an animals km^{-2} of the total area, and 0.45 per km^2 of the forest area. The course of changes in this respect over the period of 16 years is shown in Fig. 10.1. It can be seen that there were clearly higher annual bag numbers during the 1990s (roughly 0.30-0.40 animals km^{-2}), followed by lower, relatively even yields at the level of 0.20 per km^2, after 2000.

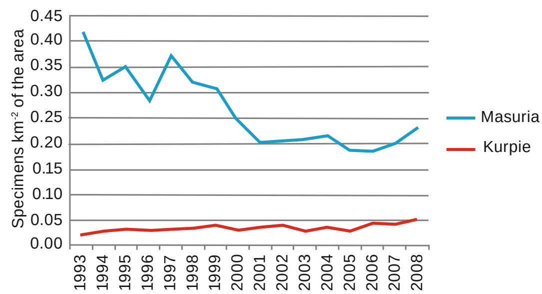

Fig. 10.1. Bag number of red deer (specimens km^{-2}) during the years 1993-2008

The bag number of red deer in the Kurpie part has had quite an even course with a slight upward trend, and it attained at the end of the period analysed the value of 0.05 per km^2 of total area, corresponding to 0.17 per km^2 of forest area.

Considering the ratio of the bag number to the population size, a relatively high yield in the Masurian part during the 1990s can be observed (more than 40%) and somewhat lower yield in the Kurpie part (approximately 30%), see Fig. 10.2. In the last years of the period analysed the bag number in the season stabilised at the level of around 20-25% of the number of animals estimated on March 31 of a given year, that is – before the calves are born.

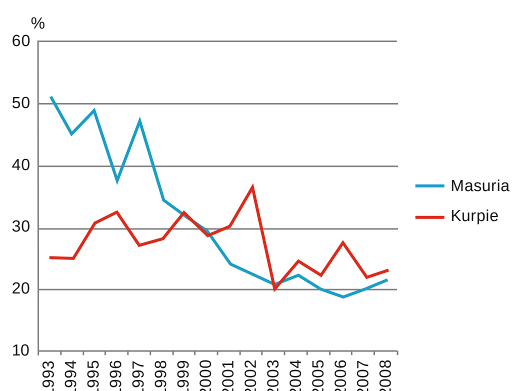

Fig. 10.2. Bag number of red deer vs. population size (%) during the years 1993-2008

By comparing the changes in the number of red deer (Fig. 9.1) with the bag number, one can conclude that yield at the level of 20-25% allows for an increase in the number of red deer, even in a situation of moderate pressure from wolves. At the same time, one can also easily note that assessing the number of animals on the sole basis of bag number is highly prone to errors.

10.2.2. Bag number of roe deer

In the years 1993-2008 in the Masurian part of the study area on average 826 roe deers were hunted per year. This is equivalent to 0.52 animals km^{-2} of the total area, and 0.88 per km^2 of the forest area. In the Kurpie part the average annual hunting yield equalled 181 roe deers, that is – 0.15 per km^2 of the total area and 0.46 per km^2 of forest area. The course of the respective changes over the considered 16 years is shown in Fig. 10.3.

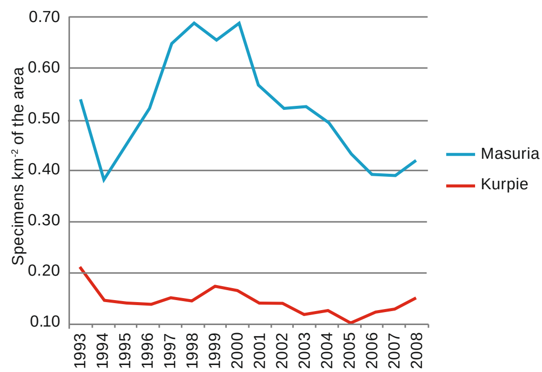

Fig. 10.3. Bag number of roe deer (specimens km^{-2} of the area) during the years 1993-2008

The data illustrate the uneven levels of roe deer bag number in Masuria, with the maximum at around 0.65 animals km^{-2} in the years 1997-2000 and the minimum of approximately 0.40 in the last years of the period considered. Within the Kurpie part the yields per unit area were much lower, between 0.20 and 0.10 per km^2.

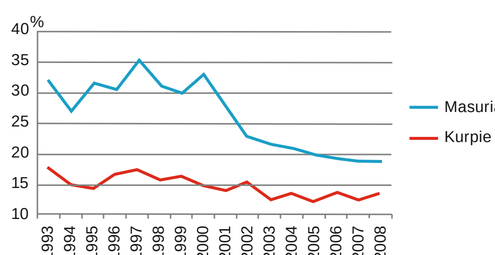

Fig. 10.4. Bag number of roe deer vs. population size (%) during the years 1993-2008

The comparison of the hunting yields with the number of animals shows – again – a much higher yield intensity within the Masurian part (35-20%) than in Kurpie (around

15%), see Fig. 10.4. Based on the comparison with the number of roe deer (see Fig. 9.2) it can be concluded that the lower values given allow for an increase in the population size, but, in general, it is difficult to establish a simple relation between the bag number and the animal number, influence also perhaps exerted by other factors, such as: climatic conditions (severe winters), pressure from the predators, and pests.

10.2.3. Bag number of wild boar

During the period considered here on average 420 boars were shot per year in the Masurian part of the study area, and 125 within the Kurpie part, this being equivalent, respectively, to 0.25 and 0.10 animals km^{-2} of the entire area, and, respectively, 0.45 and 0.32 per km^{2} of the forest area. The temporal courses of changes in the bag number of wild boar are shown in Fig. 10.5. It is interesting to see the increased bag number in the last years of the period analysed, this being parallel to the increase in the number of animals of the species considered (Fig. 9.6).

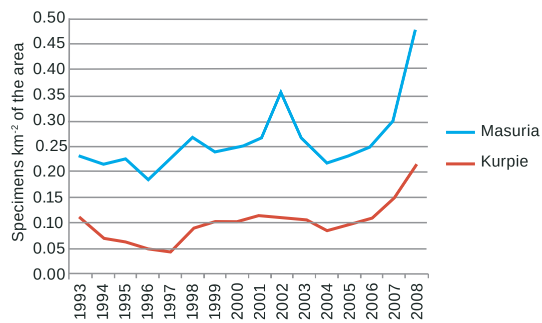

Fig. 10.5. Bag number of wild boar (specimens km^{-2} of the area) during the years 1993-2008

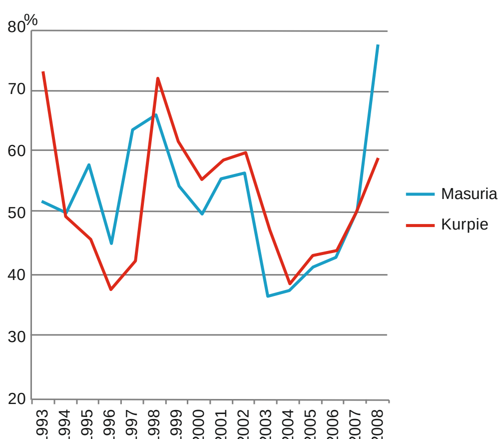

Fig. 10.6. Bag number of wild boar vs. population size (%) during the years 1993-2008

The proportions between the yields and the numbers of wild boars in the Masurian and Kurpie parts are similar. Simultaneously, one observes a high variability between the particular periods, from less than 40% to more than 70% (Fig. 10.6). In this context, it appears that the increased bag number might not entail a drop in animal numbers.

10.2.4. An attempt of estimating monetary value of the hunted game

Based on the magnitudes of bag number of ungulates within the study area an attempt was made to calculate the monetary value of the hunted game according to prices paid by purchasing agencies. The data on the weight of animals and on prices quoted have been assumed as estimates on the basis of the authors' own experience, see Table 10.2.

From the figures provided in the table it can be concluded that the total value of the hunted game animals depends only marginally on the hunting of wild boar, which is mainly due to the low purchase prices of wild boar – approximately half that for red deer and only a quarter of the price for a roe deer. The biggest share in the hypothetical revenue in the Masurian part is taken by the red deer, while in the Kurpie part – by the roe deer. One can also observe a big difference between the estimated revenues from the hunting activities regarding the three ungulate species within Kurpie and Masuria. This proportion, calculated with respect to the total area, is 1:4.5, and with respect to forest area – 1:2.4.

We do not intend to enter deeper into the economics of hunting at this point as it would have to cover many elements that are not considered here, not just the hunting income itself. However, to outline the scale of the problem, we will present a comparison with one of the cost elements. Thus, the estimates of the revenues, shown in the table, can be compared to the renting fees for hunting units. The renting fees for a hunting unit are defined in the legal act of the Minister of the Environment on December 4, 2002, where the fees are related to the prices of rye[1]. This act defines the renting fee for 1 hectare of a hunting unit, depending upon the quality category: for the very good units – 0.007 tons of rye per hectare, for the good units – 0.004 tons of rye per hectare, medium – 0.002 tons of rye per hectare, poor – 0.001 tons of rye per hectare, and very poor – 0.0004 tons of rye per hectare. It can be assumed that within the study area the hunting units in the Masurian part are classified as medium and poor, while in the Kurpie part – as poor and very poor. The average purchasing price of rye, as quoted by the Central Statistical Office on October 18, 2013, for the preceding 11 months was 692.8 Polish zloty (PLN) per tonne. This would mean that the renting fees for hunting units amounted to: 2.76 PLN for one hectare of the good units, 1.38 PLN for one hectare of medium units, 0.69 PLN for the poor precincts, and 0.28 PLN for the very poor ones. Now, taking the average annual values of the hunted game per unit area, namely 2.95 PLN per hectare for Masuria, and 0.65 PLN per hectare for Kurpie, it can be stated that the ratio of revenues to the renting fees (as an element of costs) on the scale of the regional parts is close to 1:1 if the data for Masuria are compared to the renting fees for the "good" hunting units, and the data for Kurpie are compared

[1] The rye equivalent is a traditional Polish way of calculating numerous fees and taxes related to farming and forestry. It is still being applied to a variety of items in Polish rural and forest economy.

Table 10.2. The value of hunted game

Region		Masuria				Kurpie			
Species		**red deer**	**roe deer**	**wild boar**	**total**	**red deer**	**roe deer**	**wild boar**	**total**
Parameters in purchase (estimates by the author for the year 2013)	weight [kg]	80	15	40		80	15	40	
	price per 1 kg [PLN]	7.0	14.0	3.5		7.0	14.0	3.5	
	unite price [PLN]	560	210	140		560	210	140	
Number of yearly gained for the years 1993-2008	min	302	603	296		28	131	56	
	max	669	1093	761		68	261	270	
	mean	427	826	420		45	181	125	
Annual price [PLN]	min	169,050	126,709	41,493	337,251	15,723	27,536	7,813	51,071
	max	374,430	229,425	106,575	710,430	38,186	54,898	37,736	130,820
	mean	238,954	173,486	58,828	471,268	25,302	38,025	17,543	80,870
Annual price, value km^{-2} of the area [PLN]	min	105.69	79.22	25.94	210.84	12.64	22.13	6.28	41.05
	max	234.08	143.43	66.63	444.14	30.69	44.13	30.33	105.15
	mean	149.39	108.46	36.78	294.62	20.34	30.56	14.10	65.00
Annual price, value km^{-2} of the forests [PLN]	min	179.47	134.52	44.05	358.04	40.32	70.62	20.04	130.98
	max	397.51	243.57	113.15	754.23	97.93	140.79	96.78	335.50
	mean	253.69	184.18	62.46	500.32	64.89	97.52	44.99	207.40

to the renting fees for the "poor" units. The economic rationality might be salvaged only by the fact that the majority of the hunting units have the quality categories lower than used here for comparison.

10.3. Retrospective analysis of the historical changes in the bag number of ungulates during the last 400 years in East Prussia

The Chapter 9 contained the section on the animal numbers in the period after the World War II. It would be highly interesting to perform a farther-reaching retrospective that could show the current animal population size compared to the population from several hundred years ago. Yet, there are no direct data that could be the basis for such a retrospective analysis. The sole feasible attempt would be to consider the few data available regarding the bag number.

Such data, however, are available only for East Prussia, that is, the historical territory, which includes the Masurian part of the study area. The respective data are shown in Table 10.3.

When considering the data collected in Table 10.3, one should take into account the fact that the actual area, for which the data were elaborated, varied, both in terms of the surface area and in terms of the forest cover. These two factors had a doubtless influence on the bag number of the forest fauna. Additionally, an influence was exerted by the shifts in the geographical range of voivodeships. During the process of these shifts the ratio of forest cover to deforested areas changed significantly, as well. Despite these reservations, the data on the bag number of game animals, related to the unit area, make it possible to estimate the changes over time in the numbers of ungulates in part of the study area in the past.

Attention ought to be particularly paid to the number of hunted red deer, since the red deer is a large animal – much bigger than a roe deer or a wild boar – and quite numerous (much more frequent than elk or fallow deer), and featuring definite economic significance (as, for instance, the source of meat collected historically for military purposes). The red deer exerts also an important impact on forest biocoenoses.

Red deer

The analysis of the numbers of the hunted red deer per unit area in various periods gives the basis to the conclusion that the bag number of this species have been distinctly increasing since the World War II. The 1951 yield is roughly half that of 1967-1974, which in turn is 3-5 times smaller than the contemporary bag number. Altogether, red deer yields increased between the years just after the World War II and now more than tenfold.

The bag number of red deer in East Prussia in the period preceding the World War II were decidedly higher than that – calculated for the analogous area within the voivodeship of Olsztyn – in the period just after the war. It can be assumed that there was a drop in the number of red deer, due to the war, down to 20-25% of the pre-war numbers.

The registered bag number of red deer in the second half of the 19th century was significantly lower than after the World War II. These 19th century yields constituted 27% of yields

Table 10.3. Game animals gained in different historical periods (chosen examples based on different sources)

Kind of the data	Red deer	Roe deer	Wild boar	Fallow deer	Elk	European bison
Duchy of Prussia [1525-1771] (area 36,200 km²). The data of gained animals from 1612-1618 years. Data source: Bujack, 1839.						
Annual minimum	112	22	21	-	0	0
Annual maximum	1,465	138	1,382	-	58	8
Annual mean	705	83	558	-	16	2
Annual mean on 1 km² of area	0.019	0.002	0.015	-	0.000	0.000
Annual maximum on 1 km² of area	0.040	0.004	0.038	-	0.002	0.000
East Prussia [1772-1945] (area 37,000 km²). The data of gained animals in East Prussia from 1885 year. Data source: Preussische Statistik XCIII, Der Wildabschuss im preussischen Staate während der Zeit vom. 1. April 1885 bis 31 Marz 1886.						
Annual gained	204	7,505	118	351	9	-
Annual gained from 1 km² of area	0.006	0.203	0.003	0.009	0.000	-
East Prussia [1772-1945] (area 36,992 km²). The data of gained animals in East Prussia; season year 1936/37. Data source: Fafiński, 1968; Tryk, 2005.						
Annual gained	3,179	19,637	1,522	?	149	-
Annual gained from 1 km² of area	0.086	0.531	0.041	?	0.004	-
Olsztyn Voivodeship, range from 1950-1975 (area 20,994 km²). The data of gained animals on territory of Olsztyn Voivodeship, season year 1951/52. Data source: State Archive in Olsztyn. Data of Olsztyn Regional District of State Forest.						
Annual gained	428	755	1,394	7	-	-
Annual gained from 1 km² of area	0.020	0.036	0.066	0.000	-	-
Olsztyn Voivodeship within range of the 1950-1975 years (area 20,994 km²). Data of gained animals on territory of Olsztyn Voivodeship during the years: 1967, 1970, 1972, 1974. Data source: Statistical yearbooks.						
Annual minimum	970	802	2,193	0	-	-
Annual maximum	1,183	5,318	4,364	9	-	-
Annual mean	1,083	3,127	3,074	4	-	-
Average annual on 1 km² of area	0.052	0.149	0.146	0.000	-	-
Annual maximum on 1 km² of area	0.056	0.253	0.208	0.000	-	-
Olsztyn Voivodeship within range of the 1975-1998 years (area 12,327 km²). Data of gained animals on territory of Olsztyn Voivodeship during the years: 1978, 1980, 1990, 1991, 1994, 1995. Data source: Statistical yearbooks.						
Annual minimum	1,469	1,783	3,680	2	?	-
Annual maximum	4,782	14,513	8,527	123	?	-
Annual mean	3,131	7,309	5,688	61	?	-
Annual mean on 1 km² of area	0.254	0.593	0.461	0.005	?	-
Annual maximum on 1 km² of area	0.388	1.177	0.692	0.010	?	-
Warmińsko-Mazurskie Voivodeship within the range of the 1998 year (area 24,173 km²). Data of gained animals on territory of Warmińsko-Mazurskie Voivodeship during the years: 2000, 2002, 2006, 2009. Data source: Statistical yearbook.						
Annual minimum	2,804	9,788	9,190	93	0	-
Annual maximum	3,651	13,948	22,704	260	39	-
Annual mean	3,150	12,623	14,315	158	10	-
Annual mean on 1 km² of area	0.130	0.522	0.592	0.007	0.000	-
Annual maximum on 1 km² of area	0.151	0.577	0.939	0.011	0.002	-
Study area. Northern part of the 4 "Masuria" Forest districts (area 1,600 km²). Data of gained animals during the years 1993-2008. Data source: Archival data from Olsztyn Regional District of State Forest. See, Table 10.1.						
Annual minimum	302	603	296	0	-	-
Annual maximum	669	1,093	761	14	-	-
Annual mean	427	826	420	3	-	-
Annual mean on 1 km² of area	0.267	0.516	0.263	0.002	-	-
Annual maximum on 1 km² of area	0.418	0.683	0.476	0.009	-	-

from just after the World War II, and only 6.4% of the pre-war bag number. This means that at the end of the 19th century the number of red deer in Masuria was very low. Most probably, these animals concentrated solely in bigger forest complexes.

Such a situation is confirmed by the historical sources. Thus, Mager (1941), basing upon numerous reports from several authors writing from 17th to 19th century, states in his book, "Wildbahn und Jagd Altpreussens" that (...) *intensive and chaotic exploitation of forests in the period between the 16th and 18th centuries limited animal refuges and animals as such*. In 1799 the forest inspector Schenck reported to the authorities in the capital city of Königsberg that on the territory of the entire Province the red deer can be encountered in only six forest complexes. Considering the area investigated here, these animals lived there in the forests near Szczytno (*Königliche Corpellensche Forst*) and Spychowo (*Königliche Puppensche Forst*).

In the first half of the 19th century there was further decrease in the numbers of red deer in East Prussia. Forest district supervisor Guse reported that the red deer, as the permanent resident game, disappeared from the Piska Forest in the 1830s, mainly following the great forest fire of 1834, which destroyed the woodlands between Ruciane and Pisz, that were the main rutting areas of red deer.

A decrease of the numbers – already anyway quite low – of the game in East Prussia is supposed to take place, as well, following the revolution of 1848, which brought the freedom of hunting for all owners on their property. In the opinion of Friedrich Mager, the year 1848 was the worst in the history of East Prussian hunting. The consequences were such that (...) *elk have been almost entirely eradicated, red deer managed only slightly better, and the numbers of roe deer suffered essential losses, like, anyway, all of the small game*. Only from the second half of the 19th century a slow increase in the numbers of animals, mainly of roe deer was observed. This found a counterpart in the numerous governmental decrees. In 1870 the regulation was adopted establishing the closed seasons for some of the game, especially the big game, such as elk, red deer or roe deer. The subsequent hunting law for Prussia, of July 15, 1907, introduced the closed seasons for the majority of the game animals.

Against the background of the low numbers of game animals in the 18th and 19th centuries, as described in the respective sources, the bag numbers from the beginning of the 17th century (see Table 10.3) are bigger and appear to be similar to the levels observed in 1948. Yet, still, these bag numbers from 400 years ago are at least ten times lower than nowadays. This is an enormous difference, which cannot be explained only by a different way of organising hunting activities. Thus, it has to be admitted that the density of ungulate animals four centuries ago was much lower than today.

It cannot be excluded, neither, that when analysing the numbers of red deer one ought also to consider the pressure from the large predators, that is – wolf and bear. Undoubtedly, this pressure varied considerably over time. Thus, the quoted source says that in the years 1612-1618 as many as 52 bears and 215 wolves were hunted in East Prussia, this meaning the annual averages of 7.4 and 30.7, respectively. In the later times bears disappeared completely (the last one in East Prussia was shot, on the territory of the present-day forest district of Spychowo, in 1804). The population of wolves got very limited (especially after more or less the year 1890) and these predators would appear only occasionally.

They were present in particular after World War II – in the 1951/52 season, 31 wolves were shot in the Olsztyn voivodeship (which accounts for slightly more than half of East Prussia). Afterwards, due to the planned destruction of this species their numbers decreased further, but during the last twenty years a partial renewal of the population took place.

Wild boar

The changes in the numbers of wild boar hunted take a similar course as in the case of red deer. In the initial years of the 17th century the bag numbers of wild boar were similar to that of the red deer, to then decrease by the end of the 19th century also similarly to that of the red deer (or even more so). It was a consequence of the action taken by the Prussian authorities to radically minimize the number of wild boars, in view of the damage they caused in the fields.[2] Before the World War II the number of wild boars – similarly, again, to that of the red deer – increased in comparison with the situation from the end of the 19th century more than a dozen times over, but was still quite low. Immediately after the World War II the bag number of wild boar was somewhat higher (in the case of red deer a drop in the yields was observed in comparison with the pre-war numbers), and this was followed by a further increase, relatively faster than for the red deer, so that the numbers of animals hunted comparable to the current ones have been attained already during the 1970s.

Roe deer

The numbers of roe deer hunted motivate to suppose that this species either displayed large changes in numbers, or was hunted with very different intensity. Very low numbers of roe deer were hunted at the beginning of the 17th century, while the data from the second half of the 19th century show much higher numbers. The numbers are even higher – approximating those recorded nowadays – for the period just before the World War II. The data from the years immediately after the war show the low bag number of roe deer, these yields having increased after some twenty years, to reach the levels that are observed nowadays.

Fallow deer

The numbers of fallow deer hunts (absent on the area analysed at the beginning of the 17th century) were the highest in the second half of the 19th century, which was associated with the introduction of this species. It is highly probable that spatial distribution of the fallow deer was highly uneven and the animals concentrated mainly in the specially established breeding farms.

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[2] This is well reflected through the ordinance of 1832, which says, in particular, that (...) *the royal forest districts were ordered to shoot the black game in the forests at any time of the year, with no regard to sex and age, in order to bring down the numbers of these animals, so as to liquidate it completely*. Low numbers of wild boar in the second half of the 19th century are best illustrated by the wild boar hunting effects in the season 1885/86, reportedly – for the entire territory of East Prussia – only 118, of which 74 in the state-owned forests. Yet in the 1930s wild boar was a rather rare game in Prussia, as demonstrated with the observations made by the hunters in the shooting books for the hunting areas of Kudypy forest district. These observations imply that during the season of 1930/31 in the managed forest Stary Dwór 5 red deer, 39 hares and 9 foxes were hunted, but no wild boar, and similar effects were reported for the remaining managed forest.

Elk

Incomplete data on the numbers of hunted elk do not allow for more precise analyses. It cannot be excluded that the populations of this animal underwent significant fluctuations. On the one hand, elk features high mobility, and on the other hand it is a species that is relatively easily hunted, while being attractive, especially in view of large body mass.

European bison

At the beginning of the 17th century European bisons were still being hunted in East Prussia – this information is quoted here just as a curiosity, since it is certain that at that time already European bisons were really rare. They persisted until the end of the 17th century in the vicinity of Szczytno.

10.4. Summary of considerations on historical changes in the numbers and bag numbers of the ungulates

A closer look at the historical changes in the numbers of ungulates within the territory of East Prussia reveals, first of all, very high variability of these numbers in particular periods. Hence, the ungulates are among the most unstable elements of the landscape. During the periods of wars or other "restless periods" the numbers of ungulates would significantly drop. This concerned all the species, although to a different degree. Such periods can be referred to as "catastrophes". The last such catastrophe in the area considered was the World War II, and, more precisely, its final stage and the period immediately following the war. As it can be seen from the data provided in Table 10.3, the bag number, and thus – it can be deduced – also the numbers of animals, dropped very sharply for the roe deer, red deer and elk, and only in the case of wild boar the war, and perhaps first of all the depopulation just after the war, brought an increase in densities.

Important losses in the animal numbers were also registered within East Prussia in the consequence of World War I, even though that war did not bring – on the territory considered – any essential political and social transformations. In this case it was not so much poaching – which flourishes usually during all kinds of wars – that contributed to the decrease in the animal numbers, as the governmental ordinances, which raised the hunting quotas in order to produce as much game meat as possible, especially in the second stage of the war. This was linked with the common shortages of food supplies and the generally present hunger. The numbers of all game animals decreased during the period of the World War I quite significantly.[3]

There exist data showing that the earlier wars or revolutionary periods would bring the decreases in the numbers of animals, as well. A local catastrophe might be caused

[3] Thus, for instance, in Romincka Forest, the respective inventory made in 1912 contained 1638 red deers, while their number after the war dropped to 1000. The situation was similar in other forest complexes of East Prussia. The losses among the roe deer were similarly serious. It was estimated before the war that there had been approximately 31,000 roe deers in East Prussia. This level was not regained until the World War II, since just on the eve of this war the number of roe deer was estimated at roughly 21,000.

by a vast forest fire, like the one that ravaged the Pisz Forest (*Johannisburgerheide*) in 1834, encompassing the north-eastern fragment of the study area.

Between the catastrophes the numbers of ungulates would usually more or less distinctly increase, but the accompanying circumstances, were also important, like: the laws introduced and the attitude of the authorities as well as the local inhabitants towards the individual species, the manner of conducting the hunting economy, the population density, the ratio of fields and forests, the numbers of natural predators, and other ones. Some species were treated as pest and so were more or less intensively limited – as this was the case of wild boar in Prussia in the 19th century, while some other ones were artificially introduced, like fallow deer.

Having analysed the historical data from the territory of East Prussia, one can conclude that the periods of the accompanying political-social-economic stabilisation, accompanied by the not too intensive agricultural pressure on the landscapes, were advantageous for the growth of the ungulate populations. The periods of instability or of very intensive pressure from the side of farmers have been disadvantageous for this group of animals.

The historical data on the numbers of ungulates within the Kurpie part of the study area are very scarce and could not constitute any basis for an actual analysis. It is beyond doubt, though, that in the first half of the 20th century the ungulate populations living in Kurpie were very small. It is highly probable that their numbers were much higher in the times, when the proper settling of this area had not yet really started, that is – in the 17th century – but these are just suppositions, not supported by any kind of reliable evidence.

Summarising the considerations, concerning the changes in the numbers of ungulate animals within the study area, we can dare to state that such high numbers of these animals (and hence also of the bag number as the ones observed currently), have not occurred over the last 400 years, and it cannot be excluded that they have not occurred in history at all. This is especially true of red deer – the most important ungulate species, both economically, and in terms of the pressure it exerts on forest ecosystems.

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11. THE CONCEPT AND MODEL OF SUSTAINABLE FOREST DISTRIBUTION – SUFOD

Andrzej Affek

11.1. Research problem and the concept of sustainable development

The Brundtland Commission (United Nations, 1987) highlighted the importance of sustainable development as *a development that meets the needs of the present without compromising the ability of future generations to meet their own needs*. Since then, sustainable development and sustainability has become a major theoretical framework for spatial planning, including management of natural environment and its ecosystems.

The key issue of sustainability policy is to maintain human well-being from generation to generation. Materials for good life, health and security are necessary to lead a satisfactory existence. Human well-being is affected by changes in the composition and functioning of ecosystems and the resultant flow of ecosystem services (ES) (MEA, 2005b). "Ecosystem service" is a generic term that has arisen to describe the relationship that exists whenever a natural resource or process is expressed in terms of the benefits it provides for humans (EUSTAFOR & Patterson, 2011). Among the many ES definitions that can be found in the literature, we followed the one first proposed by TEEB saying that ES are the contributions that ecosystems (i.e. living systems) make to human well-being (TEEB, 2010). The most recent European classification of ecosystem services (CICES 5.1) destingiushes three major ES sections and defines them as follows (Haines-Young & Potschin, 2018, p. 10):

- provisioning services – all nutritional, non-nutritional material and energetic outputs from living systems,
- regulating services – all the ways in which living organisms can mediate or moderate the ambient environment that affects human health, safety or comfort,
- cultural services – all the non-material, and normally non-rival and non-consumptive, outputs of ecosystems that affect physical and mental states of people.

In this understanding ES are *conceptually different from goods and benefits because the things considered as services are still part of the ecosystem that generates them. For the benefit to be realised some transformation by human action or perspective that lies outside that ecosystem is needed* (Haines-Young & Potschin, 2018, p. 12).

There are important issues of both efficiency and equity of access to ecosystem services. In the past few decades the global loss and degradation of natural areas, sometimes with catastrophic results, have highlighted human reliance on the healthy operation of whole ecosystems. The potential supply of an ecosystem service is not necessarily equal to what is actually used. The reasons for this include changes in demand in relation to the other options available to people, the technology available for the exploitation of ecosystem services, the level of knowledge and individual preferences, and restricted access to the service (Affek & Kowalska, 2017; MEA, 2005a). The ecosystems that provide services are sometimes referred to as "natural capital" – a kind of a stock that yields a flow of services over time (Costanza & Daly, 1992), or more explicitly – as "ecosystem capital" (European Commission, 2013). In order for the nature-derived benefits to be realised, natural capital must be combined with other forms of capital that require human intervention to build and maintain. These include (Costanza et al., 1997):

- built or manufactured capital,
- human capital,
- social or cultural capital.

These four general types of capital are all required in complex combinations to produce any and all human benefits.

In this chapter, due to the clearly defined framework of this book and research project, only issues related to forest ecosystem services and their contribution to sustainable development will be discussed. Forest ecosystems are a major source of highly valued services, and also very important contributors to wider processes around fresh water, the atmosphere and global temperature. In the most general approach, forest ecosystem services can be divided into broader and finer scale services (Table 11.1). Services provided by forests cover a wide range of ecological, political, economic, social and cultural considerations and processes. This diversity means that there are no easy management solutions, and management is not a technical, mechanical process but one that must necessarily incorporate a variety of competing interest groups and views. The importance of a particular service varies according to the perceptions and needs of the beneficiary, the scale and the regional context.

In 1993, The Ministerial Conference on the Protection of Forests in Europe (MCPFE) defined Sustainable Forest Management as *the stewardship and use of forests and forest lands in such a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfill, now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems* (EUSTAFOR & Patterson, 2011, p. 5). The crucial part of managing the forest is to define the adequate spatial distribution of forest cover in the region, so as to *meet the needs of the present generation without compromising the ability of future generations to meet their own needs*. To determine the optimal forest distribution and to assess the size of forest distribution discrepancies in a given settlement network and natural conditions, the concept and model of Sustainable Forest Distribution (SuFoD) is introduced.

11.2. The concept of Sustainable Forest Distribution (SuFoD concept)

The idea of sustainable forest distribution (SuFoD) is located conceptually and logically in the paradigm of sustainable development. It is close to the German concept of sustainable forest management, which underlies the modern understanding of forest sustainability. The concept of ecosystem services, particularly forest ecosystem services and its worldwide growing recognition was the major inspiration in developing SuFoD.

Table 11.1. Forest ecosystem services

<table>
<tr><th></th><th></th><th>Costanza et al. (1997)</th><th>Nasi et al. (2002)</th><th>MEA
(2005b)</th><th>TEEB
(2010)</th><th>EUSTAFOR (2011)</th><th>CICES
(2018)</th></tr>
<tr><td rowspan="2">Finer scale services</td><td>provisioning</td><td>Food production
Water supply
Raw materials
Genetic resources</td><td>Non-wood forest products (NWFPs)
Timber
Fuelwood</td><td>Food
Fresh water
Timber and fiber
Fuelwood
Genetic resources
Biochemicals</td><td>Food
Water
Raw materials
Genetic resources
Medicinal resources</td><td>Forest products /
Biomass</td><td>Biomass (plant, animal) for nutrition, materials and energy</td></tr>
<tr><td>cultural</td><td>Recreation
Cultural</td><td>Tourism
Amenity values
Cultural values</td><td>Aesthetic
Recreation & Ecotourism
Educational
Inspirational
Spiritual & Religious
Sense of place
Cultural heritage</td><td>Aesthetic
Recreation & tourism/ Ecotourism, Wilderness (remote-non-use)
Educational
Spiritual & artistic inspiration
Cultural heritage and identity</td><td>Quality of life services</td><td>Physical and experiential, intellectual and representative, spiritual, symbolic and other interactions with natural environment
Other biotic characteristics that have a non-use value</td></tr>
<tr><td rowspan="2">Broader scale services</td><td>regulating</td><td>Gas regulation
Climate regulation
Disturbance regulation
Water regulation
Waste treatment
Erosion control
Pollination
Biological control</td><td rowspan="2">Water quality and quantity
Carbon storages
Climate regulation
Pollination
Seed dispersal
Natural pest control</td><td>Climate regulation
Water regulation
Water purification
Disease regulation
Pollination</td><td>Air quality regulation
Climate regulation
Moderation of extreme events
Regulation of water flows/ Hydrological regimes
Water purification/ detoxification, waste treatment/pollution control
Erosion prevention
Pollination
Biological control</td><td>Climate mitigation
Water quality
Protective services</td><td rowspan="2">Mediation of wastes, toxic substances and nuisances of anthropogenic origin
Regulation of baseline flows and extreme events
Lifecycle maintenance, habitat and gene pool protection
Pest and disease control
Water conditions
Regulation of soil quality
Atmospheric composition and conditions</td></tr>
<tr><td>habitat/ support</td><td>Habitat/ refugia
Nutrient cycling
Soil formation</td><td>Primary production
Nutrient cycling
Soil formation</td><td>Biodiversity & Nursery service
Gene pool protection/ endangered species protection
Nutrient cycling
Soil formation /conservation</td><td>Biodiversity & habitat</td></tr>
</table>

Source: own elaboration based on: Costanza et al. (1997), EUSTAFOR and Patterson (2011), Haines-Young and Potschin (2018), MEA (2005b), Nasi et al. (2002), TEEB (2010).

Sustainable Forest Distribution is such a spatial distribution of forest cover (size of forest area and spatial pattern) in a given settlement network and natural conditions that supports sustainable development and well-being of local communities. Sustainably distributed forests provide optimal access to forest ecosystem services in optimal amount. In this case, optimal access and amount means that every other (access or amount) would violate sustainability and limit human well-being.

In the SuFoD concept, as in the whole idea of sustainable development, the anthropocentric perspective was adopted that places human being and its needs, welfare, and above all survival, as the primary objective that determines the shape of surrounding environment. In this concept it is assumed that the forest distribution is secondary to the existing settlement network. The structure of the existing settlement network is assumed to be the best spatial organisation of a given number of farms in a particular geographical and natural environment in a given historical moment. In other words, decision about the location of the farm or its abandonment should be considered as an activity that optimises human well-being and is consistent with the idea of sustainable development.

The dependence of forest distribution on the shape of settlement network implements the demand of the necessary coexistence of various types of capital (beside natural) in order to benefit from forest ecosystem functions.

The SuFoD concept can be easily generalised to every type of land cover that is consistent with the potential natural vegetation of the habitat. It means, for example that sustainable steppe vegetation distribution or sustainable tundra (vegetation) distribution may also be considered. The sustainable distribution of vegetation consistent with potential natural vegetation is the most general approach.

11.3. Research questions

The main objective of this paper is to answer two research questions:

- How has forest spatial distribution changed over time and how much it differs from sustainable distribution?
- What differences can be observed in the spatial distribution of forests between Kurpie and Masuria?

To answer these research questions, the model based on the SuFoD concept was developed, along with the forest distribution sustainability indicators.

11.4. The model of Sustainable Forest Distribution (SuFoD model) – operationalisation of the SuFoD concept

The SuFoD model describes in a simplified manner the spatial distribution of forests in the given settlement network. To assess the level of forest distribution sustainability a reference model of forest distribution was developed with sustainability measures (indicators). This is a first release of the SuFoD model and it is still a development version. Its application in this project has a pilot character and aims to verify the correctness of the proposed operationalisation.

The construction of the model is simple. The advantage of this solution is the easy interpretation of the results, the applicability in various scales and areas of research, giving ample room for comparability of the results. If necessary, the model can be easily expanded.

This model is applicable at the local and regional scale, but not at the global scale. It does not take into account the complex relationships in international timber trade, national deficits or surpluses of timber, etc. It is particularly applicable to the analysis of changes in the forest distribution sustainability in the historical perspective, when the man was more closely related to land, and the world was not a global village.

11.5. Assumptions of the model construction

In order to answer the first research question, that is, to what extent forest distribution differs from the sustainable forest distribution, a referenced model of distribution has to be developed. Such a distribution would in 100% correspond to sustainable forest distribution, since it is assumed that for every shape of the settlement network such forest distribution exists that is sustainable. According to the SuFoD concept, sustainable forest distribution is the one that provides optimal access to ecosystem services. As it is known, some forest ecosystem services can be delivered simultaneously from the same system or landscape without mutual interference, while others are partly or fully antagonistic (MEA, 2005a). It is also important to recognise that a minimum level of ecosystem "infrastructure" is necessary in order to allow production of the range of services (Costanza et al., 1997). This "infrastructure" can be destroyed as a result of the intensive exploitation of ecosystems. It is also clear that in order to benefit from some of the ecosystem services, particularly finer scale services (provisioning and cultural ES, see the division in Table 11.1), direct physical access to the ecosystem is required. On the contrary, to take advantage of regulating services, it is enough for the forest to be located somewhere in the broader area.

On this basis it was decided to divide the entire space into two categories in such a way that forests within the first area would be intended primarily for delivery of finer scale services (provisioning and cultural ES), while forests within the second area would be intended primarily for delivery of broader scale services (regulating ES). In this model, the division into two areas is based on the existing shape of settlement network, assuming that, in general, forest intended primarily for delivery of finer scale services should be closer to human dwellings. Similarly, forests intended primarily for broader scale services should be located further from human dwellings, thus less penetrated and less exposed to the destruction of ecosystem "infrastructure". For simplicity, further in the text the first area will be referred to as Human Direct Impact Area, the second area will be referred to as Maternal Area (by association with Mother Nature). Forests growing in the Human Direct Impact Area will be called exploitable forests, those growing in the Maternal Area – backwoods.

Next issue to be solved is to determine the share of forest cover in each area that would correspond to sustainable distribution. Maternal Area, by definition, is outside Human Direct Impact Area, and is potentially free from agricultural or industrial development.

It is assumed that the following side effects of human activity have lower intensity there: noise, air and water pollution, the amount of waste, loss of biodiversity, etc. Backwoods should be composed of old-growth forests consistent with the habitat, where large mammals can hide, more demanding species of flora and fauna survive. It is also assumed that the sustainable land use in Maternal Area should correspond to the potential of the habitat. In another words, vegetation should by consistent with potential vegetation. In the case of the analysed study area, the only type of potential vegetation is forest. Thus, forest communities consistent with the potential vegetation deliver maximum amount of regulating services. Therefore, it is assumed that backwoods intended primarily for broader scale services should cover 100% of terrestrial Maternal Area in the SuFoD model. The share of backwoods in the Maternal Area serves as a first indicator of SuFoD model (SFD1). The greater the share, the closer the given forest distribution to sustainable distribution.

Determination of the optimal share of exploitable forest in the Human Direct Impact Area seems to be a bit more difficult. The area of exploitable forest should be large enough, so that the amount of provisioning and cultural services corresponds to the sustainable demand of local population. This area also should not, on the other hand, excessively restrict the amount of services provided by other non-forest ecosystems and limit welfare derived from agriculture and industry. Balance between exploitable forest cover and the rest of the Human Direct Impact Area should be maintained in such a shape that the sustainability requirements could be met and the joint benefit derived from ecosystem services and human activity maximised. The optimal percentage of forest cover in the Human Direct Impact Area is difficult to estimate and depends largely on the nature of the study area, development level of the community and many other characteristics. There is no doubt that the optimal value (or range of values) should be at some distance from the extreme values of 0% and 100%, since both extreme values definitely limit human well-being. Zero natural capital implies zero human welfare, because it is not feasible to substitute, in total, purely "non-natural" capital for natural capital (Costanza et al., 1997).

For the Masuria-Kurpie borderland – an agricultural lowland with temperate climate, the range 10-50% is assumed to be the optimal forest cover of the Human Direct Impact Area. This range is calculated on the basis of empirical modelling and simulation, assisted by scarce reports from the literature (e.g. the average share of private forests on farms according to the Central Statistical Office). Lower values would not guarantee a sufficient amount of services of finer scale to lead a satisfactory existence. Values above 50% would highly restrict the possibility of creating capital any other than natural. Higher percentage of forest cover would violate the assumption of the SuFoD concept that beside natural capital there are other forms of capital necessary in order to benefit from ecosystem services. The percentage of forest cover in the Human Direct Impact Area was indirectly used to construct second indicator of the SuFoD model (SFD2).

The method of delimitation of the Human Direct Impact Area is a matter of investigator's choice. It will depend on the scale of analysis, the characteristics of the area, the history of settlement and many other parameters. In the pilot study on the Masuria-Kurpie borderland, to determine the Human Direct Impact Area, a relatively coarse and simple measure was used. It was decided to follow this path, because in addition to measuring the level of sustainability of the current forest distribution, it was planned to explore the historical forest distribution in six time slices, dating back to 1800. Due to the limited amount of information available on the history of land use, a simple circular buffering around settlement centres was applied. The buffer area corresponded to the number of farms in the village multiplied by the arbitrarily adopted optimal farm area of 1 łan (17 ha). It was assumed that such land area can ensure well-being of the farmer family. In fact, it was accepted as sufficient for one family at the time of granting land to settlers in medieval times. In the SuFoD model this area was maintained for all time slices, since it was assumed that the increase in yield per hectare, farming development and overall labour productivity growth corresponds to the increase of quality of life, maintaining which requires proportionally greater supply of ES.

The SFD2 indicator shows, by definition, the share of farmers in the region having optimal access to exploitable forest. Farmers that have optimal access to exploitable forest live in settlements, around which the Human Direct Impact Area is forested in 10 to 50%. If in the region 100% farmers had optimal access to exploitable forest, exploitable forest would be sustainably distributed.

The part of the study area left after deducting of Human Direct Impact Area is a good approximation of the size of Maternal Area. Due to the sharp angles and irregular edges of polygons formed after deducting of circular shapes of Human Direct Impact Area, polygon outlines has been smoothed to better match the natural boundaries. The method of Polynomial Approximation with Exponential Kernel (PEAK) was applied with the Smoothing Tolerance Parameter equal to 3000 m (tool available in the ArcGIS for Desktop Standard software).

11.6. Source data and processing

To calculate the proposed indicators of sustainable forest distribution, the following data were needed for each time slice:

- map of forest cover,
- map of settlement network,
- number of farms in each settlement.

Data on forest cover and settlement network was obtained from contemporary and historical topographic maps (Table 11.2). Also, source data used to calculate the number of farms in each locality was in the majority read from the maps (Table 1.3). Only for Masuria in the 1930s maps did not contain adequate statistics. Instead, detailed data on population was obtained from the website https://treemagic.org/rademacher/www.verwaltungsgeschichte.de/ of historian M. Rademacher that provides detailed demographic data for the German Reich in 1871-1945.

To obtain information on the number of farms in each settlement in each time slice, it was necessary to make some transformations and extrapolations of the source data. Usually, data sets regarding number of residential buildings or number of inhabitants per settlement were available. These datasets were transformed using the following algorithms:

- all residential buildings in regular villages were considered as households making use of fruits of the earth, further referred to as farmers' houses,

- 2/3 of residential buildings in villages that were seats of municipalities were considered as farmers' houses,
- half of the residential buildings in regular towns were considered as farmers' houses,
- there are 5 (7 before World War II) persons per household in villages, 8 in regular towns and 10 in district towns.

Table 11.2. Data sources on forest cover and settlement network

Source	Scale	Measurement date
Karte von Ost-Preussen nebst Preussisch Litthauen und West-Preussen nebst dem Netzdistrict	1:150 000	1800
Topographische Karte vom Preussischen Staate unter Einschluss der Anhaltinischen und Thüringischen Länder	1:100 000	1870
Novaya Topograficheskaya Karta Zapadnoy Rossii	1:84 000	1885
Messtischblätter	1:25 000	1928
Topographic map of Poland (Datum: "Borowa Góra")	1:100 000	1950
Topographic map of Poland (Datum: PL-1965)	1:50 000	1970
VMap Level 2 (spatial data set)	1:50 000	2000

Table 11.3. Data sources on the number of farms in each settlement

Source	Scale	Measurement date
Karte von den Provinzen Litthauen, Ost- und West-Preussen u. d. Netz-Distrikte	1:50 000	1800
Novaya Topograficheskaya Karta Zapadnoy Rossii	1:84 000	1885
https://treemagic.org/rademacher/www.verwaltungsgeschichte.de/ (original source: Statistics of the German Reich)	–	1933
Tactical Map of Poland	1:100 000	1930
Topographic map of Poland (Datum: "Borowa Góra")	1:100 000	1950
Topographic map of Poland (Datum: PL-1965)	1:25 000	1970
Topographic map of Poland (Datum: PL-1992)	1:50 000	2000

For Masuria in 1885 and Kurpie in 2000 data were not complete and required interpolation. The interpolation of number of farms for Kurpie in 2000 was conducted on the basis of 28% of settlements, for which data were available. Linear interpolation was chosen, giving the best fit value ($R^2 = 0.9$). For settlements up to 100 farms the equation was Farm2000 = Farm1970 × 0.89 + 4, for settlements above 100 farms: Farm2000 = Farm1970 × 1.13 – 18.

The linear interpolation of number of farms for Masuria in 1885 did not give satisfying fit. Therefore, a simple empirical calculation was adopted. For settlements up to 100 farms the equation was Farm1880 = Farm1800 × 1.25, for settlements above 100 farms: Farm1880 = Farm1800 × 1.75. The sample accounts for 26% of all Masuria settlements. There were no data available for Kurpie at the beginning of the 19^{th} century.

The Millennium Ecosystem Assessment (MEA, 2005c) proposed a list of criteria for effective ecological indicators. They can be also applied to measure the level of sustainability. An effective ecological indicator, according to MEA (2005c), should, *inter alia*:
- provide information about changes in important processes,
- be sensitive enough to detect important changes but not so sensitive that signals are masked by natural variability,
- be able to detect changes at the appropriate temporal and spatial scale without being overwhelmed by variability,
- be based on logical and well-understood models of the system to which it is applied,
- be based on reliable data,
- be easily understood by policy-makers.

Indicators SFD1, SFD2 and a general combined measure of the level of total forest distribution sustainability were designed in such a way as to meet the above criteria.

11.7. Results

For each of the six time slices from the years 1800-2000 (except for the Kurpie of 1800) a model extent of Human Direct Impact Area was generated around each village / town existing in a given historical moment in the study area (Fig. 11.1). The percentage share of exploitable forest within each Human Direct Impact Area was marked indicating whether, according to the model, there was excess (≥ 50%), optimum (10-50%) or deficiency (< 10%) of forest for the sustainable development of local community. On the maps from the 1950s and 1970s a military area is marked. Without taking it into consideration, it would be difficult to interpret the sudden disappearance of several settlements in the south-west of Masuria.

The remaining area, according to the SuFoD model, was the basis for the delimitation of Maternal Area (after excluding lakes and smoothing polygons). With such a simplified method of determining the Human Direct Impact Area the distribution of Maternal Area is indicative only (Fig. 11.2). In turn, aggregated results from particular time slices for the two comparative areas (Masuria and Kurpie) bring significantly higher informative value.

Kurpie Maternal Area declined steadily from 41% in 1880 to 16% in 1970 (Fig. 11.3). The downward trend was stopped only recently. Masuria Maternal Area also decreased over the years, the exception to this rule was the World War II period, when the Maternal Area increased of more than 30%. The share of Maternal Area in Masuria in each section is much higher than in Kurpie, the greatest difference falls on the 1950s and reached 43 percentage points.

Indicators SFD1 and SFD2, calculated on the basis of aggregated data for both regions, show trends and differences in the spatial forest distribution sustainability. The share of Maternal Area under forest cover (SFD1) increased steadily throughout the study area, with the rate of growth in Masuria significantly higher than in Kurpie (Fig. 11.4). As a result, even though the initial (in 1880) level of Maternal Area forestation was similar, the difference in 2000 reached as much as 21 percentage points in favour of Masuria.

Maternal Area forest cover in both regions has always been higher than the total forest cover across all time slices (Fig. 11.5). For time slices 1970 and 2000 the percentage

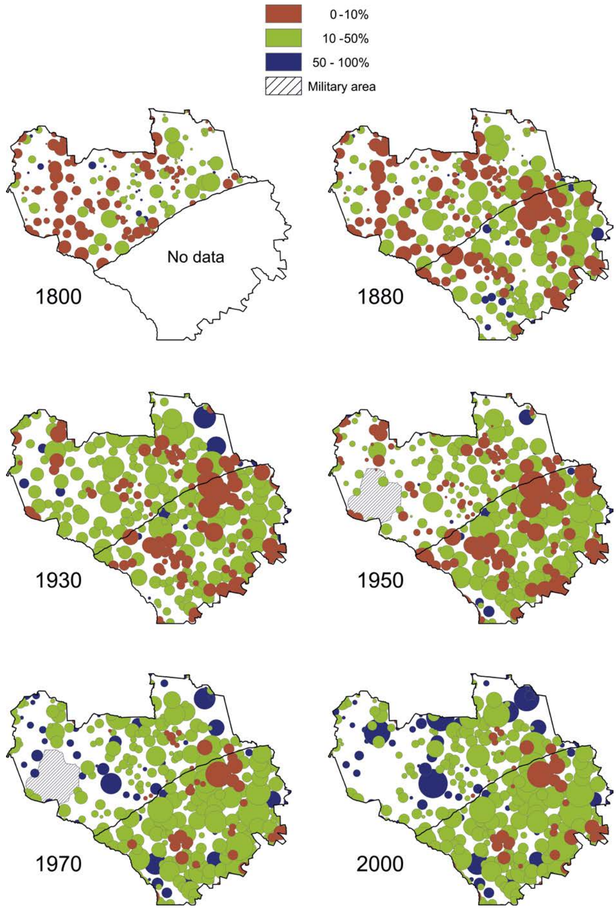

Fig. 11.1. The percentage share of exploitable forests in the Human Direct Impact Area around each settlement

of Maternal Area under forest cover in Kurpie was lower than the percentage of the whole Masuria area under forest. Pearson's correlation coefficient between total forest cover and Maternal Area forest cover is equal to 0.97 for Kurpie and 0.85 for Masuria.

According to the applied method, to determine the Direct Human Impact Area a circular buffering around settlement centres was used. Buffer was proportional to the number of farms in a given settlement. The number of farms per km^2 continues to grow throughout the whole study period. The only exception from this trend was in the World War II period in Masuria, when it decreased from 4.3 to 2.7 per km^2 (Fig. 11.6). This period in Masuria is probably the only case in the study, when the assumed sustainable development of settlement network was violated to that extent, since decisions taken by inhabitants to leave their farms did not result from their free choice. The graph representing changes in the number of farms per km^2 (Fig. 11.6) is more or less symmetric with respect to the x-axis to the graph representing changes in the Maternal Area (Fig. 11.3), which results directly from the method of Maternal Area delimitation.

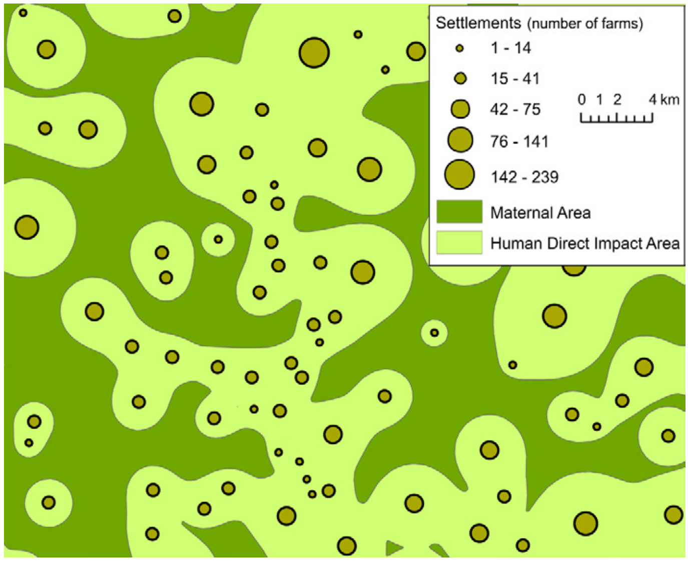

Fig. 11.2. Visualisation of the SuFoD model. The space divided into Maternal Area and Human Direct Impact Area based on existing settlement network

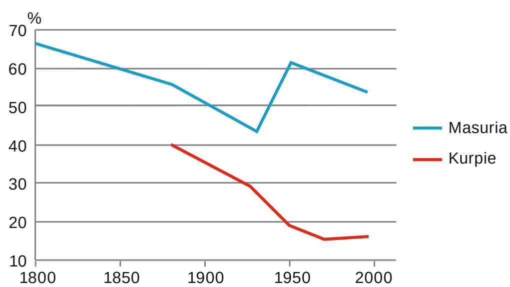

Fig. 11.3. Share of Maternal Area in the total area of each region

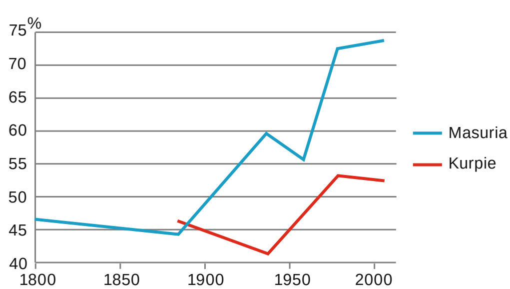

Fig. 11.4. Share of Maternal Area covered by forest (SFD1 indicator)

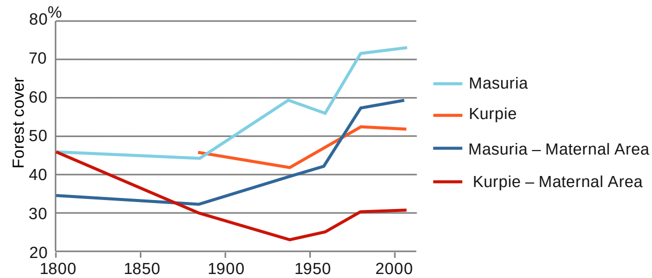

Fig. 11.5. Percent of total forest cover in comparison with Maternal Area forest cover in each region

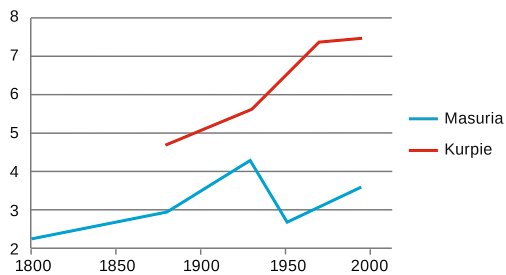

Fig. 11.6. Number of farms per km²

The area of exploitable forests in the Human Direct Impact Area per farm varies regionally and temporally (Fig. 11.7). Thus, access to exploitable forest and patterns of discrepancies from the optimal exploitable forest distribution vary considerably between regions. While temporal variation for Masuria is quite complex, for Kurpie two distinct and internally consistent periods can be distinguished: 1880-1950 and 1970-2000. In the first period, more than 40% of farmers experienced deficit of exploitable forest, whereas in the second half of the 20th century forest deficit affected only 14% of farmers.

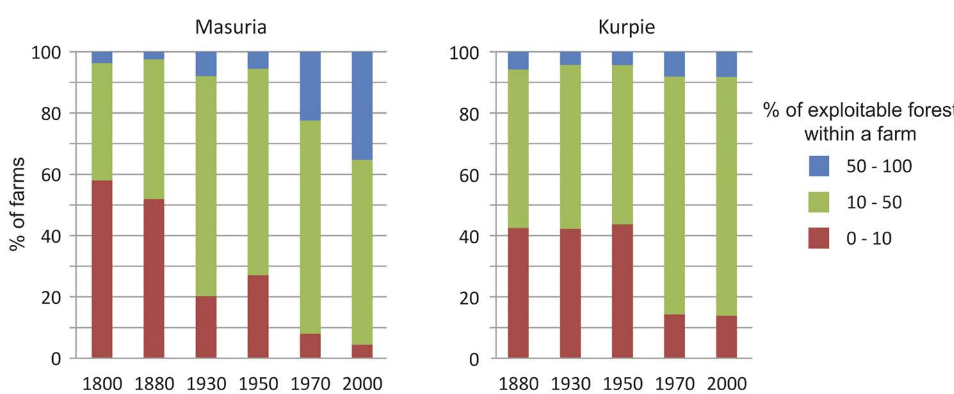

Fig. 11.7. Percent of farms having certain share of exploitable forest within their area

SFD2 indicator, defined as the percentage of farmers in the region having optimal access to the exploitable forest, reached the highest value in Masuria in 1930 (72%) and in Kurpie in 2000 (78%) (Fig. 11.8). Pearson's correlation coefficient between SFD1 and SFD2 for Kurpie is equal to 0.84, while for Masuria – 0.70.

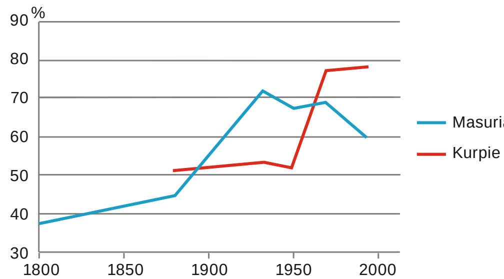

Fig. 11.8. Share of farmers having optimal access to exploitable forest (SFD2 indicator)

The arithmetic mean of SFD1 and SFD2 values served as a measure of total forest distribution sustainability (Fig. 11.9). The highest level of total forest distribution sustainability in both regions was achieved in 1970. The greatest difference in the total forest distribution sustainability between regions was recorded in 1930s and reached 18 percentage

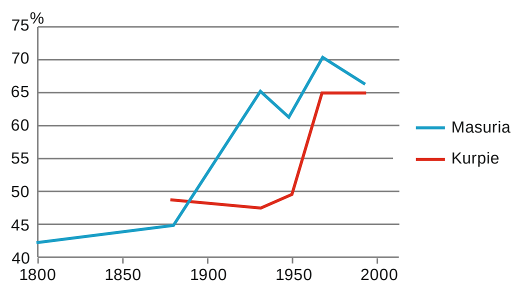

Fig. 11.9. Level of total forest distribution sustainability in Masuria and Kurpie in the 19th and 20th century expressed as a percent of theoretical optimal sustainability

Table 11.4. Comparison of forest distribution sustainability between Kurpie and Masuria in the 19th and 20th century

	Masuria		Kurpie	Masuria		Kurpie	Masuria		Kurpie
	SFD1 [%]			SFD2 [%]			Total [%]		
1800	47	-	no data	38*	-	no data	42*	-	no data
1880	45	<	46	46	<	52	45	<	49
1930	60	>>	41*	72	>>	53	66	>>	47
1950	56	>	48	67	>>	52	61	>>	50
1970	73	>>	53	70	<	78**	71**	>	65
2000	74**	>>	52	60	<<	78**	67	>	65

* the lowest value of a given measure across all time slices; ** the highest value of a given measure across all time slices

points in favour of Masuria. The comparison of the two indicators and a total measure of forest distribution sustainability is presented in Table 11.4.

11.8. Discussion and conclusions

The results and conclusions drawn on their basis give rise to generalisations and search for relationships that are explicitly unobservable.

11.8.1. Masuria

The results obtained for Masuria clearly show that in terms of sustainability and human well-being in the context of forests, there was a sudden collapse in the period 1930-1950. After years of significant improvement there was a decline that needs to be associated with rapid geopolitical changes, including the change of the nationality of the region, exchange and loss of population, the establishment of a military area, etc. Vast areas were excluded from human direct impact but remained unforested. The share of farms with forest deficiency increased, since most of the settlements that have ceased to exist, had optimal access to exploitable forest.

In turn, period 1970-2000 is a time of significant increase in forest cover, both in Maternal Area and in Human Direct Impact Area. This contributed to the increase of the SFD1 indicator value. However, forest cover within the Human Direct Impact Area around several settlements in the west and north of the region exceeded the optimal value adopted in the SuFoD model for the sustainable development of local communities. One might suppose that the local community had a reduced level of well-being due to the limited space for industrial and agricultural activities. It can be presumed, though, that the benefits derived from lacustrine ecosystems that constitute an important part of the space, can compensate for agricultural deficits. Otherwise, large population centres surrounded by forest would not have developed that well.

In contrast, Masuria in the 19th century, according to the results of the model, had far less sustained forest distribution. This directly results from the smaller forest cover, particularly from the deficiency of exploitable forest near settlements that would be easily accessible. Taking into account only the 19th century, it is clear that forest distribution at the end of the century was much more sustained than at the beginning. However, drawing conclusions should be rather cautious in this case, because some of the results may be distorted by map inhomogeneity. Older maps and maps in smaller scales simplify forest cover structure (skipping small polygons, smoothing forest edges, etc.) (see Affek, 2016).

11.8.2. Kurpie

The changes in forest distribution sustainability have different character in Kurpie, than in Masuria, but initial (1880) and final (2000) levels of sustainability are comparable. The curve illustrating changes resembles the shape of the leaned "S" letter, so called sigmoid curve. After a period of stagnation came rapid development and again stagnation. On the background of slight changes in the remaining periods the period 1950-1970 stands out, when a qualitative change in the forest distribution took place towards sustainability. This change is a result of rapid improvement of the exploitable forest accessibility (SFD2). Other measures that could affect the total value (for instance overall forest cover, Maternal Area forest cover, the number of farms, etc.), did not alter that much. The 1960s was a time of the emergence of forests near human settlements on land previously cultivated and left for pastures or wasteland. Interestingly, the decline in the share of farms with forest deficiency did not resulted in considerable increase in the share of farms with the excess of forest, as it was in Masuria. The increase in forest cover in the Human Direct Impact Area stopped on values adopted as optimal (10-50%). Although the share of farms with excess forest in 1950-1970 has doubled, it did not exceed 8% of all the farms.

11.8.3. Limitations of inference

The process of deriving logical conclusions from premises underlying the concept and model of SuFoD has certain limitations related to the construction of SuFoD and to the quality of source data and processing. The links of the chain of inference that are most vulnerable are:

- high generalisation of Human Direct Impact Area delimitation,
- arbitrarily adopted share of forest cover in the Human Direct Impact Area considered as optimal,
- heterogeneous source materials (e.g. maps of various scales and accuracy),
- data processing based mostly on generalised, empirical algorithms.

Nonetheless, maintaining simple construction and high level of generalisation of the SuFoD model was a deliberate action intended to ease comparability of results and allow long-term historical analysis.

To enhance the strength of scientific inference in future research it is necessary to assess construct and content validity[1] of the SuFoD model. To conduct a reliable validity assessment there should be an external source of information on forest distribution sustainability that may serve as reference data. For now on, there is no such source available. The solution possible to apply in the future is to carry out research based on interviews with local inhabitants about their perception of forest distribution. This may help solve the issue of SuFoD validity.

11.9. Summary

The analysis of long-term changes in forest distribution sustainability reveals some similarities between Masuria and Kurpie. These similarities are particularly evident, when one imagines shifting for a few decades one of the sigmoid curves representing dynamics of forest distribution sustainability (Fig. 11.10). The only major departure from the sigmoid

[1] Validity of an assessment is the degree to which it measures what it is supposed to measure. Construct validity refers to the extent to which operationalisation of a construct (e.g. practical tests developed from a theory) do actually measure what the theory says they do. Content validity refers to the degree to which the content of the model matches a content domain associated with the construct.

curve pattern applies to the World War II period in Masuria, associated with the replacement and displacement of the population. The rapid sustainability growth distinctive for Masuria in the period 1880-1930 can be observed in Kurpie in the period 1950-1970. Phase shift in the path of development may reach half of a century in favour of Masuria, depending on when exactly the core growth in Masuria took place (rather before or rather after World War I).

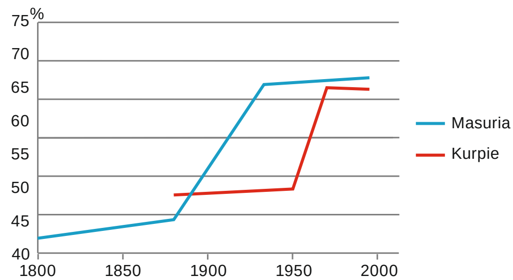

Fig. 11.10. Sigmoid patterns representing change in forest distribution sustainability in Masuria and Kurpie in the 19th and 20th century

Close similarity between patterns of change suggests that there is a common direction, leading to improvement of human well-being and poverty reduction of local communities. The differences in the patterns of change resulting from the shift in time of the corresponding processes reveal the size of inequalities in the civilisation development between regions. This inequality was most apparent in the interwar period (reaching 18 percentage points), when regions still had a distinct national affiliation. The second half of the 20th century was the time of unification in terms of level of forest distribution sustainability. This resulted in an almost complete equalisation of the level of sustainability between regions at the end of the analysed period in the year 2000.

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12. FOREST ECOSYSTEMS AND RURAL COMMUNITIES – COMPONENTS AND INDICATORS OF SUSTAINABLE DEVELOPMENT

Jan Marek Matuszkiewicz, Jerzy Solon, Anna Kowalska

12.1. Sustainable development – definitions and principles

The classic definition of sustainable development provided by World Commission of Environment and Development (so called G.H. Brundtland Commission), established in 1983, says that it is *development that meets the needs of the present without compromising the ability of future generations to meet their own needs* (WCED, 1987). Later, this definition was expanded and reformulated more than once focusing on various aspects: maintenance of environmental values, economic development, and social welfare. Reviews of several concepts and their descriptions can be found in numerous publications (see Mebratu, 1998; Pakulska & Poniatowska-Jaksch, 2015).

In the documents of the United Nations, the idea of sustainable development is defined as *a development that meets the basic needs of all human beings and which conserve, protect and restore the health and integrity of the Earth's ecosystem, without compromising the ability of future generations to meet their own needs and without going over the limits of long term capacity of the Earth`s ecosystem*.

In Poland, the principles of sustainable development are written in the article 5 of the Polish Constitution. In the Environmental Protection Law (2001), sustainable development is defined as *socio-economical development which integrates political, economical and social activities with the maintenance of nature equilibrium and persistence of basic natural processes to guarantee the ability to meet basic needs of communities and inhabitants respective to present and future generations*.

Sustainable development (SD), called sometimes eco-development, was determined by 27 rules adopted at the World Summit in Rio de Janeiro (so-called *Rio Declaration*). There are some of them, important for further analysis:

Rule 1. Human beings are in the spotlight of SD process, they have the right to a healthy and creative life in harmony of nature.

Rule 4. To achieve SD, environmental protection should be an integral part of the development process and cannot be considered separately.

Rule 22. Indigenous people, their communities and other local communities play a significant role in environment and development management because of their knowledge and tradition.

Rule 24. Warfare is inherent in SD destroying.

SD assumes interaction of three basic components: society, natural environment and economy. Interactions between society and natural environment should be acceptable (tolerable), between society and economy – fair, between natural environment and economy – feasible. In this study, we concentrate on two SD components only: society and natural environment, analysing social and environmental indicators. This approach is called a socio-ecological analysis.

Looking on SD in regard to the relationship between the society and natural environment, the main problems concern:

- excessive use of natural resources and environment devastation including deforestation,
- decline in biodiversity,
- adverse global climate changes.

Therefore, the objectives of SD are: biodiversity protection at the levels of: landscape, ecosystem, species and gene, maintenance of basic ecological processes and systems which are life refuges, persistant use of ecosystems and species.

Problems of SD are considered at the global (as in international documents), national, regional or local level. In this publication, the area of interest covers parts of two geographical regions: Masuria and Kurpie (see Chapter 1).

12.2. Components of sustainable development and their indicators

12.2.1. The analysed elements of sustainable development

General reflections on SD served as a base for the analysis of the local relationship between natural environment and society limited to some aspects.

Natural environment

This component was limited to the degree of forest cover in the landscape. It was considered in regard to the accepted model of sustainable landscape with defined forest cover thresholds for habitat types, spatial structure of forest complexes and their proper fauna inventory. A great significance of forests in natural environment causes that they best reflect historical, landscape changes. Deforested areas (except lakes) were regarded as strongly modified and subjected to greater human pressure. To simplify, we ignored an issue of forest deformation which causes that deforested semi-natural habitats (wetlands, grasslands) might be more valuable than strongly deformed forests. They should be included and valorised in more detailed research.

As SD should consider human needs (**rule 1**), in the studied rural communities the most important are deforestation and agricultural land use. However, agricultural potential of habitats is various that is why uneven habitat deforestation is socio-economically justified.

Simultaneously, it was adopted that biodiversity demands forest maintenance and landscape cohesion in at least a part of each habitat. These guidelines were used to determine thresholds of forest cover in the sustainable landscape (Chapter 6). Implementation of sustainable landscape is necessary for SD. The standards of sustainable landscape are minimal conditions which have to be fulfilled to accept that natural component is well preserved and needs of local community satisfied (**rule 22**).

Obviously, these standards would be different for an area of other leading function. For instance, nature protection would demand higher minimal limits of forest cover in several habitats. The thresholds of forest cover were presented in Chapter 6, but it should be stressed that they refer to the specific, local socio-ecological system (**rule 4**) and might not have an universal character.

In forest ecosystem – phytocenosis formed by trees and other plants, the significant role is played by animals, fungi and other organisms. Their richness as well as flora richness comprise for the biodiversity determined at different organization levels e.g. ecosystem and landscape. The availability of long-term data limited analysis of fauna biodiversity to large game species – ungulates e.g. red deer, roe deer, elk, wild boar and fallow deer (Chapters 9 and 10). The present data of these species abundance are quite detailed because they concern specific forest districts which cover the whole study area. The data from first decades after the World War II had to be converted because they concern different (usually larger) spatial units. The earlier data (before the World War II) were derived from data corresponding to big administrative units or other inaccurate information sources. The old data compared with present detailed information allowed to create a relative measure of past game species abundance. Characteristics of the only big predator – a wolf were derived in a similar way. Data on other animal species were so random that they were not suitable for analysis.

Therefore, the component "environment" was characterised by "the cover of forest and its big inhabitants".

Society

This component was characterised using data of the local residents living in rural areas. Urban inhabitants were ignored in our case since towns were situated outside the study area. In majority, rural residents of the study area live from agriculture. A part of them work in forestry, administration, services and other sectors outside the study area or are retired. However, the dominance of farmers causes that the local community can be described as "rural and agricultural community" which needs deforested agricultural space to live and work. It was adopted that the study area can be divided into deforested land (open landscape) used directly by the rural community and afforested land used indirectly or in a limited way. This division is contractual since forests are used for both non-agricultural activities (forestry, use of firewood, undergrowth and game) as well in the past (nowadays only incidentally) was used as woodland pastures for livestock animals. The deforested land is also partially used for non-agricultural purposes.

Livestock animals were also included in the analysis since they are often the base of farmers' existence. Due to data accessibility livestock was limited to a few ungulate species e.g. horses, cattle (cows), pigs, sheep and goats together.

The "society" component comprised of the local residents (mainly farmers) and their livestock animals.

12.2.2. Characteristics of the indicators used

Indicators of the environment component used in the study:
- general forest cover determined with topographical maps,
- forest cover in habitat types characterised with percentage share of afforested area or with indicator of habitat exploitation,
- degree of landscape modification characterised with indicator of landscape unsustainability,
- homogeneity of forest complex structure,
- population status of five big forest mammal species: four herbivore ungulates (red deer, roe deer, elk and wild boar) and one predator (wolf),
- amount of biomass collected by livestock treated as food competitors of wild animals.

Indicators of the society component based on statistical data and their compilation:
- population density of rural residents – number of people per unit area: a) the whole study area, b) only deforested area (without lakes),
- number of farms per unit area as above a) the whole study area, b) only deforested area (without lakes),
- number of residents per one farm,
- number of particular livestock animals species and number of big animals per area unit and per one farm,
- ratio of human population size to cattle number,
- amount of biomass collected by wild animals treated as food competitors of livestock animals.

All indicators are presented in Table 12.1.

12.3. Indicators of "environment" change

12.3.1. Forest cover in the regions

The changes in the forest cover in 1800-2000 were analysed in detail in Chapter 6. They differ completely between the studied regions divided with the state border (Fig. 12.1). In Masuria, a low forest cover (35%) at the beginning of 19th century, further decreased slightly in the middle of the century (32%) and then started constantly increasing. The biggest increase was noticed in 1950-1970 after the change of Masuria state affiliation. After 1970 this increase was rather marginal and the forest cover reached 60%. In Kurpie, higher forest cover at the beginning of 19th century (46%) decreased significantly to 23% in the first decades of 20th century. Since then it has been increasing slowly (30% in 1970).

Changes in the forest cover in both regions are quite distinct: in Masuria the forest cover has increased within 200 years, in Kurpie it has decreased. Nowadays, the forest cover in Masuria is twice as high as in Kurpie. Nevertheless, there are some similarities between the regions: relatively stable forest cover level at the beginning of 19th century and at the end of 20th century. Moreover, in last decades, the forest cover in both regions has become stable or increased slightly.

Table 12.1. Indicators of "environment" and "society" components – data sources, methods of calculation and meaning description

Indicators	Data sources and their characteristics (substantial, spatial and temporal)	Data transformation	Figure with data
Indicators of "environment" component			
Forest cover – positive indicator of "environment" component; high values indicate a good state of environment, low values a poor state; one of the basic valorisation assumptions.	Topographic maps of the studied regions from seven time periods between 1800 and 2000 (see Chapters 2, 3, 5, Table 5.1).	Source maps were transformed using GIS technique to determine forest range ("forest – non-forest"). Forest cover (%) in two studied regions was calculated (Chapters 3 and 5); theoretical range: 1-100%, recorded range: 23.3-59.3%.	Fig. 12.1
Forest cover in various habitat types – positive indicator of "environment" component; high values indicate a good state of environment, low values a poor state; with regard to all or only the most widespread habitats.	Topographic maps – forest range in seven time periods; own data – map of present potential natural vegetation (see Chapter 6).	Forest cover in various habitat types in seven time periods was determined after intersection of forests maps (Chapter 3) with the map of potential natural vegetation (Chapter 4); theoretical range: 1-100%, recorded range in division of five widespread habitat types: 2.7-99.6%.	Fig. 12.2
Indicators of habitat exploitation – based on adopted minimal forest cover in habitat types; positive indicator of "environment" component; the higher values the better state of environment; excessive agricultural exploitation causes negative values.	Own data and derivatives – forest cover of habitat types in seven time periods.	Index value was calculated as a difference between actual forest cover and a norm for sustainable landscape for habitat type in % (see Chapter 6, Fig. 6.39); theoretical range: -100-400%, recorded range: -93.0-104.6%; the most important for the analysis are negative values.	Fig. 12.3 and 12.4
Indicator of landscape unsustainability – based on a set of habitat exploitation indicators; positive indicator of "environment" component; the higher values the better state of environment	Own data and derivatives – habitat exploitation indexes in seven time periods and spatial share of habitats in the regions (acc. to map of potential natural vegetation).	Index was calculated as a sum of 12 negative habitat exploitation indexes valorised by the spatial share of these habitats in the regions; theoretical range: -100-0%, recorded range: -63.6-0.6%.	Fig. 12.5
Nearest neighbour distance metrics – mean distance from a forest patch to the nearest neighbour forest patch; negative indicator of "environment" component; the higher values the worse state of environment	Topographic maps – forest range in seven time periods (see Chapter 7).	Calculated in ArcGIS environment on digital maps of forests in seven time periods, with the help of PatchAnalyst extension; theoretical range: 0-∞, recorded range: 99.9-470.2 m.	Fig. 12.6
Biggest patch metrics – mean area of 50 the biggest forest patches; positive indicator of "environment" component; the higher values the better state of environment	Topographic maps – forest range in seven time periods (see Chapter 7).	Calculated in ArcGIS environment on digital maps of forests in seven time periods, with the help of PatchAnalyst extension; theoretical range: 0 – (whole area/50), recorded range: 742-5300 ha.	Fig. 12.7
Population size of four wild ungulates: red deer, roe deer, elk, wild boar; positive indicactors of "environmental" component; wild ungulates populations are a significant part of forest ecosystems and indicators of their functioning; population size is determined with population density.	Data from various sources that were transformed and modelled (Chapters 9 and 10). Partly, they concern wild animal population size in the area and others game statistics; data from 1993-2009 refer exactly to the study area, older data had to be recalculated to it; the most recent data are annual, previous data are episodic; more data of previous periods were gathered for Masuria than Kurpie. Basic data were recalculated to unit area (animals km^{-2}) of the regions and modelled. Numerical data were complemented with descriptive data from the literature.	Population size was estimated using ten-degree scale (expert evaluation) and then compared with forest cover in seven time periods (1800-2000).	Fig. 12.8 and 12.9
Population size of wolf; positive indicator of "environment" component; the higher values the better state of environment.	Descripive data that allowed to estimate population size; scarce data on game; mostly from Masuria region.	Population size was estimated using ten-degree scale (expert evaluation) in seven time periods (1800-2000).	Fig. 12.8 and 12.9
Mean population size of five wild forest animals; based on five foregoing indicators; positive indicator of "environment" component; the higher values the better state of environment.	Own data and derivatives – received numbers of five animal species population size.	Arithmetic average of population size of red deer, roe deer, elk, wild boar and wolf estimated using ten-degree scale (expert evaluation) in seven time periods (1800-2000).	Fig. 12.8 and 12.9
Pressure of livestock animals treated as food competitors of wild animals and reducers of vegetation cover; negative indicator of "environment" component.	Own data and derivatives – livestock (horses, cattle, pigs, sheep) density and data on their daily requirement on plant biomass; in Masuria data were available from 1864, in Kurpie from 1883; they were rarely correlated in time with forest cover data.	Indicator values calculated as a product of "big animals" density to daily cattle requirements on plant biomass; theoretical range: 0-∞, recorded range: 58-1311 t km^{-2} year^{-1}; some data had to be extrapolated.	Fig. 12.20
Pressure of cattle treated as main food competitors of wild animals and reducers of vegetation cover; negative indicator of "environment" component.	Own data and derivatives – cattle density and data on their daily requirement on plant biomass; in Masuria data were available from 1864, in Kurpie from 1883; they were rarely correlated in time with forest cover data.	Indicator values calculated as a product of cattle density to daily cattle requirements on plant biomass; theoretical range: 0-∞, recorded range: 18-860 t km^{-2} year^{-1}; some data had to be extrapolated.	Fig. 12.20
Pressure of sheep treated as main food competitors of wild animals grazing in forests and reducers of vegetation cover; negative indicator of "environment" component.	Own data and derivatives – sheep density and data on their daily requirement on plant biomass; in Masuria data were available from 1864, in Kurpie from 1883; they were rarely synchronized with forest cover data.	Indicator values calculated as a product of sheep density to daily sheep requirements on plant biomass; theoretical range: 0-∞, recorded range: 0.5-123 t km^{-2} year^{-1}; some data had to be extrapolated.	Fig. 12.21
Indicators of "society" component			
Human population density – basic measure of human population, its size, condition and area possession; only rural residents were included; positive indicator of "society" component.	Data from statistical yearbooks and other sources with different spatial range in different time periods. The most recent data (from 1950s) refer to five communes in Ostrołęka county (Kurpie): Baranowo, Kadzidło, Łyse, Myszyniec, Rozogi and five communes in Szczytno county (Masuria): Jedwabno, Pasym, Szczytno, Świętajno, Wielbark; their spatial range corresponds to the study area. Data from 1913-1950 refer to Szczytno and Ostrołęka counties in their past range. Data from 19th century refer to larger administrative units. Some estimated data were also included.	The most recent population size data was adopted directly for the region. Older data were recalculated from larger spatial units to the region area. Some data were not synchronized in the regions so they had to be partialy estimated and interpolated for selected time periods (1800-2010); theoretical range: 0-∞, recorded range: 13.3-43.3 inhabitants km^{-2}.	Fig. 12.11
Human population density in open landscape – basic measure of population density in deforested part of the area (used in agriculture).	Own data and derivatives – data on population density (see above) and forest cover in seven time periods.	Data on population density were recalculated to open landscape area in seven time periods; theoretical range: 0-∞, recorded range: 17.6-57.9 inhabitants km^{-2}.	Fig. 12.11
Farm density – positive indicator of "society" component; rural population is strongly associated with farms which number indicates society welfare.	Topographic maps of the studied regions from 1800 to 2000; six periods in Masuria and five in Kurpie (see Chapter 11).	Farms number was recalculated to the region area; theoretical range: 0-∞, recorded range: 2.3-7.6 farms km^{-2}.	Fig. 12.12
Farm density in open landscape – positive indicator of "society" component; farm density should be mainly refered to area used in agriculture – deforested part of landscape.	Own data and derivatives – data on farm density (see above) and forest cover between 1880 and 1995.	Farms number was recalculated to open landscape area; theoretical range: 0-∞, recorded range: 3.7-11.0 farms km^{-2} of open landscape area.	Fig. 12.12
Livestock animal density: cattle, horses, pigs, sheep – positive indicators of "society" component because rural communities welfare depends strongly on farming animals; it is visible in the studied regions where animal farming dominates due to habitat limitations. Each species demands different treatment and shows different dynamics.	Data from statistical yearbooks and other sources with different spatial range in different time periods. Masuria's data: the most detailed from 1976-1991 for 5 communes: Jedwabno, Pasym, Szczytno, Świętajno, Wielbark; 1936-1973 and 2002 for Szczytno county, 1993-1997 for olsztyńskie voivodeship, 1864-1913 for East Prussia. Kurpie's data: the most detailed from from 1975-1995 for 5 communes: Baranowo, Kadzidło, Łyse, Myszyniec, Rozogi, 1907-1960 and 2002 for Ostrołęka county, 1965 for warszawskie voivodeship, 1883-1907 for Polish Kingdom.	The data on livestock population size in five communes were directly recalculated to the region area. Other data were recalculated from larger spatial units to the region area. Some data were not synchronized in the regions so they had to be partially estimated and interpolated for selected time periods; theoretical range: 0-∞, recorded ranges: horses – 0.9-13.6, cattle – 0.9-45.3, sheep – 0.2-51.8 and pigs – 0.4- 58.8 animals km^{-2}. Livestock density can be calculated for open landscape as well.	Fig. 12.14 and 12.15
Big animals' density – synthetic indicator of livestock population size, positive indicator of "society" component.	Own and original data on animal species density (see above).	Data on livestock population size were recalculated according to the formula: "Big animal" = horses × 1.2 + 50% cattle × 1 + 50% cattle × 0.6 + pigs × 0.2 + sheep × 0.09; theoretical range: 0-∞, recorded range: 17.6-57.9 "big animals" km^{-2}. Some data had to be extrapolated for selected time periods.	Fig. 12.16
Cattle number per one inhabitant – positive indicator of "society" component showing its wealth; nowadays and in the past a big part of local agriculture focuses on cattle farming.	Own and original data on human population density and cattle density.	Cattle number was recalculated to the human population density in the region. Some data had to be extrapolated for selected time periods. In Masuria, data concerned the period 1864-2002, in Kurpie 1883-2002; theoretical range: 0-∞, recorded range: 0.07-1.40 animals inhabitant^{-1}.	Fig. 12.18
Big animals' number per one farm –positive indicator of "society" component showing a wealth level of average farm.	Own data and derivatives on all livestock density and farm density (see above).	The ratio of livestock population size determined as "big animals" population size to farms number was calculated for 1880, 1930, 1950, 1970 and 1995; theoretical range: 0-∞, recorded range: 1.4-11.8 "big animal" farm^{-1}; cattle 0.7-7.4 animal farm^{-1}.	Fig. 12.19
Pressure of wild animals treated as food competitors of livestock animals; negative indicator of "society" component.	Own and original data on wild animal species density between 1993-2009 (see above) and earlier data derived from models and estimations.	Index was calculated as a product of wild animal (red deer, roe deer, elk, wild boar) density to their daily requirements on plant biomass; theoretical range: 0-∞, recorded range: 0.2-12.3 t km^{-2} year^{-1}; some data had to be extrapolated.	Fig. 12.10

Generally, the degree of forest cover in Masuria is adequate for landscape sustainability, on contrary, in Kurpie, it is too low in comparison to its historical state and the neighbouring area.

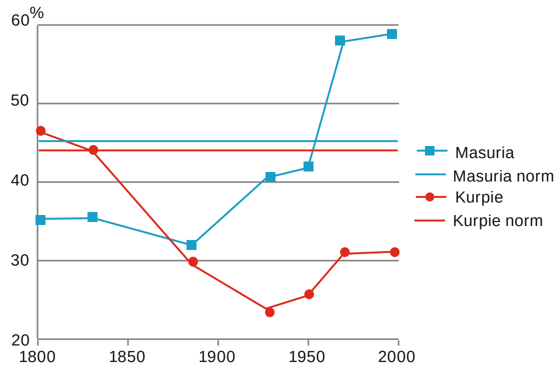

Fig. 12.1. Forest cover in Masuria and Kurpie between 1800-2000. The actual forest cover in different periods and the forest cover level that meets the standards of sustainable landscape

12.3.2. Selective deforestation of habitats – indicator of excessive habitat exploitation

The deforestation rate in various habitat types is a very important indicator. Habitat types were identified with potential natural vegetation – Fig. 12.2 (five the most widespread types).

The deforestation degree in various habitats was different during the studied period and in the studied regions. In Masuria, at the beginning of 19th century, the diversity of forest cover in five the most important habitat types was low (26-45%); in Kurpie four habitat types differ even less (36-49%), only in oligotrophic *Peucedano-Pinetum* the forest cover was higher. In the middle of 19th century, the forest cover in the studied habitats was diversified: in oligotrophic habitats of *Peucedano-Pinetum* the forest cover increased, in eutrophic habitats of *Fraxino-Alnetum*, *Tilio-Carpinetum,* on contrary, it decreased. In mezotrophic habitats of *Ribeso-Alnetum*, *Querco roboris-Pinetum* the forest cover was similar to the mean value for the study area.

In the second half of 20th century, the forest cover changed with the trophic gradient.

In Masuria two habitat groups were observed: pine and mixed oak-pine forest habitats with the forest cover 85-98% and remaining three habitat types with the forest cover reaching 19-49%.

In Kurpie, three groups were noticed: pine forest habitats with high forest cover (94%), mesotrophic habitats of alder carrs and mixed oak-pine forests afforested in 40-44%, eutrophic lime-oak-hornbeam forests and alluvial forests nearly completely deforested (4-5%).

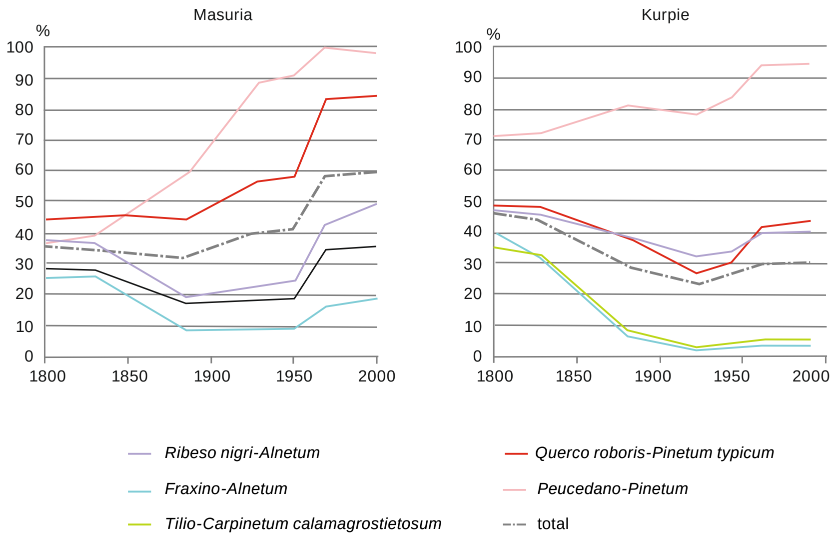

Fig. 12.2. Changes in forest cover in the most widespread habitat types

The degree of deforestation in various habitat types was considered as a basic repercussion of human pressure on the landscape. The thresholds of minimal forest cover in various habitat types for sustainable landscape were adopted (Chapter 6). For alluvial forest and moist and rich lime-oak-hornbeam forest habitats, valuable for agricultural use, the forest cover was established at 20%. For oligotrophic habitats, useless in agriculture, the forest cover was established at 98%.

The forest cover thresholds in various habitat types: *Fraxino-Alnetum* – 20%, *Tilio-Carpinetum stachyetosum* – 20%, *Tilio-Carpinetum typicum* – 20%, *Tilio-Carpinetum calamagrostietosum* – 30%, *Querco roboris-Pinetum typicum* – 50%, *Ribeso nigri-Alnetum* – 50%, *Querco roboris-Pinetum molinietosum* – 66%, *Sphagno squarrosi-Alnetum* – 66%, *Molinio-Pinetum* – 75%, *Querco-Piceetum* – 80%, *Vaccinio uliginosi-Pinetum* – 80%, *Peucedano-Pinetum* – 98%.

Achieving these thresholds, taking into account the present spatial share of the habitats (Chapter 4), would result in the cover reaching 44.9% in Masuria and 44.0% in Kurpie (Fig. 12.1). These values correspond to the forest cover at the beginning of 19th century in Kurpie, and are higher than the forest cover in this period in Masuria and the present cover in Kurpie but lower than the present value in Masuria.

The deviation from the adopted thresholds was described as **indicator of habitat exploitation** calculated as:

$$\mathbf{WE = Zs - Ns / Ns\ 100\%}$$

where

Zs – is forest cover in the habitat type,

Ns – the minimal accepted value of the forest cover in this habitat type.

This indicator shows a deforestation level higher than the standard deforestation value so the most important are results with negative sign (Fig.12.3 and 12.4).

In Masuria, in the period 1800-1830 the forest cover level was optimal or only slightly lower in most habitat types (Fig. 12.3). Only, widespread pine forest *Peucedano-Pinetum* habitats were excessively deforested. In 1830-1885 moist eutrophic habitats were severely deforested. This process was continued until the World War II. In the same time, the forest cover in oligotrophic pine and mixed oak-pine forest habitats increased. It means that in the middle of 19th century agricultural pressure concentrated on moist habitats. It was probably associated with drainage works carried out to make wetlands available to use. As a consequence, poor sandy habitats, previously used in agriculture could be afforested.

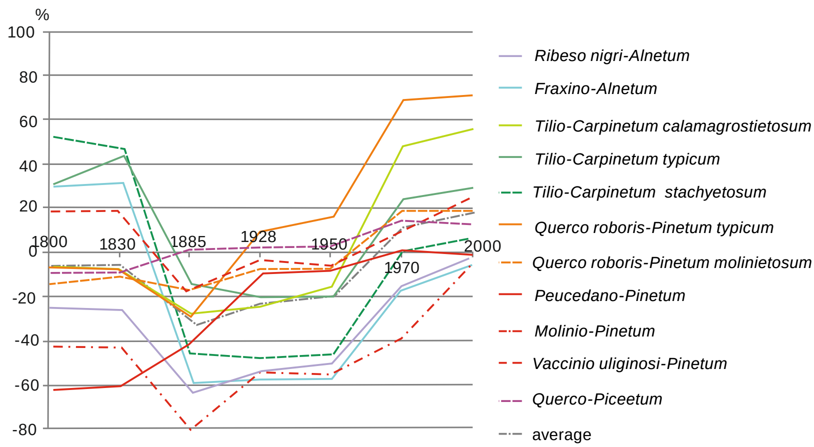

Fig. 12.3. Indicator of habitat exploitation in Masuria in 19th and 20th centuries (difference between the forest cover and the adopted standard value in %). Rare habitats were ignored

In the period 1885-1950, the deforestation level was stable and the forest cover increased only in oligotrophic habitats. The biggest change succeeded after the World War II (1950-1970) most habitats, even those very valuable for agricultural use were intensively afforested. It was associated with demographic and socio-political changes after changes in the state affiliation and socio-economic system as well as with population movements. During the last three decades of 20th century the forest cover in different habitat types was stable or increased slightly.

In Masuria, there were three stable periods and two periods of a deep change. First stable period (1800-1830) demonstrates landscape partially unsustainable (in case of oligotrophic habitats), the second (1885-1950) with unsustainable landscape regarding eutrophic habitats and sustainable oligotrophic habitats, the third (1970-2000) almost completely sustainable landscape concerning the forest cover at the end of 20th century.

In Kurpie, the period 1800-1830 was rather stable, with some exceptions in case of oligotrophic habitats (Fig. 12.4). Between 1830 and 1885 most eutrophic habitats were deforested. It was continued until the second half of 20th century when their forest cover slightly increased. Similarly to Masuria, it was associated with wetlands' drainage and river regulations. Oligotrophic habitats were slowly afforested. The landscape was strongly unsustainable regarding eutrophic habitats and moderately unsustainable regarding mesotrophic habitats. This status, only with small improvement persisted until 2000. As before, eutrophic habitats are over-exploited in agriculture.

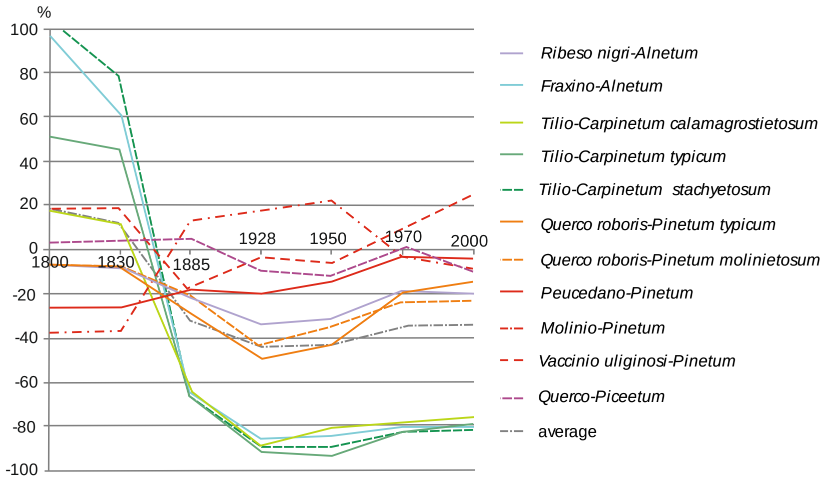

Fig. 12.4. Indicator of habitat exploitation in Kurpie in 19th and 20th centuries (difference between the forest cover and the adopted standard value in %). Rare habitats were ignored

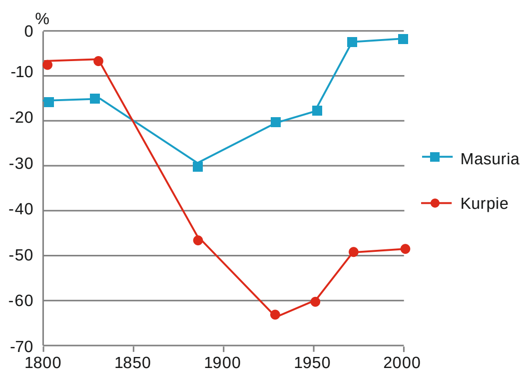

Fig. 12.5. Changes in indicator of landscape unsustainability in terms of habitat forest cover. This indicator was calculated as a sum of the all habitat exploitation indicators with negative values valorized by the share of these habitats in the region

Analysisng general changes in habitat deforestation in both regions **indicator of landscape unsustainability in terms of forest cover** was used. This indicator was calculated as a sum of the all habitat exploitation indicators with negative values valorized by the share of these habitats in the region (Fig. 12.5). In both regions, at the beginning of 19th century moderate landscape unsustainability was observed. In Kurpie this indicator was higher. In the middle of 19th century, both regions experienced a deep change associated with selective deforestation of moist eutrophic habitats and lower pressure on oligotrophic habitats.

In Kurpie this process worsened until the first decades of 20th century. Then the status ameliorated but the landscape is still unsustainable in most habitat types. In Masuria the landscape status had got better with some fluctuations since the end of 19th century. In 2000 its status met the standards of sustainable landscape.

12.3.3. Degree of landscape sustainability in regard to the spatial structure of forest cover

Analysis of spatial structure of forest cover within 200 years (Chapter 7) provided two metrics of change: mean distance of a forest patch to the nearest neighbouring forest patch and mean area of 50 the largest forest patches.

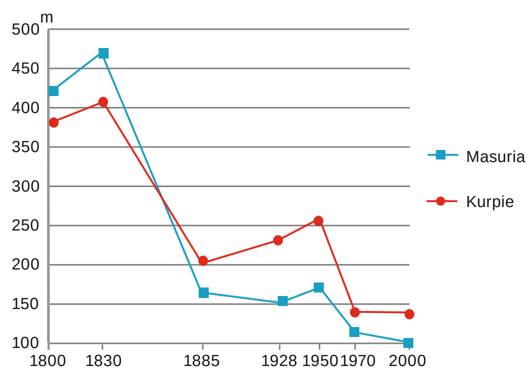

Fig. 12.6. Forest structure – the "distance to the nearest neighbour" (m)

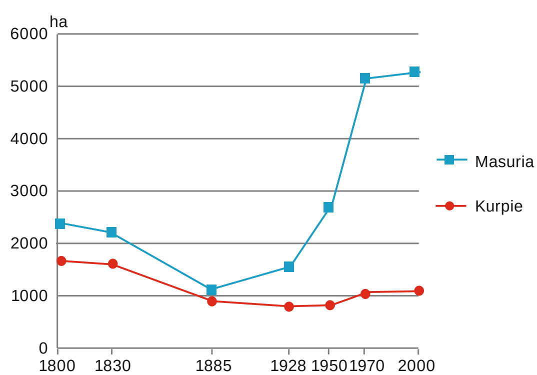

Fig. 12.7. Forest structure – the mean area of 50 the biggest forest patches (ha)

Changes in the "distance to the nearest neighbour" metric was presented in Fig. 12.6. In both regions the similar trend was observed. The highest values were noted in 1800-1830. This can be explained by a lower accuracy of topographical maps from the first half of 19th century in comparison to the later maps (Chapter 2). They cannot be treated equally. Since the second half of the 19th century the indicator values decreased. It indicated better migration possibilities for forest species in the landscape. However, the detailed analysis showed some differences between the regions. In Masuria, the forest complex consolidation was rather uniform. In Kurpie, for 100 years the forest complex fragmentation had dominated. The reverse process started only in the second half of 20th century. Although the trends were similar for both regions, their reasons were different. In Masuria, the forest consolidation was caused by the expansion of forest patches, whereas in Kurpie, it was caused by the fragmentation of big forest complexes and the appearance of new, small patches.

Changes in the "mean area of 50 the biggest patches" metric were presented in Fig. 12.7. It shows the concentration of forest complexes. In the period 1800-1885 the mean area of 50 the biggest patches decreased from 2400 to 1080 ha in Masuria and from 1670 to 884 ha in Kurpie. It indicates the domination of fragmentation processes. However, in Masuria the indicator value has increased since the second half of 19th century. It reached 5170 ha in 1970 and 5300 ha in 2000. As a result, its present value is twice as high as 200 years ago. This is beneficial for forest species demanding compact forest complexes. At that time in Kurpie, the indicator value had been slightly fluctuating until 1950 and then increased to 1080 ha in 1970 and 2000, but generally, it decreased during 200 years. The habitat conditions of forest species might have got worse.

12.3.4. Assessment of changes in the population density and the pressure of big wild animals

To assess forests as a landscape element we need to know the abundance and the condition of their inhabitants – forest animals. The detailed analysis of ungulates abundance was described in Chapters 9 and 10 (detailed data were available for 1993-2009, less precise data for earlier periods). It was really difficult to compare the data of animals populations with the analysis of the forest cover structure but it finally allowed to valorise particular periods of the 200-years-history in the study area by the population size of the selected species (red deer, roe deer, elk, wild boar, and wolf). The assessment criteria were developed on the basis of current detailed dataset. Historical data, in part random and inaccurate, served for the indication of the probable population size in the ten-degree-scale. Its historical distribution was presented in Figs. 12.8 and 12.9.

In Masuria, the first half of the 19th century was unfavorable for all ungulates. It was caused by Napoleonic Wars, social changes, the attitude of authorities toward some species e.g. wild boar was exterminated in some periods. Nevertheless, the historical sources say that that period was characterised by the high density of wolves (although this may raise doubts considering their food base). The Spring of Nations in the mid-19th century seems to be the worst period for forest animals.

From the second half of the 19th century until the World War I, the ungulate (especially roe deer and not presenting on the figure introduced fallow deer) population had been increasing. This trend was stopped during the World War I but was continued afterwards. The wolf did not appear in this period in the region.

The World War II and the period afterwards brought significant changes in wild animal population in Masuria. Populations of roe deer and red deer were strongly limited, elk became almost extinct, while the wild boar population increased. Wolves appeared again.

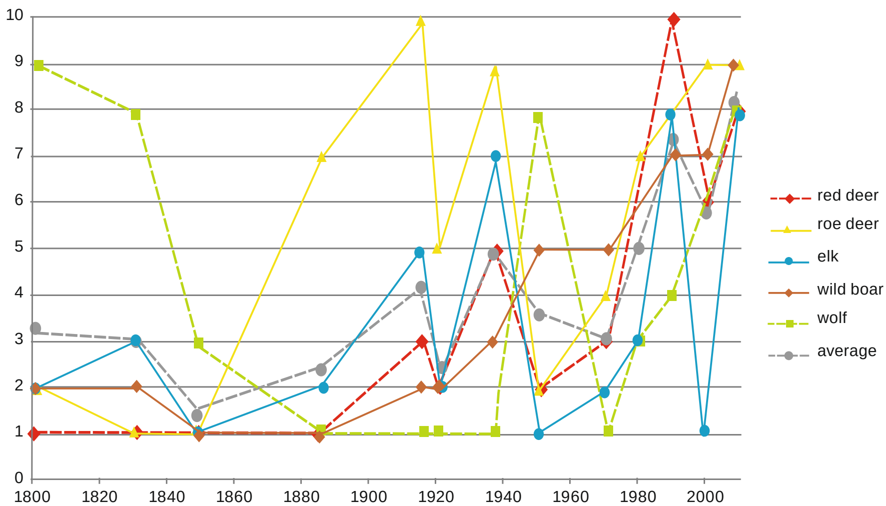

Fig. 12.8. The population size of five wild animal species in Masuria within 200 years

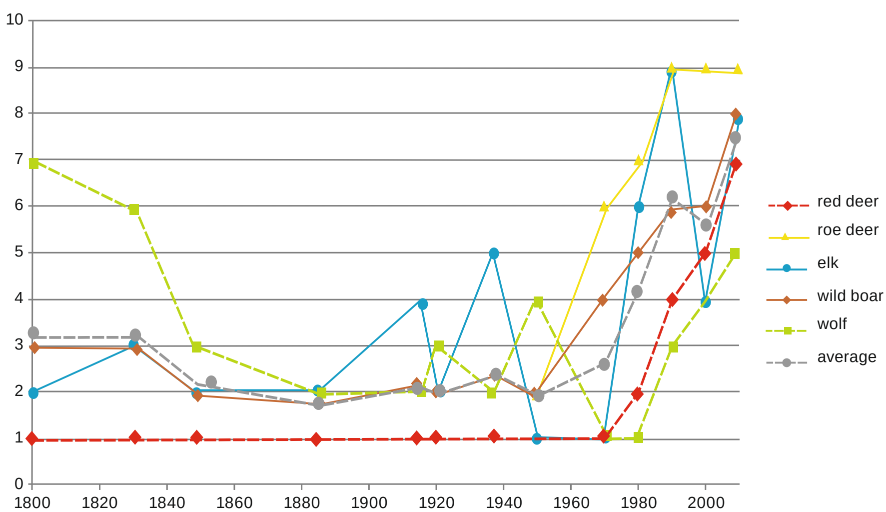

Fig. 12.9. The population size of five wild animal species in Kurpie within 200 years

From the beginning of 1950s and 1970s until the end of 1980s (although not synchronously), the increase in all species population was observed. It was fallowed by a short-term decrease in elk and red deer population at the end of 1990s. Their populations regenerated after 2000. In the last decade of the study period, the number of wolves has increased significantly. In four Masurian forest districts, their population in March 2009 was estimated at 57 individuals.

To conclude, the best period for five analysed forest mammals falled on modern times. For some species the turn of 19th and 20th centuries and 1980s were also quite good. The war time was the least favorable.

The assesment of forest animal population in Kurpie is even more disputable than in Masuria. Modern times (since 1970s)[1] seem to be the most favorable period. The return of elk, red deer and wolf were the most important events, while also the increase in two remaining species density. Earlier, wild animals were rather scarse in Kurpie.

The wild animal pressure on the area is a derivative of their population size. Fig. 12.10 presents supposed past and present pressure of wild ungulate animals. In both regions, this pressure is much higher nowadays than it was in the past. It results from the present biggest forest animal population within the 200 studied years.

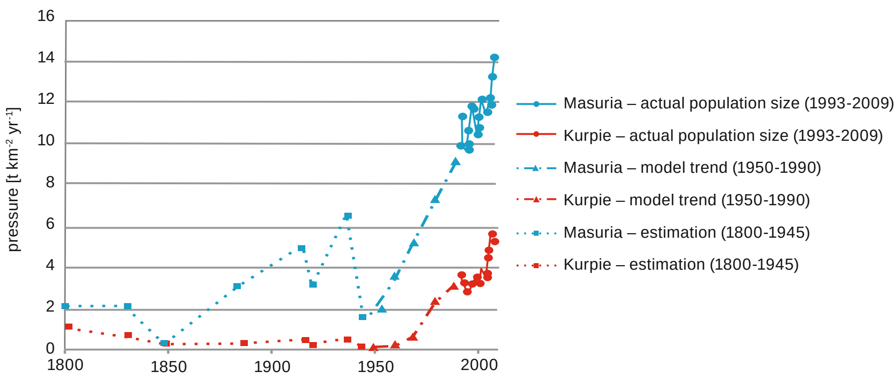

Fig. 12.10. Changes in the wild ungulate animal pressure based on detailed data, models and the assesment of population size

12.4. Indicators of changes in "society" component

12.4.1. Population density in the studied area

Deforestation is undoubtedly executed by people. On the other hand, human welfare determines sustainable development. Human influence is characterised by the population size or more precisely the population density. We analysed the population density in two studied regions and its changes within 200 years. Unfortunately, data on population density was not easily accessible. The main problem concerned a different spatial range of the datasets from different periods.

The data on population density presented in Fig. 12.11, were set together from various data sources and recalculated to adapt them to the studied regions. They concern the population of 5 communes in Masuria and Kurpie, excluding the population of towns. The population density was calculated for the whole study area and for the deforested area (without lakes).

The population density in Masuria was increasing during the whole 19th century, till its last decades. It doubled up between 1818 and 1890. The next 50 years were more stable (till 1939). The increase in population density reached only 5%. The severe decrease

[1] The number of wolves in two Kurpie forest districts was estimated in March 2009 at 8.

took place during the World War II and directly afterwards. In 1950, the population density reached 40% of the value from 1939. During next 15 years, the population density increased by 34%, but its value was still much lower than before the war. After that, it decreased very slightly again and this trend persisted until 2009. Concluding, in Masuria, two stable periods were observed: 1890-1939 and 1975-2009; while the World War II brought very distinct and persistent changes.

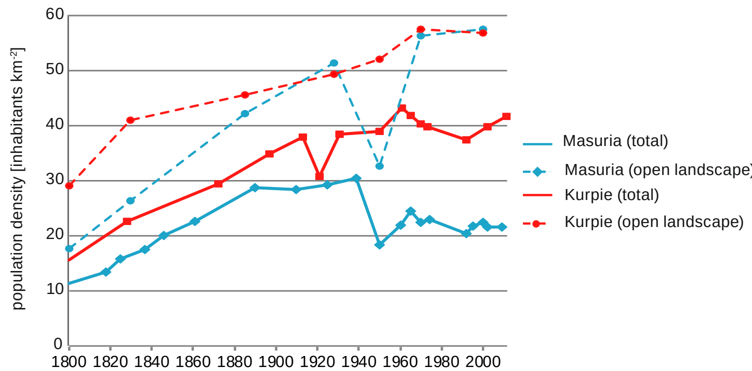

Fig. 12.11. Rural population density in the studied area

In Kurpie the increase in population density by 69% was noticed during the whole 19th century. The World War I caused a short-term decrease by 20%. After the war, the population density increased again to the previous level and it persisted until 1950. The World War II did not have the significant influence on the population density in Kurpie. After the war it was changing slightly in both directions. It is difficult to indicate any stable period in population density in Kurpie, unless the period from 1931 till the present time can be referred as quite stable with minor fluctuations (in 2011 the population density was only 7% higher than in 1931; maximal density in 1961 was 12% higher, while minimal density in 1992 was only 3% lower).

Comparing both regions, the direction of population changes was similar in 19th century and after the World War II, but in Kurpie the population density was twice as high. In the first half of 20th century the population changes proceeded differently.

Regarding problems analysed in the study, the population density in a part of the study area that was deforested (without lakes) was more important. This approach resulted in smaller differences between the regions (Fig. 12.11). We could still observed in Masuria depopulation effect after the World War II but the increase in forest cover caused that in 1970 the population density of the deforested area came close to the value observed in Kurpie. At present, the population density is similar in both regions (55-57 inhabitants km^{-2} in 2000). Interestingly, the similar state though lower values were noticed at the beginning of 20th century. It seems that the present population density in the deforested area can be accepted as a level of stabilization.

12.4.2. Density of rural settlements

Rural settlements described in Chapter 11 show the similar variability to that of rural population size. The farm density in Kurpie (Fig. 12.12) was increasing till 1970s and then stabilized. In Masuria, the increase in farm density was suddenly stopped by the World War II but started to rise afterwards. At present, the farm density in reference to the whole area is twice as high in Kurpie as in Masuria.

However, the results are different if we analyse the farm density in open landscape (without forests and lakes) – Fig. 12.12. At the end of 19th century, the farm density in deforested area was lower in Masuria than in Kurpie and equalized just before the World War II. After the war, the farm density was quickly increasing till 1970s and then slowed down in Kurpie. The S-shaped curve that describes those changes suggests that it has reached the satisfactory threshold.

The situation was different in Masuria. The World War II and its consequences caused a great decrease in the farm density but the return to previous state was quite fast and the rise was observed till 2000. However, the maximal density was not noted. This state was mainly achieved by the decrease in deforested area not by a higher farm number. Present afforestation will cause a further increase in farm density and the growing similarity of both regions.

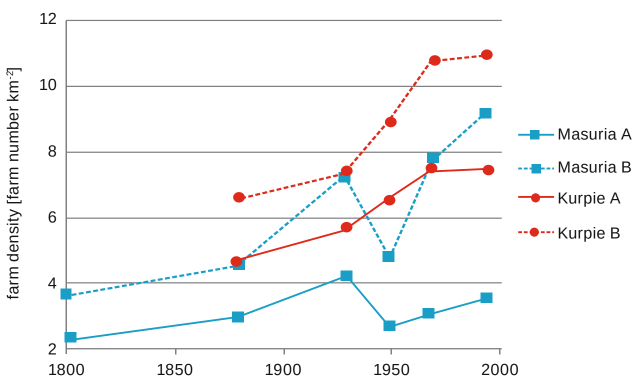

Fig. 12.12. The farm density in Masuria and Kurpie regarding the whole study area (A) and the deforested part, without lakes (B)

The course of change in farm density of deforested area was more similar in both regions than regarding the whole study area.

Comparing the population density and the farm density we can conclude:

- The increase in population density ongoing through 19th and most of 20th centuries slowed down at the end of 20th century. In Kurpie, it has reached its threshold. In Masuria, this process was highly disturbed by the World War II but it seems that now the population density value is close to its optimum.
- The regions dissimilarity from 19th century disappeared just before the World War II, but was intensified by the war and started to decline in the last decades.

The compensation of rural population density is associated with changes in the population size, the number of farms as well as changes in the forest cover.

It is probable that the current value of population density (55-60 inhabitants km^{-2} of deforested area) is close to maximum for the present landscape structure and level of productive forces.

The ratio of rural population size to a farm number constitutes the measure of changes in life standard and social structures (Fig. 12.13). The decrease in the ratio was observed at the end of the 19th century. Moreover, in Kurpie its values were lower. This is reflected in the old farm buildings size and architecture different in both regions.

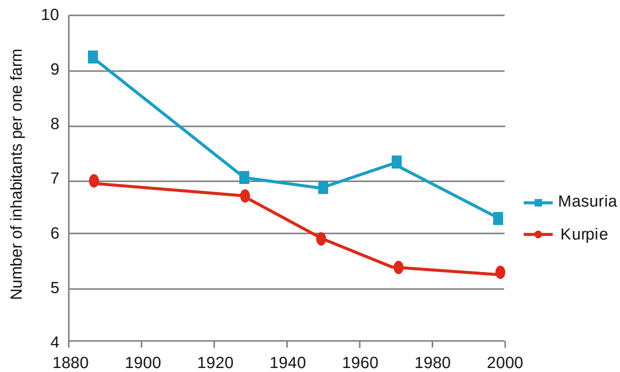

Fig. 12.13. Number of residents per farm in the regions

The data on the residents' number per farm indicated a decrease in the population density. During 120 years a mean number of residents per farm decreased by 25% in Kurpie and 33% in Masuria. It was higher in Masuria where big farms, not owned by one family only (estates and state farms after the war) dominated. These data are difficult to interpret regarding the social welfare. The present values, especially in Kurpie, show a stable community comprised of not too big families. Taking the mean value, farms are neither overpopulated nor depopulated and this state is positive. Therefore, the data from 19th century might indicate that farms were overpopulated, at least from today's perspective. The big differences between regions were noticed at the end of 19th century and after the World War II while the population sizes were similar between the wars and in modern times.

12.4.3. Density of livestock animals and their pressure on the environment

Human pressure on landscape depends partly on the pressure of livestock animals breeded by rural communities. Livestock nutritional needs have the biggest impact on this pressure that is why the density of four livestock species (horses, cattle, pigs, sheep and goats together) was analysed.

Livestock data referred to different spatial units within the study period that is why they have estimated values (Fig. 12.14 and 12.15) based on various sources and developed according to different procedures (see Table 12.1).

The analysis of changes in livestock density in Masuria is presented in Fig. 12.14.

- The density of each animal species was changing in a different way. Only a sharp decline after the World War II was common for all species. It was even more distinct than a decline of human population presented for a comparison.
- The curve of cattle density shows the symmetric configuration before and after the World War II. The maximal density (over 30 animals km^{-2}) was recorded before the World War I and in 1970s, while minimal after the World War II. The starting and final points were similar (20 animals km^{-2}).
- The similar course of change was noticed for pigs although the maximal value before the World War I was higher than in 1970s.
- The highest horse density was recorded before the World War I (over 13 animals km^{-2}). The World War II caused the strong decline in the horse number. Post-war maximal values were noticed in 1960s (5 animals km^{-2}) since then the decrease in the horse density has been observed.
- The sheep density changes were completely unique. The data from 1864 show the density of 50 animals km^{-2}. This was a final stage of big sheep breeding in East Prussia which was limited by the massive European export of wool from Australia. The decline was continued until the World War II. Afterwards, the sheep density increased in some periods but did not exceed 10 animals km^{-2}. The present value reaches 0.2-0.3 animals km^{-2} and is 230 times lower than in the mid-19th century.

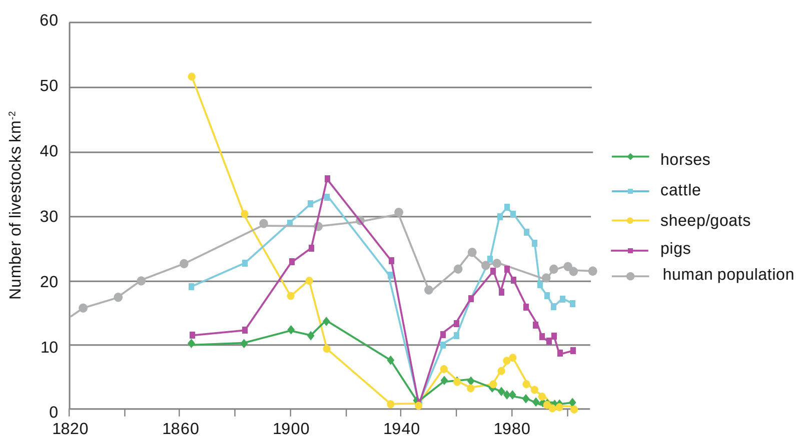

Fig. 12.14. Changes in livestock animals density in Masuria (the human population density for comparison)

In Kurpie changes in the livestock density were less intensive than in Masuria (Fig. 12.15 – shorter data series from 1883).

- The livestock density changes were significantly different before and after the World War II but they were not symmetric as in Masuria.
- The cattle density was decreasing since the last decades of 19th century (below 30 animals km^{-2}) until the World War II (1 animals km^{-2}) and then was sharply increasing until the late 1970s (40-45 animals km^{-2}).

– The pigs' density was quite low before the World War II (2-5 animals km^{-2}). After the war it was increasing until the mid-1970s (60 animals km^{-2}) to decrease in 1980s and 1990s to the current value about 20 animals km^{-2}.
– The horse density was not changing strongly comparing other species. The World War II did not bring bigger shift as well. At the beginning of 20th century and in 1960s and 1970s the horse density reached 5-10 animals km^{-2}. The post-war maximum was noticed in 1965 and then it has decreased (to 2 animals km^{-2} after 2000).
– Sheep and goats were the most numerous at the end of 19th century (over 20 animals km^{-2}) but their density declined afterwards. The bigger values were also observed in 1960s but nowadays these animals are rare (0.2-0.3 animals km^{-2} – similar to Masuria). The final density constituted 1% of the initial value.

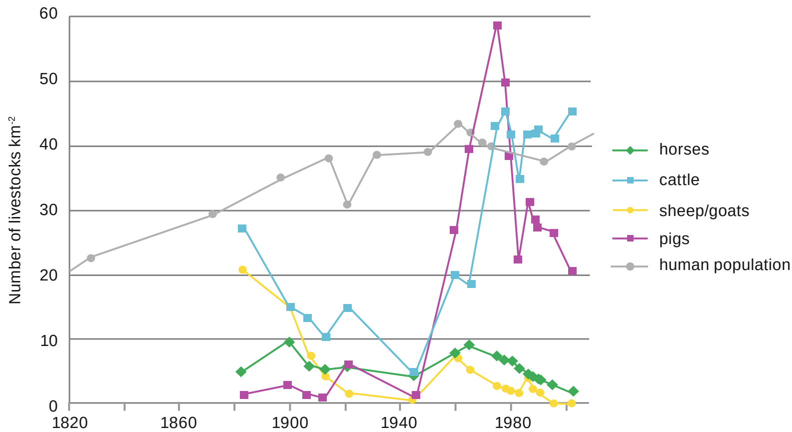

Fig. 12.15. Changes in livestock animals density in Kurpie (the human population density for comparison)

To compare the livestock density in Masuria and Kurpie the recalculation on "big animals" (b.a.)[2] (corresponding cows) was used (Fig. 12.16). To summarise:
– the higher livestock density before the World War II was observed in Masuria (in 1913 this ratio was 3:1),
– a strong decline of livestock density was noticed during the World War II (especially in Masuria),
– a fast increase in livestock density was recorded after the war until the mid-1970s (more intensive in Kurpie 50 b.a. km^{-2} than in Masuria 30 b.a. km^{-2}),
– there were observed a decline of livestock density in mid-1970s and at the beginning of 1990s and the stabilization in 2000 at the level of 40 b.a. in Kurpie and 15 b.a. in Masuria what stands for the reverse proportion in comparison to 1913,

[2] Big animal (b.a.) = horses × 1.2 + 50% cattle × 1 + 50% cattle × 0.6 + pigs × 0.2 + sheep × 0.09. The "cattle" category division was associated with the data which selected "cows" (share of 50%) from the general "cattle" category. One "big animal" corresponds to an adult cow.

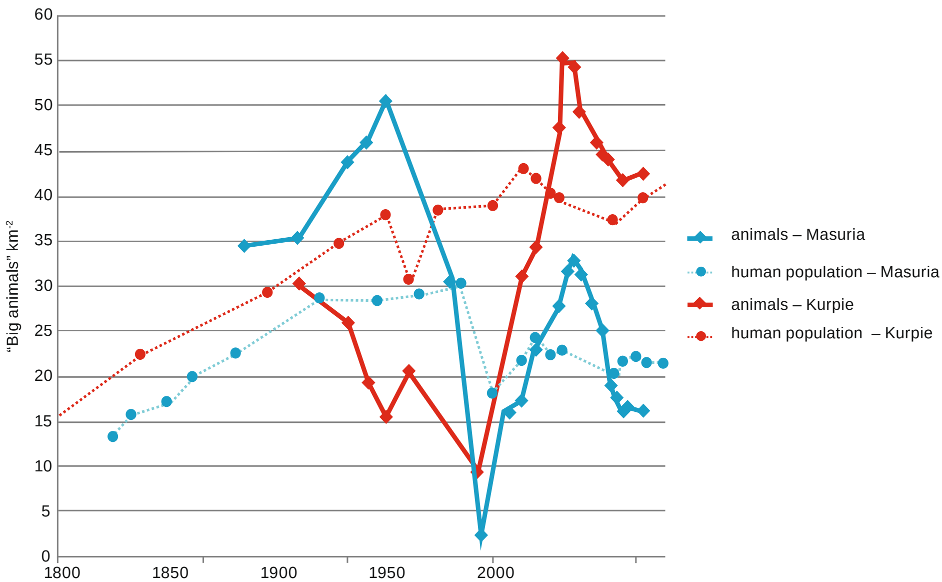

Fig. 12.16. Changes in livestock density recalculated to "big animals" in Masuria and Kurpie (the human population density for comparison)

– at the end of the studied period, the number of b.a. per area unit is similar to the number of rural residents in Kurpie, while in Masuria is much lower.

The ratio between human population density and livestock density was analysed. Fig. 12.17. shows this dependence for four communities/villages in Kurpie 1921. Its values were similar for all villages. The most important species were cattle. A half of them constituted dairy cows. In 1921, two residents fell on one cattle animals or four residents on one adult cow. Changes in this ratio in Masuria and Kurpie were presented in Fig. 12.18.

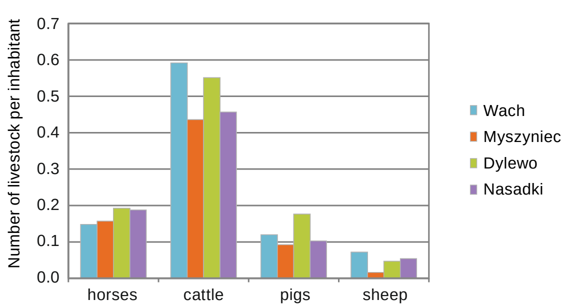

Fig. 12.17. The number of livestock animals per resident in four communities in Kurpie (Wach, Myszyniec, Dylewo, Nasadki) according to the census from 1921

At the end of 19th century in both regions the ratio of cattle to human population was similar and amounted to 0.8 animals per resident. At the turn of 19th and 20th centuries until the World War I, the ratio increased in Masuria (to 1.2 animals per resident) and decreased in Kurpie. After the war the change was opposite. The World War II caused a severe decline of the ratio in both regions (to 0.1 animals). After the war the ratio was strongly increasing till the end of 1970s. In particular, this growth was very significant in Masuria where the state farms dominated. In Kurpie the value from 1970s has been maintained on 1.1. However, in Masuria it has declined below 0.8.

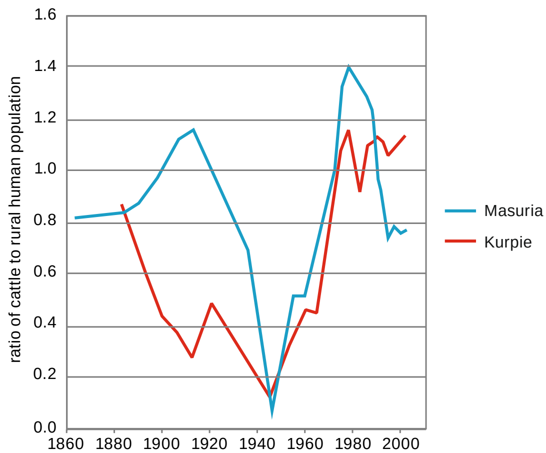

Fig. 12.18. The ratio of cattle to rural population in Masuria and Kurpie

The ratio changes indicated a considerable diversity of farming intensification between the regions. In Kurpie the stabilization started in 1970s after a long growth period and is still observed. Changes of socio-economic character from 1990s did not influence much the ratio values because the state farms that closed down in that period were not widespread in this region. A shape of the curve might suggest that the balance between cattle and human population density was achieved. This value can be interpreted as the environmental threshold in Kurpie.

In Masuria, the stabilization started just in the mid-1990s. It was preceded by the strong decline after the maximum (1.4) at the end of 1970s. These were the final years of "Gierek's era" followed by the collapse of the state farms in 1990s. A shape of the curve was determined not only by environmental conditions but also by socio-economic changes.

To conclude, the stabilization was earlier in Kurpie though the livestock farming was more intensive there than in Masuria.

The analysis has given rise to questions:

– Are there any reasons of the ratio stabilization (value 0.8) in Masuria in the periods 1864-1890 and 1995-2000? Is this the optimal value? Is this the real stabilization or other changes in ownership would cause another transformations?
– How should we interpret the higher ratio in Kurpie than in Masuria in terms of sustainable development? Is the livestock farming too intensive in Kurpie or underdeveloped in Masuria as a result of unfinished ownership transformation?

It is worth noting what the changes in the ratio of livestock animals' number to farm number were, meaning how many animals were in one farm (Fig. 12.19). The course of most curves was similar in both regions though Masuria was more resourceful in livestock animals. It corresponds with higher number of residents per farm, lived in bigger farms, observed in Masuria (see Fig. 12.13).

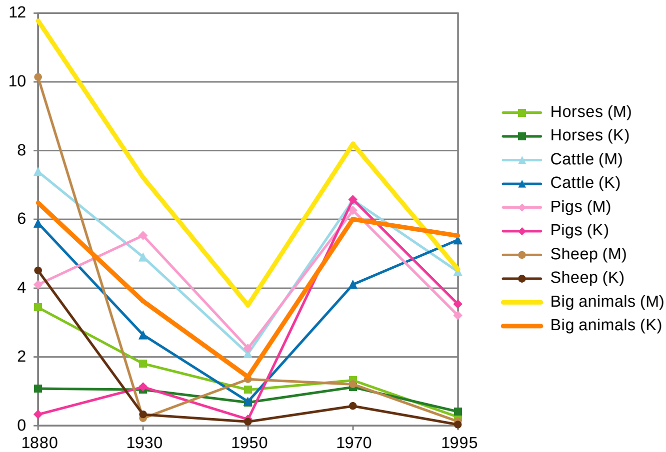

Fig. 12.19. The number of livestock animals per farm

Between the end of 19th century and the period just after the World War II the animal number of most species per an average farm decreased in both regions. Afterwards, until 1970s the number of cattle and pigs was increasing significantly and the number of horses and sheep slightly. The difference between the regions decreased. The end of 20th century was characterised by the decrease in most livestock animals' number. The exception concerns the higher cattle number in Kurpie. At the end of the studied period livestock numbers on an average farm became similar in both regions. There were about five cattle animals and three pigs. In Kurpie the farms became richer in animals, especially in cattle, because the farming is based mainly on dairy cows.

Assessing rural community welfare by the number of livestock animals per farm, we can indicate the reduction of difference between the regions during 120 years. Nevertheless, the rural community in Kurpie, poorer in the past, became richer in livestock animals than residents of Masuria.

The livestock animals farming (an important element of rural residents' welfare) has an important consequence for the natural environment. The livestock pressure was estimated based on calculations of "big animal" density to the amount of fresh plant biomass using standard of 65 kg day^{-1} cow^{-1} (Fig. 12.20).

Changes in livestock animal pressure show a twofold course and were mostly influenced by the World War II. In Masuria the highest pressure was observed just before the World War I (over 1130 t km^{-2} year^{-1}) where cattle contribution amounted to 50-55% because the share of horses and sheep was substantial these times. In Kurpie the pre-war pressure was lower and was decreasing since the end of 19th century.

After the World War II livestock pressure increased considerably in Kurpie while in Masuria it rose but it did not reach the pre-war value (except cattle). At the end of 1970s, the uppermost livestock pressure was observed in both regions. It was followed by the animal number decrease (bigger in Masuria). During the last decade the animals' pressure stabilized in both regions and was dominated by cattle (over 80%). However, the level of animals' pressure was different: it amounted 1000 t km^{-2} and 360-380 t km^{-2} in Kurpie and Masuria respectively.

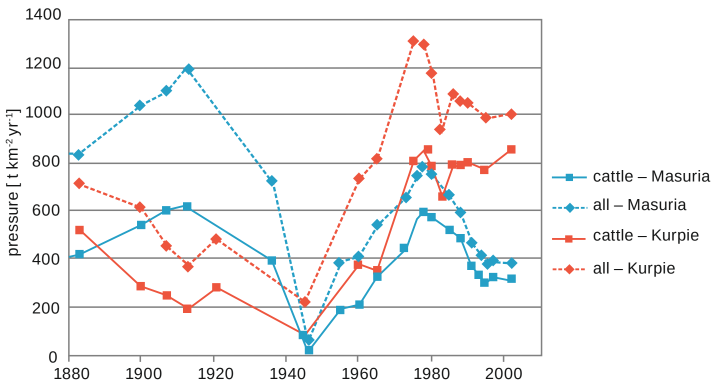

Fig. 12.20. The feeding pressure of livestock animals on the environment

It is worth looking at the pressure of the smallest species – sheep, often accounted together with goats in the statistics (Fig 12.21). Their contribution in the general livestock pressure was rather small but they were grazing not only in open pastures but also in forests. Therefore, their pressure on landscape could be compared with wild animal pressure.

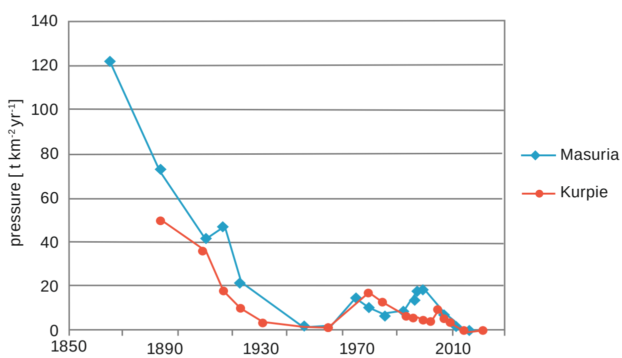

Fig. 12.21. The feeding pressure of sheep on the environment

The sheep pressure was quite strong in the 19th century in Masuria. In 1864, at the end of sheep farming in East Prussia it amounted to 120 t km^{-2} year^{-1}. It constituted 13% of the all livestock animals' pressure. In Kurpie, the sheep pressure was lower and reached 50 t km^{-2} year^{-1} (6.5% of total pressure) in 1883. The sheep number was decreasing systematically until the World War II outbreak in both regions. After the war their pressure increased to 20 t km^{-2} but it constituted only 1% of the total value. At present it is minimal.

12.4.4. Comparing the pressure of two ungulate groups – wild and livestock animals

The pressures of wild and livestock animals were presented above (Fig. 12.10 and 12.20). Their values were completely different making them difficult to compare (Fig. 12.22). In Masuria the pressure of wild ungulates constituted 0.5-1% of the total ungulates pressure until the latest increase in wild animals number (mainly red deer) changed it to 2.5%. In Kurpie the wild ungulate contribution was extremely low, even with the latest quite high animal number (in recent decades this share is 0.3-0.4%; indicating lower values than an error in estimating pressure).

The wild animal pressure compared with sheep pressure is presented in Fig. 12.23. At the end of 19th century this ratio could be estimated at the level 1:24 in Masuria and 1:250 in Kurpie (what should be taken only as estimates beacause of data). Sheep ate up much more biomass than all wild ungulates. This dominance was observed during almost the whole 20th century. The latest data show only the opposite situation. The wild animals eat up 5-20 times more biomass.

These results show that at present and in the past livestock animals gathered much more biomass than wild ungulates in both regions.

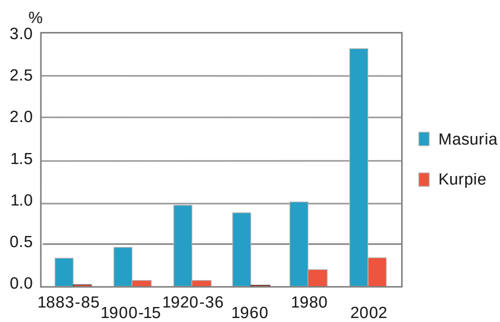

Fig. 12.22. Wild animal pressure in the total pressure of ungulates (wild and livestock)

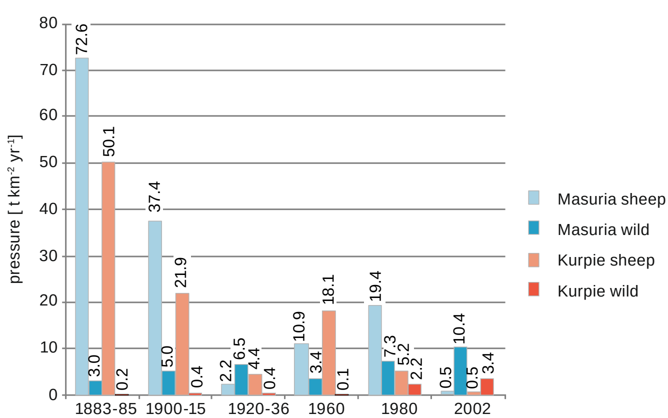

Fig. 12.23. Comparison of wild ungulates pressure to sheep pressure

12.5. Variability of the studied indicators

To assess the variability of studied indicators within the studied period the ratio of their minimal to maximal values was calculated for the regions. In Masuria the farm density and the forest cover were the most stable characteristics (Fig. 12.24). Low ratio values were also observed for the forest cover in the five most widespread habitats and for human population density. Within habitat types the most stable was the forest cover in mixed oak-pine forest habitat (*Querco roboris-Pinetum*) and the most variable in ash-alder alluvial forest habitat (*Fraxino-Alnetum*). Less stable were indicators associated with the density and the pressure of wild and livestock animals. The highest ratio value was recorded for the sheep density. These animals were breeded on a massive scale in 19th century but afterwards they nearly disappeared from the region.

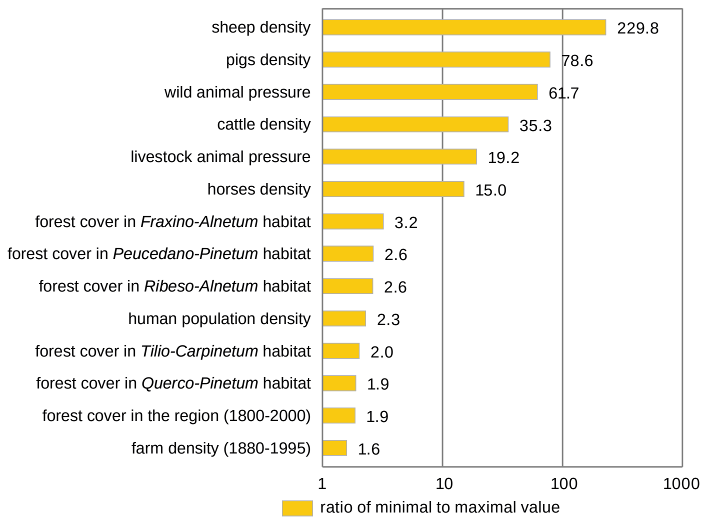

Fig. 12.24. Comparison of the studied indicators variability in Masuria

In Kurpie (Fig. 12.25), the most stable were the general forest cover, the forest cover of pine and mixed oak-pine forest and alder carrs habitats as well farm and population density. The livestock pressure, horses and cattle density and the forest cover in lime-oak-hornbeam and ash-alder forest habitats were less stable. The highest ratio values were observed for the density of pigs and sheep and wild animal pressure.

Comparing the regions:

- The studied indicators can be divided into two groups: the first with lower ratio: forest cover and farm and population density and the second with higher ratio: wild and livestock animals' density.
- In Kurpie the higher variability of forest cover in eutrophic habitats (*Tilio-Carpinetum* and *Fraxino-Alnetum*) and wild animal pressure were observed.
- Masuria can be characterised by the higher variability of forest cover in pine forest habitats and livestock density.

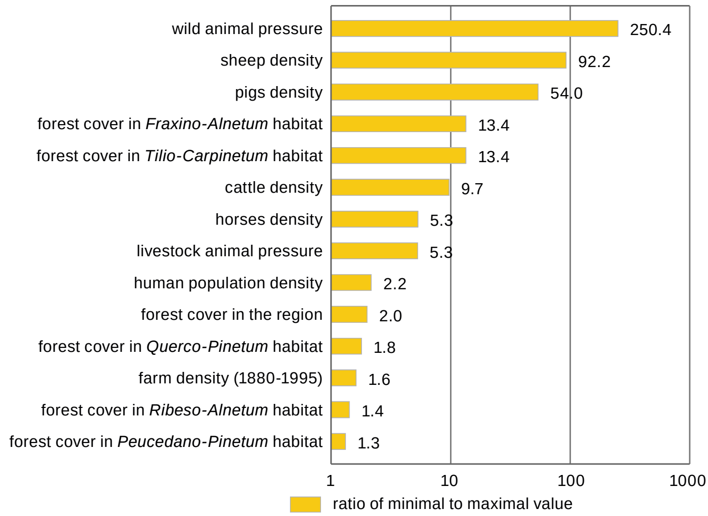

Fig. 12.25. Comparison of the studied indicators variability in Kurpie

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13. ASSESSMENT OF HISTORICAL CHANGES IN LANDSCAPE SUSTAINABILITY BASED ON SELECTED INDIRECT INDICATORS

Jan Marek Matuszkiewicz, Jerzy Solon, Anna Kowalska

13.1. Approaches to sustainable development evaluation

The principles of sustainable development are included in the most important Polish legal acts as the Constitution and other laws (Chapter 12). The detailed definition is written in the Second National Environmental Policy. According to this document: *the main objective of SD is carrying a policy and activities in various social and economic sectors to maintain qualities and resources of the environment for present and future generations preserving the same time persistence of environmental processes and biodiversity at the landscape, ecosystem, species and gene levels. The equal treatment of social, economic and ecological issues is an essence of SD and it means that the environmental protection should be integrated with various sectors of economy* (*II Polityka*…, 2000). From the perspective of ecology and landscape the most important is a need to preserve the persistence of ecological processes and biodiversity at the landscape level. In this context, we can speak about sustainable landscape (Solon, 2004).

Introduction of SD to the strategic planning at various spatial levels resulted in the development of indicators describing the state of its various components. Phillis and Andriantiatsaholiniaina (2001) stated rightly that extremely different approaches to indicators of SD are the consequence of its wrong or fuzzy definitions.

Nowadays, two procedures are used the most frequently. The first determines SD using one indicator describing for instance "ecological footprint" (Lenzen & Murray, 2001; Rees, 1992) or which is built of partial indicators calculated using various conversion algorithms e.g. fuzzy logic approach (Phillis & Andriantiatsaholiniaina, 2001).

The second method involves the use of several indicators ordered by different classification schemes. The most important are:

- "pressure-state-response" (PSR) model (OECD, 1994, 2013),
- "driving forces" (economic sectors, human activities) – "pressures" (emissions, waste) – "states" (physical, chemical and biological) – "impacts" (on ecosystems, human health and functions) – "responses" (prioritization, target setting, indicators) (DPSIR) framework (EEA, 1999), based on cause-effect relationships between variables.

In this group there is also an approach proposed by EUROSTAT which divides indicators into sections: Socio-economic development; Sustainable consumption and production; Social inclusion; Demographic changes; Public health; Climate change and energy; Sustainable transport; Natural resources; Global partnership; Good governance (*Sustainable*…, 2013).

In Poland, the official publications present the similar indicator system with some modifications associated with Polish statistical data specifics (*Wskaźniki…*, 2011) and with regard of five subsystems: social, economic, environmental, spatial and additionally institutional and political which together form an integrated order (see Borys, 1999, 2005, 2011).

All foregoing methods demand numerous and detailed statistical data and imply time-stable hierarchy of rules and strategic objectives describing SD. Both these reasons exclude them from direct historical analysis.

The objective of this chapter was to determine, even in an approximate way, the level of SD in the regions of Masuria and Kurpie. To achieve this aim adequate assumptions and methods, specific for available data and consistent with modern conceptions, had to be adopted.

13.2. Theoretical assumptions of the sustainable development analysis

The theoretical assumptions and scope of the SD analysis is presented in Fig. 13.1.

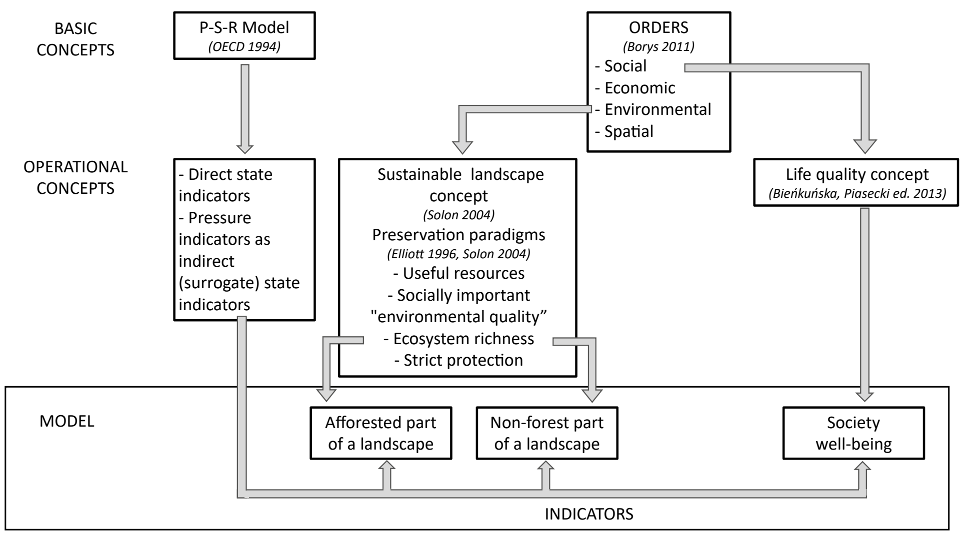

Fig. 13.1. Transition scheme from general SD concepts to a detailed scope of the analysis

The specifics of available data made it impossible to use a rich set of indicators based on cause-effect relationships and relating to all subsystems recognized by Borys (2011). Therefore, the analysis was based on the indicators of state and additionally of pressure considering them as proxy or surrogate indicators of state. Environmental subsystem was the main subject of the analysis, the social subsystem was supplemental.

The environmental subsystem was limited to sustainable landscape defined by Solon (2004) using the paradigm of ecosystem richness preservation (Elliott, 1996). The landscape was divided into two complementary parts: afforested and deforested, used in agriculture.

The social subsystem was characterised with the conception of life quality (Bieńkuńska & Piasecki, 2013) and especially social welfare determined with direct and indirect indicators.

The relationship between measured values and their interpretation in SD categories can be ambiguous. There are three patterns of such a relationship (Fig. 13.2).

Variant A (Fig. 13.2) presents the simplest case: a level of SD is directly proportional to a feature value (e.g. the larger the area of the biggest forest patch, the better the afforested part of the landscape is developed).

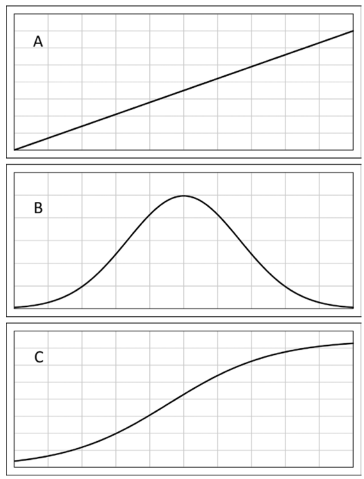

Fig. 13.2. Main types of relationship between absolute value of measured feature (x axis) and its indicator value of SD (y axis). Details in the text

Variant B shows the situation when the lowest and the highest feature values indicate a worse sustainability level. For instance wild animals density in forests: low values suggest negative processes: natural as epizootic or strong anthropogenic pressure; a very high density indicates disturbance in the flow of matter and energy in ecosystem, a lack of an adequate number of predators, limitations in the natural forest renewal.

Variant C demonstrates the situation where small changes of a feature value in lower and upper ranges do not influence the SD level e.g. forest cover in various habitats inducing species richness.

The foregoing assumptions influenced the choice of variables (see previous chapters) that can be interpreted as direct or indirect characteristics of sustainable development.

13.3. Procedures and identification of partial indicators

Changes in social, economic and technological patterns and the lack of appropriate statistical data preclude the use of indicators recommended in Poland (*Wskaźniki…*, 2011). Nevertheless, the assessment of SD according to the approved scheme can be carried out based on available data of forest cover, human population dynamics, wild and livestock animals' density.

The input data (see Chapter 12) were used to define a set of indicators and to calculate their values for 1800, 1830, 1885, 1928, 1950, 1970 and 2000. In some cases, these values were interpolated on the basis of data from previous or subsequent years or were extrapolated on the basis of long-term trends. The wolf population was described with ranked rating based mainly on descriptive data.

All indicator values were juxtaposed separately in Kurpie and Masuria but afterwards they were standardized together to be comparable.

In total, there were used 20 indicators of forests, six indicators of open landscape and three indicators of rural community welfare. Their characteristics are presented in Table 13.1. The values of SD partial indicators are displayed in Table 13.2.

The sums of partial indicators were adopted as synthetic indicators of SD of both landscape parts (afforested and deforested) and the society.

13.4. Synthetic indicators of historical changes

The synthetic indicators showing sustainability of landscape and rural community welfare determine the level of ecological and social orders as indirect indicators of SD.

The synthetic indicator of afforested landscape sustainability was changing in a similar but not same way in both regions (Fig. 13.3). At the beginning its value was decreasing and then increased. In Masuria the decrease was continuing till 1885 (from 5.4 to 4.5), in Kurpie until 1950 (from 6.2 to 3.5). The periods of increase, though of different length, had a similar pace of change (about 0.32 per 10 years). In 2000, the indicator values reached 8.1 and 5.1 respectively. It is worth noting that in Masuria the present value of ecological sustainability in the afforested part of landscape is the highest comparing previous dates. In Kurpie, the highest value was observed at the beginning of 19th century but the present positive trend could result in a similar value in 2030.

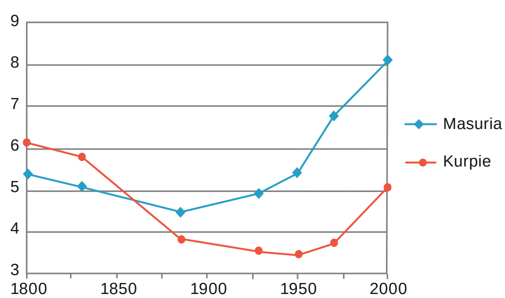

Fig. 13.3. Changes in synthetic indicator values of SD in the afforested part of the landscape

The synthetic indicator values of open (deforested and used in agriculture) landscape sustainability were changing in a different way till 1950 and then unified in both regions (Fig. 13.4). In Masuria, its values were increasing till 1928 from 0.9 to 1.8. In the same time, in Kurpie the changes were minimal, from 0.97 to 1.04. In the period 1928-1950, the indicator value decreased strongly in Masuria (to 0.7) affected by the war. The next 20 years were associated with the increase in open landscape sustainability (from 0.7 to 2.0

Table 13.1. Selected indicators of sustainable development and their interpretation

Indicators	Variable type	General relation type	Adopted relation type	Variable interpretation	Comments
Afforested landscape part					
Forest cover (%)	continuous	C	A	measure of general landscape and forest natural character (the higher values the better state)	
Forests – the distance to the nearest neighbour (m)	continuous	A	A	measure of forest connection and cohesion (the lower values the better state)	calculations were completed to 1 normalized value
Forests – the mean area of 50 the biggest forest patches (ha)	continuous	A	A	measure of biocenotic processes feasibility (the higher values the better state)	
Forest cover in various habitat types divided to groups (%)	continuous	C	A	partial indicators of biodiversity preservation in various habitats and in forests (the higher values the better state)	
Swamp pine and spruce forests (*Vaccinio uliginosi-Pinetum* and *Sphagno girgensohnii-Piceetum*)					
Moist pine forests (*Molinio-Pinetum*)					
Moist mixed pine and spruce forests (*Querco roboris-Pinetum molinietosum* and *Querco-Piceetum*)					
Swamp alder forests (*Alnetea glutinosae*: *Ribeso nigri-Alnetum*, *Sphagno squarrosi-Alnetum* and *Betula pubescens – Thelypteris palustris* community)					
Alluvial ash-alder forests (*Fraxino-Alnetum*)					
Moist lime-oak-hornbeam forests (*Tilio-Carpinetum stachyetosum*)					
Typical lime-oak-hornbeam forests (*Tilio-Carpinetum typicum*)					
Poor lime-oak-hornbeam forests (*Tilio-Carpinetum calamagrostietosum*)					
Mixed oak-pine forests (*Querco roboris-Pinetum typicum*)					
Pine forests (*Peucedano-Pinetum*)					
Typological forest diversity	continuous	A	A	direct measure of typological diversity and indirect measure of species diversity (the higher values, the better state)	acc. to Shannon index $H = -\sum p_i \log_2 p_i$, p = forest spatial share in a habitat of i-type to the whole forest area
Wild ungulates density in forests (animals 100 ha^{-1})	continuous	B	A	indirect indicator of fauna state and its pressure on forests though the pressure cause is unknown (the higher values, the better state)	it was assumed that the density was never so high to result in negative consequences for forest vegetation
red deer					
roe deer					
elk					
wild boar					
Wolf density (population grading assessment)	ordinal	B	A	indirect index of natural trophic chains (the higher values, the better state)	
Forest area (ha) per one inhabitant	continuous	A	A	indirect indicator of forest synantophisation (the higher values, the better state)	
Open landscape part					
Human population density in open landscape (inhabitants km^{-2})	continuous	B	A	indirect measure of agricultural use and segetal communities formation (the higher values, the better state)	it was assumed that the human population density was never so high to result in agricultural landscape degradation
Farm number km^{-2} of open landscape	continuous	B	A	measure of open landscape fragmentation and indirect indicator of ecosystem and general floristic diversity of the region (the higher values, the better state)	it was assumed that higher farm number resulted in more bounds and other ruderal communities
Number of small forest patches (<= 3 ha)	discrete	B	A	indirect measure of landscape ecological connectivity and habitat and fauna diversity in agricultural landscape (the higher values, the better state)	it was assumed that small forest patches have positive biocenotic value for agricultural landscape provided that they are not too big and too numerous
Livestock animal density in open landscape (animals 100 ha^{-1})	continuous	B	A	indicator of grasslands use and indirect measure of grasslands species (the higher values, the better state)	it was assumed that the density was never so high to result in negative consequences for open landscape
horses					
cattle					
pigs					
Welfare of society					
Farm number	discrete	B	A	indirect measure of rural community income source	it was assumed that there are not too small farms
Human population density (inhabitats km^{-2} of the area)	continuous	B	A	increase in human population density results from: (a) immigration from the neighbourhood, (b) reproduction increase, (c) mortality decrease. All these processes indicate good life conditions and indirectly welfare of society	it was assumed that there are not many residents with the lowest income
Big animals $inhabitant^{-1}$	continuous	A	A	direct indicator of rural community welfare	in Kurpie this measure mainly depends on cattle, in Masuria on other livestock species as well e.g. sheep

(1) acc. to models in Fig. 13.2.

Table 13.2. Partial indicator values used to determine sustainable development level

Indicator	Masuria							Kurpie						
	1800	1830	1885	1928	1950	1970	2000	1800	1830	1885	1928	1950	1970	2000
Afforested landscape part														
Forest cover (%)	35.2	35.3	31.8	40.2	41.8	58.1	59.3	46.6	44.1	29.4	23.3	25.4	30.7	31.0
Forests – the distance to the nearest neighbour (m)	421.1	470.2	170.3	154.0	169.6	114.6	99.9	382.0	407.6	203.6	234.0	260.4	140.8	138.4
Forests – the mean area of 50 the biggest forest patches (ha)	2,388.1	2,206.8	1,078.0	1,543.5	2,752.5	5,174.0	5,300.1	1,666.5	1,598.7	884.5	742.5	802.6	1,087.1	1,078.6
Forest cover in various habitat types (%)														
Vaccinio uliginosi-Pinetum and *Sphagno girgensohnii-Piceetum*	72.6	73.0	58.5	73.4	74.3	87.7	92.1	95.2	95.8	61.9	75.9	73.8	86.5	82.8
Molinio-Pinetum	73.2	73.3	65.6	76.9	76.9	88.0	87.5	46.5	46.7	84.9	89.2	92.4	73.8	68.7
Querco roboris-Pinetum molinietosum and Querco-Piceetum	58.1	60.2	55.8	60.7	61.5	79.2	78.7	63.5	62.9	55.0	40.8	44.3	52.5	52.7
Alnetea glutinosae (together)	37.5	37.6	18.4	24.1	25.6	42.4	50.0	43.9	43.7	40.1	33.7	35.6	39.9	38.4
Fraxino-Alnetum	26.0	26.4	8.2	8.5	8.6	16.6	18.9	39.7	32.2	7.1	3.1	3.2	4.1	3.7
Tilio-Carpinetum stachyetosum	30.4	29.4	10.7	10.6	10.9	20.2	21.4	40.9	35.9	6.7	2.3	2.2	3.3	3.7
Tilio-Carpinetum typicum	27.8	30.5	18.5	17.2	17.4	26.6	27.7	30.3	29.2	6.8	1.8	1.4	3.6	4.3
Tilio-Carpinetum calamagrostietosum	28.7	27.6	21.9	23.3	25.3	44.6	46.9	35.1	33.6	11.3	3.5	5.9	6.5	7.1
Querco roboris-Pinetum typicum	43.2	43.6	43.8	55.6	58.4	84.5	85.9	47.0	46.8	35.2	25.7	28.8	40.8	42.6
Peucedano-Pinetum	37.7	38.6	58.9	88.6	90.5	99.6	99.3	71.9	72.8	80.9	79.1	84.1	94.5	94.0
Typological forest diversity	2.7	2.7	2.4	2.3	2.3	2.4	2.4	2.7	2.7	2.3	2.0	2.0	2.0	2.0
Wild ungulates density in forests (animals 100 ha^{-1})														
red deer	0.0	0.0	0.2	0.6	0.5	0.5	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.4
roe deer	0.7	0.3	5.5	0.9	0.7	0.3	3.9	0.2	0.2	0.1	0.1	0.1	0.2	3.7
elk	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.1
wild boar	0.0	0.0	0.0	0.3	0.6	0.6	0.6	0.4	0.4	0.2	0.2	0.2	0.2	0.6
Wolf density (population grading assessment)	9.0	8.0	1.0	1.0	8.0	1.0	6.0	7.0	6.0	2.0	3.0	4.0	1.0	4.0
Forest area (ha) per one inhabitant	3.1	2.1	1.1	1.3	2.2	2.4	2.5	3.0	1.9	0.9	0.6	0.7	0.8	0.8
Open landscape part														
Human population density in open landscape (inhabitants km^{-2})	17.6	26.4	42.3	51.7	32.7	56.6	57.9	29.0	41.2	45.7	49.6	52.3	57.8	57.1
Farm number km^{-2} of open landscape	3.7	4.0	4.6	7.4	4.8	7.8	9.3	5.3	5.8	6.6	7.4	8.9	10.8	11.0
Number of small forest patches (<= 3 ha)	1.0	2.0	155.0	69.0	59.0	356.0	451.0	0.0	0.0	74.0	26.0	17.0	443.0	569.0
Livestock animal density in open landscape (animals 100 ha^{-1})														
horses	15.9	15.9	15.2	17.8	4.8	8.9	2.4	9.5	9.1	7.2	7.8	7.4	12.1	2.7
cattle	15.4	20.3	32.7	45.0	9.7	55.7	40.5	51.7	49.4	39.1	19.6	13.1	44.3	65.7
pigs	15.4	15.5	18.2	49.6	10.4	51.2	22.5	2.9	2.7	2.2	8.4	13.2	71.0	29.5
Welfare of society														
Farm number	3,620.0	4,041.0	4,813.0	6,695.0	4,223.0	4,874.0	5,772.0	4,832.0	5,553.0	6,025.0	7,248.0	8,457.0	9,503.0	9,655.0
Human population density (inhabitants km^{-2})	11.0	16.5	27.9	29.8	18.3	22.5	22.3	15.5	23.0	32.3	38.0	39.0	40.0	39.4
Big animals inhabitant^{-1}	2.5	1.8	1.3	1.4	0.5	1.2	0.7	2.0	1.3	0.9	0.5	0.4	1.1	1.1

in Masuria and from 1.0 to 2.4 in Kurpie). In the last period, until 2000, in both regions the indicator value decreased about 0.35 points what corresponds to the general trend of open landscape changes in Poland[1].

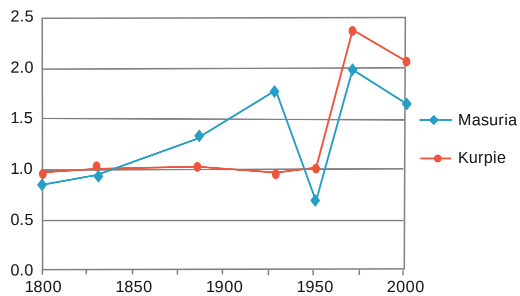

Fig. 13.4. Changes in synthetic indicator values of SD in the deforested part of landscape

Changes in the synthetic indicator values of rural community welfare (Fig. 13.5) conformed generally the changes in open landscape sustainability. In particular, in the period 1800-1928 its value increased in both regions form 0.7 to 0.8. The increasing tendency was maintained in Kurpie until 1970 and reached 1.0, but in Masuria the indicator value, affected by the war and political changes, decreased to 0.45 in 1950. It increased to 0.7 during the next 20 years. The studied last 30 years showed a slight indicator decline in both regions, though higher in Masuria. It is worth noting that directions of the rural community development were divergent during 200 years. The starting points were similar (about 0.75) while the final values were visibly lower in Masuria (0.6 – less than in 1800) and higher in Kurpie (1.0 – higher than in 1800).

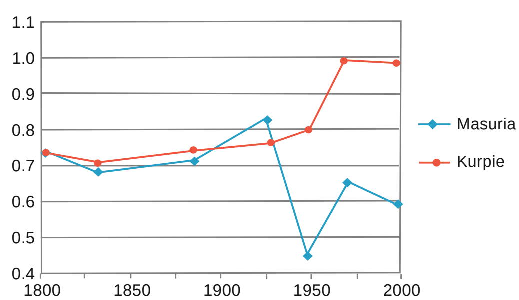

Fig. 13.5. Changes in synthetic indicator values of rural community welfare

The presented changes of synthetic indicators of landscape sustainability and social welfare were rather independent. Only, the correlation between the degree of open landscape sustainability and the level of welfare was more distinct (correlation coefficient = 0.59; p = 0.027). Less significant was the correlation between afforested landscape

[1] It results mainly from changes in the profitability of the agricultural economy and reconstruction of the agrarian structure (Solon, 2007).

sustainability and the level of welfare (correlation coefficient = -0.49; p = 0.074). Changes in all synthetic indicators were presented in Fig. 13.6 as a deviation from threshold values indicating sustainable development.

Optimal indicator values for SD were not observed in any region during 200 years. The character of changes in environmental indicators was distinctly different than in social and economic indicators. In general, environmental indicators evolved slowly and similarly in both regions. Indicators that described rural community welfare and especially indicators of rural economy were changing more rapidly and differently in each region.

During almost the whole 19th century the values were rather low what means that regions development was unsustainable wherein socio-economic indicators were increasing and environmental indicators were decreasing. Afterwards, in Masuria all indicators achieved satisfactory level till the World War II. Its outbreak contributed to the subsequent decrease in socio-economic indicators. The environmental indicators improved slightly. Post-war changes led to the environmental recovery. Socio-economic indicators reached maximal values at the end of 1970s. The measure of rural economy exceeded pre-war values but the measure of society welfare was significantly lower and the region development was not entirely sustainable at the end of 20th century.

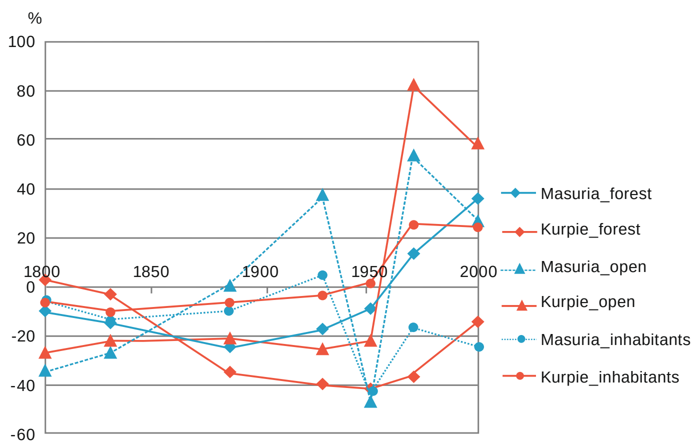

Fig. 13.6. Comparison of three synthetic indicators used to describe SD in the studied regions

In Kurpie, at the end of 19th century and in the first half of 20th century all indicators had low values. The World War II did not change this state. After the war, socio-economic indicators achieved the level corresponding SD but the environmental one was still too low. However, if the pace of its change maintained it would achieve sustainability within 20-30 years.

13.5. Final remarks

The foregoing analysis and assessment were rather estimation since they were based on simplified assumptions and proxy indicators built on the available datasets.

Nevertheless, they reflected the main directions of changes at the level of landscape sustainability (static approach) and sustainable development (dynamic approach).

It is important to know if the studied indicators and their threshold values could be used in regional or local studies/analysis. There are two examples providing their regional significance.

The landscape sustainability was determined using the density indicators of five wild animals since it was assumed that their high values reflected the richness of the studied ecosystems. In the western part of Europe where there are no wolves and elks the indicator set values would be artificially low. In contrast, in the north-eastern Europe, another predator species should probably be added and absent ungulate species skipped.

Moreover, historical analysis demands adoption of adequate criteria for the studied period. For instance, 400 years ago, the study area was inhabited by presently absent bison, aurochs, wild horses and bears. These permanent changes do not exclude the landscape sustainability. This can be achieved in the given social and environmental conditions. The set of detailed indicators of sustainable landscape and their assessment criteria have to be relevant to the region and time period. The principles of historical relevance and regional adequacy should be applied.

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14. SOCIAL-ECOLOGICAL ANALYSIS – IN SEARCH OF THE BEST CRITERIA FOR SUSTAINABLE DEVELOPMENT

Jan Marek Matuszkiewicz, Anna Kowalska

14.1. Assessment of selected indicators

The sustainable development requires the accepted balance between "natural environment" and "society" (Mebratu, 1998; Pakulska, Poniatowska-Jaksch, 2015).

Inevitably, it might be associated with relative and arbitrary opinions and evaluations because it depends on requirements, preferences and expectations of an assessor. Evaluations (especially of the past states) are frequently carried out by experts. They are based on modern hierarchy of problems importance and available knowledge of the past.

The relationships between environment and local community of two studied regions within 200 years were evaluated using the set of selected indicators. This is a complementary approach to the parametric evaluation based on strictly calibrated indicators presented in the previous chapter.

The evaluation of relationships between environment and local community – their states and directions of change was presented in Table 14.1. It was based on the simple rating scale adopted from the assessment of protection areas in Natura 2000 programme which distinguishes three categories:

- Favourable (FV) – all states meeting the basic criteria of the indicator (sufficiently, well, very well)[1],
- Unfavourable-Inadequate (U1) – some criteria are not fulfilled or norms decline periodically,
- Unfavourable-Bad (U2) – significant deficiency of the indicator (*Assessment* ... 2011).

Following the scheme of Natura 2000 habitat assessment, the most important indicators (cardinal indicators) were distinguished and the general evaluation consisted of several indicators evaluation. Components "environment" and "society" could be rated as:

- FV – when all cardinal indicators were estimated as FV, the remaining indicators as FV or U1 (one U2 allowed);
- U1 – when all cardinal indicators were estimated at least as U1 and U2 category was rare within remaining indicators;
- U2 – the indicators did not comply the higher rate conditions.

[1] Since principles of SD presume that the relationship between environment and society should be "acceptable" more detailed valorisation is not necessary.

Table 14.1. Thresholds of indicator evaluation

Indicator	Evaluation base	FV	U1	U2
Indicators of "environment" component				
Forest cover*	In sustainable landscape with regional habitat range, forest cover should overcome 45% (Masuria) or 44% (Kurpie); 45% was adopted acc. to Fig. 12.1.	> 45%	30-45%	< 30%
Habitat exploitation: *Peucedano-Pinetum, Querco-Pinetum, Ribeso-Alnetum, Tilio-Carpinetum, Fraxino-Alnetum.*	Difference between actual forest cover and a norm of sustainable landscape for habitat type in % acc. to Fig. 12.3 and 12.4. Norms: P.-P. – 98%, Q.-P. – 53%, R.-A. – 50%, T.-C. – 25%, F.-A. – 20%.	> 0%	-30-0%	< -30%
Degree of landscape sustainability*	Degree of landscape sustainability in 12 habitats (see Fig. 12.5).	> -5%	-5-30%	< -30%
Wild animal (red deer, roe deer, elk, wild boar, wolf) population size	Population size estimated using ten-degree scale acc. to Fig. 12.8 and 12.9.	> 7 points	4-7 points	< 4 points
Mean population size of five wild forest animals*	Mean population size of the foregoing values Fig. 12.8 and 12.9.	> 7 points	4-7 points	< 4 points
Pressure of livestock animals and cattle (separately)	Based on daily plant biomass requirements in t km^{-2} $year^{-1}$ acc. to Fig. 12.19.	< 400	400-800	> 800
Pressure of sheep	Based on daily plant biomass requirements in t km^{-2} $year^{-1}$ acc. to Fig. 12.20.	< 5	5-20	> 20
Indicators of "society" component				
Human population density (Masuria)	Stable human population size from 1890-1939, amounting 30 (28.4-30.4) inhabitants km^{-2} of the region was adopted as optimal (FV) acc. to Fig. 12.11.	> 27	20-27	< 20
Human population density (Kurpie)	Stable human population size from 1931-2011, amounting 40 (37.5-43.2) inhabitants km^{-2} of the region was adopted as optimal (FV) acc. to Fig. 12.11.	> 37	26-37	< 26
Population density in open landscape*	The same evaluation scale was adopted for both regions (number of inhabitants km^{-2} of open landscape) acc. to Fig. 12.11.	> 50	35-50	< 35
Farm density in the region (Masuria)	Number of farms km^{-2} based on the change analysis acc. to Fig. 12.12.	> 4	2-4	< 2
Farm density in the region (Kurpie)	Number of farms km^{-2} based on the change analysis acc. to Fig. 12.12.	> 7	4-7	< 4
Farm density in open landscape	Number of farms km^{-2} based on the change analysis acc. to Fig. 12.12.	> 8	5-8	< 5
Cattle density	Number of animals km^{-2} based on the change analysis acc. to Fig. 12.14 and 12.15.	> 25	10-25	< 10
Horses density	Number of animals km^{-2} based on the change analysis acc. to Fig. 12.14 and 12.15. The value from 2000 was ignored because of the changed role of horses in rural communities since 1970s.	> 5	1-5	< 1
Pigs density	Number of animals km^{-2} based on the change analysis acc. to Fig. 12.14 and 12.15.	> 25	10-25	< 10
"Big animals" density	Number of "big animals" km^{-2} based on the change analysis acc. to Fig. 12.16.	> 30	15-30	< 15
Cattle number per inhabitant*	Number of animals $inhabitant^{-1}$ based on the change analysis acc. to Fig. 12.18.	> 0.8	0.5-0.8	< 0.5
Number of "big animals" per farm*	The ratio (%) of "big animal" number to inhabitant number per farm was concerned acc. to Fig. 12.19. Higher "big animal" number than inhabitant number was adequate.	> 100%	75-100%	< 75%
Wild animal pressure	Comparison between the pressure of wild forest ungulates and of livestock ungulates (see Fig. 12.10).	minimal or slight pressure	low but significant pressure	strong pressure

* cardinal indicator

Table 14.2. Evaluation of the indicators selected for the "environment" and "society" components in the studied regions

Region	Masuria													Kurpie												
Indicator	1800	change 1800-1830	1830	change 1830-1885	1885	change 1885-1930	1930	change1928-1947	1947-50	change 1950-1970	1970	change 1970-2000	2000 (2009)	1800	change 1800-1830	1830	change 1830-1885	1885	change 1885-1930	1930	change 1928-1947	1947	change 1950-1970	1970	change 1970-2000	2000
Indicators of "environment" component																										
Forest cover*	U1	0	U1	-	U1	+	U1	+	U1	+	FV	+	FV	FV	-	FV	-	U2	-	U2	+	U2	+	U1	+	U1
Indicator of *Peucedano-Pinetum* habitat exploitation	U2	+	U2	+	U2	+	U1	+	U1	+	FV	0	FV	U1	+	U1	+	U1	-	U1	+	U1	+	U1	0	U1
Indicator of *Querco-Pinetum* habitat exploitation	U1	+/-	U1	-	U1	+	U1	+	U1	+	FV	+	FV	U1	0	U1	-	U1	-	U2	+	U2	+	U1	+	U1
Indicator of *Ribeso-Alnetum* habitat exploitation	U1	0	U1	-	U2	+	U2	+	U2	+	U1	+	U1	U1	-	U1	-	U1	-	U2	+	U2	+	U1	0	U1
Indicator of *Tilio-Carpinetum* habitat exploitation	FV	+/-	FV	-	U1	-	U1	+	U1	+	FV	+	FV	FV	-	FV	-	U2	-	U2	+	U2	+	U2	+	U2
Indicator of *Fraxino-Alnetum* habitat exploitation	FV	0	FV	-	U2	+/-	U2	+/-	U2	+	U1	+	U1	FV	-	FV	-	U2	-	U2	+	U2	+	U2	0	U2
Degree of landscape sustainability*	U1	0	U1	-	U1	+	U1	+	U1	+	FV	+	FV	U1	0	U1	-	U2	-	U2	+	U2	+	U2	+	U2
Reed deer population size	U2	0	U2	0	U2	+	U1	-	U2	+	U1	+/-	FV?	U2	0	U2	0	U2	0	U2	0	U2	0	U2	+	U1
Roe deer population size	U2	-	U2	+	FV	+/-	FV	-	U2	+	U1	+	FV	U2	0	U2	-	U2	0	U2	0	U2	+	U1	+	FV
Wild boar population size	U2	0	U2	-	U2	+	U2	+	U1	+	U1	+	FV	U2	0	U2	-	U2	0	U2	0	U2	+	U1	+	FV
Elk population size	U2	+	U2	+/-	U2	-/+	U1	-	U2	+	U2	+/-	U1	U2	+	U2	-	U2	+?	U1?	-	U2	0	U2	+	U1
Wolf population size	FV	-	FV	-	U2	-	U2	+	FV	-	U2	+	FV?	U1	-	U1	-	U2	+/-	U2	+	U1	-	U2	+	U1
Mean population size of five wild forest animals*	U2	-	U2	-/+	U2	+	U1	-	U2	+	U1	+/-	FV?	U2	0	U2	-	U2	+	U2	-	U2	+	U2	+	U1
Livestock animal pressure	XX		XX		U2	-/+	U1	+	FV	-	U1	+	FV	XX		XX		U1	+	FV	+	FV	-	U2	-/+	U2
Cattle pressure	XX		XX		U1	-/+	U1	+	FV	-	U1	+	FV	XX		XX		U1	+	FV	+	FV	-	U1	-	U2
Sheep pressure	XX		XX		U2	+	FV	+	FV	-	U1	+	FV	XX		XX		U2	+	FV	+	FV	-	U1	+	FV
"Environment" in total	**U2**		**U2**		**U2**		**U1**		**U2**		**U1**		**FV**	**U2**		**U2**		**U2**		**U2**		**U2**		**U2**		**U2**
Indicators of "society" component																										
Population density in the region	U2	+	U2	+	FV	+	FV	-	U2	+	U1	-	U1	U2	+	U2	+	U1	-/+	FV	+	FV	+/-	FV	-/+	FV
Population density in open landscape*	U2	+	U2	+	U1	+	FV	-	U2	+	FV	+	FV	U2	+	U1	+	U1	+	FV	+	FV	+	FV	-	FV
Farm density (1880-1995) in the region	U1		XX		U1	+	FV	-	U1	+	U1	+	U1	XX		XX		U1	+	U1	+	U1	+	FV	0	FV
Farm density (1880-1995) in open landscape	U2		XX		U2	+	U1	-	U2	+	U1	+	FV	XX		XX		U1	+	U1	+	FV	+	FV	+	FV
Cattle density	XX		XX		FV	+/-	FV	-	U2	+	FV	+/-	U1	XX		XX		U1	-	U1	-	U2	+	FV	-	FV
Horses density	XX		XX		FV	+/-	FV	-	U1	+	U1		XX	XX		XX		FV	+/-	FV	-	U1	+	FV		XX
Pigs density	XX		XX		U1	+/-	FV	-	U2	+	U1	-	U2	XX		XX		U2	+	U2	-	U2	+	FV	-	U1
"Big animals" density	XX		XX		FV	+/-	FV	-	U2	+	FV	-	U1	XX		XX		U1		U1		U2		FV		FV
Number of "big animals" per farm*	XX		XX		FV		FV		U2		FV		U1	XX		XX		U1		U2		U2		FV		FV
Cattle number per inhabitant*	XX		XX		FV	+	FV?	-	U2	+	FV	-	U1	XX		XX		FV	-	U2	-	U2	+	FV	-/+	FV
Wild animal pressure	FV	0	FV	-	FV	-	U1	+	FV	-	U1	-	U1	FV	-	FV	0	FV	0	FV	+	FV	-	FV	-	U1
"Society" in total	**XX**		**XX**		**U1**		**FV**		**U2**		**FV**		**U1**	**XX**		**XX**		**U1**		**U2**		**U2**		**FV**		**FV**

* cardinal indicator

Table 14.3. Degree of development sustainability in the regions within 200 years

Region	Masuria			Kurpie		
Period	"environment" evaluation	"society" evaluation	sustainable development evaluation	"environment" evaluation	"society" evaluation	sustainable development evaluation
About 1800	U2	XX	environment – unsustainable development, society – indeterminate	U2	XX	environment – unsustainable development, society – indeterminate
About 1830	U2	XX	environment – unsustainable development, society – indeterminate	U2	XX	environment – unsustainable development, society – indeterminate
About 1885	U2	U1	both components – unsustainable development, severly in environment, moderately in society	U2	U1	both components – unsustainable development, severly in environment, moderately in society
About 1930	U1	FV	slightly unsustainable in environment	U2	U2	both components – unsustainable development
About 1947-50	U2	U2	both components – unsustainable development	U2	U2	both components – unsustainable development
About 1970	U1	FV	slightly unsustainable in environment	U2	FV	unsustainable in environment
About 2000 (2009)	FV	U1	slightly unsustainable in society	U2	FV	unsustainable in environment

The lack of standards in the indicators evaluation caused that the SD evaluation was also based on expert assessment. Therefore, the SD evaluation is also based on the selected indicators and their criteria. Table 14.2 presents the evaluation of indicators selected for "environment" and "society" components in the studied regions.

In Masuria, the component "environment" got a general satisfactory rate in 2000. Only a few indicators were assessed negatively. Previous rates were less favourable though in 1930 and 1970 they were only slightly worse. In other periods negative assessment dominated. Negative rates were associated with low densities of wild animals and deforestation of hydrogenic habitats.

In Kurpie, the component "environment" was assessed negatively within the whole study period (since the second half of 19th century). The negative evaluation was caused by the past low densities of wild animals and excessive deforestation of moist, eutrophic habitats. Recent improvements were not sufficient for a general amelioration.

In both regions the component "society" started to be evaluated from the second half of 19th century. In Kurpie, it got a satisfactory rate in 1970 and 2000, previous rates were unfavourable. In Masuria, the component "society" was assessed as satisfactory in 1930 and 1970. The lowest rate it got during the World War II. Recent less favourable rate was caused by the decline in livestock density.

14.2. Relations between historical changes in the regions and concepts of sustainable development

General evaluation of "environmental" and "society" components made possible to assess the degree of development sustainability in the regions (Table 14.3).

The sustainable development was not observed in any term. The state close to sustainability was noticed in 1930s, 1970s and 2000 in Masuria. In two first periods, "society" indicators were high but "environmental" indicators were slightly lower. In 2000, conversely, "environment" had higher rates and "society" lower. This could result from adopted indicators of rural community welfare. Having numerous livestock animals was of great importance. The decreasing role of agriculture in Masuria could modify the welfare criteria and the present state could be considered sustainable.

In Kurpie, the sustainable development was not observed in any term either (since the second half of 19th century). The "environment" state was evaluated negatively within 200 years, while the "society" state was improved in the second half of 20th century. To change this situation forest cover should increase in excessively deforested habitats.

The World War II was the worst period in both regions what confirms 24. principle of SD included in "Rio Declaration" (see Chapter 12).

It should be noted that welfare indicators have always historical and cultural constraints and they cannot diagnose equally well the welfare of different communities. It was observed in Masuria and Kurpie where local communities had definitely a different history.

In Masuria, the World War II and change in the state affiliation caused the deep transformation of local community. War's losses, escapes, displacements influenced the local population density and changes in its national and cultural background. In Kurpie, the local community did not change so dramatically, that is why conversely to Masuria, pre- and post-war community could be compared directly. In Masuria, a lower post-war value of the welfare indicator cannot be interpreted as an obstacle for SD because it describes newly formed local community. Therefore, the simplest indicators (e.g. population density) should be evaluated differently in each community. The use of SD indicators is required and even necessary but they should be evaluated taking into account historical and cultural conditions and the changing knowledge of socio-ecological relationships. These relationships were studied within 200 years in two neighbouring regions, similar in the natural environment but with a different history and it was fortunately found that the SD criteria have been fulfilled the best in the last period. In Masuria, SD could be diagnosed already in 2000 if the present local community was separated from the more numerous pre-war population. In Kurpie, SD can be achieved in 20-30 years if the condition of the environment, accompanying the community welfare improves.

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