Remote Sensing Techniques and Geographic Information Systems for Wetland Conservation and Management: Monitoring scrub encroachment in Biebrza National Park

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ABSTRACT

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The Biebrza National Park is one of the most precious wetland areas in Europe. It was established in 1993 and designated Ramsar site in 1995. Despite its protection status, the open wetland landscape is currently being threatened by the encroachment of shrubs and trees, assumed to have a negative effect on biodiversity. The BNP is looking for effective management strategies to halt this unwanted vegetation succession. Information is required on the current situation, the rate of scrub encroachment and the underlying causes, and more insight is needed in into the different succession types, succession stages and phases (temporal aspects) and scrub expansion types (spatial aspects) in relation to site conditions. In the present project, the first step was made towards a scrub encroachment monitoring system based on remote sensing and GIS.

Keywords: GIS, Remote Sensing, scrub encroachment, vegetation and monitoring, Wetland conservation

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The Biebrza National Park is perceived, both nationally and internationally, as an area with outstanding natural and cultural values. This open wetland area is currently being threatened by the encroachment of shrubs and trees, assumed to have a negative effect on biodiversity. We would like to thank all those who have supported us in the present project which focussed on this problem.

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Summary

The Biebrza National Park, situated in northeast Poland, is one of the most precious wetland areas in Europe. The Biebrza National Park (BNP) was established in 1993 and designated a Ramsar site in 1995. Despite its protected status, the open wetland landscape of the BNP is currently being threatened by the encroachment of shrubs and trees, assumed to have a negative effect on biodiversity. Possible causes of this scrub encroachment process are climate change, drainage activities (both former and ongoing), and land use changes.

The BNP management is looking for effective strategies to halt this unwanted vegetation succession. More information is required on the current situation, the rate of scrub encroachment and the underlying causes, and more insight is needed into the different succession types, succession stages and phases (temporal aspects), and scrub expansion types (spatial aspects) in relation to site conditions.

In the present project, the first step was made towards a scrub encroachment monitoring system based on remote sensing and GIS.

A general survey of different land cover types in the Biebrza National Park (ca. 60.000 ha) using satellite imaging (Landsat-TM) was made. Based on this survey it would seem that about 44% of the National Park is currently covered by scrub and forest communities. Post-classification revealed a net land cover change from open wetland to forest of about 300 ha a year, which is about 0.5% of the total BNP.

Comparable results were obtained using both aerial photography and satellite classification. In addition, more detailed aspects of the scrub encroachment process were studied. A differentiation was made between different scrub and forest cover categories based on density (stocking) and species composition. These categories can to a certain extent be related to different succession stages, i.e. initial, intermediate and final. In the initial succession stage further differentiation was made based on species composition, i.e. birch-willow, birch, willow, aspen and alder encroachment. Spatial expansion types were distinguished by comparing aerial photograph interpretations from 1962/63 and 1997. A differentiation was made between zonal, surface, point, integrative and anthropogenically enforced expansion. The expansion types are often related to succession types, such as secondary creative, secondary recreative, secular and regenerative succession.

The underlying factors of the scrub encroachment process were studied by field observations combined with soil sampling. So far, the spontaneous succession of scrub communities onto open wetlands with meadows, reed and sedge communities, seem to have a regional or sometimes even a local character, revealing the unique condition of each site. Such a finding is crucial for future activities aimed at restoring and regenerating previous conditions. The most important soil indicators for the

ongoing degradation of open wetland ecosystems are total Nitrogen (N_{tot}), Nitrate (NO_3), Phosphorus (P) and Potassium (K).

Although the results of the present project are not sufficient to formulate a complete and comprehensive monitoring system for scrub encroachment in the Biebrza National Park, recommendations are made for future monitoring activities. Several processes, variables and management activities to be monitored for a better understanding of the scrub encroachment process are presented. Some variables can be measured using remote sensing techniques, but additional field observations and measurements are often required.

Within the framework of the BNP management plan 2000-2020, a GIS has been designed and implemented on behalf of those responsible for managing the BNP. All the data collected on vegetation, soil, water, etc. will be available to them in digital form. These geographical data sets can be combined with the results of the present project. More information can be extracted from these data sets. For example, on the influence of site conditions on the rate of scrub encroachment, and the species composition of the site affected by scrub encroachment, etc.

1 Introduction

1.1 Background

There is increasing recognition of the importance of wetland ecosystems. Wetland inventories are required to provide a basis for effective conservation and management. Remote Sensing and Geographical Information Systems are helpful techniques for mapping and monitoring wetlands.

One of the most valuable wetlands in Central and Western Europe is the Biebrza river valley situated in northeast Poland. For many centuries (from the Middle Ages until shortly after the Second World War) this area was valued for its good hay-growing meadows. In the 19th and 20th centuries the land was drained to improve agricultural production. Soon after the Second World War the meadows were abandoned. Due to the effects of drainage, abandonment of the meadows, and climate change, the open wetlands of the Biebrza river valley are now threatened by the encroachment of shrubs and trees.

The management of the Biebrza National Park is looking for effective strategies to stop this unwanted process. Information is therefore needed about the actual state and rate of scrub encroachment and about the factors influencing this process. More insight is required into different succession types, succession stages and phases (temporal aspect), and scrub expansion types (spatial aspect) in relation to site conditions.

At present a management plan is being created for the next twenty years (2000-2020), and will be updated every five years. The general plan needs to be translated into specific management activities on an annual basis. Within the framework of the plan several surveys have been carried out simultaneously with the present project on scrub encroachment.

1.2 Research objectives

The aim of the present project is to contribute to the development of an operational system for monitoring scrub encroachment in wetland areas using Remote Sensing and GIS techniques. An approach is being sought which will take advantage of satellite imaging, aerial photography and field surveys.

The research objectives are as follows:
- Estimating the state and rate of scrub encroachment
- Identifying the different succession types, succession stages and phases (temporal aspects), and spatial expansion types (spatial aspects)

- Preliminary analysis of the underlying causes of the scrub encroachment process, such as climate and land use changes

1.3 Project organisation

The project was carried out by the Institute of Land Reclamation and Grassland Farming (IMUZ) based in Falenty in Poland and by Alterra Green Research Institute, at Wageningen in the Netherlands, with the close cooperation of both the Biebrza National Park Management and Warsaw University. The project was financed by the Dutch Ministry of Agriculture, Nature Management and Fisheries and the Dutch Ministry of Foreign Affairs (MATRA Fund), and the Netherlands Remote Sensing Board.

1.4 Report

In Chapter 2 a general description is given of the Biebrza National Park. In Chapter 3 the phenomenon of 'scrub encroachment' is explained. Chapter 4 is concerned with materials used in the project. In Chapter 5 the methodology and results of satellite interpretation are presented. Chapter 6 deals with the methodology and the results of aerial photograph interpretation whilst Chapter 7 presents conclusions and recommendations.

2 The Biebrza National park

2.1 Introduction

In the following chapters, the historical and geographical settings are described based on the results of former research projects carried out in the Biebrza National Park. Unfortunately, the management plan and results of these different surveys were not available at the time of writing and are therefore not included.

2.2 Historical setting

During the Middle Ages, land use in the Biebrza river valley was restricted to hunting, pasturage, woodcutting and the harvesting of hay and reed. In the eighteenth and nineteenth centuries, the land was drained to improve agricultural production. Following the Second World War, local populations successively abandoned the river valley. During the Communist era plans were made to intensify farming activities (animal husbandry, milk and meat production and hay making). During the sixties, seventies and eighties, peatland reclamation was intensified in Poland and some areas in the Biebrza river valley and its vicinity suffered as a result.
Drainage activities and abandonment of the meadows are thought to be possible causes of scrub encroachment. The groundwater level has fallen due to drainage activities, causing mineralisation of the peat soils which favours scrub and tree species. The abandoned meadows are no longer being harvested, thus allowing the encroachment of shrubs and trees.

2.3 Geographical setting

In the following chapters a summary is given of the different geographical aspects of the Biebrza river valley (figure 1). Special attention is paid to the spatial differentiation of geographical characteristics at both regional and local levels. This differentiation contributes to the biodiversity of the area including the diversity of the wetland ecosystems, flora and fauna, and also determines the different forms of scrub encroachment. In relation to spatial variation, the temporal differentiation in geographical characteristics (seasonal differences) is also discussed.

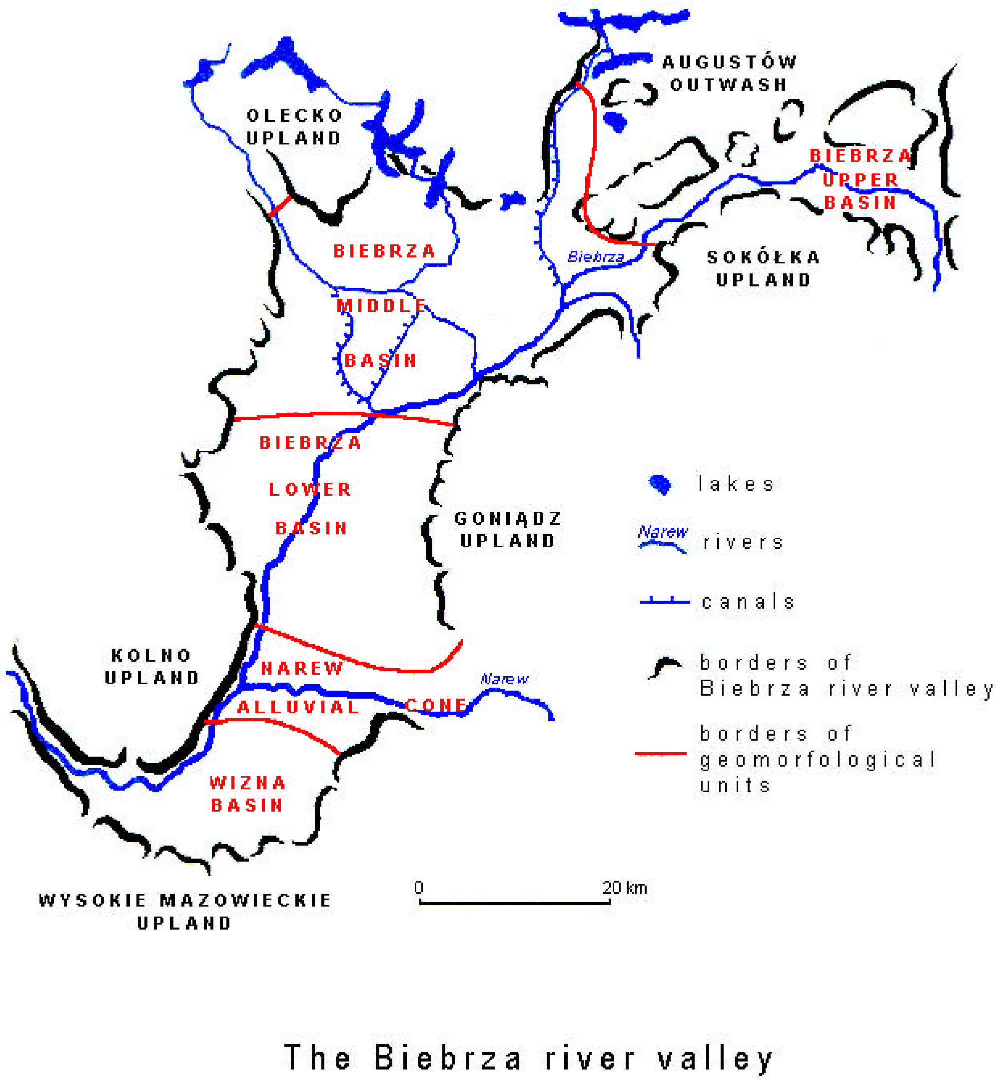


Figure 1 The different geographical aspects of the Biebrza river valley

2.3.1 Climate

The climate of the Biebrza river valley is determined by three main factors: its location in northeast Poland, its characteristic landform and the presence of widespread peat deposits. The first factor is mainly related to global atmospheric circulation which provides a general framework for climatic conditions. The other two factors have a more regional significance, providing the Biebrza river valley with its individual character and determining the spatial differentiation within the river valley.

Temperature

The mean annual temperature in the region does not exceed 7 °C and for the northern part of the region is only 6.5 °C (Kossowowska-Cezak and Olszewski, 1991). Both values are below the mean annual temperature for Poland (8 °C).

In winter (January) temperatures range from 5.5 °C below zero in the northern part (upper basin) to 4.5 °C below zero in the southern part (lower basin). During this season the thermal conditions of the valley do not differ significantly from those of the surrounding upland areas. The snow cover masks the influence of the peat deposits (Kossowowska-Cezak and Olszewski, 1991).

In summer (July) the mean monthly air temperatures range from 17 °C in the northern part of the valley to 19 °C in the southern part. Due to the influence of peat deposits, there are significant differences in temperature between the river valley and the surrounding upland areas during this season.

Humidity

The influence of peat deposits on the regional climate is also obvious when considering the spatial differentiation in humidity.

In winter the differences are relatively small. A tendency towards a slightly higher humidity over peatland areas is observed, particularly in the lower basin. In spring the differences are greater, up to 0.8 hPa. More or less the same as in winter, the highest concentration of water vapour is observed in the lower basin (80% relative humidity).

The greatest differences in humidity between the river valley and the uplands occur in summer. The most humid area during this period is the middle basin where the relative humidity reaches 75% (Kossowowska-Cezak and Olszewski, 1991).

Cloud cover

Cloud cover over the Biebrza river valley is mainly determined by global atmospheric circulation.

Cloud cover is thickest in autumn and winter and often results in precipitation (Kossowowska-Cezak and Olszewski, 1991). In winter (January) the duration of cloud cover is 7.5 to 8 hours per day, while in spring and summer it is only 6 to 7 hours per day (Kossowowska-Cezak and Olszewski, 1991).

Differences in cloud cover between the river valley and the surrounding upland areas are most noticeable in summer. Over the upland areas vertical air currents are more intensive and more effective which cause rapid cloud formation. Over the peatlands, vertical currents expire which limits cloud formation.

The mean annual insolation in the region ranges from 3.6 to 4.2 hours per day. In the lower basin it is slightly higher being 4.2 to 4.8 hours (Kossowowska-Cezak and Olszewski, 1991).

Rainfall
The annual rainfall in northeast Poland is similar to the national mean value of 650 mm. The relief of the river valley and the thick widespread peat deposits are responsible for the spatial differentiation of rainfall in the region. The river valley receives less precipitation than the surrounding upland areas (over 600 mm). Differences within the river valley are discernable. The upper basin receives 470-550 mm while the lower basin receives over 550 mm (Kossowowska-Cezak and Olszewski, 1991).

During spring and summer precipitation is relatively high and accounts for 67% of the annual value (Kossowowska-Cezak and Olszewski, 1991). During autumn and winter the lowest values occur in the middle and upper basins (Kossowowska-Cezak and Olszewski, 1991) which correspond to the latitudinal course of the valley. During this season rainfall in the lower basin is much more abundant. In summer the least rainfall is observed in the upper basin, while rainfall in the middle and lower basins is similar to that in the upland areas.

Snow cover
Snow cover in the Biebrza river valley is present for 110-120 days in the lower basin, for 120-130 in the middle basin and for over 140 in the upper basin. The spatial differentiation corresponds to the gradient of mean annual temperature, which is related to geographical conditions. In general, snow cover within the valley is of less duration than on the surrounding upland areas.

2.3.2 Geomorphology

The Biebrza river valley has a polygenetic character. The main features of the current relief of this area were established in the Pleistocene period (WÜRM or Vistulian) during the last phases of glaciation. In front of the Vistulian ice sheet a large marginal valley was formed in which extraglacial water was collected. In addition to fluvioglacial processes, eolic, melt-out, biogenic, thermokarst and fluvial processes participated in the morphogenesis of the valley. The sketch of the morphogenesis of the Biebrza river valley is presented in Figure 1 Based on the geomorphology, the river valley can be divided into three relatively isolated sections called the upper, middle and lower basins:

Upper basin
The upper basin stretches for 45 km, almost from the spring area located on the slopes of the Sokolka Uplands to the village of Czarniewo. The width of the valley varies from 1 to 3 km. The relative altitude between the bottom of the valley and the uplands is 20 to 25 m.
The northern slopes consist of sand deposits from the Augustow outwash plain shaped by water flowing down from the Vistulian ice sheet. The southern slopes, moraine deposits of former glaciations, are composed of clay and sandy-clay. The bottom of the valley is covered by a peatland plain with some isolated hills, which are

remnants of moraine uplands or 'mineral islands' (Zurek, 1975; Zurek, 1991; Okruszko, 1991).

The eastern part of the valley runs along deep erosional depressions which were formed by glacial processes. The thickness of peat deposits in this part of the valley exceeds 8 m. These peat layers are usually underlain by 3 m thick calcareous gyttja deposits (Zurek, 1975; Zurek, 1991; Okruszko, 1991). The bottom layer of the organic deposits is formed from slightly decomposed sedge-moss peat containing *Carex lasiocarpae, Carex paradoxae, Carex stricta, Scorpidium scorpioides, Drepanocladus sp., Calliergon giganteum* (Zurek, 1975; Zurek, 1991; Okruszko, 1991). The peat lying above this layer is more decomposed and was formed from sedges and, in some parts, reed communities. The upper layer of the organic deposits also contains slightly decomposed sedge-moss peat. Sedge peat containing particles of *Magnocaricion* species is found in the narrow zone along the riverbed (Zurek, 1975; Zurek, 1991; Okruszko, 1991).

The peat deposits in the western part of the basin are 3 m thick, composed of sedge communities and underlain by detrito-calcareous gyttja deposits. The degree of decomposition of the peat is higher than that found in the eastern part (Oswit, 1991). Forest peat deposits and peat bog deposits rarely occur in the whole of the upper basin.

Middle basin

The middle basin is a large irregular depression that stretches along the course of the Biebrza from Czerniewo to Goniadz. The maximum length of the basin is 40 km, while the width is about 20 km.

In its northern and western parts, the middle basin meets the Vistulian sandy outwash plains and clayey moraine uplands, while the southern border is formed of clayey moraine uplands of former glaciations (Zurek, 1975, Zurek, 1991).

Landforms at the bottom of the basin are diversified and correspond to shallow geology. The largest area, about 450 km^2 (Zurek, 1991), is occupied by a flood plain covered with peatlands The average thickness of organic sediments in this area is 2 to 3 m (Oswit, 1973; Zurek, 1975). The peat deposits vary according to different hydrological conditions. At the beginning of peat deposition, early Holocene organic materials accumulated in shallow lakes of stagnant water that were fed sporadically by groundwater under pressure (Oswit, 1973; Zurek, 1975). The slightly decomposed sedge-moss peat and gyttja layers reveal specific hydrological conditions during the initial phase of peat growth (Oswit, 1973; Zurek, 1975). The next phase of peat accumulation is connected with the Atlantic period when the climate was warmer and more humid. The peatlands were fed mainly by groundwater and floods. During this period the total area of peatlands in the middle basin was significantly enlarged (Zurek, 1975). Most of the organic deposits from this period contain well-decomposed sedge peat. Near the edges of the basin and around the mineral islands, forest peat with *Alnus glutinosa* particles occurs (Oswit, 1973; Zurek, 1975). In the upper layers of the peat deposit, sedge peat is the most common, indicating different hydrological conditions. During the next Holocene period the climate became more humid and the role of river water flooding the surrounding areas became less important. Reed peatlands together with alluvial organic and mineral deposits occur only in the direct vicinity of the riverbed (Oswit, 1973; Zurek, 1975).

The northern part of the basin is related to the outwash plain. Its relief is diversified. During the early Holocene, complexes of latitudinal dunes and depressions filled with peat arose in this area. Beneath fluvioglacial sand, are sediment layers of impermeable lacustrine clays (Oswit, 1973; Zurek, 1975).

Lower basin

The lower basin is 30 km long and 12 to 15 km wide. The northern border is formed by a narrow part of the valley near Goniadz. The southern border is the confluence with the river Narew. The south-western and north-eastern slopes of the valley have an erosional character. The relative altitudes between the bottom of the valley and the surrounding upland areas are 10 to 20 m. These areas consist of moraine clays, sands and gravels. In certain areas sandy hills occur. The bottom of the valley is divided into a floodplain covered with peat deposits and a sandy fluvioglacial terrace, 2 to 3 m above the floodplain.

The floodplain consists of a separate riverain zone with alluvial mud (organic) deposits in the northern part of the basin and mineral deposits in the southern part.
The zone is up to 2 km wide, and the borderline is marked by oxbows and by the old riverbed of the Biebrza (Oswit, 1973; Zurek, 1975).

The largest area of the floodplain is covered with peat. The thickness of the organic deposits in the whole basin does not exceed 3 m (Oswit, 1973). Among the organic materials, sedge peat and sedge-moss peat predominate. Sedge-moss peat occurs in the bottom layers. In comparison to other basins sedge-moss peat deposits are less widespread (Oswit, 1973; Zurek, 1975). During the later stages of peat formation the peatlands expanded into the whole area of the basin (Zurek, 1991). In the peat deposits reed and forest peat predominate. In the upper layer sedge and sedge-moss peat are often encountered (Oswit, 1973; Zurek, 1975). Below the alluvial and organic materials lie the sandy-gravel sediments of the fluvioglacial terrace which is more than 30 m thick (Zurek, 1975). Large areas of sandy fluvioglacial terrace with dunes are preserved in the eastern part of the valley. Parts of this terrace occur as isolated mineral islands surrounded by peatland area.

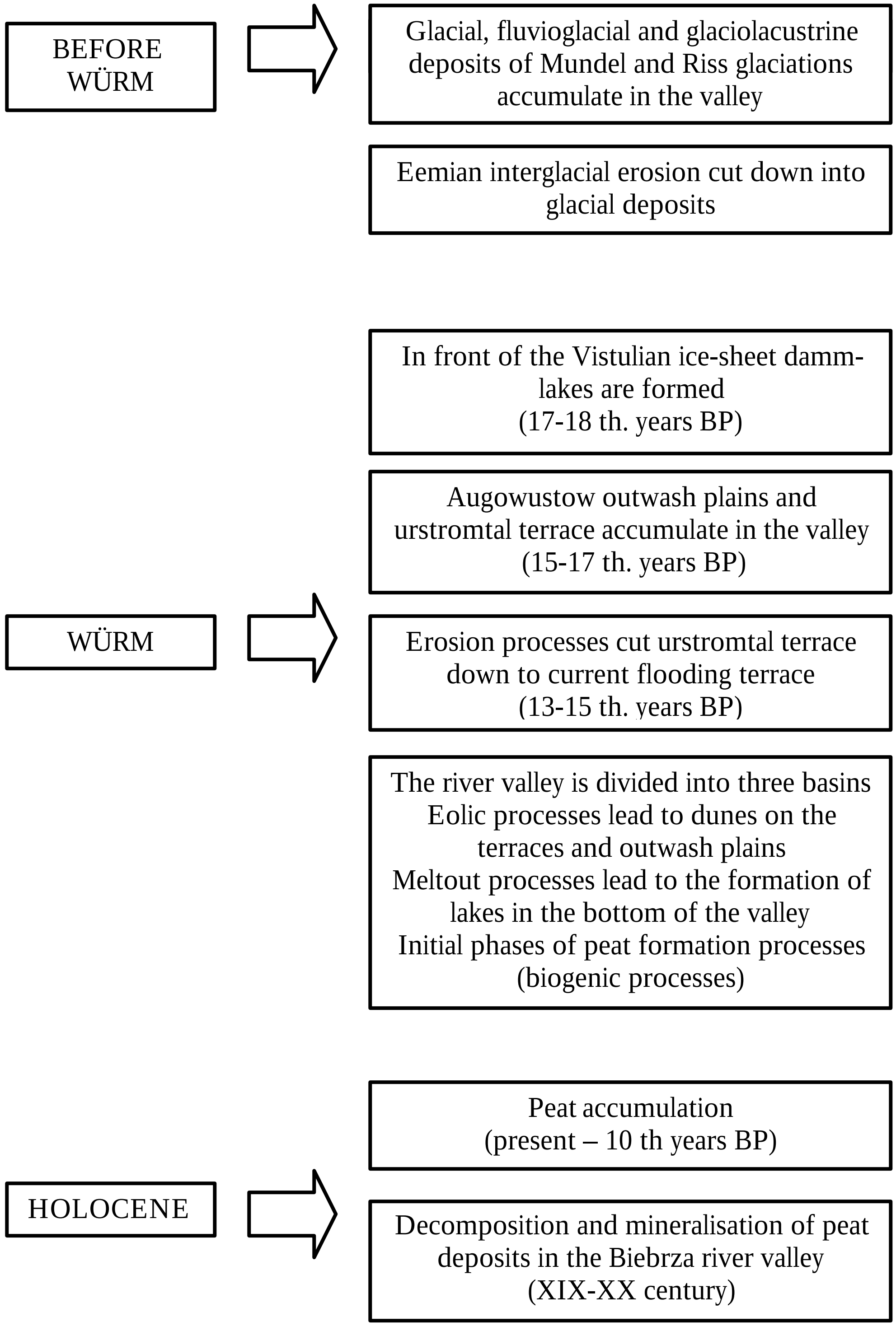


Figure 1 Scheme of the morphogenesis of Biebrza river valley (after Zurek 1975, 1991)

2.3.3 Soil

Different types of hydrogenous sites cover about 60% of the Biebrza River valley. About 46% consist of peatlands and about 14% of organic-mineral and mud sediments. The remaining 40% consists of mineral deposits (Churski and Szuniewicz, 1991) which are the result of alluvial, glacial or fluvioglacial processes.

Two different groups of peat soils are found: soils in the accumulation phase of peat formation and soils in the decession phase with a mineralised upper layer. The first group is found less frequently within the Biebrza river valley and covers about 30% of the total area of peat soils (Churski and Szuniewicz, 1991; Okruszko, 1991). These soils occur mainly in the upper basin and only in certain parts of the middle (Czerwone Bagno) and lower (Bagno Lawki) basins. Within the whole group slightly swamped peat soils predominate (17.400 ha).

The mineralisation process in the Biebrza valley is a consequence of over-drainage caused by the ditches and canals dug in the nineteenth century, the lowering of the groundwater table, changes in land use and changes in climate. The largest mineralised areas are in the middle and lower basins.

Mud, mud-peat and moorshy-mud soils belong to the organic soils that cover a vast area of the valley, particularly in the lower and middle basin where they form a strip-zone running along the riverbed. The width of the zone reaches 2 to 3 km, and covers an area of 4000 ha.

Mineral-organic soils are limited to the Augustow outwash plain, the narrow zone between the lower and middle basins and the southern part of the lower basin. The total area of this type of soil is 21.800 ha.

2.3.4 Hydrology

The Biebrza is the longest right tributary of the Narew. Its length from the spring area located at Bagna Jatla on the slopes of the Sokolka Uplands to its mouth (near the village of Wizna) is approximately 170 km (Byczkowski and Kicinski, 1991).

The longitudinal profile of the river is diversified. The steepest gradients are found in the upper course of the river, where the mean gradient values reach 3 per mil. The shallower gradients are found along parts of the river valley filled with peat deposits (less than 0.1 per mil). The mean gradient of the longitudinal profile is 0.36 per mil (Byczkowski and Kicinski, 1991).

The area of the whole Biebrza catchment exceeds 7000 km^2 (Byczkowski and Kicinski, 1991). The longest tributaries of the Biebrza are the Netta, Jegrznia, Elk, Sidra, and Brzozowka. The asymmetry of the catchment area is pronounced, with the right side of the catchment encompassing more than 75% of the total area (Byczkowski and Kicinski, 1991). A large fragment of the Suwalki Lakelands is situated within this part of the catchment. The lakes cover 157 km^2 (2.3% of the total area of the catchment).

Outflow values from subcatchments within the Biebrza catchment are spatially diversified and related to the heterogeneous geomorphological and geological conditions. The highest values are representative of subcatchments located on old moraine and young glacial uplands (over 7 $l/s/km^2$). The lowest values occur in subcatchments in outwash plains and within the ice marginal valley (over 5 $l/s/km^2$).

The temporal variation in the maximum values of runoff is greatly influenced by the heterogeneous geomorphology of the valley. In the lower basin over 60% of runoff occurs in spring and summer (Byczkowski and Kicinski, 1991). Maximum runoff is observed in April. In the upper basin over 65% of the runoff occurs in autumn and winter (Byczkowski and Kicinski, 1991). The differences are caused by the temporal retention of surface and ground water in the Suwalki Lakelands, which postpones the spring floods in the valley. For tributaries running through old glacial uplands, which have smaller storage capacities, the maximum values of outflow occur in March (Byczkowski and Kicinski, 1991).

The Biebrza river valley has the largest retention capacity of all Polish rivers (Byczkowski and Kicinski, 1991). With an average discharge, the flooded area encompasses 166 km^2, and retention capacity exceeds 125 mln m^3 (Byczkowski and Kicinski, 1991). The value of retention per unit for the whole valley is about 1 mln m^3/m^2. Each basin has a different retention capacity. The largest is observed in the lower basin, the smallest retention capacity is in the upper basin (Byczkowski and Kicinski, 1991).

The mean annual runoff is 4$l/s/km^2$, the total amount of annual runoff being 867m^3. The mean annual discharge is 27 m^3/s.

2.3.5 Vegetation

Natural zones of plant communities occur in the Biebrza National Park (Oswit, 1973; Palczynski, 1984), which can be divided into transversal zones (from river to the edge of the valley) and longitudinal zones (from upper basin to lower basin).
The transversal zones consist of the following:

- An immersion zone with reed and tall sedge communities (*Phragmition, Sparganio-Glycerion* and *Magnocaricion)*
- An immersion-emersion zone where a transition occurs from tall sedge communities to short sedge-moss communities (*Caricion fuscae*)
- An emersion zone with sedge-moss communities (*Caricion lasiocarpae*)
- A marginal zone with forest communities (*Carici elongatae-Alnetum*)

The longitudinal zones may be recognised in various formations of transversal zones in particular sections in the valley. For instance, in the upper basin neither immersion nor marginal zones are to be found, while at the valley periphery, near the Vistua-

Niemen watershed, oligotrophic bogs (*Spagnetum magellanicum*) have developed (Palzynski, 1984).

Due to mowing and drainage, part of the natural reed and sedge-moss communities have been transformed into grassland (meadow) communities *(Molinion, Filipendulion, Calthion* or *Arhenatherion*). Meadows that have been abandoned, mowing or grazing having ceased, have been (or are being) transformed into scrub and forest communities (*Alnion glutinosae, Carici Betulion or Alno-Padion*).

For the purpose of the management plan 2000-2020 an actual vegetation map has been created using typology partly based on typologies used by Oswit (1973) and Palzynski (1984). The legend of this map (Appendix 1) contains only a general description of the vegetation (alliances and in some cases associations) of the non-forested areas.

3 Scrub encroachment: terminology

Vegetation dynamics is a major research topic in ecology. A list of terms, theories and models has been elaborated to describe and explain this phenomenon. An abundance of terminology might be confusing. To avoid misunderstanding, the most important terms and theories in the scope of the scrub encroachment process in the Biebrza river valley are described and defined in the following chapters.

3.1 Vegetation succession

Vegetation succession is a continuous process of change in vegetation, which can be separated into a series of stages and phases. Different types of succession are distinguished.
Primary succession is the establishment of plants on land which has not previously been vegetated, and includes the development from pioneer vegetation to climax vegetation.
Secondary succession is the invasion by plants of a habitat that was previously vegetated. Removal of past vegetation may be the result of natural or human disturbance such as fire or logging.

Falinski (1991) made a distinction between secondary creative and secondary recreative succession.
Secondary creative succession is a set of processes leading to the formation of a climax vegetation, dissimilar to the previous vegetation at a given place.
Secondary recreative succession is a recreation of the climax vegetation, formerly occurring at a given place.

Beard (1974) introduced another term, namely secular succession.
Secular succession means long-term (in a geological sense) vegetation variability in a landscape, due to climate change.
Regenerative succession is a term used for the reconstruction of a mature community after its destruction, for example by fire, when the destructive factor ceases to have an effect.

The presence of thick sedge peat deposits in the Biebrza river valley indicates the longevity of sedge communities, which formed here as climax vegetation under specific climate conditions. Due to climate change during the Holocene period, the present climax vegetation consists of forest communities instead of sedge communities. Scrub encroachment in the Biebrza river valley should thus be considered as secular and secondary creative succession.

Besides climate change one should also consider the impact of human activities on vegetation dynamics. As described in Chapter 2, human impact in the Biebrza river valley in the Middle Ages was restricted to hunting, pasturage, woodcutting and the harvesting of hay and reed. These activities resulted in the transformation of the natural wetland vegetation (reed and sedge communities) into meadow vegetation in some parts of the Biebrza river valley, but also prevented these areas from being overgrown by shrubs and trees.

Within the framework of the action for peatland reclamation, hydro-technical works consisting of amelioration of canals and troughs were carried out. Due to these drainage activities the groundwater level fell in some parts of the river valley, causing mineralisation of the peat soils, which favoured shrub and tree species. Because peatland reclamation required considerable labour and financial input, and since the effects in the sense of high agricultural production were minimal, people gradually left the area. The troughs are currently overgrown with vegetation, which has resulted in a rise of the groundwater table and consequently reswamping of the area.
Due to abandonment of the area (cessation of mowing and grazing) the semi-natural meadow communities are becoming overgrown with shrubs and trees. The vegetation succession in this case should be considered as secular and secondary creative succession. The vegetation succession on the reswamped areas could be considered as secondary recreative succession, but only if the vegetation changes favour the primeval plant community.

3.2 Succession stages and phases (temporal aspects)

Succession stages and phases are terms for successive steps by means of which the vegetation succession process can be described. Commonly, three main stages are distinguished.
The initial stage: the first stage of the succession process in which a habitat is invaded by plant species, in this case called the pioneer vegetation.
The transitory stage: the second and most dynamic stage of the succession process in which, due to population processes, many changes occur in species composition.
The climax stage: the third and last stage of the succession process in which the plant community is stabilised.

Scrub encroachment on abandoned sedge and meadow communities takes place relatively quickly. Areas adjoining forest complexes face particular pressure. Falinska (1989) assessed that on fertile wet meadows initial forest phases appear fifteen to twenty years after abandonment. Besides these initial forest phases are many other transitional communities forming vegetation mosaics.

Based upon observations carried out on *Cirsietum rivulare* meadows in the vicinity of the Bialowieza National Park (Falinska, 1989), initial transitory and terminal stages and phases have been distinguished.

The initial stage lasts about nine years. During this stage two phases of succession have been observed in which reconstruction of the species and spatial structure of the meadow community have taken place. Herbs become dominant and form a mosaic spatial structure. Stage-forming species are *Filipendula ulmaria*, *Carex caespitosa*, *Carex acutiformis, Lythrum salicaria, and Lysimachia vulgaris.* First individuals of willows appear among herbs.

The transitory stage involves two subsequent phases leading to the formation of a mosaic of meadow, herb and willow scrub communities, in which the first trees of *Alnus glutinosa, Betula pubescens* and *Frangula alnus* appear. Falinska estimates that the transitory stage could be prolonged for up to fifteen years.

The climax stage likewise consists of two phases. As a result, relative spatial and temporal stabilisation established in the willow-alder scrubs, are considered to be an initial stage in the formation of *Circaeo-Alnetum.*

Typical of succession on abandoned meadows is a gradual increase in structure complication. Transitory stages dominated by herbs are relatively stable. Acceleration of change takes place with the appearance of the successive tree species. The first is associated with the appearance of willow; the stage of a mosaic of sedges, herbs and willow patches may last for several years. The next acceleration is associated with the appearance of alder and birch.

The above observations demonstrate temporal and spatial sequences of transformation of the *Cirsietum rivulare* community. Although they cannot be extrapolated to the wet sedge and meadow communities of the Biebrza National Park, they represent a temporal scale and some general trends of the process.

There are no similar, detailed, studies of the phenomenon and the rate of succession in the Biebrza valley. Approximate data can be obtained by comparing archive and current aerial photographs. Considering the results of studies of succession on meadows in the Bialowieza National Park, and in particular the finding that the time span of the sequence of stages from initial to terminal is thirty to forty years, the aerial photos available from 1962 and 1997 (see Chapter 4) should show the whole spectrum of transitory stages of succession.

3.3 Spatial expansion types (spatial aspects)

Apart from the different succession stages, characterised amongst others by vegetation structure and plant species composition, different spatial patterns are observed. During the succession process, the frequency of occurrence of certain plant species and the way the plant species occupy space, alters. The way plant species colonise space depends on their biological and morphological properties and particularly their ability to expand and occupy new sites even in small numbers (Falinski, 1991). Besides species ecology other factors influence the spatial differentiation of plant communities such as site conditions (e.g. soil type and water regime) and neighbouring plant communities.

In a pilot study based on aerial photograph interpretation (Piórkowski, 1997, Piórkowski and Rycharski, 1999), different spatial expansion types were detected in the Biebrza river valley:

Zonal expansion: shrub and tree species forming zones and bands similar in shape to the adjacent areas covered by scrub and forest communities, according to Chessel (Falinska, 1991) a gradient type of spatial structure;

Surface expansion: large open wetland areas (natural reed and sedge communities or semi-natural meadow communities) being invaded by shrub and trees species of similar age, height and stem thickness, according to Chessel (Falinska, 1991) a randomly distributed or regular type of spatial structure;

Point expansion: shrub and tree species forming expansion centres, usually isolated patches of dense, moderately dense or open scrub communities, according to Chessel (Falinska, 1991) a dispersed type of spatial structure;

Integrative expansion: open scrub communities or single tree species filling in gaps, according to Chessel (Falinska, 1991) a cluster type of spatial structure;

Anthropogenically forced expansion: scrub expansion restricted to the abandoned parcels or plots characterised by a network of regular geometric patches.

4 Materials

4.1 Thematic maps

Among materials widely used in studies on vegetation succession, topographical and thematic maps (geomorphological maps, soils maps and vegetation maps) are of great significance. The thematic maps provide information that is to some degree interpreted, transformed and often generalised. They serve as valuable reference sources for interpreting remotely sensed data and are important for analysing vegetation succession. In the following paragraphs the thematic maps used for analysing the scrub encroachment process in the Biebrza National Park (Table 1) are described briefly.

Atlas of the Wetlands of Poland
IMUZ has created a 1:300,000 Atlas of the Wetlands of Poland (Okruszko, 1995) based on the elaborated 1:100,000 map of Poland’s wetlands and grasslands (286 sheets). The latter was based on several sources such as topographical maps, soil maps and vegetation maps. The Atlas is in two parts. The first section shows the distribution of wetland areas distinguished into natural and transformed areas. The second indicates their differentiation into peatlands and non-peat wetlands. Both sections show the plant communities associated with the highlighted areas.

Tourist map
There is a 1:120,000 tourist map of the Biebrza National Park available, which indicates the Park boundaries. On this map, 28 ‘physiocoenoses’, defined as spatial ecological units relating to plant communities and the characteristic accompanying fauna, are also indicated and described in a supplement.

Vegetation maps
Oswit (1973) and Palczynski (1984) carried out two extensive vegetation surveys that resulted in two analogue vegetation maps on a scale of 1:25,000. Both maps were made for the whole of the Biebrza valley using direct field cartography. Different classifications (typologies) are used to characterise the vegetation. Some attention was also given to the expansion of forest and scrub communities.

In 1999, an actual vegetation map was prepared for the purpose of the management plan (see Chapter 2.1). The map contains a general description of the main characteristics of the plant communities of the non-forested ecosystems using a phytosociological approach (Appendix 1) and contains only general information on the advancement of scrub and tree communities. An unambiguous phytosociological classification of areas undergoing succession towards forest communities is however missing.

4.2 Remotely sensed data

Direct information on land cover, vegetation cover, the extent of areas affected by scrub encroachment, and other land surface characteristics can be obtained from satellite images and aerial photographs. In the following paragraphs the remotely sensed data used for mapping and monitoring scrub encroachment in the Biebrza National Park (Table 1) are briefly described.

Aerial photographs

Two series of aerial photographs were selected from the archives. The first series consists of panchromatic photographs taken in July / August 1962 / 1963 on a scale of 1:16,000 and enlarged to a scale of 1:10,000. The photographs were taken for military purposes and cover about 90% of the Biebrza National Park. Missing photographs refer to the eastern part of the upper basin (from the source of the Biebrza in the east, to Lipsk in the west) and a fragment bordering the middle and lower basins (from Goniadz in the north to Osowiec in the south).

The second series used in the project consisted of colour photographs taken in October 1997 on a scale of 1:20,000. These photographs were taken specifically for the protection plan (management plan) of the Biebrza National Park and cover the whole area of the park.

Satellite images

Landsat TM images of spring (May 1988 and May 1997) and summer (July 1988 and August 1997) covering a period of about ten years were selected.

Table 1 Data sources

Type of data		**Date**	**Scale**
Remotely sensed data	Landsat TM images	May 1988 May 1997 July 1987 August 1997	1 pixel = 25m^2
	Panchromatic photographs	July / August 1962 / 1963	1:16,000
	True colour photographs	October 97	1:20,000
Reference data	Topographical map 1:100,000	1995	1:100,000
	Topographical map 1:25,000	1982	1:25,000
	Atlas of the Wetlands of Poland		1:300,000
	Tourist map	1998	1:120,000
	Vegetation map (Palczynski)	1977-1979	1:25,000
	Vegetation map (Oswit)	1973	1:25,000
	Actual vegetation map	1999	1:25,000

5 Satellite image interpretation

5.1 Introduction

Landsat TM images were used to map and monitor scrub encroachment in the Biebrza National Park. Image analysis and classification were carried out using Erdas Imaging software. Vector layers were created using Arc/Info and Arc/View software.

In Chapter 5.2 the selection and pre-processing of the materials and data is discussed. The methodology is described in Chapter 5.3. The results are presented in Chapter 5.4.

5.2 Pre-processing of the data

Table 2 gives an overview of the materials used. For a description of these materials see Chapter 4. In the following paragraphs, the pre-processing of the data is described.

Table 2 Materials used for satellite interpretation

Type of materials		Date	Scale
Remote sensed data	Landsat TM	May 1987 May 1997 August 1997	1 pixel = $25m^2$
	Aerial photographs (10 selected examples)	October 97	1:20,000
Topographical and thematic maps	Topographical map	1995	1:100,000
	Tourist map	1998	1:120,000
	Atlas of the Wetlands of Poland		1:300,000
	Vegetation map (Palczynski)	1977-1979	1:25,000
	Vegetation map (Oswit)	1973	1:100,000

5.2.1 Remotely sensed data

Satellite images

The satellite images were geometrically corrected using the digitised topographical map 1:100,000. A first order polynomial equation was applied using an RMS (root mean square) < 1 pixel (= $25m^2$). Subsets were made of the upper, middle and lower basins of the Biebrza river valley using the digitised tourist map.

Aerial photographs

Ten aerial photographs 1:20,000 taken in October 1997 were selected and scanned with a resolution of 500 dpi in order to assist interpretation of the satellite imaging.

5.2.2 Topographical and thematic maps

Topographical map

The topographical map (scale 1:100,000), published by the Polish National Cartographic Publishing House, was used as a base map. This analogue map was scanned and geo-referenced according to the coordinate system indicated on the map, before being used for geometric correction of the satellite images and geo-referencing of the tourist and Atlas maps.

Tourist map

The tourist map (scale 1:120,000) was scanned and geo-referenced using the digitised topographical map. The Biebrza National Park boundaries and the borders of the 28 physiocoenoses were digitised and this vector layer was then used to subset the satellite images and to assist image interpretation and automated classification.

Atlas of the Wetlands of Poland

The Atlas data were not available in Arc/Info format. Two analogue map sheets covering the Biebrza river valley were therefore scanned and geo-referenced using the digitised topographical map. A vector layer with regular polygons (grid cells) was created and then transformed to the coordinate system of the topographical map. Attributes and attribute values were assigned to these polygons according to the information on the maps (Table 3) and this vector layer was also used to assist image interpretation.

Table 3 Attributes and attribute values of the vector layer derived from the Atlas of the Wetlands of Poland

Wetland type		**Wetland Status**		**Plant community**	
Code	**Description**	**Code**	**Description**	**Code**	**Description**
1	Peatland	1	Natural	1	Reed swamp
2	Non-peat wetland	2	Transformed	2	Tall sedge mires
		3	Woodland and scrub	3	Tall sedge mires with moss and moss-sedge mires
				4	Minerotrophic raised bog
				5	Ombrotrophic raised bog
				6	Hay and grazing grassland with variable moisture content
				7	Slightly moist and dry grassland
				8	Woodland and scrubland on hydrogenic soils
99	Non-wetland	99	Non-wetland	99	Non-wetland

5.3 Methodology

5.3.1 Visual interpretation

Landsat TM images of May 1997 and August 1997 were visually interpreted. A combination of spectral bands 3, 4 and 5 (Table 4) was made. Bands 3 and 4 were selected for identifying the vegetation structure types. Vegetation absorbs red and reflects infrared depending on the amount of living biomass. Band 5 was selected for the discrimination of vegetation moisture and soil moisture content. Mid-infrared is well absorbed by water, so the Mid-infrared response from inundated areas or from areas of high soil moisture is very low.

Table 4 Thematic Mapped spectral bands (adapted from Lillesand and Kiefer, 1997)

Band	**Wavelength ? m**	**Nominal Spectral Location**	**Principle Applications**
1	0.45-0.52	Blue	Designed for water body penetration making it useful for coastal water mapping. Also useful for soil/vegetation mapping, forest type mapping, and cultural feature identification.
2	0.52-0.60	Green	Designed to measure green reflectance peak of vegetation for vegetation discrimination and vigour assessment. Also useful for cultural feature identification.
3	0.63-0.69	Red	Designed to sense a chlorophyll absorption region aiding in plant species differentiation. Also useful for cultural feature identification.
4	0.76-0.90	Near-Infrared	Useful for determining vegetation types, vigour and biomass content, for delineating water bodies, and for soil moisture discrimination.
5	1.55-1.75	Mid-Infrared	Indicative of vegetation moisture content and soil moisture. Also useful for differentiating between snow and clouds.
6	10.4-12.5	Thermal Infrared	Useful in vegetation stress analysis, soil moisture discrimination, and thermal mapping applications.
7	2.08-2.35	Mid-Infrared	Useful for discriminating between mineral and rock types. Also sensitive to vegetation moisture content.

Using the tourist map, the Atlas maps and the vegetation maps of Oswit (1973) and Palczynski (1984), the following land cover types have been distinguished.

Arable land

Arable land can easily be distinguished in the upper and middle basins. This arable land actually falls outside of the Biebrza National Park boundaries. In spring (May) some parcels are covered with crops. Such parcels have a low reflection in the red band and a high reflection in the infrared band. Other parcels are bare and therefore have a high reflection in the red and a low reflection in the infrared bands. In summer (August) most of the crops cultivated in these areas are harvested which results in a high reflection in the red band and low reflection in the infrared band. Apart from the spectral characteristics, the arable land can be distinguished by the rectangular pattern of the parcels.

Grasslands or meadows

Grasslands or meadows can be distinguished in the upper, middle and lower basins. Most of the grassland vegetation has already developed by the spring (May). These areas therefore have a low reflection in the red and a high reflection in the infrared bands. In summer (August) some of these grasslands are mown and such areas have a high reflection in the red and a low reflection in the infrared bands. Similar to arable land, some grassland can also be distinguished by the rectangular pattern of the parcels.

Reed swamps, tall sedge mires, tall sedge mires with moss and moss-sedge fens

On the May images, areas covered by reed swamps, tall sedge mires, tall sedge mires with moss and moss-sedge mires can be clearly distinguished from the areas of arable land, grasslands and forests. In spring, the swamp and mire vegetation has not yet fully developed and therefore has a relatively high reflection in the red (possibly also because of the dead plant material or litter) and a low reflection in the infrared bands. Because of their irregular pattern the areas with more natural vegetation can be clearly separated from the arable land and most of the grassland communities still in use.

Within the areas covered with swamp and mire vegetation there is considerable differentiation in spectral characteristics. This differentiation might be explained by differences in vegetation structure as well as by differences in soil moisture. Based on the reference materials available, it is difficult to relate these characteristics to actual vegetation structure types. The low reflection in the red and the high reflection in the infrared bands in August most probably indicate reed and tall sedges and scrub vegetation because they consist of more biomass than moss sedge fens.

Deciduous and coniferous forest

Forested areas can clearly be distinguished from other land cover types on the May images. In this period the trees are foliated and have a low reflection in the red and a relatively high reflection in the infrared bands. Forested areas can be separated from areas covered by grasslands, because they have a relatively lower reflection in the infrared band. A differentiation can be made between deciduous and coniferous forests. Coniferous forests have a lower reflection in the infrared band than deciduous forests. The coniferous forest on hydrogenic sites (mainly organic soils, peat soil) can be separated from the coniferous forest on non-hydrogenic sites (mainly mineral soils) because of the relatively low reflection in the Mid-infrared band. In deciduous forests, this distinction (hydrogenic versus non-hydrogenic) is not as clear.

Water

Areas covered by water have a low reflection in both the red and infrared bands throughout the whole year and can therefore be clearly distinguished from other land cover types. In spring, part of the river valley is flooded. In summer, this area is covered with vegetation; mainly reed, tall sedges and willow scrub.

5.3.2 Automated classification

Landsat images of May 1987 and 1997

A supervised classification was carried out of the Landsat TM images of May 1987 and May 1997.

Using the tourist map, the Atlas map, vegetation maps and aerial photographs, signatures of the following land cover types were created:

1. Water
2. Reed and / or sedge communities on relatively wet sites
3. Reed and / or sedge communities on intermediate wet sites
4. Reed and / or sedge communities on relatively dry sites
5. Grassland communities (meadows)
6. Deciduous forest communities on relatively dry sites (mainly mineral soils)
7. Deciduous forest communities on relatively wet sites (mainly organic soils))
8. Coniferous forest communities on relatively dry sites (mainly mineral soils)
9. Coniferous forest communities on relatively wet sites (mainly organic soils)
10. Agricultural areas (bare fields)

Some of the spectral differences of the land cover types described above were assumed to have been caused by differences in 'soil moisture content' (relatively wet versus dry sites). No reference material or field data were available to verify this assumption.

Figure 2 depicts the mean values of these signature sets in a feature space plot of band 4 (Mid-infrared, MIR) and band 5 (Infrared, IR). Two gradients are assumed to be observed, namely a 'vegetation and soil moisture' gradient (MIR) and a 'biomass content' gradient (IR), see also Table 4.

The grassland or meadow communities can be distinguished from other land cover types because of the relatively high reflection in the IR band (high biomass content). The coniferous and deciduous forest communities can be distinguished from other land cover types because of the relatively low reflection in the MIR band (high vegetation moisture content), although the distinction of forest communities on the relatively wet and dry sites is less successful. The signature set for water shows some overlap with the signature sets for reed and sedge communities and coniferous forest communities. This is probably caused by 'mixed pixels'. In the upper and middle basins the water surfaces are relatively small (river and tributaries and canals). The resolution of Landsat TM (30 x 30 m) images is not high enough to enable homogeneous 'water pixels' to be distinguished. The different signatures for reed and sedge communities also show some overlap, which is quite logical considering the (assumed) gradient from relatively wet to relatively dry sites and the resulting 'mixed pixels'. The signature set for the bare agricultural fields shows some overlap with the reed and sedge communities.

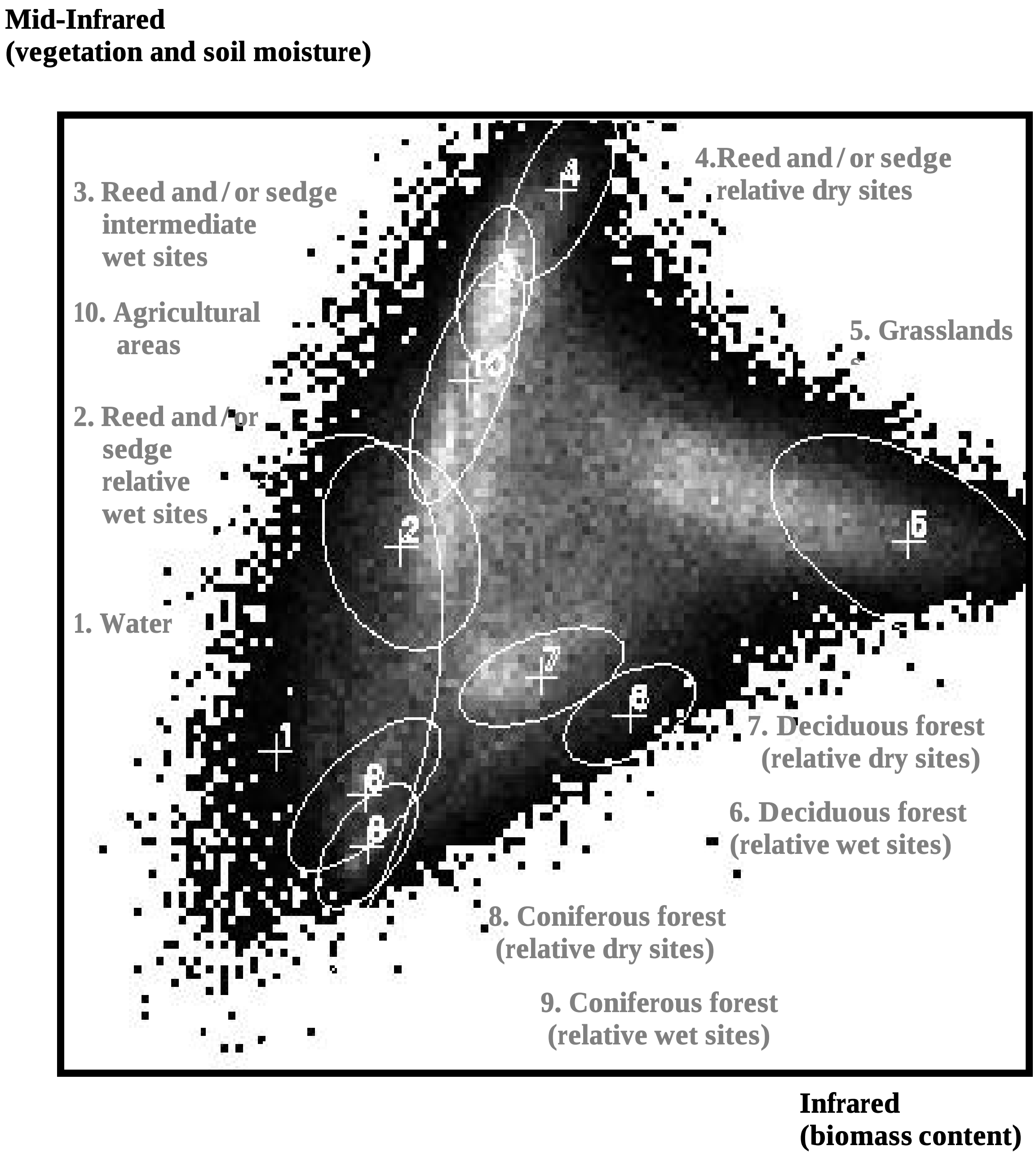


Figure 2 Feature space plot of band 4 (Infra-red) and 5 (Mid-infrared) and the mean values of the signature sets used for supervised classification of the Landsat TM images of May 1997, middle basin

Based on the signatures described above, supervised classification was done using the Maximum Likelihood decision rule (Lillesand and Kiefer, 1997). The agricultural areas were excluded from the classification by means of visual interpretation.

Accuracy

Normally, in order to assess the accuracy of image classifications a confusion matrix or error matrix is created. Such a matrix summarises the results of a sample survey in which a reference data set is compared to corresponding spots on the classified images.

This procedure is only successful if the reference data (thematic maps, aerial photographs and field data) correspond with the classified images in terms of classification (e.g. with regard to plant communities or land cover types) and in terms of temporal (date) and spatial (level of detail) scales. In this case, apart from the aerial photographs, the reference materials (tourist map, Atlas map, vegetation maps) are all out of date and, in addition, the Atlas map is on a different scale (1:300,000). Also, the information on most of these maps is of a generalised nature. The tourist map for example gives only a general description of 'physiocoenoses'.

In this project, the following procedure was observed in order to give some indication of the accuracy of the classifications. Of each land cover type, 5 to 6 signature sets (sets of training samples) were created and considered as subsets representing subclasses of the main land cover classes. The training sets were evaluated by means of a contingency matrix (comparable to the error matrix described above). In order to create such a contingency matrix, quick classification of the pixels belonging to the signature sets is performed. Percentages of the pixels that are actually classified as expected are calculated. Two of each of the 5 to 6 subsets representing the land cover classes were treated as test data sets (reference data) and given a probability of zero. In this way they had to be classified as one of the other subclasses, preferably within the same land cover class. The other subsets were treated as normal training samples and given a probability of one.

In Appendix 2 the contingency matrices are presented for both the training data sets and the test data sets. The values on the diagonal of the matrices represent the number of pixels correctly classified. The off diagonal values represent misclassified pixels. Those values that have been classified incorrectly along a column are called errors of omission and the values that have been classified incorrectly along a row are called errors of commission. Note that the errors of omission of one class are the errors of commission of the other class.

The contingency matrices give some idea of the classification accuracy, but one should realise that the signature sets contain relatively homogeneous pixels, which results in relatively accurate classifications. If all the pixels of the images are classified many heterogeneous pixels or mixed pixels are also included in the classification, which results in less accurate classifications.

The inaccuracy or uncertainty might be better described by means of posterior probability vectors (Wel, 2000). Such vectors provide, for each pixel in the image, the posterior probabilities that define the probability of membership to all n distinguished classes. The value for the maximum posterior probability is responsible for the thematic label in the eventual classification.

Landsat image of August 1997

The areas that have been interpreted and classified in the May image as meadow, deciduous and coniferous forest communities have been removed from the August image to pinpoint the classification to the main area of interest, namely the natural areas covered with reed, sedge and scrub communities. The agricultural fields outside the park have been excluded.

Using the tourist map, Atlas maps, vegetation maps and the aerial photographs taken in October 1997, signatures were created of the following land cover types:
1. Reed and tall sedge communities
2. Sedge-moss communities
3. Scrub communities

In Figure 3 mean values of these signature sets are depicted in a feature space plot of band 4 (MIR) and band 5 (IR). The same gradients are assumed to be observed as in the May images, namely a 'vegetation and soil moisture' gradient (MIR) and a 'biomass content' gradient (IR), see also Table 4.

The reed and tall sedge communities have a relatively high reflection in the IR band (high biomass content) whereas the scrub communities have a relatively high reflection in the MIR band (low soil moisture content). The sedge-moss communities have a relatively low reflection in both the IR (low biomass content) and MIR bands (high moisture content).

Based on these signatures, a supervised classification was made using the Maximum Likelihood decision rule (Lillesand and Kiefer, 1997).

Accuracy

The same procedure was followed as with the May images with regard to the accuracy assessment (Appendix 2).

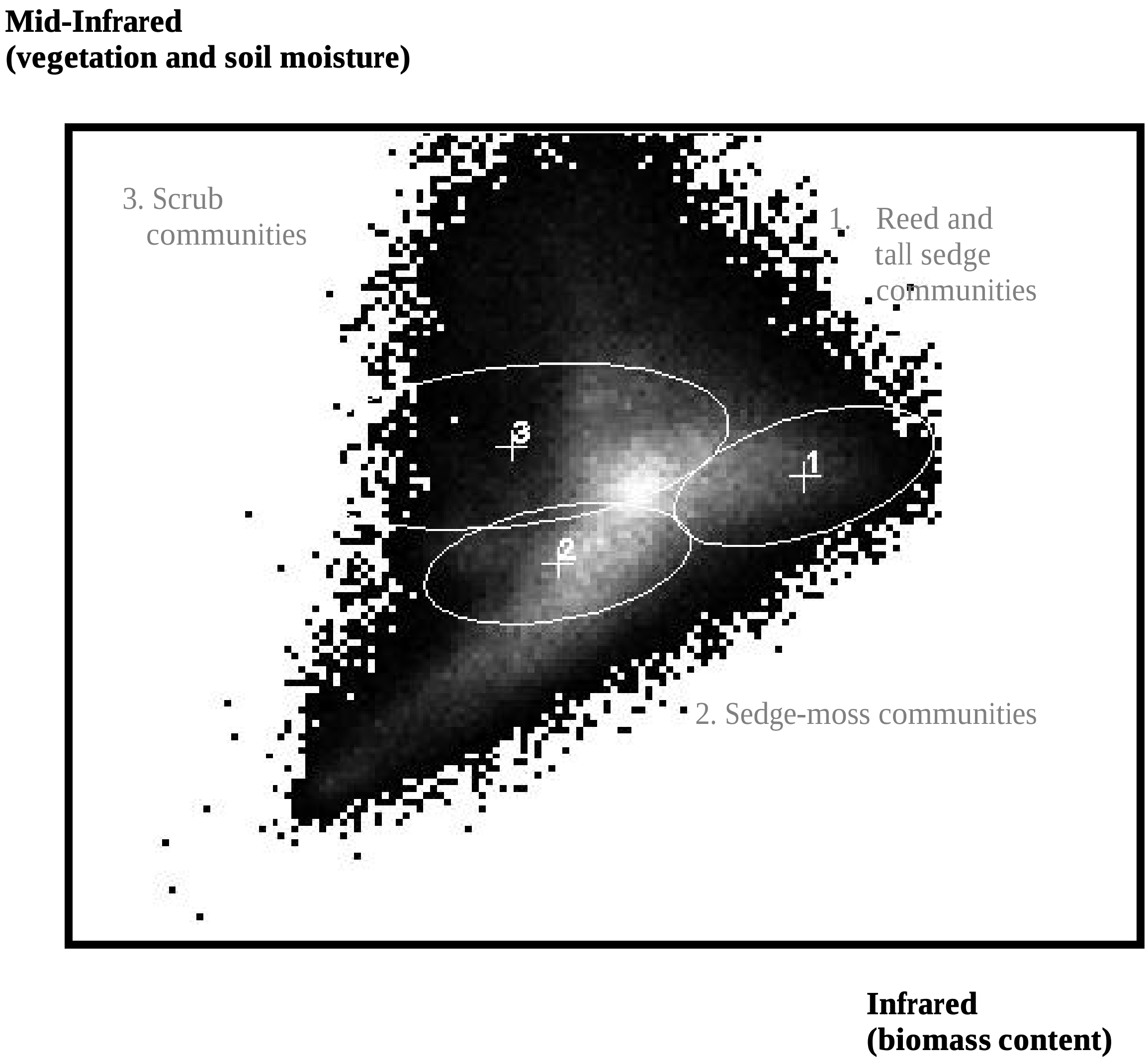


Figure 3 Feature space plot of band 4 (Infrared) and 5 (Mid-infrared) and the mean values of the signature sets used for supervised classification of the Landsat TM images of August 1997

5.4 Results

5.4.1 State and rate of scrub encroachment

The classified August images (1997) have been put together with the classified May images (1997), see Appendix 4. This combination gives a general overview of the distribution of the different land cover types in the Biebrza National Park. In addition the total coverage of the different land cover types was estimated (Table 5). Based on these estimates it can be concluded that at present about 44% of the Biebrza National Park is covered by scrub and forest communities (18% + 26%).

Table 5 The distribution of different land cover types in the Biebrza National Park, distinguished by means of supervised classification of Landsat TM images of May and August 1997

	Biebrza National Park		Upper basin		Middle basin		Lower basin	
Land cover types	**ha**	**%**	**ha**	**%**	**ha**	**%**	**ha**	**%**
Reed and tall sedge communities[1]	7547	12	476	5	2939	10	4132	17
Sedge-moss communities	19424	31	3558	36	9679	34	6187	25
Grassland communities	7130	11	2258	23	3061	11	1811	7
Scrub communities	11505	18	1703	17	3908	14	5894	24
Deciduous forest communities	11992	19	1107	11	6172	22	4713	19
Coniferous forest communities	4377	7	492	5	1824	6	2061	8
Agricultural areas	865	1	300	3	565	2	0	0
Total	62840	100	9894	100	28148	100	24798	100

1 Water surfaces have been included in this land cover type

Table 6 Land cover changes in the Biebrza National Park, distinguished by means of the supervised classification of Landsat TM images of May 1988 and May 1997 (post classification analysis)

	Biebrza National Park		Upper basin		Middle basin		Lower basin	
Land cover changes	ha	%	ha	%	ha	%	ha	%
Open wetland to forest	5825	10	832	17	2857	11	2136	9
Forest to open wetland	2733	5	707	15	826	3	1200	5
No change, open wetland	34176	61	553	12	18084	69	15539	63
No change, forest	13099	23	2699	56	4475	17	5925	24
Total	55833	100	4791	100	26242	100	24800	100

The results were checked visually by comparing the original Landsat TM images of May 1988 and 1997 and by means of field observations. Based on these observations the areas affected by scrub encroachment could clearly be identified.

The net change from open wetland into forest is about 3000 ha in a ten year period (5825-2733 = 3092ha), or about 300 ha/year. This corresponds to approximately 5% of the total area of the Biebrza National Park.

One should realise that these are only rough estimates. They might serve as an indication of the actual state of the scrub encroachment process, but should be checked in more detail by means of aerial photograph interpretation (Figure 4) and fieldwork (see Chapter 6).

Based on the classifications of the Landsat TM images of May 1988 and May 1997 the percentages of certain land cover changes of the past ten years in the Biebrza National Park were estimated (Table 6). Special attention was paid to land cover changes from open wetland (reed, sedge and meadow communities) to forest (deciduous and coniferous forest communities), see Appendix 5.

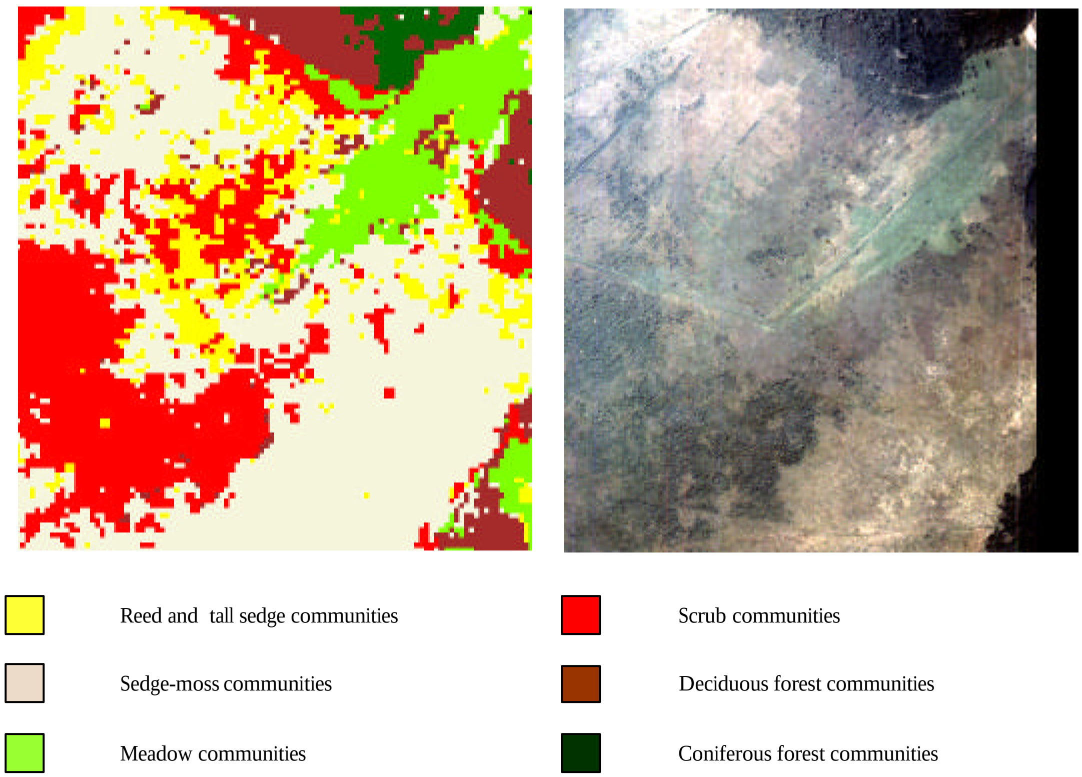


Figure 4 Comparison of satellite image classification and aerial photograph

6 Aerial photograph interpretation

6.1 Introduction

Aerial photography was used to monitor scrub encroachment in the Biebrza National Park. Vector layers were created using Arc/Info and Arc/View software.

The selection and pre-processing of data is discussed in Chapter 6.2, Methodology in Chapter 6.3 and the results are presented in Chapter 6.4.

6.2 Pre-processing of data

Table 7 gives an overview of the materials used. For a description of these materials see Chapter 4. Pre-processing of the materials is described in the following paragraphs.

Table 7 Data sources used for aerial photograph interpretation

Type of data	Type of Materials	Date	Scale
Remotely sensed data	Aerial photographs	1961/1962	1:16,000
		1997	1:20,000
Topographical and thematic maps	Topographical map	1982	1:25,000
	Tourist map	1998	1:120,000
	Vegetation map (Palczynski)	1977-1979	1:25,000
	Vegetation map (Oswit)	1973	1:25,000
	Actual vegetation map	1999	1:25,000

6.2.1 Remotely sensed data

Aerial photographs
The photographs were interpreted stereoscopically on transparent sheets. Control points recognisable both on the topographical maps and on the photographs (crossroads, channels or forest clearings) were marked on the sheets. Information on the transparencies was digitised, geo-referenced and geometrically corrected using the control points.

6.2.2 Topographical and thematic maps

Topographical map
The National Cartographic Publishing House topographical map (1:25,000) was used as a base map for geo-referencing the information derived from the thematic maps and aerial photographs, and as working material useful for fieldwork and detailed

localisation of observation points. The contour lines indicated on the topographical maps enabled preliminary determination of the range of the valley form, localisation of the mid-valley mineral islands and comparison of the surface relief with various forms of succession.

Tourist map
The tourist map (1:125,000) was used as auxiliary material. Due to the scale of the study it was used during fieldwork for localising objects and later as material for illustrating fieldwork documentation.

Vegetation maps
The actual vegetation map served as auxiliary material in the preparation of the photo-interpretation key and as reference material for field observations. The vegetation maps of Oswit (1973) and Palczynski (1984) served as comparative material elaborating the photo-interpretation key, analysing vegetation succession (estimating the rate of scrub encroachment) and evaluating vegetation succession (identifying the plant communities overgrown by shrubs and trees).

6.3 Methodology

6.3.1 Visual interpretation

One of the research objectives of the project was to compare the extent of forest and scrubs on archive and actual photographic materials. The actual state of the scrub encroachment process was assumed to be visible on the most recent aerial photographs taken in 1997. The situation observed at the beginning of the sixties was treated as a reference state and all observed changes referred to it.

In order to monitor and analyse the scrub encroachment process, the scrub and forest cover was classified into nine categories (Table 8). Two features were selected as main classification criteria, namely the density of the scrub or forest cover (stocking) and the dominant species.

According to the succession theory (Clements 1916, Falinska 1997) succession stages and phases are characterised by a specific species composition. In the initial succession stages of the scrub encroachment process, the age of the shrubs and tree species and the density of the scrub and forest cover are also important characteristics. Due to habitat diversity (differences in site conditions) and consequently climax stage diversity (the climax vegetation differs depending on the site conditions), the succession stages assume different forms.

The ideal setting would have been a situation where it was possible to relate the scrub and forest cover categories derived from aerial photograph interpretation directly to specific succession stages and phases. However, the relationship between the scrub and forest cover categories and the succession stages is ambiguous and only in the case of the initial succession stages could the scrub and tree species be identified as giving some information on species composition.

Table 8 Scrub and forest categories distinguished by means of aerial photograph interpretation and the possible relationship with different succession stages (this relationship is ambiguous)

Category	**Vegetation characteristics**			**Image characteristics**		**Succession stage**
	Density / Stocking	**Height**	**Species composition**	**Texture**	**Colour**	
1	Fully stocked old tree stands	> 10 m	Not identified	Coarse	Different colours	Climax
2	Not fully stocked old tree stands	Variable height	Not identified	Coarse	Dark grey/green spots against brighter background	Transitory
3	Moderately stocked old thickets, accompanying fully stocked old tree stands	5 to 10 m	Not identified	Fine	Uniform dark grey/green	Transitory
4	Mosaic of scrub, reed and sedge vegetation	2 to 3 m	Birch, Alder or Aspen	Fine	Combined dark and pale grey/green	Transitory
5	Mosaic of open scrub, sedge and reed vegetation, distinctly visible scrub/trees	2 to 10 m	Birch, Alder or Aspen	Spotty	Combined dark and pale grey/green	Transitory
6	Relatively large distinct clumps of willow scrub	< 5 m	Willow	Spotty	Dark grey/green spots against brighter background	Transitory
7	Relatively large but open clumps of willow scrub, adjacent to dense forest complexes	< 5 m	Willow	Spotty	Dark grey/green patches surrounded by pale grey/green	Transitory
8	Dispersed birch scrub located far from dense forest complexes	< 3 m	Birch	Single spots	Dark grey/green	Initial
9	Dispersed willow scrub located far from dense forest complexes	< 3 m	Willow	Single spots	Small dark grey/green spots on brighter background	Initial

The aerial photograph interpretation was verified by field observations, a total of 133 locations throughout the Biebrza river valley being visited.

However, the following factors contribute to the uncertainty of the results of the aerial photograph interpretation:

- A lack of sharp borders between particular succession stages
- A lack of sharp borders between particular forest and scrub cover categories that are characterised by the density of scrub cover, especially in case of the scrub cover categories with a low density
- The distortion of photographic material and errors in the later technical processing
- The different scales of basic materials (maps), upon which interpretation was carried out

6.3.2 Field observations and soil sampling

For a better understanding of the underlying causes of the scrub encroachment process seventeen areas were selected for more detailed observation (Figure 5). Of these areas the most important background information, such as land use changes and fire events is known. Based on this historical information the different succession types, succession models (description of the original habitat and invading shrub and tree species), spatial expansion types and succession rates are described.

In addition, information was collected on the chemical and physical features of the upper soil layers as being one of the main determining factors of vegetation change. A total of 72 soil samples was taken from more than twelve transects each located within one of the seventeen selected areas, and from three different vegetation cover types representing different succession stages, namely open area (O), scrub (S) and forest (F). Samples were taken from two separate soil layers: an upper layer (0 to 10 cm) and a lower layer (40 to 50 cm). Soil sampling was carried out between 10 and 30 September 1999.

Information was collected on:

- soil type
- type of peat deposit
- depth of the first groundwater level
- predominant plant species
- height of the trees and shrubs species

Analysis of the soil samples was conducted on nine soil-condition variables, namely:

1. dry weight
2. bulk density
3. humidity (gravimetric soil moisture)
4. ash content
5. $N_{(tot)}$
6. NH_4
7. NO_3
8. K
9. P

Soil-condition variables was analysed in order to allow for variations within each location condition (transect, vegetation cover and soil layer) to be seen. For this purpose the data was initially divided into four distinct data sets. Each data set contains all the same data points, but is arranged to show the effects of a different location condition.

The first data set encompasses all the collected data points, containing all of the location samples and the nine soil-condition variables in one large data set. The second data set was separated into twelve distinct subsets, each representing a single transect and the data points included in it. The third set was organised by vegetation cover (succession stage) into three data subsets, each showing data related to a single vegetation type. The fourth data set was organised by layer, creating two separate subsets, showing only those data points relating to the top layer in one subset and the bottom layer in the other subset.

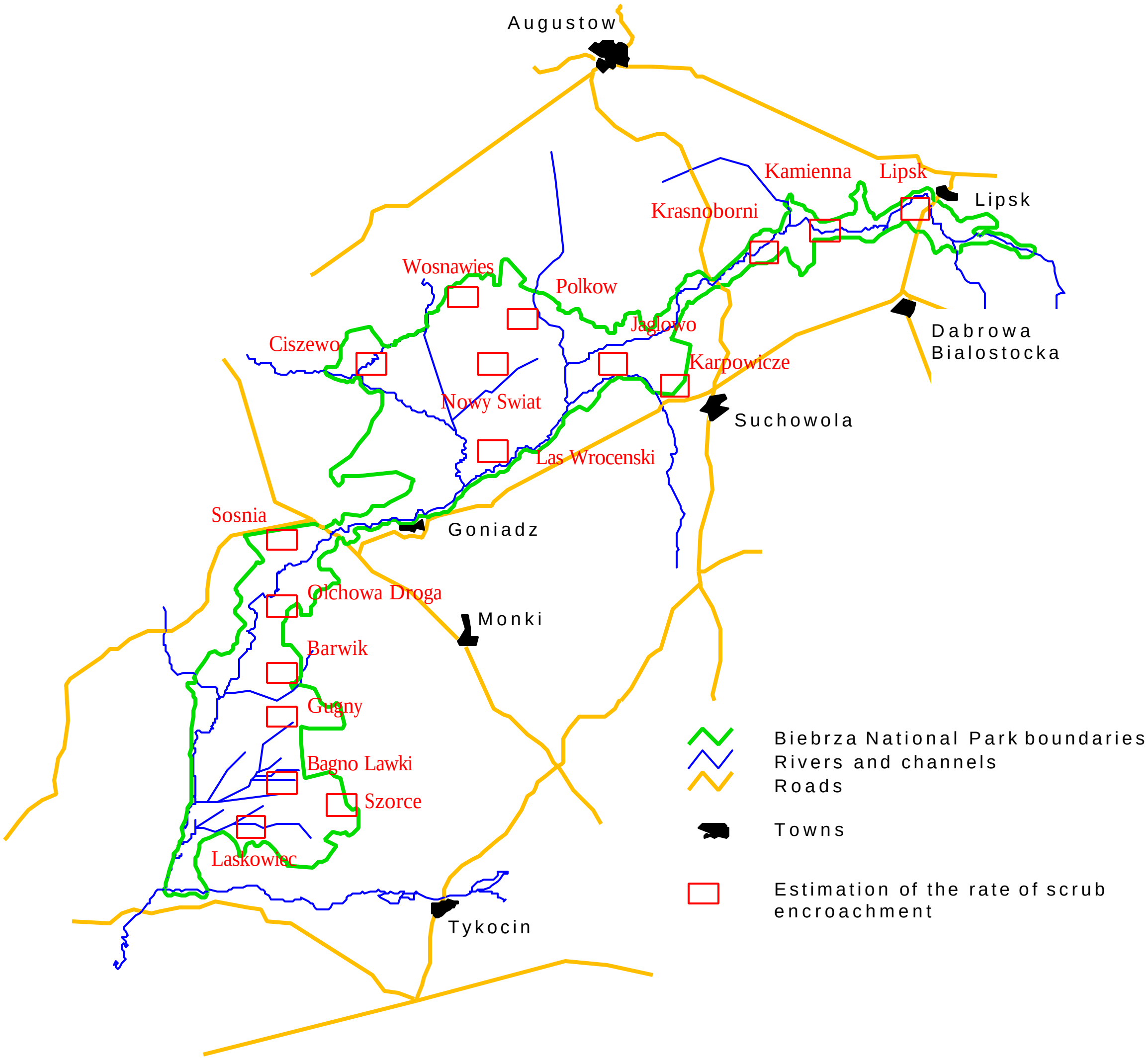


Figure 5 Location of the areas for which scrub encroachment has been investigated in more detail

6.4 Results

6.4.1 State and rate of scrub encroachment

The results of aerial photograph interpretation are presented in Table 9 and Tabel 10. Based on these results it can be concluded that about 43% of the Biebrza National

Park is currently covered by forest and scrub communities. This corresponds closely with the results obtained by the automated classification of satellite images (Table 5). The border between the upper and middle basins was defined differently by the Dutch and Polish project partners, making it difficult to compare results of the aerial photograph interpretation with those of the satellite classification per river basin.

The aerial photographs taken in 1961/62 do not cover the whole of the Biebrza National Park, which explains the differences in total hectares presented in Table 9 and Tabel 10. Care needs to be taken when comparing the results, but in general it can be concluded that there is an increase in the total coverage of forest and scrub categories 1 to 3 and a decrease in coverage of forest and scrub categories 4 to 9 (Figure 6).

It is difficult to estimate exactly the rate of scrub encroachment based on the forest and scrub categories. In general it can be concluded that during the last thirty-five years, about 7% of the open wetland area has been transformed into areas covered by scrub and forest. In addition it can be concluded that in the same period the areas with a relatively open scrub and forest cover (categories 4 to 9) have decreased by about 6% whereas the areas covered with a relatively dense scrub and forest cover have increased by about 12%.

The rate of scrub encroachment depends on many factors, such as the habitat type (plant community) invaded by shrub and tree species, the history of the site (e.g. former land use type and drainage activities) and site conditions (e.g. soil type and water regime). In Chapter 6.4.4 a more detailed description is given of several sites that were visited during fieldwork. The land use changes of these sites are known and no traces of burning were observed in the field.

Table 9 Distribution of different tree and scrub cover categories in the Biebrza National Park based on aerial photographs taken in 1961/62 (in 1961/62 aerial photographic cover was incomplete)

		Biebrza Park	National	Upper basin		Middle basin		Lower basin	
	Tree and scrub cover categories	**ha**	**%**	**ha**	**%**	**ha**	**%**	**ha**	**%**
1	Fully stocked old tree stands	1912	3	448	12	113	0	1351	5
2	Not fully stocked old tree stands	4031	7	4	0	3881	13	146	1
3	Moderately stocked old thickets	2336	4	65	2	1007	3	1264	5
4	Mosaic of birch, alder or aspen scrub with reed and sedge vegetation	4388	7	91	2	2517	8	1780	7
5	Mosaic of birch, alder or aspen scrub with reed and sedge vegetation (distinct trees)	3082	5	58	2	1211	4	1813	7
6	Relatively large distinct clumps of willow scrubs	515	0	13	0	239	1	263	1
7	Relatively large open clumps of willow scrub	2008	4	11	0	741	2	1256	5
8	Dispersed birch scrub	2611	4	121	3	1724	6	766	3
9	Dispersed willow scrub	882	2	8	0	543	2	331	1
0	Open area	38389	64	3026	79	19183	62	16180	64
	Total	60154	100	3845	100	31160	100	25150	100

Table 10 Distribution of different tree and scrub cover categories in the Biebrza National Park based on aerial photographs taken in 1997

		Biebrza Park	National	Upper basin		Middle basin		Lower basin	
	Tree and scrub cover categories	**ha**	**%**	**ha**	**%**	**ha**	**%**	**ha**	**%**
1	Fully stocked old tree stands	9824	15	673	10	4004	13	5147	20
2	Not fully stocked old tree stands	4849	8	747	11	3511	11	591	2
3	Moderately stocked old thickets	1881	3	205	3	1256	4	420	2
4	Mosaic of birch, alder or aspen scrub with reed and sedge vegetation	2945	5	297	4	1818	6	830	3
5	Mosaic of birch, alder or aspen scrub with reed and sedge vegetation (distinct trees)	2675	4	249	4	977	3	1449	6
6	Relatively large distinct clumps of willow scrubs	357	0	130	2	150	1	77	0
7	Relatively large open clumps of willow scrub	1228	2	98	2	550	2	571	2
8	Dispersed birch scrub	3137	5	302	5	808	3	2027	8
9	Dispersed willow scrub	378	0	38	1	179	1	161	1
0	Open area	36741	57	3966	59	17898	57	14877	57
	Total	64015	100	6705	100	31160	100	26150	100

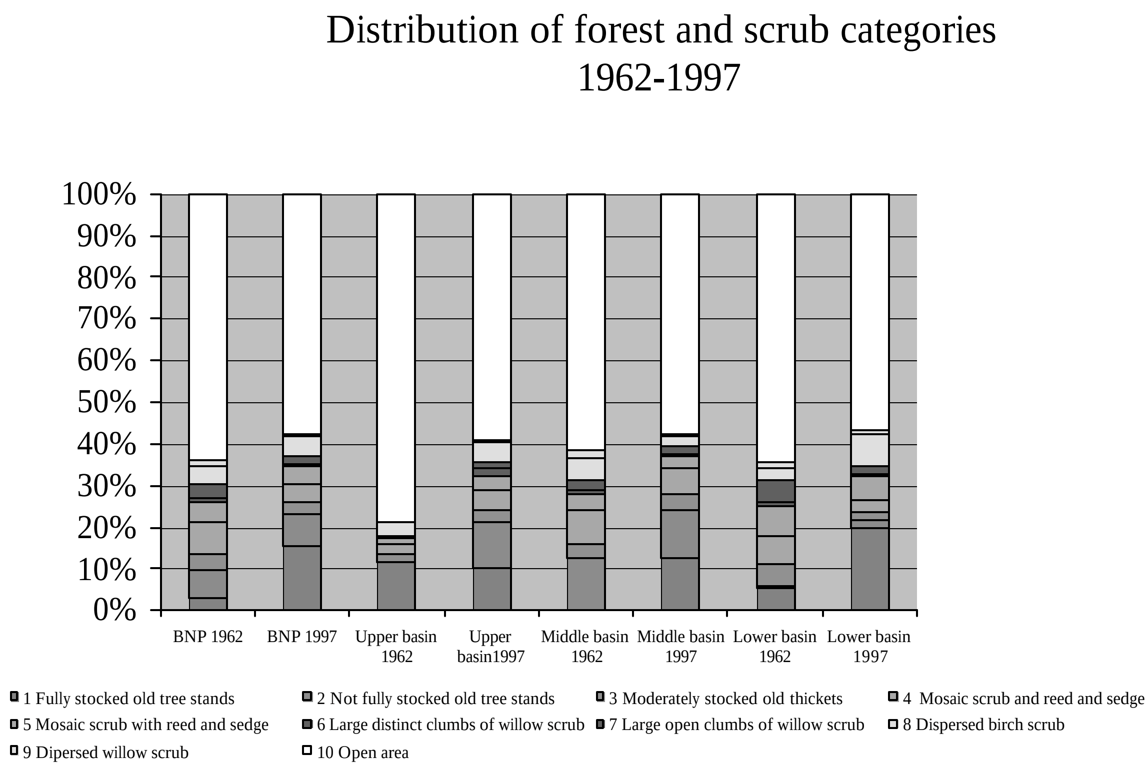
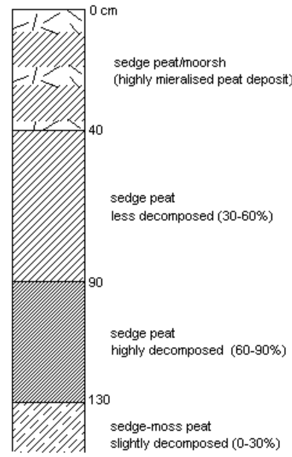


Figure 6 Distribution of different forest and scrub cover categories in the Biebrza National Park (BNP) in 1962 and 1997

6.4.2 Initial succession stages

Different initial succession stages of the scrub encroachment process were identified based on aerial photograph interpretation and field observations. The following initial succession stages were distinguished: birch-willow, birch, willow, aspen and alder. Since the project was not directed towards a detailed phytosociological study of the consecutive succession stages and phases, only a general description of these initial succession stages is given below. Each is described by the following characteristics: location (occurrence in BNP), species composition, spatial expansion type, possible succession model, succession rate and soil conditions.

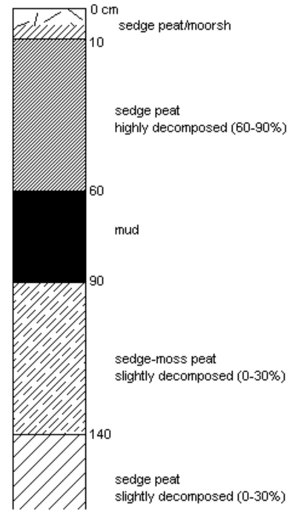
The initial stage of birch-willow encroachment



Location:	Widespread in the lower and middle basins, near the edge of the valley, as well as in the middle of open peatlands
Species composition:	*Salix cinerea, Salix rosmarinifolia, Betula pendula, Carex lasiocarpa, Thelypteris palustris, Phragmites australis, Calamagrostis canesce*
Spatial form of expansion:	Forms dense carpets of scattered scrubs together with dense reed
Possible model of expansion:	*Caricetum chordorrhizae* – shrub phase with reed – *Thelypteri-Betuletum* – *Carici elongatae-Alnetum*
Succession rate:	Rapid, but difficult to estimate based on interpretation of photographs (encroach on burnt-out areas)
Soil conditions:	Deep sedge peat deposits with thick top moorsh layer

Figure 7 Initial stage of willow-birch encroachment

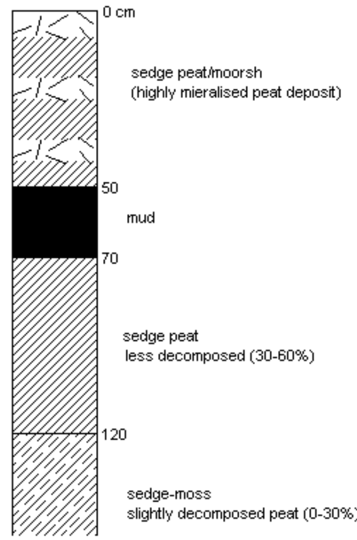
The initial stage of birch encroachment



Location:	Occurs throughout the Biebrza National Park, near the edge of the valley as well as in the middle of open peatlands. The most typical for the upper basin
Species composition:	*Molinietum var. Carex panicea*
Spatial form of expansion:	Forms widespread carpet of scattered scrubs in the middle of peatland, fulfil areas between patches with more dense scrub cover
Possible succession model:	*Scropidio-Caricetum hudsonii – Molinietum – Betuletum pubescentis verrucosae – Sphagno-Piceetaum*
Succession rate:	Moderate to rapid – over a 30 year period, areas with dense birch scrubs increased by more than 50% (data from test area)
Soil conditions:	Deep, sedge and sedge-moss peat, slight to moderate decomposition with relatively thin moorsh layer

Figure 8 Initial stage of birch encroachment

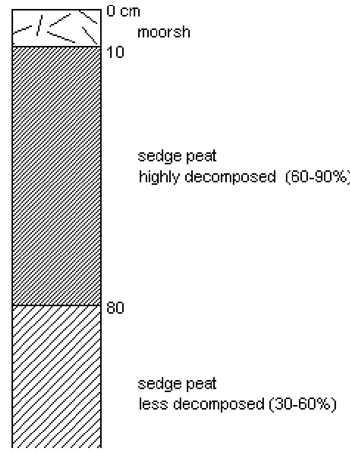
The initial stage of willow encroachment



Location:	Occurs mainly in the middle and lower basins in different locations: near the edge and in the middle of peatlands
Species composition:	*Salix cinerea, Thelypteris palustre, Carex lasiocarpa, Phragmites australis, Calliergonella cuspidata*
Spatial form of expansion:	Forms zones around areas with more dense scrub cover, isolated – island-like – patches in the middle of open wetlands, fulfil gaps between patches with more dense scrub cover.
Possible succession model:	Sedge-moss communities – initial phase of willow scrubs– *Carici elongatae-Alnetum*
Succession rate:	Moderate to rapid – over a 30 year period, areas covered with scrubs increased by 50% (date from test area)
Soil conditions:	Deep, high-nutrient peat deposits, with top layers made of highly decomposed peat and thick moorsh layer; mud areas in oxbows, shallow organic materials

Figure 9 Initial stage of willow encroachment

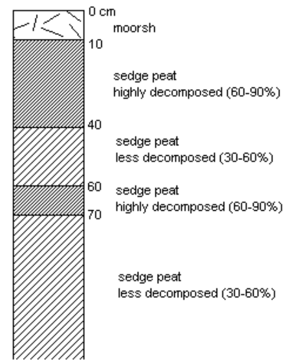
The initial stage of aspen encroachment



Location:	North-western part of the middle basin; vast area of burnt-out fen
Species composition:	*Populus tremula*, *Calamagrostis canescens*, *Salix cinerea*, *Phragmites australis*, *Betula pendula*
Spatial form of expansion:	Forms easily expanding, thick carpet of young stands
Possible succession model:	Communities with *Calamagrostis canescens* – communities with *Populus tremula* – *Betuletum pubescentis verrucosae* – *Carici elongatae-Alnetum/Sphagno-Alnetum*
Succession rate:	Rapid – in five years the initial phase covered ca 2000 ha
Soil conditions:	Different types of deep peat deposits

Figure 10 Initial stage of aspen encroachment

The initial stage of alder encroachment



Location:	Widespread in the Biebrza National Park, occurs near the edge of the valley and around mineral islands
Species composition:	*Carex appropinquata, Carex elata, Carex rostrata, Alnus glutinosa, Potentilla palustris*
Spatial form of expansion	Forms regular fringe-zones around patches covered with more dense scrub cover
Possible succession model:	*Caricetum elatae* – initial phase of alder scrubs – *Carici elongatae-Alnetum*
Succession rate:	Extremely rapid – the front of alder forest advanced up to 300 m in 40 years
Soil conditions:	Deep, well-decomposed sedge peat deposits, mud, mineral-organic sediments

Figure 11 Initial stage of alder encroachment

6.4.3 Spatial expansion types

Comparative analysis of scrub ranges in the Biebrza valley (Piórkowski, 1997, Piórkowski and Rycharski, 1999) enabled different spatial expansion types to be distinguished, namely zonal, surface, point, integrative and anthropogenically forced expansion (see Chapter 3 for definitions). In the present chapter the occurrence of these different spatial expansion types within the Biebrza river valley is described.

Zonal expansion
Zonal expansion is usually associated with the valley edge, where extensive and dense forest complexes occur on the higher terraces, above flood areas. There are forest communities with *Alnus glutinosa*, *Betula pubescens* and *Salix cinerea*, at the foot of terrace slopes in the transitional zone between hydrogenic and non-hydrogenic sites. Plots adjoining forest patches gradually become covered with scrubs after cessation of harvesting. Within several years different zones are formed, dominated by specific shrub and tree species. The outer zone is made up of small clumps of willow scrubs, with single birch and alder trees appearing amongst them. Towards the valley edge, the occurrence of willow gradually decreases to give way to birch followed by alder, which forms a dense almost homogeneous thicket at the very edge. The succession is mainly of a secular and recreative character (see Chapter 3 for explanation).

Surface expansion
Surface expansion is associated with the specific situation, when during a short period of time a large load of easily available nutrients is mobilised. This may happen in peat or muddy sites, which due to disturbances in the water budget undergo mineralisation. Fire is another factor able to mobilise available plant nutrients in a short time. Among species taking part in the surface expansion the most common are willow, birch and, on burnt areas, aspen. Succession is of a regenerative character.

Point expansion
Point expansion mainly occurs in the centre of the valley, frequently in the form of single willow clumps which were consecutively omitted from annual cutting. Such clumps, after total termination of harvesting, become expansion centres which enable occupation of the fragments of the valley bottom, sometimes quite remote from larger scrub complexes. This process has a character of secular succession.

Point expansion might also be associated with the mineral islands. Succession here is limited due to the marked moisture gradient between the peat covered bottom of the valley and the elevated and dry areas (mineral islands). If the primary water regime has been disturbed by drainage, scrub expands over previously unsuitable areas. By definition, this process has a character of secondary creative succession.

Integrative expansion
Integrative expansion is often combined with point expansion and mobilised when site conditions change drastically. The main species filling gaps in the scrub cover are *Salix cinerea* and *Betula pubescens*. Integrative expansion occurs in the form of a mosaic

of scrub patches of irregular shape, different species composition and variable height. Succession assumes many forms, but most often can be considered as secular.

Anthropogenically forced expansion is associated with the valley fragments, in which a mosaic of land use is still present. Scrub expansion is restricted to the abandoned plots. The area is characterised by a network of regular, geometric patches covered by scrubs at different stages of development, depending on the time of abandonment. Among the expanded species are *Betula pubescens, Salix cinerea* and *Alnus glutinosa*. Succession is of a secondary creative and secular character.

6.4.4 Soil conditions

Analysis of total data set

Initial analysis of the soil-conditions variables was done by calculating the arithmetic mean and standard deviation for each variable utilising all the data points (Appendix 3A-1). The next analysis focused on the correlation between variable-pairs throughout the sample set (Appendix 3A-2). Initially, correlation values for all variable-pairs possible were calculated within each of the four data sets created for analysis. Finally, twenty-one variable-pairs were chosen for more detailed analysis (Appendix 3A-3).

The correlation values of the selected variable-pairs do not usually indicate significant relationships between them. Most of the correlation values are below 0.5. Only five variable-pairs have higher values (Appendix 1A-1 and 1A-2), namely:

1. dry weight and ash content
2. dry weight and humidity
3. total nitrogen ($N_{(tot)}$) and ash content
4. $N\text{-}NO_3$ and humidity
5. Potassium (K) and Phosphorus (P)

Two of the variable-pairs mentioned above are connected with interrelated physical and chemical characteristics of the soil. The most important relationships are between $N_{(tot)}$ and ash content, and $N\text{-}NO_3$ and humidity. Total nitrogen with its negative correlation with ash contents, together with NO_3 negatively correlated with humidity, might describe the decomposition of peat soils. The other significant correlation coefficient value is between K and P.

In general, the results of the soil data analysis show high diversification (Appendix 3A-1).

Analysis of data set organised by transect

The large differentiation of physical soil features within the transects indicates a variety of site conditions (Appendix 3B).

Ash

The lowest ash content is observed in the Gugny and Bagno Lawki transects (Appendix 3B-1), where it does not exceed 15% in either of the layers analysed. The highest ash content is observed in the Woznawies transect (>80%), particularly in the bottom layer. Slightly lower values of ash content are observed in the Jaglowo and Nowy Swiat transects. A high ash content is mainly connected with a thin layer of organic material.

Differentiation of the values within transects is not high, particularly in the bottom layer. It indicates more or less homogenous primeval site conditions. One exception is the Jaglowo transect, with shallow organic soils and different mineral sediments beneath (sand and silt).

Bulk density

The highest values of bulk density (Appendix 3B-2) are connected with transects on shallow organic soils (Krasnoborki, Karpowicze, Jaglowo and Ciszewo). Within those transects, the most significant differences are observed between the upper and lower layers. On transects with deep organic soils, the bulk density of the upper and lower layer is similar and does not usually exceed 0.2 g/cm^3.

Within the transects, the differentiation of bulk density in the lower layer is low, which confirms the primeval homogeneity of the sites, with the clear exception of Jaglowo.

Humidity

Humidity (Appendix 3B-3) also reflects site condition differences between transect location. The highest values, exceeding 90%, occur in Bagno Lawki, slightly lower humidity is observed in Lipsk, Sosnia, Gugny and Szorce (80% to 90%). All those transects are located in the lower and upper basins on deep, slightly decomposed peat deposits. Humidity within the transects, particularly in the lower layer, is stable. In the upper layer, the minimum is connected with an open site. In this case, the largest difference occurs between the upper and lower layers, while on the other sites humidity values of both upper and lower layers are almost equal.

In the Ciszewo and Barwik transects, high humidity in the lower layer and significantly lower values in the upper layer are observed. At the same time humidity increases from forest through scrub to open sites, where it is the highest. In both locations, the top layer is remarkably over dried. The smallest changes are found on the open sites with sedge communities.

Humidity in both soil layers on the transects at Krasnoborki, Karpowicze, Jaglowo and Woznawies is less. The differences between upper and lower layers are remarkably higher –the lower being more humid.

When comparing humidity values in individual site conditions, several regularities can be identified:

For the lower layer the highest humidity is observed under scrub communities (seven transects), while differences between sites within one transect are low.

On three transects with high humidity (in general), the lowest value of humidity in the top layer is observed within scrub communities.

Within transects with shallow and remarkably over dried peat deposits, the maximum value of humidity occurs in sites with sedge communities.

Total nitrogen content

Differentiation of total nitrogen within transects is high (Appendix 3B4). Highest values are observed on transects with deep peat deposits: Sosnia, Gugny, Bagno Lawki and Szorce. Only on the Bagno Lawki transect is the maximum in the lower layer. On the other transects it is in the upper layer. The lowest values of total nitrogen content are observed on transects with shallow peat deposits: Jaglowo and Woznawies. The minimum amounts occur in the lower layer, which contains the highest content of mineral particles.

Differentiation of total nitrogen content throughout all transects is relatively low. The greatest differences occur in Lipsk, Krasnoborki, Jaglowo, Sosnia, Barwik, and Szorce.

There is no clear relationship between the total nitrogen content of the soil and the type of vegetation. In several cases maximum content occurs under scrubs – the highest values are observed in both layers (Krasnoborki, Lipsk and Bagno Lawki). In two cases, total nitrogen content in the lower layer changes from forest communities, where it is the highest, through scrub communities to sedge communities where it is the lowest. The total nitrogen content in the upper layer is more or less stable. For four transects the opposite situation is observed – an increase in total nitrogen content in the lower layer moving towards more dense communities.

The highest values of NH_4 content occur throughout transects Lipsk, Jaglowo, Woznawies and Ciszewo (Appendix 3B-5). The most remarkable concentrations are observed on sites with forest and scrubs, while the maximum value is usually found in the bottom layer. Apart from Lipsk, all other transects are associated with shallow peat deposits.

The NO_3 content in the upper layer differs significantly in particular transects. Two main subsets of the whole transect population are clearly distinguished. The first is comprised of transects with very low NO_3 (Lipsk, Nowy Swiat, Bagno Lawki, Sosnia, Gugny and Szorce), whereas the second subset has a much higher content. Remarkably higher NO_3 contents occur in areas with shallow peat deposits or with advanced peat decomposition. The concentration of NO_3 in the bottom layer, apart from the Jaglowo transect, is extremely low (Appendix 3B-6).

Phosphorus content

The phosphorus content differs significantly per transect, but in all cases the top layer contains more P than the bottom layer (Appendix 3B-7). Maximum values occur in the Nowy Swiat transect on the site with open, sedge communities. Relatively high concentrations are also found in Krasnoborki, Karpowicze, Jaglowo and Ciszewo – on transects with shallow peat deposits. The lowest values are typical of Lipsk, Woznawies, Barwik and Szorce. Apart from Barwik, all other transects are associated with minerotrophic communities.

In four transects, the minimum values of phosphorus in the upper layer occur on sites with scrub communities. These transects are connected with minerotrophic communities (Lipsk, Woznawies) or with burnt-out fen areas (Ciszewo, Nowy Swiat). On the minerotrophic sites of the Szorce transect, a decrease in phosphorus from forest towards open communities is observed in the upper layer. In the lower layer the phosphorus content is relatively stable.

For five transects, low concentrations of phosphorus are observed in the upper layer on sites with scrub communities. In most cases, on transects with soils formed on deep peat deposits (Sosnia, Gugny and Bagno Lawki), the differences between the top and bottom layers are very low. Much greater differences are found on sites with shallow peat deposits (Jaglowo) or with mineralised peat deposits (Barwik).

The Karpowicze transect is characterised by an increase in phosphorus in the upper layer from forest to more open communities. The phosphorus content of the lower layers are stable and relatively low.

Potassium content

Potassium content throughout most transects is higher in the top layer than in the bottom layer (Appendix 3B-4). The exception is noted in Jaglowo – in its scrub community site, the maximum potassium concentrate is observed in the bottom layer. The reverse situation is also reported in Nowy Swiat, in its forest site.

In most transects, the highest potassium content is observed on sites with scrub communities. The highest values occur in both layers, but the most visible differences between particular sites are in the top layer. On the Sosnia transect, on its scrub community site, the K content in both layers is almost equal.

The minimum potassium content is observed on forest sites (seven transects). Only within three transects in forest conditions does the maximum value occur, in the upper layer at Lipsk and Woznawies, and in the lower layer in the Lipsk and Nowy Swiat sites.

Analysis of data set organised by vegetation cover

Secondly the data were reorganised according to vegetation cover (succession stage). Thus three subsets with twenty-four data points each were analysed. The first subset was comprised of sites with forest vegetation, the second with scrubs and the third with sedge communities. The same variable-pairs are used in analysing this data set, using correlation coefficients (Appendix 3C).

The relationships between selected physical characteristics of the soils are remarkably more significant. In particular, dry weight and humidity are markedly negatively correlated in all subsets. Dry weight and ash content are correlated well on scrub sites and open vegetation, whilst on forest sites the value of the correlation coefficient is low.

Total nitrogen and ash content is markedly negatively correlated in all three vegetation cover types. The most marked correlation is within scrub communities. A similar situation is seen between NO_3 and humidity. These two variable-pairs might be crucial in determining habitat changes.

Also of importance, particularly for scrub sites, is the interrelationship between total nitrogen and dry weight. In spite of its correlation with total nitrogen, potassium is also clearly correlated with certain physical site conditions. The most obvious relationship to be considered is potassium content and dry weight, which occurs on forested sites. Other significant relationships important for estimating changes are the correlation between potassium and total nitrogen on forest sites, and phosphorus and ash content in forest and open sites.

Some results of the analysis highlighted elements that might be used as indicators for ongoing degradation of open wetland habitats ($N_{(tot)}$, NO_3 and K). In some cases succession processes might be described through the selected elements (K, P, $N_{(tot)}$). Nonetheless, three different approaches in the analysis reveal that each transect should be analysed separately and that the role played by local conditions in forming the particular site is crucial.

Analysis of data set organised by layers (upper and lower)

The correlation calculated for the selected variable-pairs shows higher significance values (Appendix 3D). Interrelated physical characteristics have a strong correlation. In comparison with the earlier analysis of the entire data set, the relationship between dry weight and ash content has a strong positive correlation only for data from the lower layer. Ash content is associated very positively with K content in the upper layer ($r>0.7$): the higher the ash content, the higher the potassium. In the bottom layer the relationship is not so obvious.

Such results indicate that advanced mineralisation in the upper layer leads to a higher K content. The opposite situation is observed between $N_{(tot)}$ and ash content. The significant negative correlation occurs in the lower layer while in the upper layer there is no such correlation. The increase in ash content in the lower layer causes a decrease in total nitrogen. The high $N_{(tot)}$ content is connected with high humidity and a high content of slightly decomposed organic material which unequivocally indicates undisturbed peatland areas. The low $N_{(tot)}$ content, together with the concentration of potassium indicate organic soil degradation (mineralisation).

6.4.5 Detailed description of selected areas

Upper basin

Lipsk

The area is located in the upper basin on the north-western slopes of Lipsk mineral islands (Figure 5). In the surface formations, thick, moderately and slightly decomposed sedge peat prevails. In the vegetation cover, short sedge communities predominate. *Betula pubescens* with solitary *Salix sp.* individuals encroach onto open wetland vegetation. Patches of birch forest occur near the slopes of mineral islands. Shrubs and trees are new elements in the landscape – the effect of integrative expansion.

Kamienna

The area is situated in the middle part of the upper basin and occupies the central part of the valley (Figure 5). Deep sedge peat is in the substratum. Communities with a stabilised species composition belong to *Betuletum pubescentis* with the absolute dominance of *Betula pubescens*. Compared to the beginning of the sixties, the area of patches with high density has increased by about 10%. Expansion is of a forced anthropogenic character restricted to the abandoned plots.

Krasnoborki

The area is located in the upper basin, in the northern part of the river valley, half way between Sztabin and Jastrzebna (Figure 5). The bottom of the valley is floored with sedge, on highly decomposed peat. The thickness of organic deposits exceeds two metres in this area. The area contains drainage ditches and at present is still extensively used as meadow. Scrub and forest communities are limited to abandoned fields. *Betula pubescens* definitely prevails in the expanded vegetation and forms larger complexes of older forests. *Salix cinerea* is found with *Betula pubescens* in younger forms of forests or in the initial succession stages. Expansion is anthropogenically forced.

Middle basin

Karpowicze

The area is situated in the middle basin (Figure 5), in the wider part of the landform, where the river Brzozowka enters the Biebrza river valley, about 2.5 km northeast of the village of Karpowicze. Mud in the upper layers and highly decomposed peat in the lower layers prevail in the area. Sedge communities endangered by the encroachment of *Salix cinerea* and *Populus tremula* occur in the vegetation. Patches of forest and scrub are widespread in the whole area. Expansion is rapid and has a surface character. Thirty years ago, the area was covered by open wetland communities of sedges.

Jaglowo

The area is situated at the confluence of the Brzozowka and Biebrza rivers in the central part of the middle basin (Figure 5). The substratum is formed by shallow sedge and muddy peat in a mosaic with muds and alluvial formations. The expansion has a surface and partly anthropogenic character, with the invading shrub and tree species being comprised of *Populus tremula, Betula pubescens* and *Salix cinerea*. The short sedge communities are affected by this succession and scrub pressure also influences wet and utilised meadows. The area of dense scrub patches has increased by about 80% since the sixties.

Polkow

The area is located in the northern part of the middle basin and adjoins the forest complex of Czerwone Bagno on the west and the Augustowski Channel on the east (Figure 5). Deep sedge peat forms the substratum. The dominating element in the tree stand is *Betula pubescens* with solitary *Salix cinerea*. The low sedge site is undergoing succession, the main invading species being *Betula pubescens*. In comparison to the situation at the beginning of the sixties, a head of dense scrub complexes has advanced by one hundred and fifty metres. Expansion is of a zonal character.

Woznawies

The area is situated in the northern part of the middle basin along the road from Woznawies to Kuligi (Figure 5). In the surface formation thin organic material, comprising highly decomposed sedge peat underlain by fine sand, predominates. The vegetation contains low sedge communities of *Caricion fuscae* mixed with elements associated with *Molinietalia*. The forest complexes on the wet sites are mainly composed of *Betula pubescens, Salix cinerea* and *Alnus glutinosae.* Most of the area is still extensively used as meadow. Scrub encroachment is observed on abandoned fields within the borders of the BNP. The most expansive species is *Salix cinerea* which forms single clumps surrounded by low sedge communities or herbal vegetation. The succession resembles point and anthropogenically forced expansion. In comparison with the situation seen on old aerial photographs, the scrubs are new elements in the landscape.

Nowy Swiat

The area is situated in the northern part of the middle basin in the vicinity of the southern belt of the Nowy Swiat - Wilcza Gora heights and covers a fragment of the zone adjacent to the dunes (Figure 5). Relatively shallow highly decomposed and muddy reed peat forms the substratum and is up to 1.5 m thick. Betula pubescens communities with an admixture of *Alnus glutinosa* occupy the dune-foot areas. Expansion is of a zonal but poorly expressed character. Over a period of thirty years a head of dense scrubs has progressed by only about five metres.

Ciszewo

The area is situated in the middle basin, in the northern part of the triangle formed by the Jegrznia-Elk and Woznawiejski Channels (Figure 5). Highly decomposed peat deposits are situated in the upper layers of the soil. Extensively used meadows make up a mosaic with forest patches and scrub communities. *Betula pubescens* and *Salix* *cinerea* form the expansion. The former predominates in older forms of succession, the latter in younger successions, where it forms clumps.

Las Wrocenski
The area is situated in the southern part of the middle basin (Figure 5) and includes mid-valley mineral islands overgrown with *Tilio-Carpinetum* communities, along with the adjoining fragment of the valley. Deep sedge peat deposits occur in the valley bottom. The dominating pioneer species is *Betula pubescens*. Over the last thirty years the area of patches of a dense scrub cover has increased by 5% and is of an integrative character.

Lower basin

Sosnia
The area is situated in the northern part of the lower basin at the western edge of the valley (Figure 5). The bottom of the valley is floored with peat and mud formations. An extended forest complex of *Alnetum glutinosae* is situated at the edge of the valley and at the bottom it adjoins a *Magnocaricion* community with some local patches of *Equisetum palustre*. Scrubs assume the form of zonal expansion, the dominating species being *Alnus glutinosa*. *Salix cinerea* occurs sporadically as isolated low clumps. The dense tree stand of *Alnetum glutinosae* has expanded by as much as one hundred and fifty metres since the sixties.

Olchowa Droga
The area is situated in the northern part of the lower basin at the edge of the valley (Figure 5). Deep sedge peat lies in the substratum. There is a community of *Tilio-Carpinetum* at the edge of the valley, gradually transposing into a narrow belt of *Alnetum glutinosae*. Expansion is of a zonal character with *Alnus glutinosa* dominating.

Barwik
The area is situated in the middle part of the lower basin in the edge zone of the valley (Figure 5). Among the surface formations of the valley bottom, deep, moderately decomposed sedge peat dominates. *Alnetum glutinosae* with a significant admixture of *Betula pubescens* is located near the edge. Scrubs expand over the *Magnocaricion* communities. The expansion has a zonal character in the close neighbourhood of the slope, and point and integrative characters at some distance from the valley edge. In the zonal expansion the dominating species is *Alnus glutinosae*. *Salix cinerea* and *Betula pubescens* participate in point and integrative expansion. As to the rate of succession in the edge zone, the range of dense scrubs has increased locally by between five and ten metres. A relatively stable system in the edge zone is thus observed in that part of the valley. At some distance from the edge, where *Salix cinerea* expands intensively, the situation is different. During the last thirty years some patches, by incorporating successive clusters, have increased in area by 15%.

Gugny

The area is situated in the lower basin, about two kilometres southwest of Gugny (Figure 5). The area encompasses part of the bottom of the river valley situated near the edge of the landform. In the surface formations, sedge peat deposits prevail. They are highly decomposed in the upper layers, and moderately to slightly decomposed in lower parts of the soil profile. In the open wetland vegetation, *Caricion fuscae* predominates and is endangered by encroaching young stands of *Salix cinerea* about 1.5 metres high, which form small, dispersed clumps. Forest with *Alnus glutinosa, Viburnum opulus*, and isolated *Betula pubescens* grows on the outskirts of the river valley. Individuals of *Alnus glutinosa* also form a narrow zone expanding towards the centre of the valley. Scrub encroachment represents zonal expansion.

Bagno Lawki

The area is situated in the southern part of the lower basin near the '**Carska'** road (Figure 5). Deposits of slightly decomposed sedge peat more than one metre thick occur in the area. The major part of the valley bottom is covered with low sedge communities, now overgrown with reed and large numbers of young stands of *Betula pubescens* and a variety of *Salix species*. The height of scrub individuals does not often exceed reed height. The open areas with sedge communities encompass small patches. Scrub encroachment represents surface expansion and is associated with a burnt-out fen area. Comparing data from the early sixties and 1997, the current scrubs are definitely new elements in the landscape – in the sixties most of the area was used as meadow.

Szorce

The area is located in the south-eastern part of the lower basin in the edge zone (Figure 5). There is a narrow zone of communities with *Betula pubescens* and *Alnus glutinosa* neighbouring low sedge stands. The substratum is composed of deep, poorly decomposed sedge and moss peat. Expansion assumes a zonal form with *Betula pubescens* predominating.

Laskowiec

The area is situated in the southern part of the lower basin (Figure 5) and adjoins the large forest complex dominated by *Alnus glutinosa*. Shallow sedge and woody, highly decomposed peat, about one metre thick, forms the substratum. Communities affected by succession are *Magnocaricion* and low sedge communities. Expansion is of a zonal character in the belt adjacent to the forest complex and of a surface character at some distance from the complex. Invading shrub and tree species are *Betula pubescens* in the zonal expansion and *Betula pubescens* and *Salix* sp. in the surface expansion. In relation to the situation at the beginning of the sixties they have increased by 50%.

In Tables 11,12 and 13 the results of the field observations are compared with the results of soil data analysis.

Table 11 Comparison of field observations with the results of soil data analysis, upper basin

Location	**Soil conditions**	**Vegetation characteristics**	**Spatial expansion type**	**Succession rate**
Lipsk	Organic soils with thick, moderately and slightly decomposed sedge peat Relatively high NH_4 content, particularly in the upper layer Relatively low P and NO_3 content Average K and N(tot) content	Sedge communities *(Caricion fuscae)* with encroachment of birch (*Betula pubescens)*	Integrative	High
Krasnoborki	Organic soils with deep, highly decomposed sedge peat Relatively high N(tot), NO_3 and P content Relatively low NH_4 content Average K content	Meadow communities (*Molinietalia*) with encroachment of birch (*Betula pubescens*)	Anthropo-genically forced	High
Karpowicze	Organic soils composed of highly decomposed sedge peat and mud Relatively high N(tot), NO_3 and P content Relatively low NH_4 content Average K content	Sedge communities *(Caricion fuscae)* with encroachment of aspen (*Populus tremula)* and willow (*Salix cinerea)*	Surface	High

Table 12 Comparison of field observations with the results of soil data analysis, middle basin

Location	**Soil conditions**	**Vegetation characteristics**	**Spatial expansion type**	**Succession rate**
Jaglowo	Organic soils with shallow, sedge and muddy peat in a mosaic with mud and alluvial formations Relatively high K, P, N(tot) and NH_4 content Relatively low NO_3 content	Sedge communities *(Caricion fuscae)* with encroachment of aspen (*Populus tremula),* birch *(Betula pubescns)* and willow (*Salix cinerea)*	Surface and partly anthropo-genically forced	High
Woznawies	Organic soils with shallow, highly decomposed sedge-moss peat underlain by fine sand Relatively high N(tot), (particularly in upper layer) and P content Average NH_4 content (but particularly high in the forest site) Average NO_3 and K content in upper layer, very low in lower layer	Sedge communities (*Caricion fuscae)* with elements of meadow communities (*Molinietalia)*with encroachment of willow (*Salix cinerea)*	Point and anthropo-genically forced	Moderate
Nowy Swiat	Organic soils with shallow, highly decomposed muddy reed peat Relatively high N(tot) and P content (particularly in the open site) Relatively low NO_3 content Average K and NH_4 content	Tall sedge communities (*Magnocaricion)* with encroachment of birch (*Betula pubescens)* and alder (*Alnus glutinosa)*	Zonal	Low
Ciszewo	Organic soils with highly decomposed peat deposits Relatively high N(tot) and NO_3 content Average K, NH_4 and P content	Meadow communities (*Molinietalia*) with encroachment of birch (*Betula pubescentis*) and willow (*Salix cinera*)	Anthropo-genically	Moderate

Table 13 Comparison of field observations with the results of soil data analysis, lower basin

Location	Soil conditions	Vegetation characteristics	Spatial expansion type	Succession rate
Sosnia	Organic soils with highly decomposed sedge-moss peat or with mud materials Relatively high P content Relatively low NO_3 content Average N(tot), NH_4 and K content	Tall sedge communities (*Magnocaricion*) with encroachment of Alder (*Alnus glutinosa*)	Zonal	High
Barwik	Organic soil with deep, moderately decomposed sedge peat Relatively high N(tot) (particularly in the open site) and NO_3 content Relatively low P and NH_4 content Average K content	Tall sedge communities (*Magnocaricion*) with encroachment of alder (*Alnus glutinosa*), willow (*Salix cinerea*) and birch (*Betula pubescens*)	Zonal	High
Gugny	Organic soils with deep, highly and moderately decomposed sedge-moss peat Relatively high N(tot) and K content, (K particularly in upper layers) Relatively low NO_3, content Average NH_4 and P content	Sedge communities (*Caricion fuscae*) with encroachment of alder (*Alnus glutinosae*) and willow (*Salix sp.*)	Zonal	Low
Bagno Lawki	Organic soils with deep, slightly decomposed sedge-moss peat Relatively high N(tot),and K content (particularly in lower layer) Relatively low NO_3 content Average NH_4 and P content Burnt-out fen area	Sedge communities *(Caricion fuscae)* with encroachment of birch (*Betula pubescens*)	Surface	High
Szorce	Organic soils with deep, slightly decomposed sedge-moss Relatively high N(tot) content, Relatively low P and NO_3 content Average NH4 and K content	Sedge communities *(Caricion fuscae)* with encroachment of birch (*Betula pubescens*)	Zonal	Moderate

7 Conclusions and recommendations

7.1 What has been achieved?

The aim of the present project was to contribute to the development of an operational system for monitoring scrub encroachment in wetland areas using Remote Sensing and GIS techniques.

The research objectives were as follows:
- To estimate the state and rate of scrub encroachment
- To identify different succession types, succession stages and phases (temporal aspects), and spatial expansion types (spatial aspects)
- Preliminary analysis of the underlying causes of the scrub encroachment process, such as climate change, land use changes, drainage activities and mineralisation

7.1.1 State and rate of scrub encroachment

The state of the scrub encroachment process was successfully assessed using satellite image classification and aerial photograph interpretation. Both methods revealed that about 43% to 44% of the BNP is currently covered by scrub and forest communities. The rate of scrub encroachment is more difficult to assess because this depends on many factors including:
- The historical background of the site (e.g. land use changes, drainage activities, incidents of fire)
- The original habitat type (sedge or meadow community)
- The invading shrub and tree species (willow, birch, alder or aspen)
- The site conditions (e.g. soil type and water regime)

However, a net change from open wetland to forest of about 3,000 ha within ten years (about 300 ha a year) was observed by post-classification analysis. These results are to a certain extent comparable to those obtained by means of aerial photograph interpretation. The latter indicates an increase in moderately to fully stocked tree stands of about 12% during the last thirty-five years, which is comparable to an increase of about 200 ha a year.

These estimates give the BNP management some idea of the labour input required to prevent scrub encroachment, for example by mowing, grazing or burning.

7.1.2 Succession stages and phases

Little is known about the different succession stages and phases of the scrub encroachment process in the Biebrza National Park. The present project has identified different initial succession stages, namely birch-willow, willow, alder and aspen. These initial succession stages cannot be identified on satellite images (Landsat TM) although it might be possible with high-resolution satellite images (e.g. IKONOS).

The transitory and climax succession stages can to a certain extent be identified on both satellite images (forest and scrub cover) and aerial photographs (forest and scrub cover categories), the latter giving more detail. When using satellite image interpretation, multi-temporal images are required (images of May and August) to identify the scrub cover.

Succession stages are mainly distinguished by observations based on cover density and to a limited extent by species composition. The latter requires additional fieldwork.

7.1.3 Spatial expansion types

The comparison of aerial photograph interpretation of different years (1962-1997) revealed different spatial expansion types, namely zonal, surface, point, integrative and anthropogenically forced expansion. These expansion types are often related to different succession types, namely secondary creative, secondary recreative, secular and regenerative succession (for definitions see Chapter 3).

Identification of different spatial expansion types might be useful for the elaboration of a strategy to solve the problem of scrub encroachment in the Biebrza river valley. Based on spatial expansion types, the succession rate and expansion direction can be identified for the selected areas. This information can be used to evaluate the efficiency and possible success of certain restoration activities. In this case additional information on the following additional variables should be collected:

- Advancement of scrub encroachment (succession stage and / or phase)
- Vegetation type (vegetation structure and floristic composition, invading shrub and tree species)
- Soil conditions (depth of organic or mineral deposits, physical and chemical properties of the soil)
- Water regime (groundwater level, flooding area, water chemistry, etc.)
- Current land use
- Accessibility of the site (distance from the roads, villages etc.)
- Socio-economic factors (land ownership, labour costs etc.)

For some of the spatial expansion types such a preliminary evaluation was made and is described below.

Zonal expansion

Solution: maintenance of a sharp forest borderline by regular cutting in the expansion zone of willow and birch, no interference in the alder expansion zone.

Low advancement – not labour intensive, possibility of manual harvesting because of easy access (areas situated near the valley edge), possible use of machines.
Moderate advancement - very difficult, time and labour intensive, elimination dependent on manual harvesting.
High advancement - elimination of trees and scrubs very difficult, long-lasting process, no guarantee of preserving open communities.

Surface expansion
Solution: total elimination in a relatively short time following appearance of seedlings.
Low advancement - labour intensive, manual harvesting, limited access (peatlands situated in the middle of the valley), possible restriction of expansion by harvesting from the patch border to its centre.
Moderate advancement - very labour intensive, possibilities for the use of controlled burning.
High advancement - very high expenditure with no guarantee of preserving open communities (changes of habitat conditions under forest communities).

Point expansion
Solution: total elimination of the scrub centres or regular cutting on areas in close proximity to them.
Low advancement - low labour input, possibilities for the use of manual or machine cutting (on accessible areas), total elimination, mainly willow scrubs.
Moderate advancement – not labour intensive in the peripheral zone, but labour intensive in the central part of the valley with limited access.
High advancement - high expenditure, machines required, cutting around and leaving clumps.

7.1.4 Underlying causes of scrub encroachment

Based on field observations, soil sampling and soil data analysis it can be concluded that scrub encroachment has a regional and even local character. Such a conclusion is very important for future management activities aimed at restoring the original wetland ecosystems.

The most important relationships between the physical and chemical soil-condition variables are found between $N_{(tot)}$ and ash content, and between $N\text{-}NO_3$ and humidity. $N_{(tot)}$ with its negative correlation with ash contents, together with NO_3 negatively correlated with humidity, might describe the decomposition of peat soils. The other significant correlation coefficient value is between K and P. The elements that might be used as indicators for ongoing degradation of open wetland ecosystems are $N_{(tot)}$, NO_3, P and K.

Although meteorological conditions during the research period were favourable, soil samples were taken after a very long and extremely dry summer, so the analysis of humidity values does not unequivocally indicate how shrubs or trees moderate the water regime. In particular, on sites containing scrub communities the maximum values occurred, while in others the minimum was observed. Such research demands a well-established, long-term monitoring system which is also important for management of the entire area.

The results of soil data analysis are of a rather preliminary character, but at least could help to indicate the most important soil-condition variables that should be considered when establishing a comprehensive monitoring system.

Because of the inaccessibility of wetland areas remote sensing and GIS techniques can be considered with no doubt as a crucial input of a scrub monitoring system. The state and rate of scrub encroachment can not be estimated based on only field measurements. In addition remote sensing and GIS techniques make it possible to study both the spatial and temporal aspects of scrub encroachment for example by means of identifying different spatial expansion types. However these techniques should be applied in combination with field observations. By means of land cover and vegetation maps derived from remote sensing images field observations can be carried out in a stratified way. On the other hand the possibilities of distracting ecological information from remote sensing images may be improved by means of field observations. The right balance between remote sensing, GIS techniques and field observations should be figured out. Based on the results of this project one can not recommend in detail how this balance should look like but at least one can get some general idea of costs and benefits (Table 14). This table is based on Polish conditions especially concerning labour costs.

Table 14 Cost – Benefit analysis of aerial photograph interpretation versus satellite image interpretation

	Costs (euro)	Time (days)	Benefits
Aerial photographs			
Archival materials Panchromatic 1:16,000 of 1961/62, enlarged to 1:10,000	1,250		gives a detailed overview of the state and rate of scrub encroachment gives some information about different succession stages and scrub expansion types requires high labour input
True colour photographs 1:20,000 of 1997	5,000		
Labour costs	5,000	250	
Total costs	11,500		
Satellite image classifications			
Time series 1987 –1997, 4 quarter scenes of Landsat TM (100% coverage of BNP)	4,000		gives a general overview of the state and rate of scrub encroachment gives some information on succession stages requires little labour input
Labour costs	200	10	
Total costs	4,200		

7.2 How to continue?

Although the results of the present project are not sufficient to formulate a complete and comprehensive monitoring system for scrub encroachment in the Biebrza

National Park, the following recommendations for future monitoring activities are made:

- Satellite images and aerial photograph interpretations are crucial inputs for a scrub encroachment monitoring system. However, interpretation should be accompanied by field observations.
- Multi-temporal satellite images are recommended. The combination of May and August images allow a distinction to be made between relevant vegetation or land cover types. Higher resolution images such as IKONOS might give better results, but would be more expensive.
- Panchromatic aerial photographs are adequate for the analysis of scrub succession. Analysis of scrub cover based on large-scale (1:10,000) aerial photographs is more accurate than satellite image interpretation and enables more precise analysis of the state and rate of succession, succession stages and phases, and spatial expansion types. However it is much more expensive.
- By means of stratification and additional field observations more information might be extracted from the satellite images and aerial photographs than was the case in the present project. This stratification could be based on geomorphological, hydrological and soil characteristics e.g. differentiation between the river valley, river basins, valley bottom and valley walls, riverbed and flood area, hydrogenic and non-hydrogenic sites, organic and mineral soil types, etc.
- A stratified random sampling of field observations is recommended although account should be taken of the poor accessibility of the Biebrza river valley. A Global Positioning System might be of help in localising the field observation points.
- In addition to these field observations it is advisable to establish a set of test areas for permanent and more detailed monitoring. These sites should be representative of certain succession types, succession stages and phases, and spatial expansion types.
- Management activities should be monitored together with their effects on vegetation succession. Experiments, for example on mowing, cutting and grazing should be carefully monitored.
- More information is needed on the effect of the scrub encroachment process on biodiversity. For this purpose a more detailed description of the floristic composition of different succession stages is required. In addition the relationship between habitat type and fauna should be established.
- A ten year period is sufficient to analyse changes in scrub cover and to indicate the most threatened areas, although in order to have a better overview, a five year period is recommended.

Table 15 presents the processes, variables and management activities to be monitored for a better understanding of the scrub encroachment process. Some of the variables can be measured by means of remote sensing techniques, but additional field observations and measurements are often required.

Within the framework of the management plan, a GIS has been designed and implemented for the management team of the BNP, and all the data collected on vegetation, soil, water etc. will be available to them in digital form. These geographical data sets can be combined with the results of the present project. More information can be extracted from these data sets, for example on the influence of site conditions on the rate of scrub encroachment, the species composition of the site affected by scrub encroachment etc.

Table 15 Processes, variables and management activities to be monitored for a better understanding of the scrub encroachment process

Subsystem	**Processes**	**Human impact / Management activities**	**Variable**	**Methodology**
Vegetation	Succession	Mowing Cutting Grazing Burning	Vegetation structure Floristic composition	Satellite and aerial photograph interpretation. Field observations and measurements
Soil	Mineralisation	Drainage	Soil moisture Soil chemistry	Field observations and measurements
	Eutrophication	Drainage Fertilisation	Soil chemistry	Field observations and measurements
Water	Lowering of groundwater table	Drainage	Groundwater level	Field observations and measurements
	Eutrophication	Drainage Fertilisation	Water chemistry	Field observations and measurements
	Flooding	Drainage	Ranges of spring flood Surface runoff Outflow	Satellite and aerial photograph interpretation. Field observations and measurements
Climate	Climate change	No influence on regional scale	Temperature Humidity Snow cover Cloud cover Rainfall	Field observations and measurements

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Appendix 1 Legend of actual vegetation map

1. water vegetation
2. forest
3. scrubs with Betula humilis: Betulo-Salicetum repentis
4. mosaic of Betula humilis with herbal vegetation
5. mosaic of Betula humilis with moss-sedge communities
6. mosaic of Betula humilis with low birch forest
7. Phragmition
8. Phragmitetum communis
9. Glycerietum maximae
10. reedbed in the mosaic with scrubs
11. reedbed in the mosaic with forest
12. Sparganio-Glycerion
13. Sparganio-Glycerion in the mosaic with scrubs
14. mosaic of reedbed and sedge communities
15. mosaic of reedbed, sedge communities and forest
16. Magnocaricion
17. Caricetum elatae
18. Caricetum appropinquatae
19. Caricetum gracilis
20. Caricetum rostratae
21. Thelypteri-Phragmitetum
22. Phalaridetum arundinaceae
23. mosaic of sedge communities and scrubs
24. mosaic of sedge communities and forest
25. Caricion fuscae
26. Carici-Agrostietum caninae
27. Carici-Agrostietum caninae var. with Carex appropinquata
28. Carici-Agrostietum caninae var. with Carex diandra
29. mosaic of sedge-moss communities with scrubs
30. mosaic of sedge-moss communities with forest
31. mosaic of sedge-moss communities with meadows
32. mosaic of sedge-moss communities with sedge communities
33. Caricion lasiocarpae
34. Caricetum diandrae
35. Caricetum diandrae var. with Carex appropinquata
36. Caricetum lasiocarpae
37. mosaic of sedge-moss communities (probably Caricetum lasiocarpae) with scrubs
38. mosaic of sedge-moss communities (probably Caricetum lasiocarpae) withforest
39. Caricetum limosae
40. Sphagnetum magellanicum
41. mosaic of Cariciun fuscae, Caricetum limosae, Sphagnetum magellanicum
42. Alopecurion
43. Molinion
44. Moliniteum coeruleae typicum

45. mosaic of meadows with scrubs
46. mosaic of meadows with forest
47. meadows with Calamagrostis canescens
48. Filipendulion
49. mosaic of Filipendulion and scrubs
50. mosaic of Filipendulion and forest
51. Calthion
52. Arhenatherion
53. mosaic of Arhenatherion and scrubs
54. mosaic of Arhenatherion and forest
55. Cynosurion
56. Festucetum rubrae
57. Sedo-Scleranthetea i Nardo-Callunetea
58. mosaic of Sedo-Sclerentheta, Nardo-Callunetea and scrubs
59. mosaic of Sedo-Sclerentheta, Nardo-Callunetea and forest
60. Artemisietea, Plantaginetea
61. intensively used grasslands
62. communities of arable lands
63. communities of clearings
64. synanthropic vegetation
65. vegetation on burnt out areas (herbal vegetation)
66. vegetation on burnt out areas (willow, birch, aspen)
67. Calamagrostis canescens communities

Appendix 2 Accuracy assessment of satellite classifications

Contingency matrices classification May 1988, upper basin

Training data

	1	2	3	4	5	6	7	8	9	Row total	Percentage
1 water	282	0	0	0	0	0	0	0	0	282	100%
2 reed/sedge wet	0	339	0	0	0	0	25	0	0	364	93%
3 reed/sedge int.	0	0	647	0	0	0	0	0	0	647	100%
4 reed/sedge dry	0	0	2	126	0	0	0	0	0	128	98%
5 grasslands	0	0	0	0	122	0	0	0	0	122	100%
6 dec. Forest dry	0	0	0	0	0	139	0	0	0	139	100%
7 dec. Forest wet	0	1	0	0	0	0	364	0	0	365	99%
8 con. Forest dry	0	0	0	0	0	0	0	153	0	153	100%
9 con. Forest wet	0	0	0	0	0	0	0	0	200	200	100%
Column total	282	340	649	126	122	139	389	153	200		
Percentage	100%	99%	99%	100%	100%	100%	93%	100%	100%		

Test data

	1	2	3	4	5	6	7	8	9	Row total	Percentage
1 water	546	0	2	0	0	0	0	1	10	559	97%
2 reed/sedge wet	0	473	0	0	0	0	43	0	0	516	91%
3 reed/sedge int.	0	0	37	0	0	0	0	0	0	37	100%
4 reed/sedge dry	0	0	22	141	0	0	0	0	0	163	86%
5 grasslands	0	0	0	0	267	0	0	0	0	267	100%
6 dec. forest dry	0	0	0	0	0	45	0	1	0	46	97%
7 dec. forest wet	0	31	0	0	0	0	320	0	0	351	91%
8 con. forest dry	0	0	0	0	0	0	0	324	0	324	100%
9 con. forest wet	0	0	0	0	0	0	0	0	156	156	100%
Column total	546	504	61	141	267	45	363	326	166		
Percenatge	100%	93%	60%	100%	100%	100%	88%	99%	93%		

Contingency matrices classification May 1997, upper basin

Training data

	1	2	3	4	5	6	7	8	9	Row total	Percentage
1 water	27	0	0	0	0	0	0	0	0	27	100%
2 reed/sedge wet	4	205	0	0	0	0	0	0	0	209	98%
3 reed/sedge int.	0	0	274	0	0	0	0	0	0	274	100%
4 reed/sedge dry	0	0	0	100	0	0	0	0	0	100	100%
5 grasslands	0	0	0	0	91	0	0	0	0	91	100%
6 dec. forest dry	0	0	0	0	0	97	0	0	0	97	100%
7 dec. forest wet	0	0	0	0	0	0	114	0	0	114	100%
8 con. forest dry	0	0	0	0	0	0	0	60	0	60	100%
9 con. forest wet	0	0	0	0	0	0	0	0	381	381	100%
Column total	31	205	274	100	91	97	114	60	381	1353	
Percentage	87%	100	100%	100%	100%	100%	100%	100%	100%		

Test data

	1	2	3	4	5	6	7	8	9	Row total	Percentage
1 water	99	0	0	0	0	0	0	0	0	99	1000%
2 reed/sedge wet	3	28	0	0	0	0	0	0	0	31	90%
3 reed/sedge int.	0	0	211	14	0	0	0	0	0	225	93%
4 reed/sedge dry	0	0	0	10	0	0	0	0	0	10	100%
5 grasslands	0	0	0	0	26	0	0	0	0	26	100%
6 dec. forest dry	0	0	0	0	0	83	0	0	0	83	100%
7 dec. forest wet	0	0	0	0	0	0	138	0	0	138	100%
8 con. forest dry	0	0	0	0	0	0	0	692	8	700	98%
9 con. forest wet	9	0	0	0	0	0	2	2	418	431	96%
Column total	111	28	211	24	26	83	140	694	426	1743	
Percentage	89%	100%	100%	41%	100%	100%	98%	99%	98%		

Contingency matrices classification May 1988, middle basin

Training data

	1	2	3	4	5	6	7	8	9	Row total	Percentage
1 water	1030	0	0	0	0	2	0	0	0	1032	99%
2 reed/sedge wet	4	1663	0	0	0	0	0	0	0	1667	99%
3 reed/sedge int.	0	0	1910	3	0	0	0	0	0	1913	99%
4 reed/sedge dry	0	0	1	930	0	0	0	0	0	931	99%
5 grasslands	0	0	0	0	242	0	0	0	0	242	100%
6 dec. forest dry	9	0	0	0	0	662	0	0	0	671	98%
7 dec. forest wet	2	0	0	0	0	0	655	0	0	657	99%
8 con. forest dry	9	0	0	0	0	0	0	222	0	231	96%
9 con. forest wet	22	0	0	0	0	0	0	1	275	298	92%
Column total	1076	1663	1911	933	242	664	655	223	275		
Percentage	95%	100%	99%	99%	100%	99%	100%	99%	100%		

Test data

	1	2	3	4	5	6	7	8	9	Row total	Percentage
1 water	972	17	29	1	0	5	51	1003	87	2165	44%
2 reed/sedge wet	0	1393	9	0	0	0	1	0	0	1403	99%
3 reed/sedge int.	0	43	1186	0	0	0	0	0	0	1229	96%
4 reed/sedge dry	0	0	0	1145	0	0	0	0	0	1145	100%
5 grasslands	0	0	0	0	301	0	0	229	0	530	56%
6 dec. forest dry	37	0	0	0	0	127	40	0	0	204	62%
7 dec. forest wet	0	0	0	0	0	0	492	0	0	492	100%
8 con. forest dry	51	0	0	0	0	0	0	161	0	212	75%
9 con. forest wet	1	0	0	0	0	0	0	1	115	117	98%
Column total	1061	1453	1224	1146	301	132	584	1394	202		
Percentage	91%	95%	96%	99%	100%	96%	84%	11%	56%		

Contingency matrices classification May 1997, middle basin

Training data

	1	2	3	4	5	6	7	8	9	Row total	Percentage
1 water	48	0	0	0	0	0	0	0	0	48	100%
2 reed/sedge wet	0	928	0	0	0	0	0	0	0	928	100%
3 reed/sedge int.	0	0	2129	0	0	0	0	0	0	2129	100%
4 reed/sedge dry	0	0	0	1407	0	0	0	0	0	1407	100%
5 grasslands	0	0	0	0	429	0	0	0	0	429	100%
6 dec. forest dry	0	0	0	0	0	162	0	0	5	167	97%
7 dec. forest wet	0	0	0	0	0	0	2142	0	0	2142	100%
8 con. forest dry	0	0	0	0	0	0	0	1027	43	1070	96%
9 con. forest wet	0	1	0	0	0	0	0	11	2362	2374	99%
Column total	48	929	2129	1407	429	162	2142	1038	2410	10824	
Percentage	100%	99%	100%	100%	100%	100%	100%	99%	98%		

Test data

	1	2	3	4	5	6	7	8	9	Row total	Percentage
1 water	53	7	0	0	0	0	0	0	0	60	88%
2 reed/sedge wet	0	206	0	0	0	0	0	0	0	206	100%
3 reed/sedge int.	0	0	1960	0	0	0	0	0	0	1963	99%
4 reed/sedge dry	0	0	40	1659	0	0	0	0	0	1699	98%
5 grasslands	0	0	0	0	163	0	0	0	0	163	100%
6 dec. forest dry	0	0	0	0	0	142	0	4	1	147	96%
7 dec. forest wet	0	0	0	0	0	0	537	0	0	537	100%
8 con. forest dry	0	0	0	0	0	4	0	388	0	392	98%
9 con. forest wet	0	0	0	0	0	0	0	90	1999	2089	95%
Column total	53	213	2000	1659	163	146	537	482	2000		
Percentage	100%	96%	98%	100%	100%	97%	100%	80%	99%		

Contingency matrices classification May 1988, lower basin

Training data

	1	2	3	4	5	6	7	8	Row total	Percentage
1 water	1525	0	0	0	0	0	0	0	1525	100%
2 reed/sedge wet	0	2749	0	0	0	0	0	0	2749	100%
3 reed/sedge int.	0	0	271	0	0	0	0	0	271	100%
4 reed/sedge dry	0	0	0	2378	0	0	0	0	2378	100%
5 grasslands	0	0	0	0	328	0	0	0	328	100%
6 dec. forest dry	0	0	0	0	0	597	39	0	636	95%
7 dec. forest wet	0	0	0	0	0	1	444	0	445	99%
8 con. forest dry	0	0	0	0	0	0	0	1996	1996	100%
Column total	1525	2749	271	2378	328	598	483	1996	10353	
Percentage	100%	100	100%	100%	100%	99%	91%	1000%		

Test data

	1	2	3	4	5	6	7	8	Row total	Percentage
1 water	1280	0	0	0	0	0	0	0	1280	100%
2 reed/sedge wet	0	848	0	0	0	0	25	0	873	97%
3 reed/sedge int.	0	0	928	0	0	0	0	0	928	100%
4 reed/sedge dry	0	0	210	1293	0	0	0	0	1503	86%
5 grasslands	0	0	0	0	190	0	0	0	190	100%
6 dec. forest dry	0	0	0	0	0	1485	29	0	1514	98%
7 dec. forest wet	0	0	0	0	0	403	964	0	1367	71%
8 con. forest dry	0	0	0	0	0	0	0	1619	1619	100%
Column total	1280	848	1138	1293	190	1888	1018	1619	9274	
Percentages	100%	100%	81%	100%	100%	78%	94%	100%		

Contingency matrices classification May 1997, lower basin

Training data

	1	2	3	4	5	6	7	8	Row total	Percentage
1 water	750	0	0	0	0	0	0	0	750	100%
2 reed/sedge wet	0	2657	0	0	0	0	0	3	2660	99%
3 reed/sedge int.	0	1	750	0	0	0	0	0	751	99%
4 reed/sedge dry	0	0	0	1615	0	0	0	0	1615	100%
5 grasslands	0	0	0	0	1094	0	0	0	1094	100%
6 dec. forest dry	0	0	0	0	0	2425	585	0	3010	82%
7 dec. forest wet	0	0	0	0	0	390	1355	0	1745	79%
8 con. forest dry	0	0	0	0	0	0	0	2994	2994	100%
Column total	750	2658	750	1615	1094	2815	1940	2997	14619	
Percentage	100%	99%	100%	100%	100%	86%	70%	99%		

Test data

	1	2	3	4	5	6	7	8	Row total	Percentage
1 water	742	42	0	0	0	0	0	0	784	95%
2 reed/sedge wet	0	1952	1	0	0	0	0	0	1953	99%
3 reed/sedge int.	0	0	518	0	0	0	1	0	519	99%
4 reed/sedge dry	0	0	11	1676	0	0	0	0	1687	99%
5 grasslands	0	0	0	0	1054	0	0	0	1054	100%
6 dec. forest dry	0	0	0	0	0	1859	43	0	1902	98%
7 dec. forest wet	0	0	0	0	0	141	213	0	354	60%
8 con. forest dry	0	2	0	0	0	0	0	1996	1998	99%
Column total	742	1996	530	1676	1054	2000	257	1996	10251	
Percentage	100%	98%	98%	100%	100%	93%	83%	100%		

Contingency matrices classification August 1997, upper basin

Training data

	Reed	Sedge	Scrub	Row total	Percentage
1 Reed	120	0	0	120	100%
2 Sedge	0	60	0	60	100%
3 Scrub	0	0	120	120	100%
Column total	120	60	120	300	
Percent	100%	100%	100%		

Test data

	Reed	Sedge	Scrub	Row total	Percentage
1 Reed	57	0	0	57	100%
2 Sedge	0	44	0	44	100%
3 Scrub	0	16	60	76	78%
Column total	57	60	60	177	
Percent	100%	73%	100%		

Contingency matrices classification August 1997, middle basin

Training data

	Reed	Sedge	Scrub	Row total	Percentage
1 Reed	200	0	0	200	100%
2 Sedge	0	176	7	183	96%
3 Scrub	0	5	188	193	97%
Column total	200	181	195	576	
Percentage	100%	97%	96%		98%

Test data

	Reed	Sedge	Scrub	Row total	Percentage
1 Reed	82	0	0	82	100%
2 Sedge	0	41	7	48	85%
3 Scrub	0	59	93	152	61%
Column total	82	100	100	282	
Percentage	100%	41%	93%		77%

Contingency matrices classification August 1997, lower basin

Training data

	Reed	Sedge	Scrub	Row total	Percentage
1 Reed	114	0	0	114	100%
2 Sedge	0	120	0	120	100%
3 Scrub	0	0	120	120	100%
Column total	114	120	120	354	
Percentages	100%	100%	100%		100%

Test data

	Reed	Sedge	Scrub	Row total	Percentage
1 Reed	60	0	0	60	100%
2 Sedge	0	52	0	52	100%
3 Scrub	0	8	60	68	88%
Column total	60	60	60	180	
Percentage	100%	87%	100%		96%

Appendix 3 Results of the soil data analysis

3 A Analysis of total data set

3A-1 Means and standard deviations

Transect	Point	Cond.	Depth cm	Ash content %	Bulk density g/cm³	Humidity %	Dry weight	Total Nitrogen mg/dm³	N-NH4 mg/dm³	N-NO3 mg/dm³	P mg/100g	K mg/100g
Lipsk	10	O	0-10	18,26	0,168	80,34	16,81	1,87	10,65	0,83	72	10,6
Lipsk	10	O	40-50	12,93	0,112	86,89	12,12	1,62	10,77	0,55	71	12
Lipsk	11	S	0-10	14,82	0,13	78,62	14,18	2,21	8,29	0,73	53	21,2
Lipsk	11	S	40-50	9,57	0,128	87,72	12,7	2,65	17,47	0,75	24	7,6
Lipsk	12	F	0-10	16,12	0,142	81,64	14,82	2,27	17,68	0,57	63	28
Lipsk	12	F	40-50	10,14	0,132	86,19	13,91	2,44	17,86	0,73	38	27,6
Krasnoborki	20	O	0-10	15,7	0,249	67,73	26,93	2,78	6,62	51,9	171	31,6
Krasnoborki	20	O	40-50	9,53	0,135	83,03	13,91	2,36	4,16	1,66	37	12,4
Krasnoborki	19	S	0-10	16,08	0,218	64,75	25,72	2,79	6,65	18,93	260	34,4
Krasnoborki	19	S	40-50	8,47	0,135	85,93	13,6	2,8	5,56	1,7	54	14
Krasnoborki	21	F	0-10	16,18	0,181	48,48	28,92	2,67	7,08	45,65	114	25
Krasnoborki	21	F	40-50	11,02	0,131	81,09	13,88	2,7	5,34	3,11	50	10,2
Karpowicze	24	O	0-10	18,86	0,229	29,87	42,61	2,81	5,47	31,06	220	32,8
Karpowicze	24	O	40-50	15,03	0,157	83,14	15,89	2,68	10,29	21,91	58	16,4
Karpowicze	23	S	0-10	16,36	0,259	31,74	44,81	2,76	7,16	26,28	191	34,4
Karpowicze	23	S	40-50	24,64	0,145	80,14	15,32	2,35	8,53	13,9	62	19,6
Karpowicze	22	F	0-10	19,58	0,245	39,34	38,41	2,79	4,43	10,06	144	33,2
Karpowicze	22	F	40-50	20,64	0,165	72,33	18,63	2,26	5,4	2,2	66	15,2
Jaglowo	15	O	0-10	15,16	0,221	47,96	31,51	2,98	9,57	41,99	194	36
Jaglowo	15	O	40-50	12,86	0,156	83,59	15,74	2,19	6,22	3,32	48	17,6
Jaglowo	14	S	0-10	33,07	0,228	67,67	24,15	1,57	10,73	3,31	330	39,8
Jaglowo	14	S	40-50	67,57	0,497	69,95	41,52	0,78	25,49	1,97	58	61,2
Jaglowo	13	F	0-10	18,03	0,233	55,51	33,09	2,27	11,13	3,03	146	28,8
Jaglowo	13	F	40-50	17,94	0,201	68,54	22,68	2,27	9,13	7,08	58	24,4
Wozanwies	4	O	0-10	15,21	0,194	72,44	21,52	3	5,78	3,7	101	32,8
Wozanwies	4	O	40-50	92,42	0,096	50,89	68,28	0,24	5,48	2,42	30	19,6
Wozanwies	5	S	0-10	12,7	0,153	61,51	19,92	2,91	5,48	12,47	94	38
Wozanwies	5	S	40-50	86,16	0,042	64,77	50,63	0,43	5,11	3,68	20	21,6
Wozanwies	6	F	0-10	14,62	0,173	65,29	20,97	2,81	11,01	21,29	114	40,4
Wozanwies	6	F	40-50	50,4	0,244	81,59	21,05	1,34	19,65	2,61	44	17,4
Nowy Swiat	31	O	0-10	36,98	0,216	77,59	21,77	1,67	7,18	3,16	570	42
Nowy Swiat	31	O	40-50	12,36	0,191	84,74	18,37	2,97	4,77	1,37	65	21,2
Nowy Swiat	32	S	0-10	17,93	0,172	77,03	18,27	3,02	8,38	2,98	194	20
Nowy Swiat	32	S	40-50	12,6	0,176	84,98	17,14	3,06	5,9	1,21	82	37,2
Nowy Swiat	33	F	0-10	26,04	0,172	59,78	21,41	2,44	5,63	21,61	116	33,2
Nowy Swiat	33	F	40-50	13,15	0,174	85,21	16,93	2,93	4,7	1,37	74	17,4
Ciszewo	34	S	0-10	15,97	0,222	44,07	33,95	2,92	4,38	49,89	170	29,2

Ciszewo	34	S	40-50	12,86	0,161	76,95	17,31	2,45	7,53	7,17	45	15,6
Ciszewo	35	F	0-10	18,52	0,275	36,18	42,12	3	10,15	43,61	210	32,4
Ciszewo	35	F	40-50	10,21	0,134	81,5	14,07	2,65	12,53	1,64	36	17,4
Ciszewo	36	O	0-10	16,53	0,341	62,78	35,77	3,14	6,41	36,28	195	34,8
Ciszewo	36	O	40-50	10,61	0,171	80,85	17,59	2,93	5,24	4,05	62	20,2
Sosnia	8	O	0-10	16,62	0,16	81,94	16,88	2,8	5,05	1,74	136	35
Sosnia	8	O	40-50	10,7	0,149	90,08	14,17	2,81	4,82	0,91	74	19,8
Sosnia	9	F	0-10	14,53	0,196	85,96	18,05	2,81	6,24	2,01	42	17,6
Sosnia	9	F	40-50	10,38	0,145	86,72	14,56	2,6	5,04	1,7	40	13,6
Sosnia	7	S	0-10	13,39	0,148	79,8	15,66	2,86	6,66	4,95	264	39,4
Sosnia	7	S	40-50	10,66	0,14	89,82	13,5	2,77	6,11	1,44	150	39,2
Barwik	25	O	0-10	14,85	0,177	73,68	19,35	2,83	3,73	15,82	96	17,6
Barwik	25	O	40-50	10,39	0,153	84,43	15,33	2,88	4,56	1,38	59	11,4
Barwik	26	S	0-10	16,77	0,174	61,58	21,5	2,92	5,4	29	113	23,2
Barwik	26	S	40-50	8,15	0,147	83,55	14,99	2,71	4,23	3,65	36	9,2
Barwik	27	F	0-10	16,51	0,19	60,87	23,66	2,87	5,73	84,67	78	21,6
Barwik	27	F	40-50	6,96	0,175	85,08	17,06	2,75	6,14	2,14	43	10
Gugny	16	O	0-10	13,4	0,102	64,02	13,76	2,23	4,06	1,21	176	58
Gugny	16	O	40-50	11,65	0,12	88,94	11,92	2,9	3,71	1,19	102	25,2
Gugny	17	S	0-10	13,58	0,13	73,46	15,06	2,41	4,72	1,55	160	74,4
Gugny	17	S	40-50	11,92	0,148	83,77	15,04	2,62	3,95	1,36	102	24,8
Gugny	18	F	0-10	14,29	0,166	78,34	17,46	2,85	9,1	17,11	152	52
Gugny	18	F	40-50	11,77	0,152	85,83	15,08	2,53	6,25	2,16	70	26,8
Bagno Lawki	2	O	0-10	10,62	0,095	79,99	10,36	1,96	4,71	0,95	128	44,4
Bagno Lawki	2	O	40-50	11,68	0,159	89,06	15,17	2,81	5,6	1,06	86	23,6
Bagno Lawki	3	S	0-10	14,77	0,089	89,54	9,02	1,88	5,12	1,08	126	50
Bagno Lawki	3	S	40-50	11,48	0,136	91,41	12,97	3,29	5,56	1,3	102	38
Bagno Lawki	1	F	0-10	11,4	0,1	83,35	12,11	1,52	6,05	1,23	88	28,8
Bagno Lawki	1	F	40-50	13,9	0,13	89,2	12,76	2,86	5,1	1,12	72	26,8
Szorce	29	O	0-10	14,99	0,131	86,14	13,18	2,48	6,53	1,74	88	34,4
Szorce	29	O	40-50	13,1	0,193	87,68	18,06	1,44	9,16	2,01	55	19,2
Szorce	28	S	0-10	14,41	0,112	85,81	11,83	2,15	4,96	1,36	102	39,6
Szorce	28	S	40-50	12,91	0,158	88,39	15,17	2,71	5,46	1,67	57	25,2
Szorce	30	F	0-10	16,35	0,14	83,09	14,42	2,4	7,16	1,9	114	30
Szorce	30	F	40-50	11,99	0,171	87,34	16,36	3,08	8,11	1,74	62	17,2

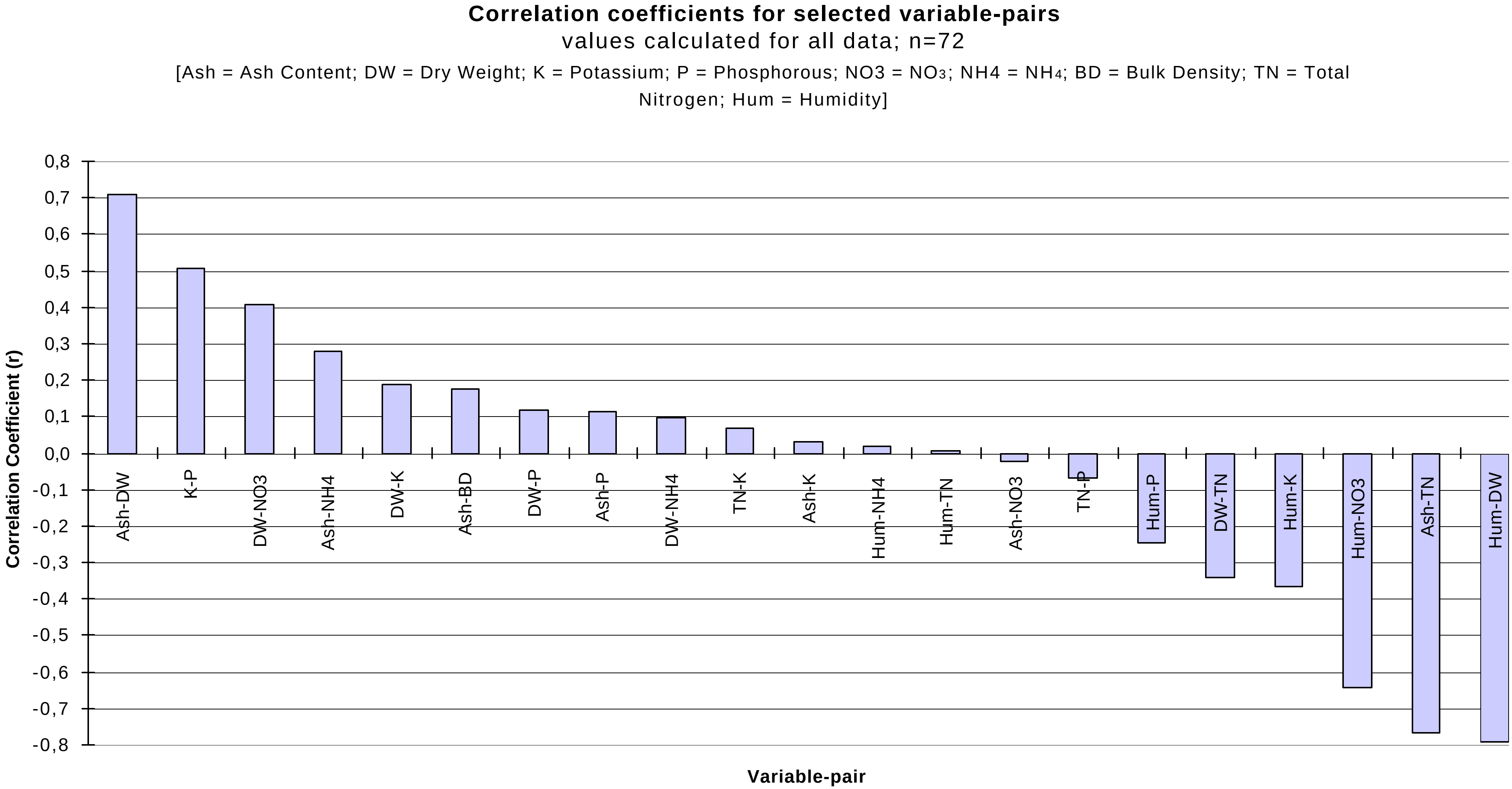
Mean				18,03	0,171	74,85	20,60	2,48	7,44	9,79	108,01	27,51
Stand. Dev.				15,06	0,062	15,08	10,65	0,60	4,01	15,97	83,87	12,92
Transect	**Point**	**Location**	**Depth**	**Content of Ash**	**Bulk density**	**Humidity**	**Dry Weight**	**Total Nitrogen**	**N-NH4**	**N-NO3**	**P. (mg/100g)**	**K (mg/100g)**

O = open
S = scrub
F = forest

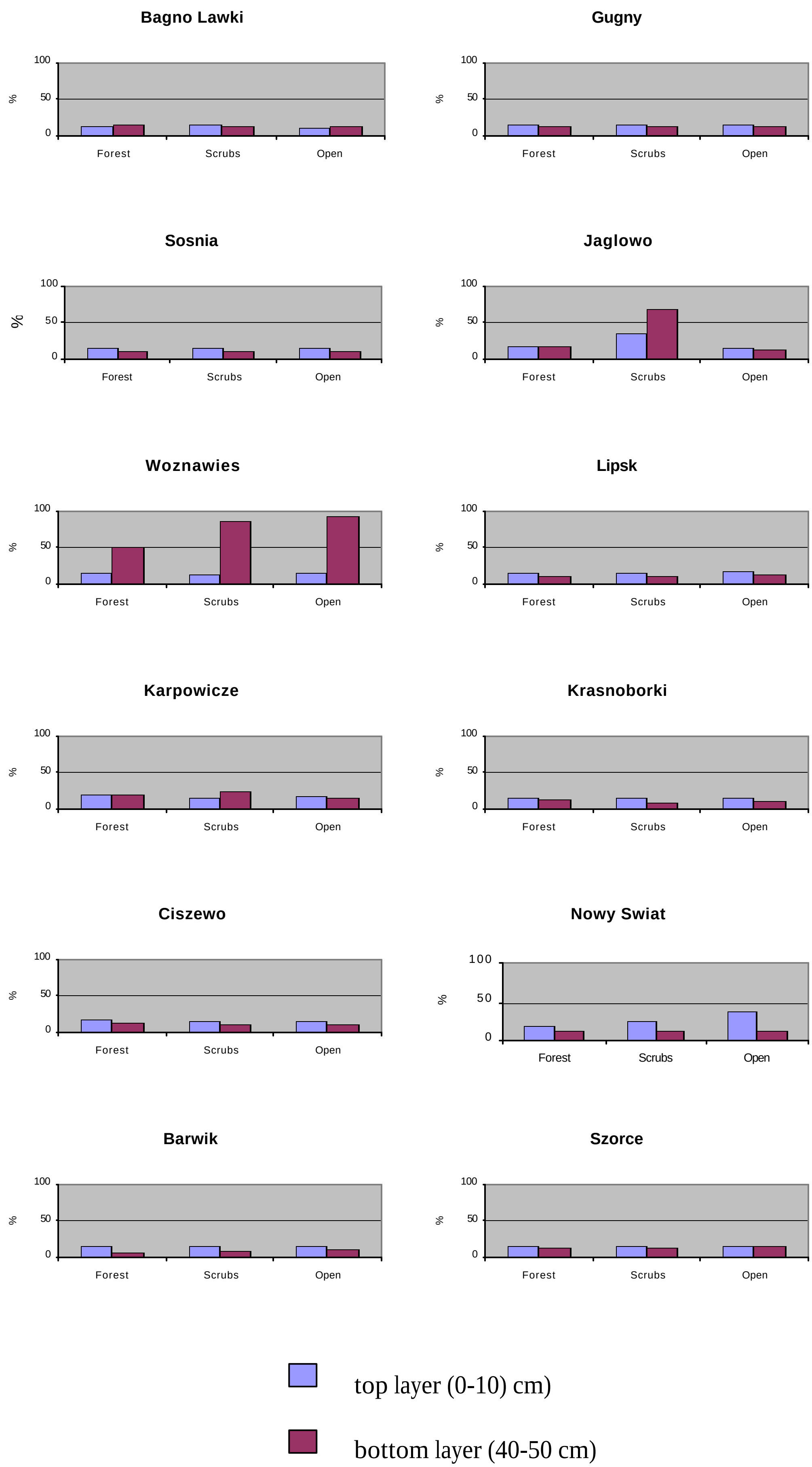
Appendix 3A-2 Analysis of total data set, correlation between variable-pairs

	Ash Content	Bulk Density	Humidity	Dry weight	Total nitrogen	N-NH4	N-NO3	Phosphorous (P)	Potassium (K)
Ash Content									
Bulk Density	0,173								
Humidity	-0,288	-0,437							
Dry weight	0,707	0,452	-0,794						
Total nitrogen	-0,769	0,056	0,008	-0,343					
N-NH4	0,276	0,434	0,018	0,097	-0,339				
N-NO3	-0,026	0,370	-0,643	0,405	0,286	-0,066			
Phosphorous (P)	0,029	0,295	-0,365	0,188	0,065	-0,096	0,239		
Potassium (K)	0,111	0,232	-0,245	0,117	-0,071	0,054	0,078	0,507	

Appendix 3 A-3 Analysis of total data set, correlation between variable pairs

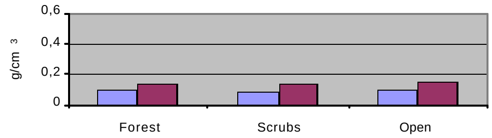


Appendix 3B-1 Ash content

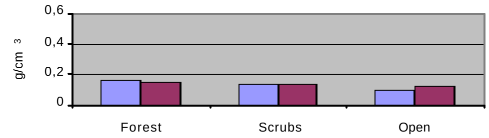


Appendix 3B-2 Bulk density

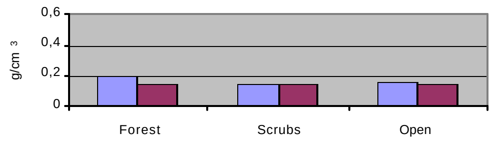
Bagno Lawki



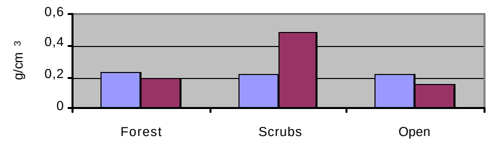
Gugny



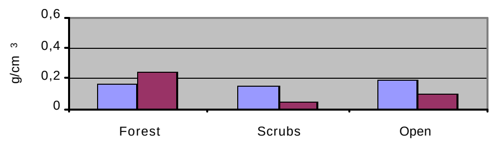
Sosnia



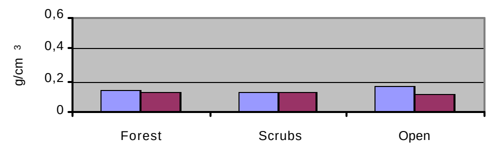
Jaglowo



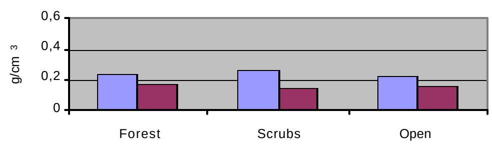
Woznawies



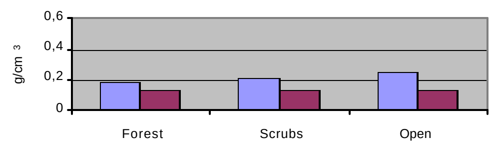
Lipsk



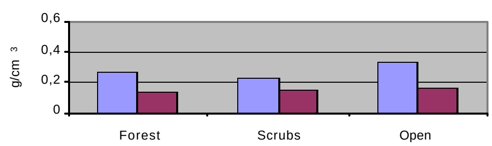
Karpowicze



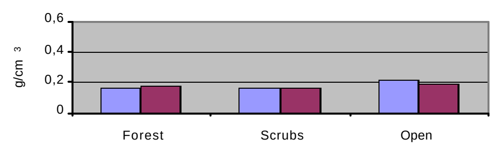
Krasnoborki



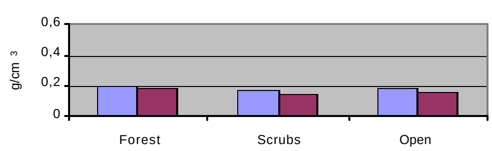
Ciszewo



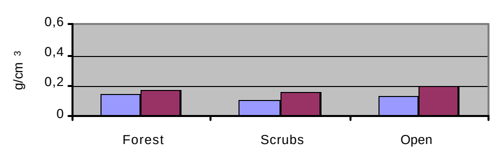
Nowy Swiat



Barwik



Szorce

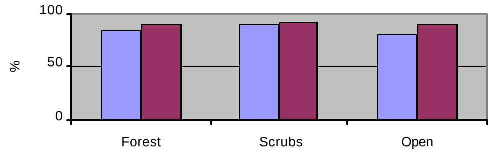


top layer (0-10) cm)

bottom layer (40-50 cm)

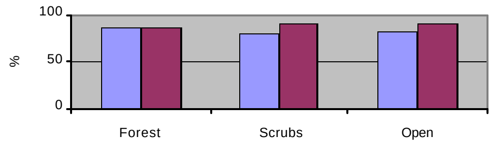
Appendix 3B-3 Humidity

Bagno Lawki

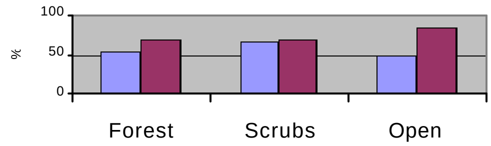


Gugny

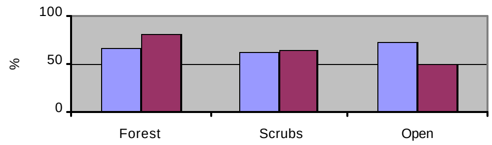
Sosnia



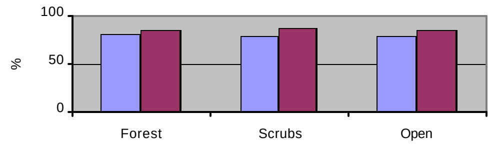
Jaglowo



Woznawies



Lipsk



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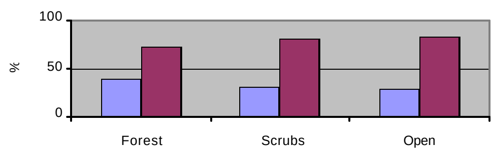

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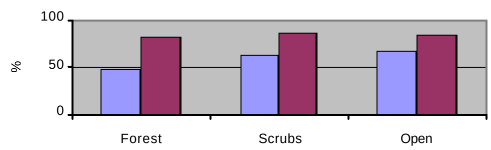
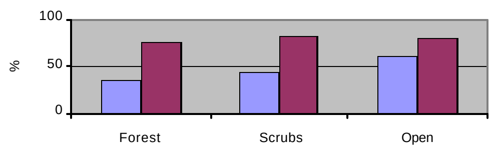
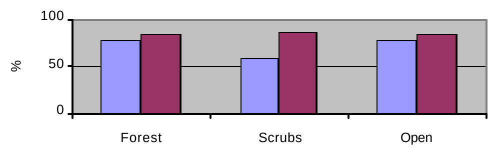


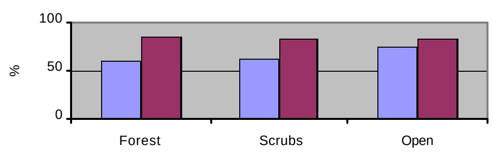
Ciszewo



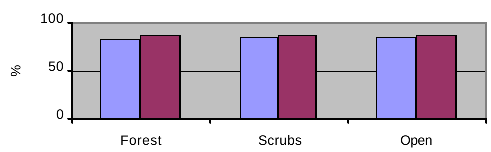
Nowy Swiat



Barwik



Szorce

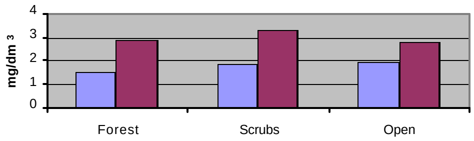


top layer (0-10) cm)

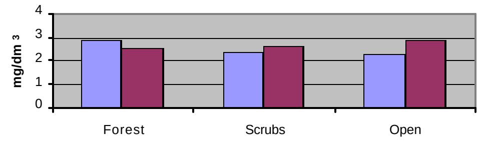
bottom layer (40-50 cm)

Appendix 3B-4 Total nitrogen (N)

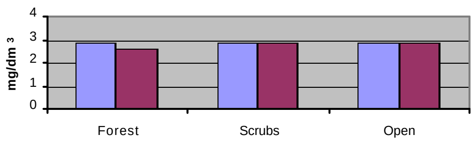
Bagno Lawki



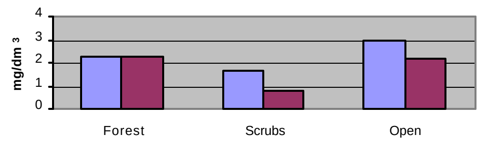
Gugny



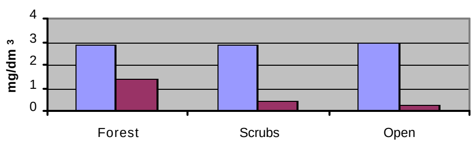
Sosnia



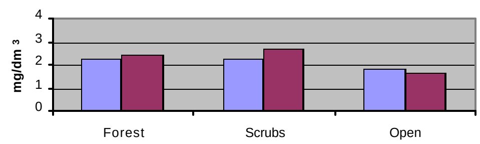
Jaglowo



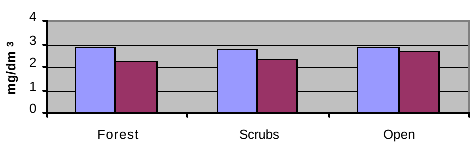
Woznawies



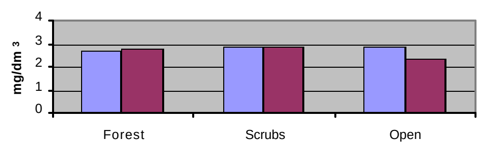
Lipsk



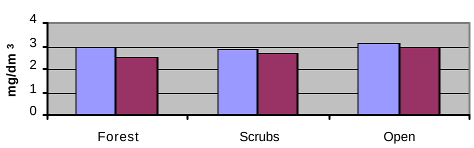
Karpowicze



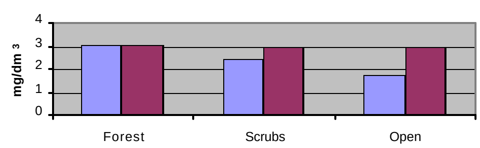
Krasnoborki



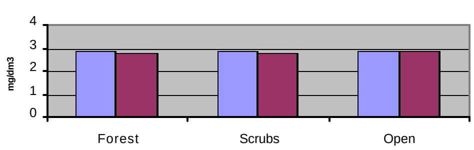
Ciszewo



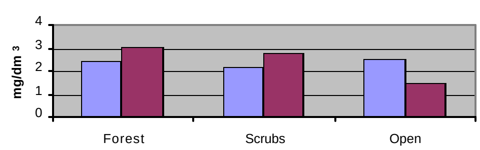
Nowy Swiat



Barwik



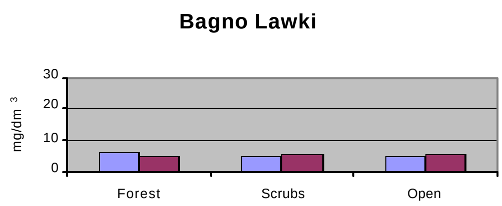
Szorce

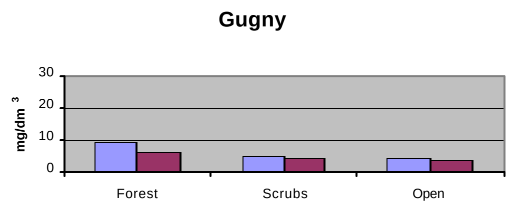


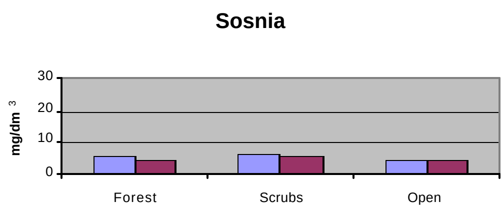
top layer (0-10) cm)

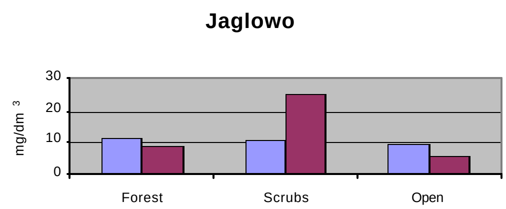
bottom layer (40-50 cm)

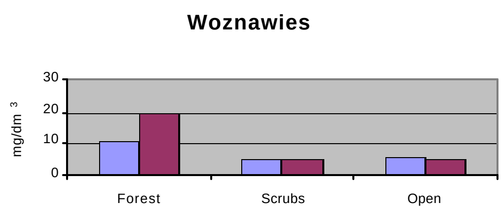
Appendix 3 B-5 NH_4

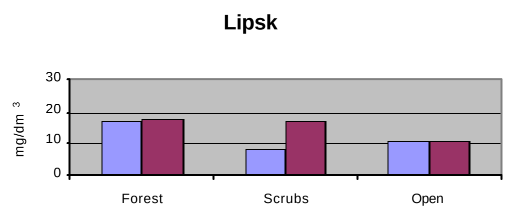


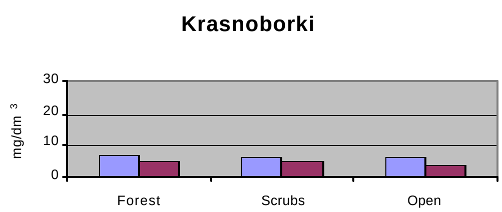


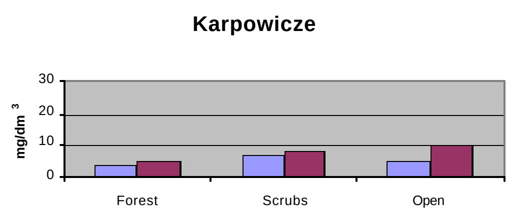


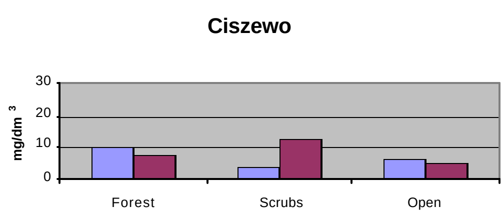


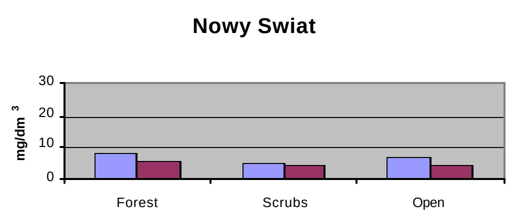


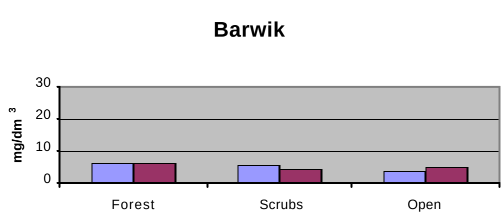


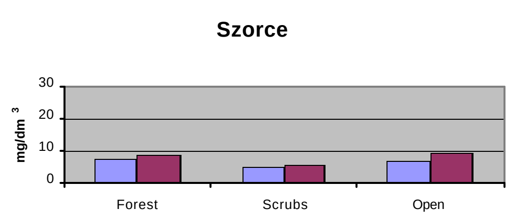








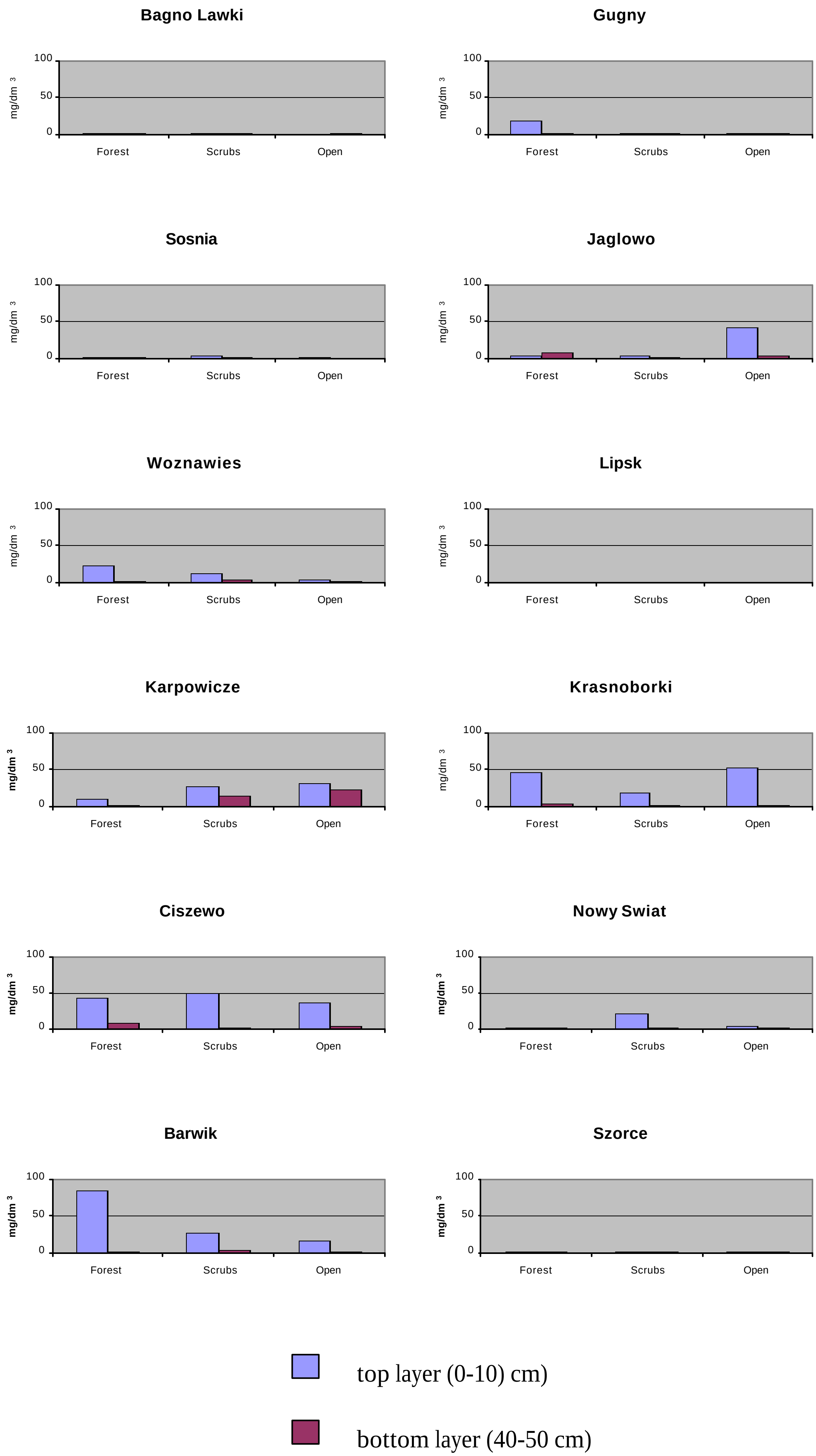




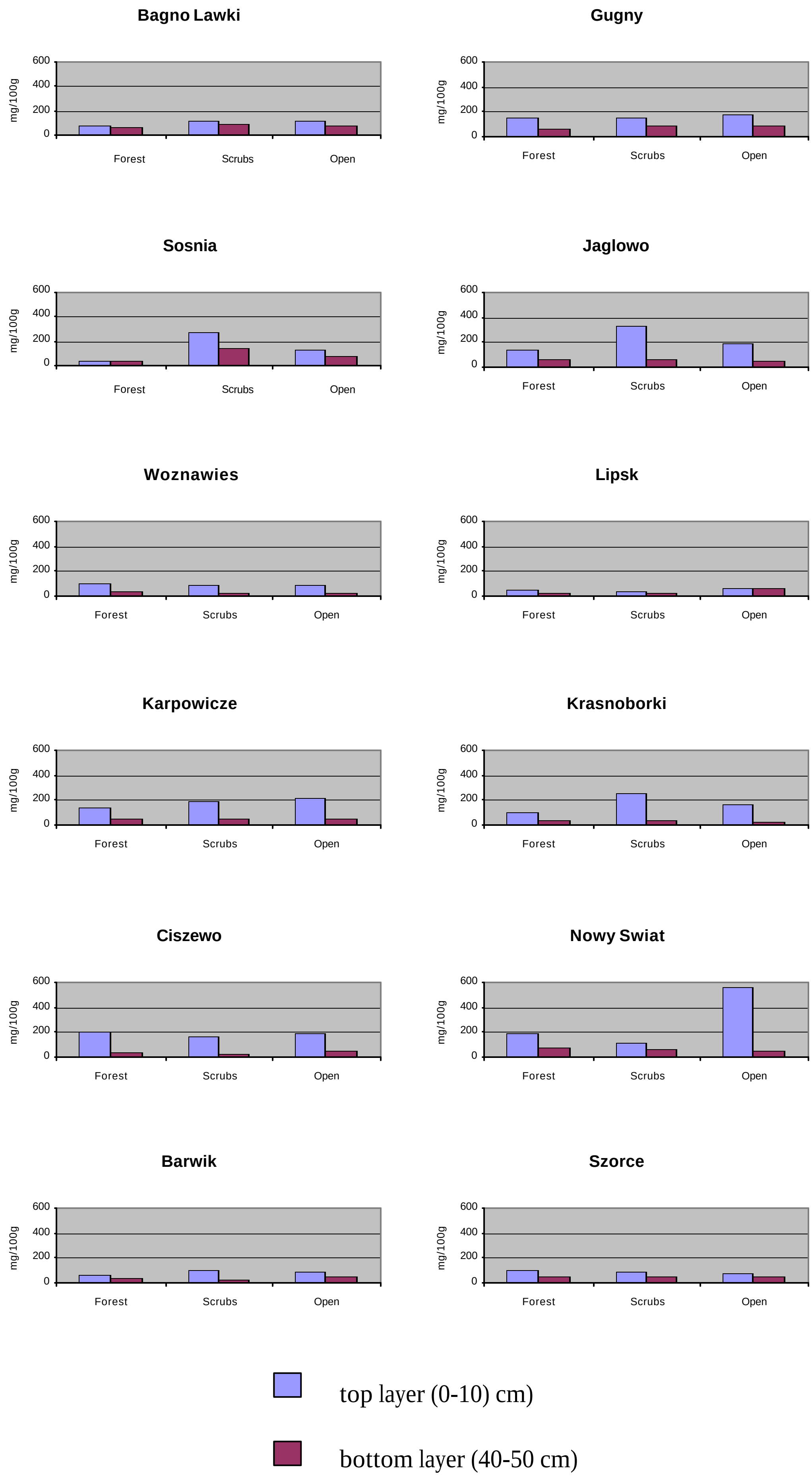
top layer (0-10) cm)

bottom layer (40-50 cm)

Appendix 3B-6 HNO_3

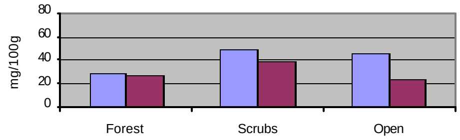


Appendix 3B-7 Phosphorous (P)

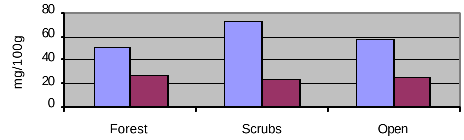


Appendix 3B-8 Potassium (K)

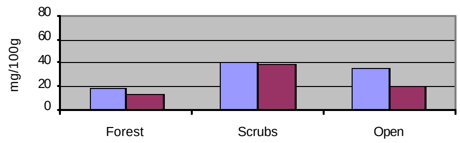
Bagno Lawki



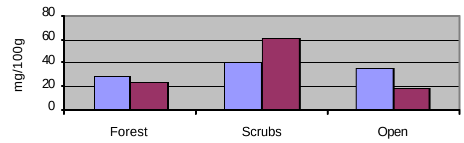
Gugny



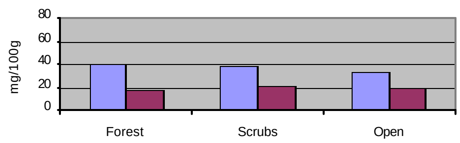
Sosnia



Jaglowo



Woznawies



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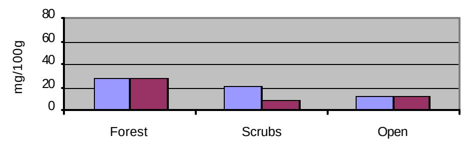
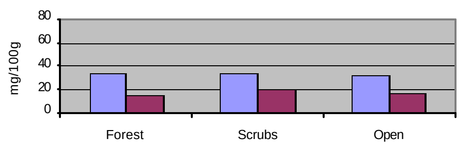


Karpowicze



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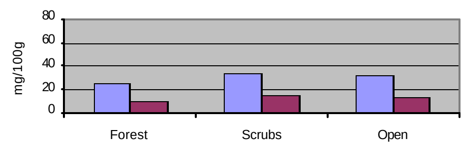
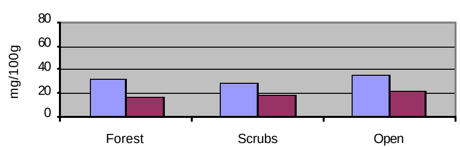
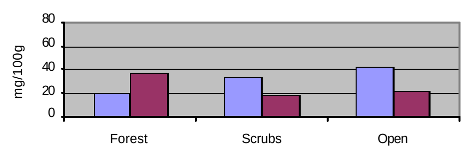


Ciszewo



Nowy Swiat



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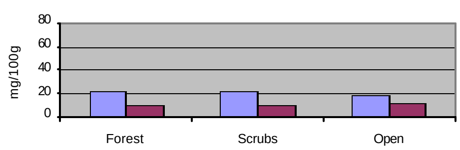
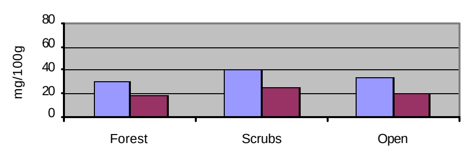


Szorce

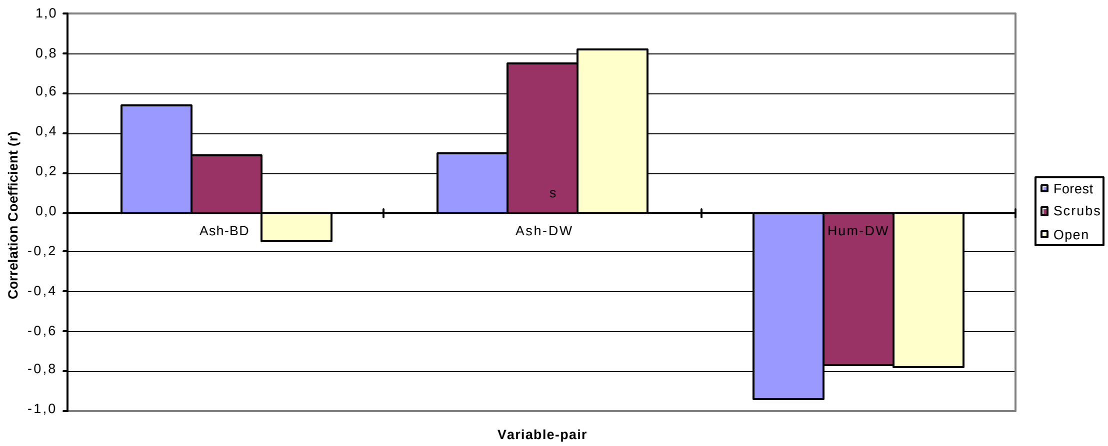


top layer (0-10) cm)

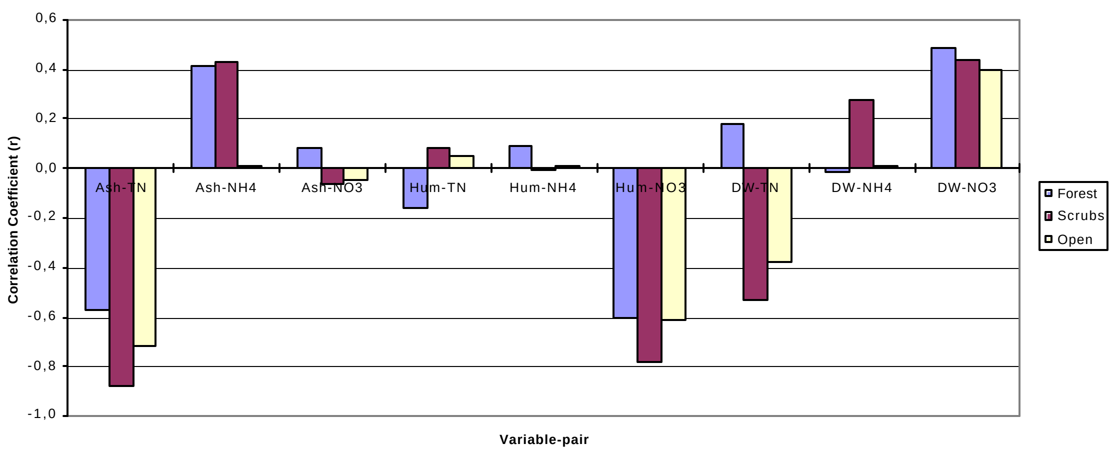
bottom layer (40-50 cm)

Appendix 3 C Analysis of data set organised by vegetation cover

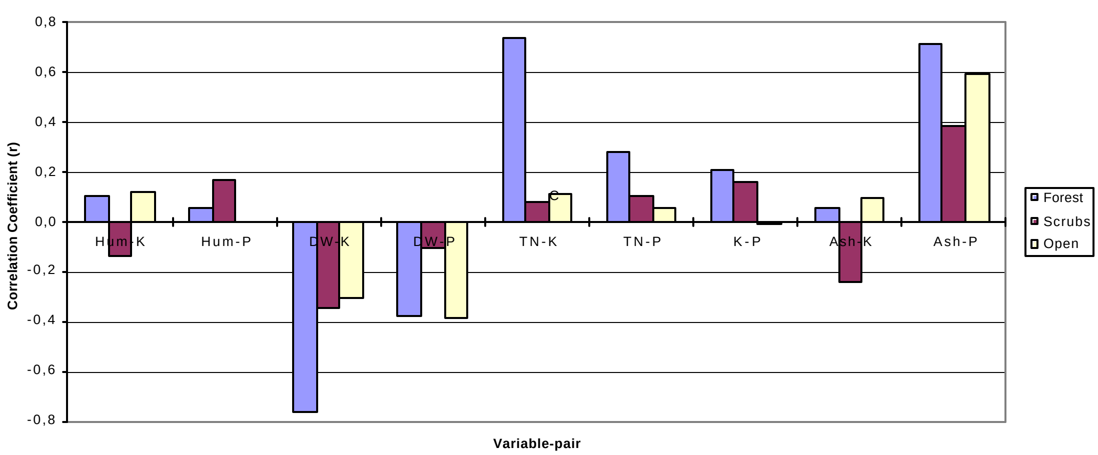
Correlation coefficients for selected variable-pairs
values calculated for all data; n=24
[Ash = Ash Content; BD = Bulk Density; DW = Dry Weight; Hum = Humidity]



Correlation coefficient for selected variable-pairs
values calculated for all data; n=24
[Ash = Ash Content; TN = Total Nitrogen; NH4 = NH_4; NO3 = NO_3; Hum = Humidity; DW = Dry Weight]

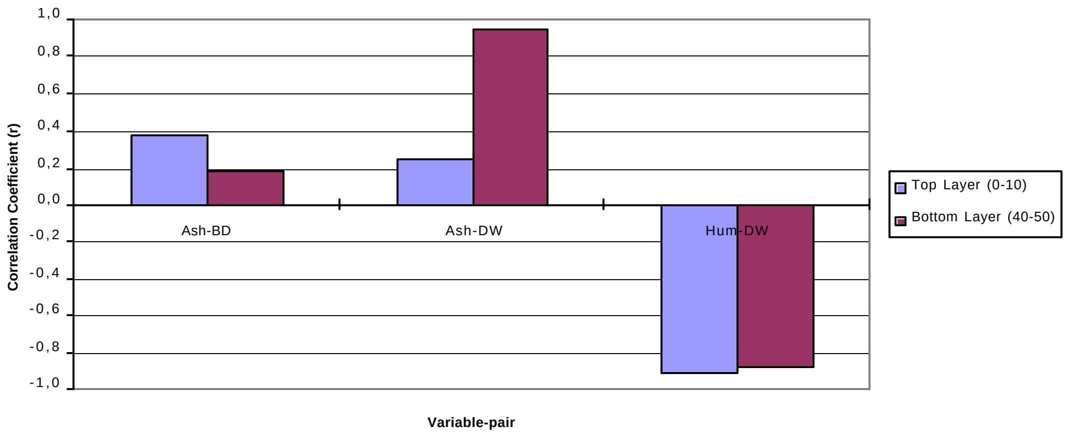


Correlation coefficient (r) for selected variable-pairs
values calculated for all data; n=24
[Ash = Ash Content; K = Potassium; P = Phosphorous; Hum = Humidity; DW = Dry Weight; TN = Total Nitrogen]

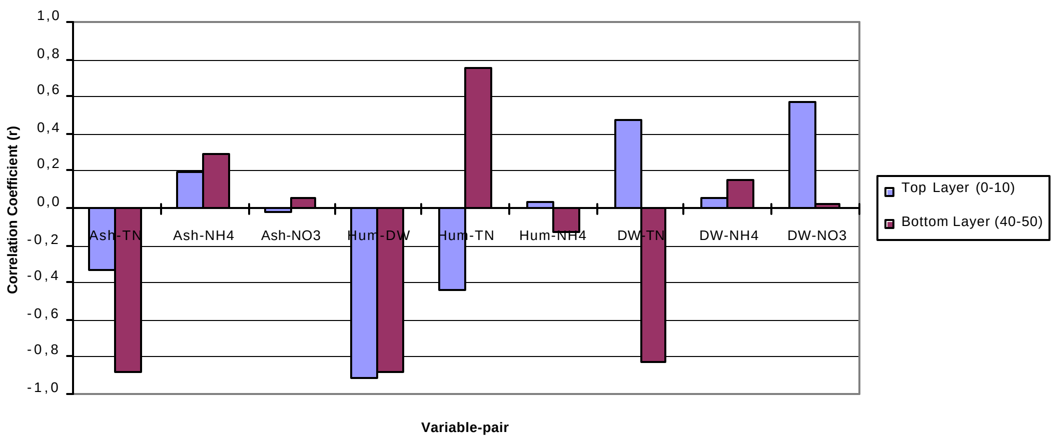


Appendix 3 D Analysis of data set organised by layer

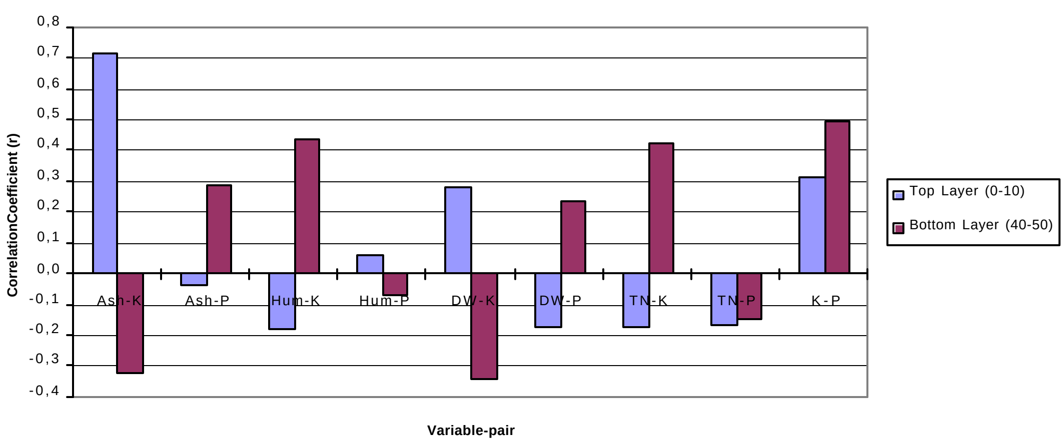
Correlation coefficients (r) for selected variable-pairs
values calculated for all data; n=36
[Ash = Ash Content; BD = Bulk Density; DW = Dry Weight; Hum = Humidity]



Correlation coeffieciencts (r) for selected variable-pairs
values calculated for all data; n=36
[Ash = Ash Content; TN = Total Nitrogen; NH4 = NH_4; NO3 = NO_3; Hum = Humidity; DW = Dry Weight]

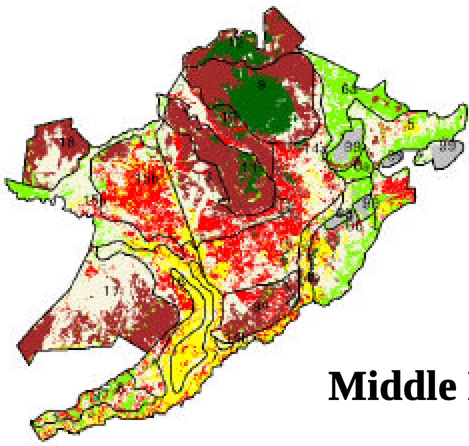


Correlation coefficient (r) for selected variable-pairs
values calculated for all data; n=36
[Ash = Ash Content; K = Potassium; P = Phosphorous; Hum = Humidity; DW = Dry Weight; TN = Total Nitrogen]

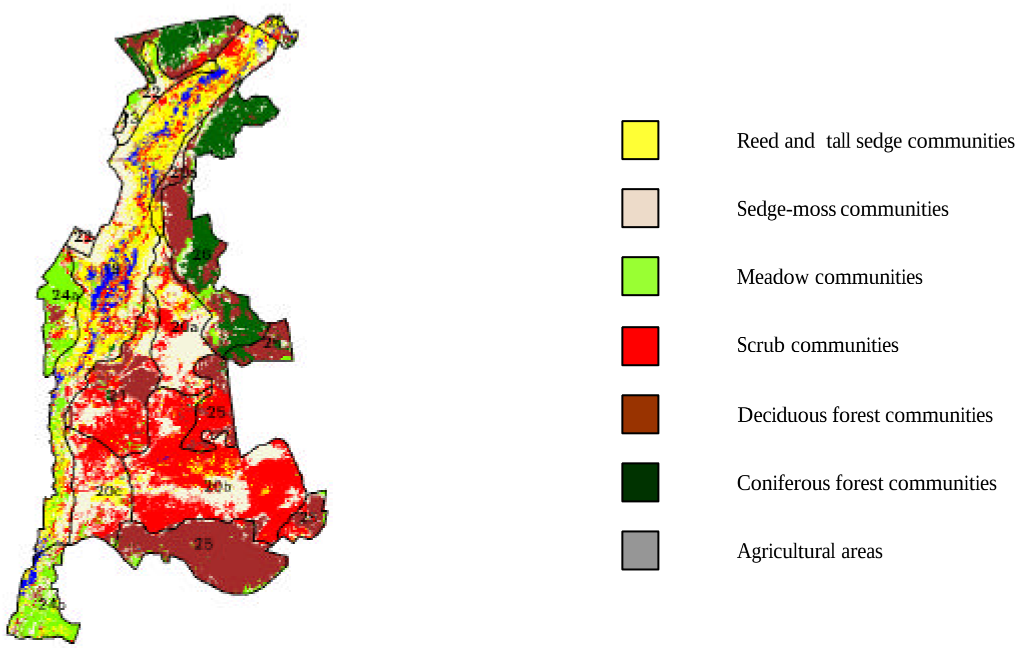


Appendix 4 Maps with the distribution of land cover types BNP, 1997

Upper Basin



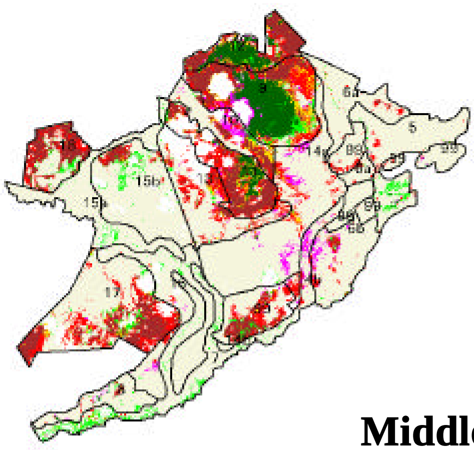
Middle Basin



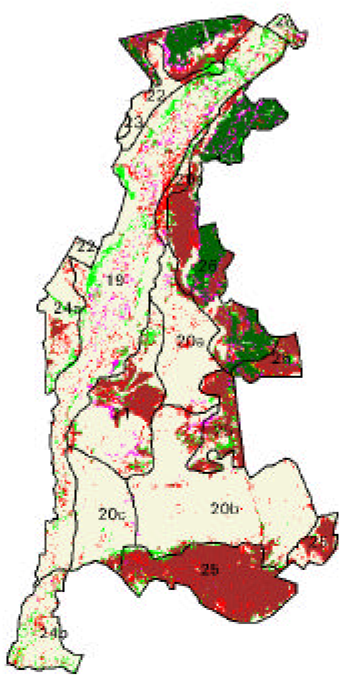
Lower basin

Appendix 5 Maps with land cover types changes in BNP 1988-1997

Upper Basin



Middle Basin



- Herbaceous vegetation changed into deciduous forest
- Herbaceous vegetation changed into coniferous forest
- Deciduous of coniferous forest changes into herbaceous vegetation
- Deciduous forest changed into coniferous forest and vice versa
- No change, herbaceous vegetation
- No change deciduous forest
- No change, coniferous forest

Lower basin