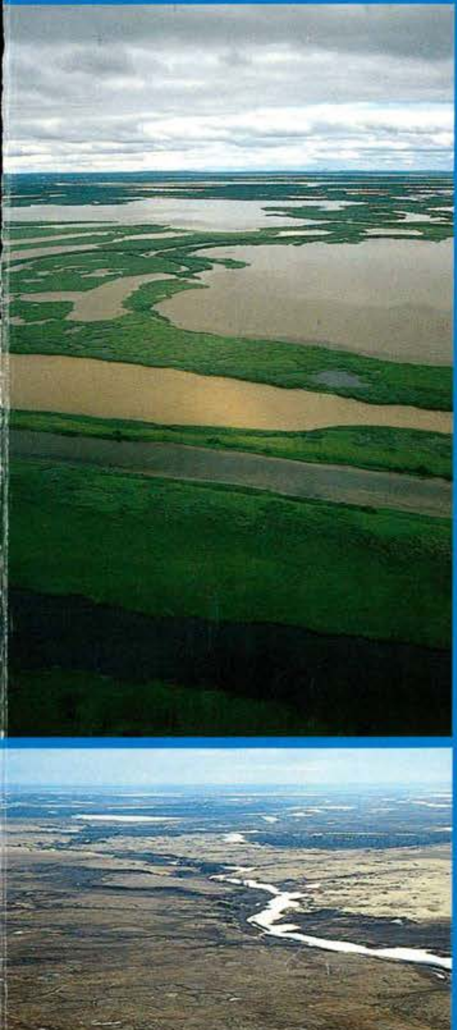

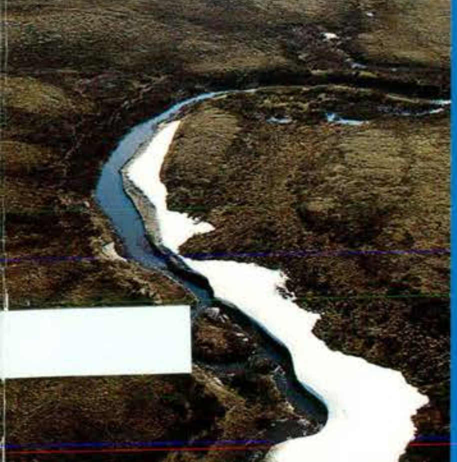

Pechora Delta

Structure and dynamics of the Pechora Delta ecosystems (1995-1999)

M.R. van Eerden (ed.)

Pechora Delta

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IB Institute of Biology
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RIZA Institute for Inland Water Management
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Предисловие

Уже на протяжении тысячелетий птицы следуют по маршруту, связывающему заболоченные земли на границе с Баренцевым морем, где они выводят птенцов, и Северного моря - места их обычной зимовки. Люди заселили лишь ограниченную часть северных территорий. Охотники и рыболовы были первыми, кто по достоинству оценили богатство северных территорий.

Печора – река европейской части России с незарегулированным стоком, протяженностью около 2000 км. Беря истоки в горном Урале, река впадает в море между островами Колгуев и Новая Земля. Ее дельта и примыкающая к ней обширная прибрежная равнина почти не испытывают вмешательства со стороны человека, немногочисленное население сосредоточено в нескольких рыболовецких поселках и временных поселениях кочующих ненцев.

В 1596 году голландскому первооткрывателю Виллему Баренцу не удалось открыть северный путь к Дальнему Востоку. Потерпев кораблекрушение, он был вынужден остаться на зимовку в "Behouden Huys" на северном острове Новой Земли. На обратном пути их неудачного путешествия он вместе с командой двигался в юго-западном направлении вдоль морского побережья, которое напоминало им родную страну.

Сегодня, с помощью современных средств исследования, мы опять хотим обратить внимание на большое сходство между дельтой Печоры и Нидерландами, правда с несколько другой точки зрения. Действительно, физиографию нижней части дельты Печоры и прилегающей прибрежной равнины (15000 км^2) трудно назвать не похожей на облик Нидерландов. Песок, глина, торф и вода являются основными образующими элементами этих низинных территорий. Слабая населенность людьми дельты Печоры сыграла решающую роль в выборе этой территории в качестве естественного участка, где нетронутые ландшафты функционируют благодаря действию исключительно биологических и физических сил. Значение таких участков как природных эталонов огромно, особенно если перед нами стоит задача восстановления утраченных ценностей природы таких густо населенных территорий, как Западная Европа. Уникальное географическое положение на границе Европы и Азии обусловливает значительное биологическое разнообразие дельты, которое на протяжении многих лет является предметом исследования специалистов из Российского Института биологии.

Спустя ровно 400 лет после драматических событий путешествия Баренца было начато осуществление совместного российско-голландского проекта по этой территории. Этот проект выполняли российский Институт биологии Коми научного центра УрО РАН в Сыктывкаре и голландский научный институт РИЗА (Министерство транспорта, общественных работ и водоуправления) в Лелистаде при тесном сотрудничестве с представителями Государственного комитета по охране окружающей среды в Нарьян Маре.

С огромным удовольствием мы представляем в этом отчете результаты пяти успешных совместных экспедиций в этот район (1995-1999). Мы приглашаем читателя к знакомству с мультидисциплинарным подходом нашего исследования, который был нацелен на интеграцию знаний специалистов в разных масштабах научного обобщения. В наши планы входит дальнейшая поддержка и развитие исследования по этим направлениям и мы выражаем нашу надежду, что полученные углубленные знания об экологических связях полезны как для целей долгосрочной охраны природы этого региона России, так и для дела восстановления утраченных ценностей природы в Нидерландах.

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Preface

For thousands of years already, birds have travelled the route between wetlands bordering the Barents Sea, where they breed, and the North Sea, where they traditionally winter. Mankind has occupied the northern territories only to a limited extent, hunters and fishermen being the first to recognise the wealth of the northern territories.

The Pechora is a ca. 2000 km long, non-regulated river in European Russia. Originating in the Ural mountains, it reaches the sea between the islands of Kolguev and Novaya Zemlya. Its vast coastal plain and delta area are largely undisturbed by human intervention and the population is limited to a few fishing villages and temporary settlements of nomadic Nenets.

In 1596 the Dutch discoverer Willem Barentsz failed to find the northern way to the far East and after shipwrecking was forced to winter in the "Behouden Huys" at the north island of Novaya Zemlya. On the unfortunate way back they rowed in south-westerly direction closely along a seashore which they described as to resemble their home country.

Today, with the aid of modern technology, we again emphasise the manifold similarities between the Pechora Delta and the Netherlands, but from a different perspective. In its physical geography the lower delta area and adjacent coastal plain (15 000 km^2) are indeed not unlike the territory of the Netherlands. Sand, clay, peat and water form the main constituents of this low-lying territory. The low degree of human occupation in the Pechora Delta was the main reason to choose this area as a possible place where intact landscapes are governed by biological and physical forces alone. For reasons of reference such areas are of eminent importance if we have to restore part of nature's losses in the densely occupied world of Western Europe. The unique geographical position between the European and Asian regions is the basis for a great biological diversity, which was already subject of study for specialists of the Russian Institute of Biology for many years.

Exactly 400 years after Barentsz' dramatic journey a Russian–Dutch project was started in this area. It is a joint venture between the Russian Institute of Biology (RAS) in Syktyvkar and the Dutch research institute RIZA (Ministry of Transport, Public Works and Water Management) in Lelystad, in close co-operation with the local managers of the State Committee for Environmental Protection in Nar'yan-Mar.

It is with great pleasure that we present in this report the findings of our joint effort during five successive expeditions into the area (1995-1999). The reader is invited to take notice of the multi-disciplinary approach of the study, aimed at integrating knowledge at different levels of scale. It is our intention to stimulate and continue work along these lines and we express the hope that the obtained insight in the ecological network is both beneficial for the long-term preservation of this area in Russia, as well as may contribute to the process of restoration of part of lost nature in the Netherlands.

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1 Summary

M.R. van Eerden & I.A. Lavrinenko

This report is a time mark of the joint venture of the collaboration between the Institute of Biology in Syktyvkar, Russia, and RIZA in Lelystad, the Netherlands, in co-operation with the State Committee for Environmental Protection in Nar'yan-Mar (1995-1999). It reflects the findings during five expeditions into the area of the Pechora Delta in northern Russia (68°00'N 53°30'E). *This report is written according to the pro*gramme of complex researches within the framework of the project "Structure and Dynamics of the Pechora Delta Ecosystems".

Structure of report and general conclusions

Following a general introduction and description of methods applied (Chapters 2 and 3), Chapter 4 provides a general description of landscape and climate. A large part of the report is devoted to the classification of the major landscape and vegetation classes by means of remote sensing techniques (Chapter 5). In Chapter 6 a detailed account on 11 species *groups is given. Chapter 7 focuses on ecological aspects for both aquatic* and terrestrial systems. In Chapter 8 observations on human interference in the ecosystem are pointed out. Chapter 9 puts the results of the study in a conservation perspective and lists possible future actions in order to preserve the area on the longer term.

Three major landscapes distinguishable within the area were investigated in all years of the study. Fieldwork was carried out late June and early July, whereas the 1998 expedition was in August during time of full development of vegetation. The early visits of 1996, 1997 and 1999 were adjusted such as to coincide with the optimal presence of breeding birds.

Main general conclusions from the study are threefold: first, the approach to describe the large-scale ecosystem by selection of study sites is workable and gives good results for the purpose of the study. The time of study for each site was short but long enough to describe the basic patterns. Concerning the vegetation, however, a visit later in the season *would seem more optimal. Second, the use of satellite images in order to* describe the basic patterns of a large area as the Pechora delta, coastal plains and uplands offers a unique possibility to quantify ecological relationships at landscape, ecosystem or species level. Third, due to the presence of a complex of just a little to undisturbed ecosystems, the area may serve as a reference area for many other places. Knowledge obtained in this area can thus be used in restoration and developing measures in areas where nature has been degraded.

Logistics

All expeditions consisted principally of five Russian and five Dutch scientists. Part of the time one member of the Ecological Committee joined the expeditions. All expeditions were carried out according to the same basic set-up. Each year three study sites (10x10 km^2) were visited, representing the major landscape types in the region. Mi-8 Aeroflot helicopters were used to transport people and equipment, including food, into the field. Per site five full days of investigation were available whereafter transport to the next site followed. Each expedition therefore lasted (3x5)+4=19 days. From our base in Nar'yan-Mar the expeditions were technically supported by a member of the Ecological Committee. Radio contact was possible by a satellite telephone which facilitated logistics (changeable weather affecting helicopter flights, safety of expedition members). For this purpose a 220 V generator was taken along. The presence of this source of power also allowed better possibilities to dry samples of vegetation and droppings of animals with the use of a magnetron oven.

Landscape and vegetation ecology

During the expeditions, much emphasis was laid upon the classification of vegetation. The fieldwork resulted in a fair description of the different vegetation units present. Both vascular plants and lichens and mosses were covered by the investigations which revealed 608 species. Identified to species level were trees (3), shrubs (18), dwarf shrubs (16), herbs and grasses (265), mosses (128) and lichens (166). The results indicate the presence of several rare species or species which were hitherto unknown to the area. The upland area showed the highest biodiversity, the coastal plain the lowest. Excluding mosses and lichens, peak dry biomass was highest in the floodplain area, 300-400 g m^{-2} for both willow stands and meadows. Including non-green biomass the wooded slopes of hills and levees in the floodplain reached values of 1500-5000 g m^{-2}. Most vegetation types in freshwater marshes to upland areas showed a remarkable constancy of green biomass, ranging between 200-300 g m^{-2} . The lowest biomass was recorded in coastal meadows (25-150 g m^{-2}) but also on eroded inland areas and coastal dunes.

Classification of landscape and vegetation units

"Ground-truthing" of Landsat TM images of August 1995 and July 1996 resulted in 15-35 spot descriptions per study site which were used for vegetation descriptions and calibration of the computerised image later on. The classification of the area was based on the image of 5 July 1996. In total 24 classes of vegetated areas could be distinguished using a mask for the floodplain area. The final classification at a scale of the entire delta and adjacent territories implies that at a local level some information is lost. For smaller areas a more precise classification can be achieved, but extrapolation to larger areas then is doubtful. The resolution of Landsat TM images does not allow a distinction within the pixels of 30x30 m^2. Especially for the spotty area of dwarf shrubs and lichen tundra this leads to many mixed pixels which are wrongly classified. However, at a landscape scale the technique revealed valuable information which can be used as a basis for GIS analysis. Water classification revealed seven classes which only partly could be ascertained due to the strong differences within one season and from year to year. This information could be worked out in greater detail than could be done in this project.

Limnology

In all years water bodies were sampled for zooplankton, phytoplankton, macrophytes, zoobenthos and aquatic insects. Water quality was determined in the laboratories at Syktyvkar where also most determinations were carried out. Due to the gradient in water quality in terms of trophic level and to the fact that boreal and arctic communities meet in the Pechora Delta area, a large number of organisms was present. In particular the presence of seven species of large branchiopods and certain other crustaceans, each linked to a specific type of habitat, points to the hydrological and ecological completeness of the Pechora Delta system as compared to many other deltas. Large natural differences in water quality lead to a diversification of phytoplankton, zooplankton and zoobenthos organisms. In areas with few or no fish, zooplankton booms are a typical phenomenon. It was frequently met in isolated and shallow areas which freeze completely in winter.

Biodiversity

Beetles and spiders were commonly observed in all study sites. In these groups the general trend was that southerly and more upland sites contained more species than lowland and northerly sites. Both groups show aspects of Siberian and European faunas as well as latitudinal and altitudinal gradients in species composition.

Bumblebees, wasps and other Hymenoptera were locally an important element of the insect fauna. The southern delta area harboured the most species whereas in the hills and especially the coastal plain species diversity was lowest. These species are important pollinators for the local flora.

Dragonflies and butterflies were rare, only a few species, mostly immigrants, were recorded; most of the sedentary species among them were found in the delta area.

Amphibians and reptiles were scarce. Only Moor Frog and Viviparous Lizard were recorded, all in the relatively protected habit of the delta and Bolshezemelskaya Tundra. These species reach their northernmost boundary in the study area.

Small mammals were sampled through continuous trapping in different habitats. The most commonly found species was the Root Vole *Microtus oeconomus*. Three species of lemming were also noticed but were never as commonly observed as the voles. However, as prey of Snowy Owls and Rough-legged Buzzards Collared Lemming and Siberian Lemming were more important than the voles. Larger mammals comprised observations of Elk, Wolf, Wolverine, Arctic and Red Fox. At the coast Bearded Seal and Ringed Seal were observed, whereas in the floodplain of the Pechora traces of Otter were spotted. Mammals of the area comprise both northern and southern species. Overall species diversity is highest in the southern part of the delta and the southern parts of the uplands on both sides of the Pechora river.

Fish were abundant in almost all waters studied. Only remote and isolated shallow lakes were with few or no fish. Due to the variety of habitats, a total number of 23 species was recorded over the years. Species composition varied across the landscape types. Riverine, lacustrine and coastal associations were recorded. An obvious aspect of the fish studied was the good condition, due to the rich food supplies, although different between water bodies (see Chapter 7.2). The interconnection of waters leads to the presence of the complete array of long-range anadromous to almost sedentary species of salmonids. These comprise still 11 species among which Atlantic Salmon *Salmo salar*, five species of whitefish *Coregonus* and Inconnu *Stenodus leucichthys nelma*.

Birds were common throughout the study area. Especially waders, geese, swans and ducks formed a conspicuous element of the visible fauna. Due to the presence of many water bodies the density of these groups is high, especially at the mouth of the Pechora river, the coast of Ruskii Zavorot and the coast of large lakes, lagoons and tidal basins. In 1997 and 1999 breeding results were lower than average, whereas in 1998 breeding results of geese, swans, ducks and waders was higher than average. In total, 112 species were recorded, several new to the area. Songbirds declined in number towards the North associated with the decrease of bush cover and height, whereas non-passerines showed the opposite trend. These long-range migrants can seasonally occupy the rich habitat of the coastal plain and river delta. A method has been developed to quantify the avian fauna with respect of habitat type. By means of a GIS, bird density per habitat type was calculated which allows further extrapolation across the landscapes and different regions in the area. The scanning flights revealed the presence of large moulting aggregations of ducks, geese and swans. These observations have been worked out and related to vegetation characteristics and plant phenology.

Conclusions and integration

Several conclusions can be drawn from our work with respect to the biological functioning. All are related to the presence of large-scale, intact landscapes, both from a geomorphological and from an ecological point of view. As shown by the diet of several plant-eaters each species showed specific preferences for part of the entire vegetation belt. Reindeer, hares and grouse frequented the dwarfshrub tundra zone, whereas geese and swans were feeding preferentially at the wet coastal plain and river delta. Within the season shifts in foraging area occurred and type of food taken differed. This example shows the interrelation between landscape types as used by animals that freely move around. Without one of the landscapes or major food sources the population would experience difficulties to survive. Probably the grazers make use of different sources of food which become available as the season progresses. The hayfields close to Nar'yan-Mar form thus an important staging area for geese, swans and ducks in early spring, before the tundra is snow free. At the end of the season many water birds take profit of the abundant food supply in the form of berries or water plants.

Also fish populations make use of the myriad waterways in the delta and coastal plain. Even the smallest streams were found to contain migratory fish such as Lake Char *Salvelinus lepechini* and Burbot *Lota lota*. The fluctuations in water level in the river, the effect of storm surges and differences in thickness of ice layer may affect local populations in lakes and streams. These processes lead to rejuvenation and subsequent recolonisation by a variable set of species. This leads to a complex population and age structure from one lake to another. It is logically to assume that such natural differences give room for a number of relationships e.g. the presence of fish-eating birds, the effect of fish on zoobenthos and zooplankton. Natural dynamics are thus responsible for biodiversity patterns which are little studied.

In Chapter 9 a series of recommendations has been formulated which need to be considered if one is to preserve the area for future generations of plants and animals, including man.

2 Introduction

I.A. Lavrinenko & M.R. van Eerden

The Pechora river delta and the neighbouring East-European tundra's are the most important landscape complexes of the European north-east of Russia. The unique character of the Pechora Delta nature complex and its flora and fauna, was already noticed by F.V. Sambuk as far back as 1929. In this region nowadays large nature reserves are located. These are "Nenetski" Reserve (zakaznik, 320 000 ha, 1985) and State Biosphere Reserve (zapovednik, 313 400 ha, 1997) having the same name (Kotkin *et al.* 2000). This area belongs to the tundra zone, but the presence of the Pechora Delta leads to intrusion of boreal plant and animal species into the region. The region's unique natural landscape complexes are determined by the close relation to the Pechora river and by the geological history of the territory. Relict "islands" of Spruce *Picea obovata*, the origin of which is associated with the Holocene climate optimum, can serve as an example of this. Boreal forests situated in this territory are at the extreme northern boundary of their distribution. The simultaneous existence of boreal, tundra and intermediate ecosystems on a rather small territory determines the unique species and community diversity of the Pechora landscapes. Taking into account that many water bird species wintering in Western Europe are nesting in this area as well as the fact that the major spawning route of Atlantic Salmon is situated here, it is hard to overestimate the biological significance of the Pechora Delta.

However, this area experienced active anthropogenic influence in recent decades. On the one hand these are traditional trades – reindeer breeding and fishing –, on the other hand activities that have started just recently – intensive development of oil and gas fields located on this territory. At the moment there are one exploited oil field (Vasilkovskoe) and four conserved oil fields in this region. In spite of this, the present state of the nature ecosystems of the Pechora Delta can still be considered as being without much anthropogenic influence and can therefore serve as a good model for restoration of biodiversity of the natural landscapes in West-European countries, which have lost their natural ecosystems during the process of the intensive economic development of their territories.

In 1995-1999 experts of the Institute of Biology, Komi Science Centre, Ural Division of Russian Academy of Science RAS (Syktyvkar, Russia) and the Institute of Inland Water Management and Waste Water Treatment RIZA (Lelystad, the Netherlands) in close co-operation with the State Committee of Environmental Protection of Nenets Autonomous District (Nar'yan-Mar, Russia) participated in the project "Structure and Dynamics of the Ecosystems of the Pechora Delta".

The main objectives of the project were assessment of ecosystem components by specialists in different fields, identification of relationships with environmental parameters, and comparing "ground-truth" data with satellite image data in order to create a delta wide survey. Different colour contours of the satellite images of the Pechora Delta were identified in the field as landscape and vegetation units with different spectral characteristics. The GIS, which is now being developed, will be used for the nature conservation management in the region and may serve as background for future work.

This report may serve as a baseline document for the studies that have been carried out in the area during the years of study. Centred around the

landscape description with the use of satellite imagery (Chapter 5), the multi-disciplinary approach provides an overview of the present state of the ecosystem (Chapter 6) as well as some important relationships (Chapter 7) and the human impact on the ecosystem (Chapter 8). To conclude, the report points to the importance of the Pechora Delta region for the long-term preservation of ecological values (Chapter 9).
Broad use of Remote Sensing together with GIS technologies for ecosystems' assessment is one of the most promising directions in ecology and nature conservation now. As Russian and foreign oil and gas companies show an increasing interest in the area as well, creation of a GIS with the use of satellite image analysis is a timely objective for this region.

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3 Methods

Remote sensing

Project activities in the Pechora Delta region were developed based on an initial unsupervised classification of two Landsat TM satellite images of 9 September 1985 and 19 August 1995 (Beekman *et al.* 1996, Fraikin *et al.* 1996). The unsupervised classification with limited fieldwork in 1993 revealed the existence of four main landscape zones in the region, each with specific spatial characteristics of the abiotic and biotic environment. Distinguished are the floodplain in the delta of the Pechora river, the rolling to hilly Nenetskaya Ridge, the coastal plain of the Ruskii Zavorot peninsula and the undulating uplands of the western part of the Bolshezemelskaya Tundra.

Following the unsupervised image analysis, a reconnaissance visit to the region was undertaken in summer 1995, based on which the Terms of Reference for the Russian-Dutch Co-operative Research Project "Structure and dynamics of Pechora Delta ecosystems" were defined. The multidisciplinary reconnaissance team included both scientific and administrative Russian and Dutch specialists, six persons in total (Bart Fokkens, Mennobart van Eerden, Theo Vulink, Alexander Ermakov, Yuri Mineev, Masha Philippova). An initial overview of landscape structures and variation and ecosystem relations was obtained by an aerial scan and multiple stopovers during two helicopter visits to the region. Additionally a boat trip was organised across the Pechora river where several landings ashore were made in areas difficult to approach otherwise.

Study sites and transportation

For the integrated study of the natural ecosystems as well as to obtain ground-truth information to improve the satellite image classification, within the distinguished landscape zones seven study sites of ca. 100 km^2 were selected (Fig. 3.1). Because of the remote location of the project region an expedition approach was chosen as most suitable to collect information within the selected study sites. Goals of the expeditions

Camp at Site 2.
June 1996.

included for each study site the description of important relations between vegetation and abiotic environment (soil, hydrology), vegetation and fauna (birds, mammals) and the relation between carrying capacity, scale and the correlation at landscape level. Additional information was obtained during short visits by Mi-2 helicopter to specific areas outside the study area such as to account for geographical variation and cross-checking the classification at a landscape level (Fig. 3.1).

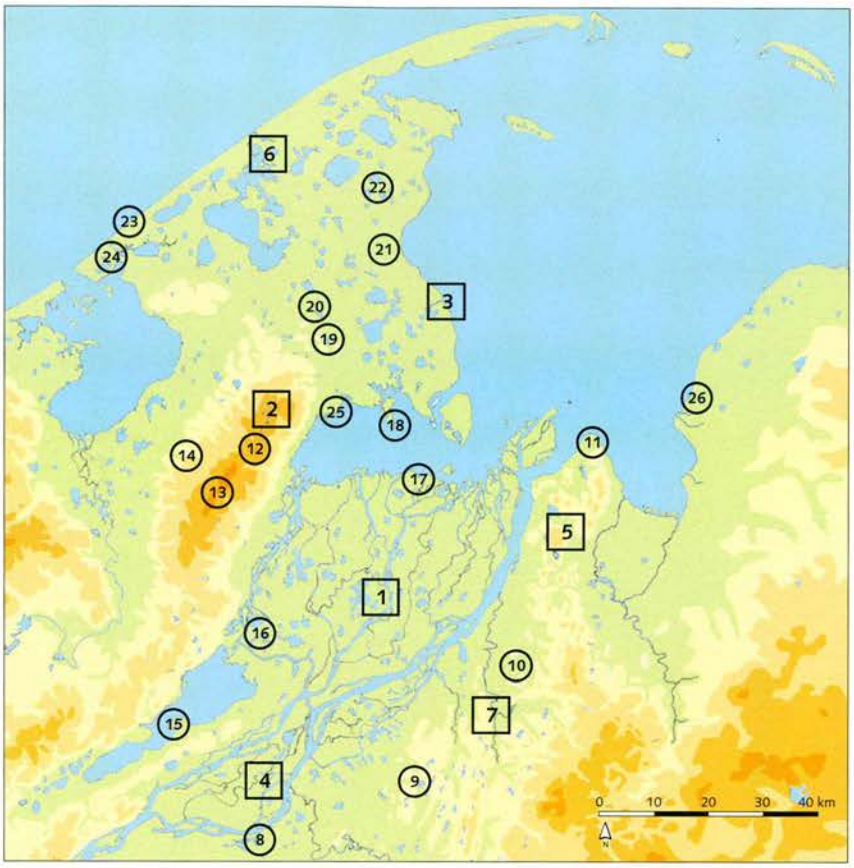


Figure 3.1
Overview of the location of selected study sites in the Pechora Delta region. Additional information was obtained from ground checks using helicopter or boat.

☐ Study area
○ Visited spot

Equipment to Nar'yan-Mar was transported from Zaandam to Arkhangelsk by ship and then by rented plane (May 1996). Due to the cancelled flights between Syktyvkar and Nar'yan-Mar in 1997 an An26 freight aeroplane was rented from Komi-Avia to transport people and equipment (ca. 3000 kg). In 1998 and 1999, the Dutch team members flew directly from Moscow to Nar'yan-Mar, the Russian members went the long way from Syktyvkar to Nar'yan-Mar by train, ship and car.

Multi-disciplinary teams

For a successful performance of expeditions a multi-disciplinary team of Russian and Dutch specialists was composed, aimed at maximising co-operation in different fields of study. The Dutch team of specialists from the Institute of Inland Water Management and Waste Water Treatment RIZA remained unchanged throughout the project, and included Mennobart van Eerden (team leader, ornithology), Theo Vulink (vegetation, herbivory), Ruurd Noordhuis (aquatic ecology), Mervyn Roos (technical support, insects, ornithology), Harald Leummens (soil, interpretation). During the 1996 expedition the Russian team of the Institute of Biology, Ural

Division of the Russian Academy of Sciences included Igor Lavrinenko (team leader, vegetation) and Vladimir Kanev (soil), additionally enforced with Yuri Mineeev (ornithology) and Oleg Mineev (ornithology) in study site 3. During subsequent expeditions the Russian team consisted of Igor Lavrinenko, Olga Lavrinenko (vegetation), Vasily Ponomarev (fish), Mikhael Sivkov (plant production) and Alla Koleshnikova (soil invertebrates). During the 1998 expedition Mrs Koleshnikova was replaced by Natalya Mazura (spiders). Stef van Rijn replaced Mennobart van Eerden at Site 5 when he in turn assisted Isaac van der Noordt with filming in the area of Khunavei river.

Expeditions

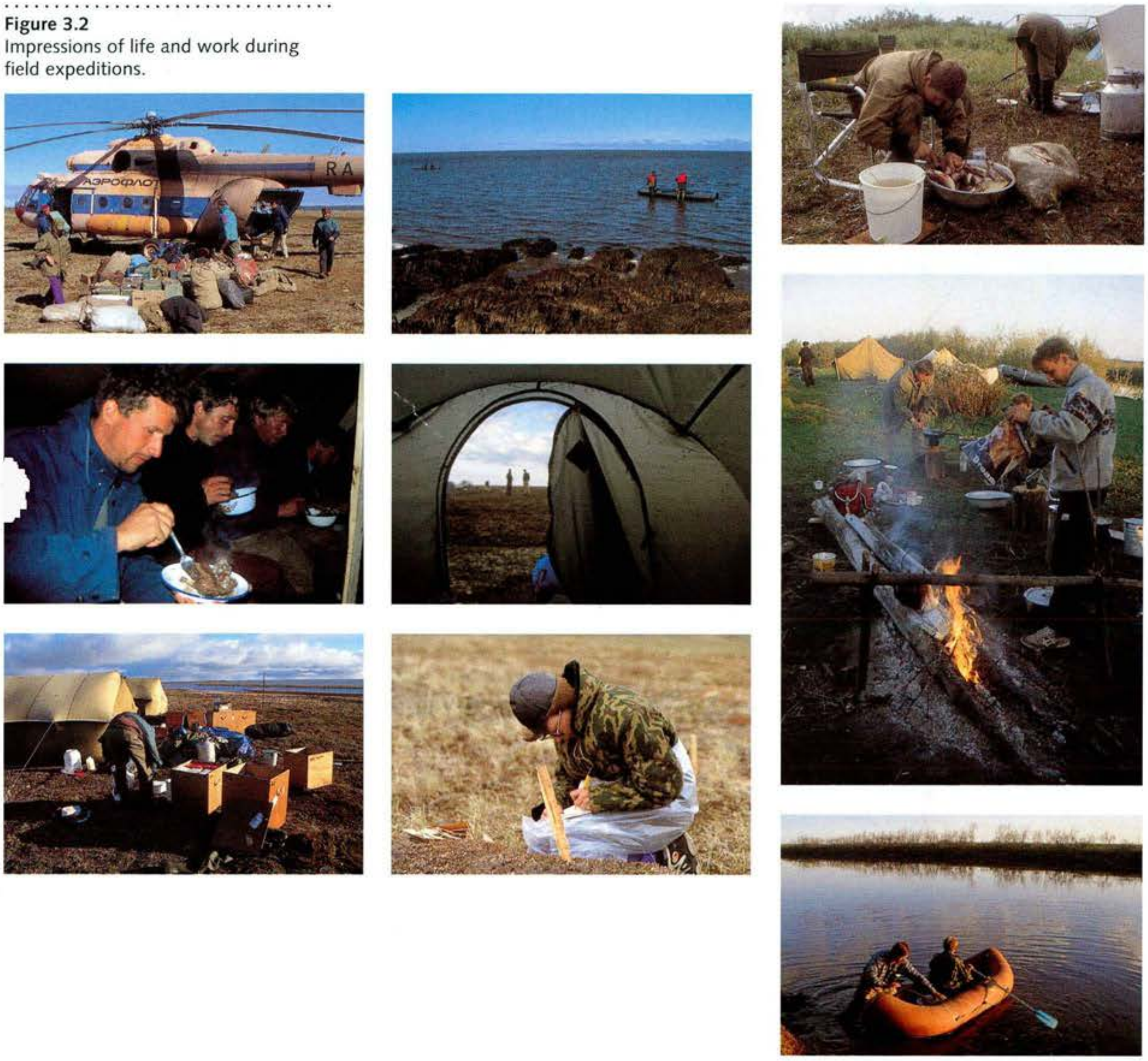
Field expeditions were organised with strong support of the State Committee for Environmental Protection of the Nenets Autonomous Region. During several stages, the expedition was joined by Stanislav Zolotoy (organisation, protected areas, hunting). Material collected during the expeditions was analysed further at the laboratories at Syktyvkar and Lelystad whereas certain samples were sent to other laboratories as well. Expeditions were organised annually between 1996 and 1999. During each expedition three selected study sites were visited, except in 1999 when two study sites were visited. In 1996, 1997 and 1999 expeditions visited the region between 20 June and 10 July. In 1998 the expedition revisited three previously visited study sites between 5 August and 31 August, in order to obtain an understanding of seasonal variation (Table 3.1). The 1998 expedition included a short 2-day visit of the herbivory specialist, interpreter and local specialist to a temporary base camp of a kolchoz Reindeer herd in the Nenetskaya Ridge.

Table 3.1
Expedition dates and study areas visited.

Year	Study Site	Date of expedition
1995	orientation	08.07 - 14.07
1996	1	21.06 - 26.06
	2	27.06 - 02.07
	3	03.07 - 09.07
1997	4	23.06 - 26.06
	5	27.06 - 02.07
	6	03.07 - 08.07
1998	1	09.08 - 14.08
	2	15.08 - 20.08
	6	21.08 - 26.08
1999	7	26.06 - 02.07
	3	03.07 - 09.07

Expeditions started from Nar'yan-Mar, where in between expeditions equipment was stored at the laboratory of the State Committee for Environmental Protection. For transport to and from study sites, as well as between study sites, use was made of Mi-8 transport helicopters. An outboard-engined dinghy and two canoes were available for travel within study areas. The expedition additionally was equipped with a satellite telephone, a generator and a magnetron for drying samples. Weather data were obtained using an automatic recorder measuring air and soil temperature, solar radiation and precipitation (LI-COR 1200S datalogger). Within study sites data collection was organised from an established base camp, composed of private sleeping tents and a main working and kitchen tent, additionally used for equipment storage and working out field data. The geographical location of data collection points within study sites was determined with a Global Positioning System. A photo impression of the life during field expeditions is included in Figure 3.2.

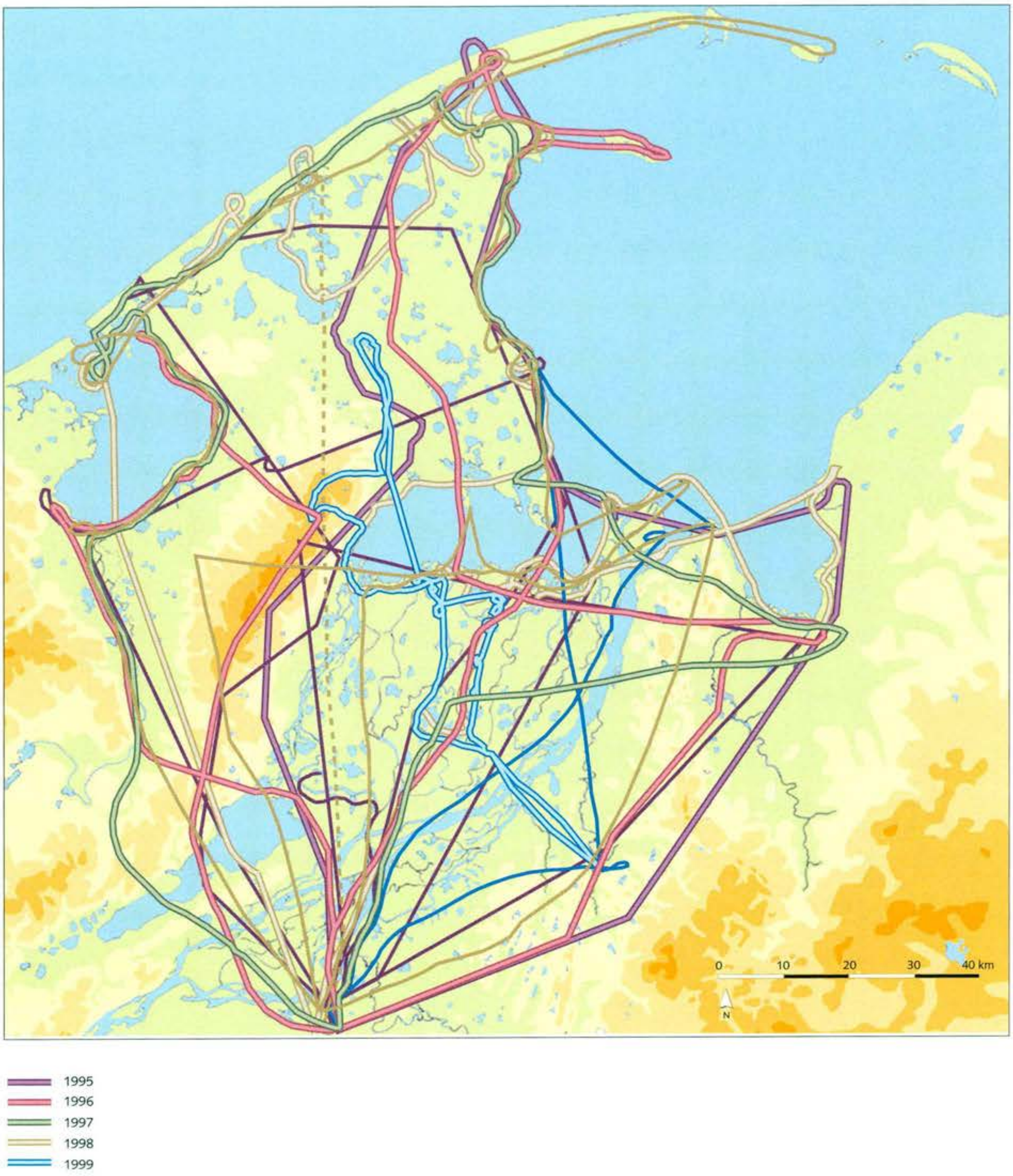
Figure 3.2
Impressions of life and work during field expeditions.



Aerial scans

In addition to field expeditions, overview scans by An-2 aeroplanes were executed in most years before and after the field expeditions. During the scans linear transects were flown over all landscape zones to collect transect counts of birds and larger mammals in order to obtain estimates of the total population density and distribution in the project area. Additionally the scans provided small-scale information on landscape heterogeneity and vegetation structure in different landscape zones. These flights were carried out 12 July 1995, 19 and 21 June 1996, 10 July 1997, 7 and 28 August 1998. In 1995, 1998 and 1999 additional information at ground level was obtained by Mi-2 helicopter visiting areas at the East bank area, Bolvanskii Nos, Ruskii Zavorot peninsula and western Nenetskaya Ridge. These and normal Mi-8 transportation flights were partly used to obtain extra information on the trajectories covered (Fig. 3.3).

Figure 3.3
Trajectories covered by aerial scans in different years.



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Fraikin, S.J., H.J. den Hollander & M.R. van Eerden 1996. Mission report 1996; Landsat TM satellite image products of the Pechora Delta. Report number MDGAT-9627, Rijkswaterstaat, Survey Department, Delft, the Netherlands.

4 General landscape and climate

I.A. Lavrinenko, G.V. Rusanova & H.J.L. Leummens

Quaternary history and geomorphological characteristics

The lower Pechora region is situated in the north-eastern part of European Russia (Fig. 4.1). The Pechora lowland is bordered by elevated areas, the Ural mountains in the East and the Timan Ridge in the West and Southwest. The lowland is a deep sedimentary basin covered by thick deposits of complex marine and continental origin. Rivers are all young, they obtained their present flow pattern features after the end of the last glaciation. The plain is dissected by the meridional Pechora river in two unequal parts, the Malozemelskaya Tundra to the West and the Bolshezemelskaya Tundra to the East. Two macro-scale relief zones can be distinguished. South of the 67th parallel the landscape is characterised by a gentle topography, extended swamps and occasional lakes, while to the North glacial landforms dominate - ice-pushed ridges, hill-and-hole pairs, kames, till hummocks, dissected by numerous small lakes (Astakhov 1994).
The geomorphological structure of the Pechora lowland is strongly related to multiple glacial, interglacial and post-glacial periods. Throughout the lowland basin Tertiary geological formations are covered by Quaternary glacial, fluvioglacial, lacustrine and alluvial sediments, and in the northern part of the plain, marine sediments (Liverovski 1987b). In general, moraine deposits of two glacial periods are identified throughout the Pechora lowland, from the Saale/Dnepr (Middle Pleistocene, 200 000-125 000 year b.p.) and the Weichsel/Valdai (Upper Pleistocene, 70 000-10 000 year b.p.) glacial periods. The most extended ice sheet cover occurred during the Saale period, while separated smaller sheets occurred during the Weichsel glacial period. Figure 4.2 illustrates the boundaries of the major ice sheets according to different authors. Throughout the region, drift deposits from the Saale glacial period are covered by more recent deposits. Often moraine deposits of the last two glacial periods are separated by deposits of the interglacial boreal marine transgression (Eemian interglacial period, 125 000-70 000 year b.p.), either dark marine clays or

Glacial deposits at Bolvanskii Nos, with cliffs at the mouth of the river Pechora. In the back ground thermokarst lakes.

Figure 4.1
Pechora Delta region.

🟩 0-25 m
🟨 25-50 m
🟨 50-100 m
🟧 100-150 m
🟧 150-200 m

Figure 4.2
Boundaries of glacier sheets in the lower Pechora region.

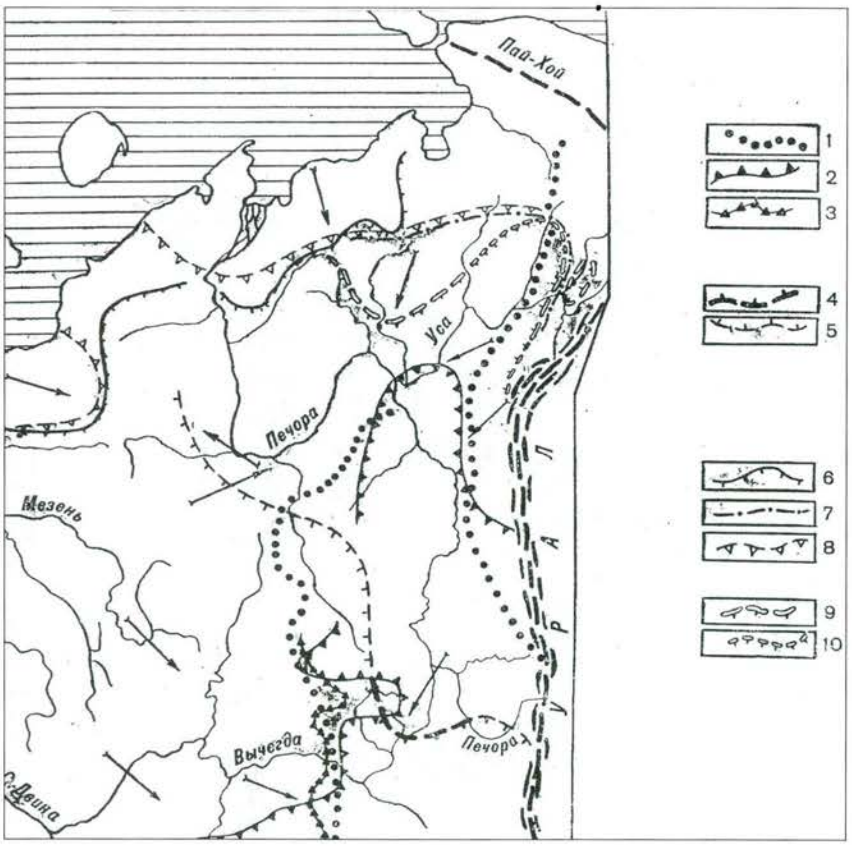
Legend:
Ice sheet boundary during the Warthe/Moscow stage of the Saale/Dnepr glaciation:
1 - according to S.A. Yakovlev;
2 - according to V.V. Lamakin;
3 - according to M.A. Spiridonov.

Boundary of the Ural-Paikhoi ice sheet during the Weichsel/Valdai glaciation:
4 - established;
5 - presumed;

Boundary of the Kalinin ice sheet during the Weichsel/Valdai glaciation:
6 - according to S.A. Yakovlev;
7 - according to G.A. Chernov;
8 - according to V.V. Lamakin;

9 - according to the author, established;
10 - according to the author, presumed.

Arrows point into the direction of ice sheet movements.



layered sand, which even penetrated the upper Pechora. In the Pechora Delta boreal transgression sediments occur at heights of 100-110 m (Astakhov 1994, Fig. 4.3). Especially North of the 67th parallel, up to five advances and retreats of glacial ice sheets can be found, alternating with fluvioglacial and marine sedimentary deposits (Astakhov 1994). This complex lateral and vertical pattern formed the basis for the present relief features of the Pechora Delta region. During the Weichsel glacial period ice sheets in the lower Pechora originated mainly from the East and North - the Ural mountains and Novaya Zemlya. Due to the variety of rock types in these source areas, the petrographic composition of glacial deposits in the Pechora lowland is heterogeneous, and includes characteristic Novaya Zemlya dolomite limestone. At present, drift moraine deposits of the various stages of the Weichsel glacial period surface only in end-moraine ridges. End-moraine deposits of the Weichsel glacial period are widespread in the Nenetskaya Ridge, on the left bank of the meridian Pechora river, and in different parts of the Bolshezemelskaya Tundra.

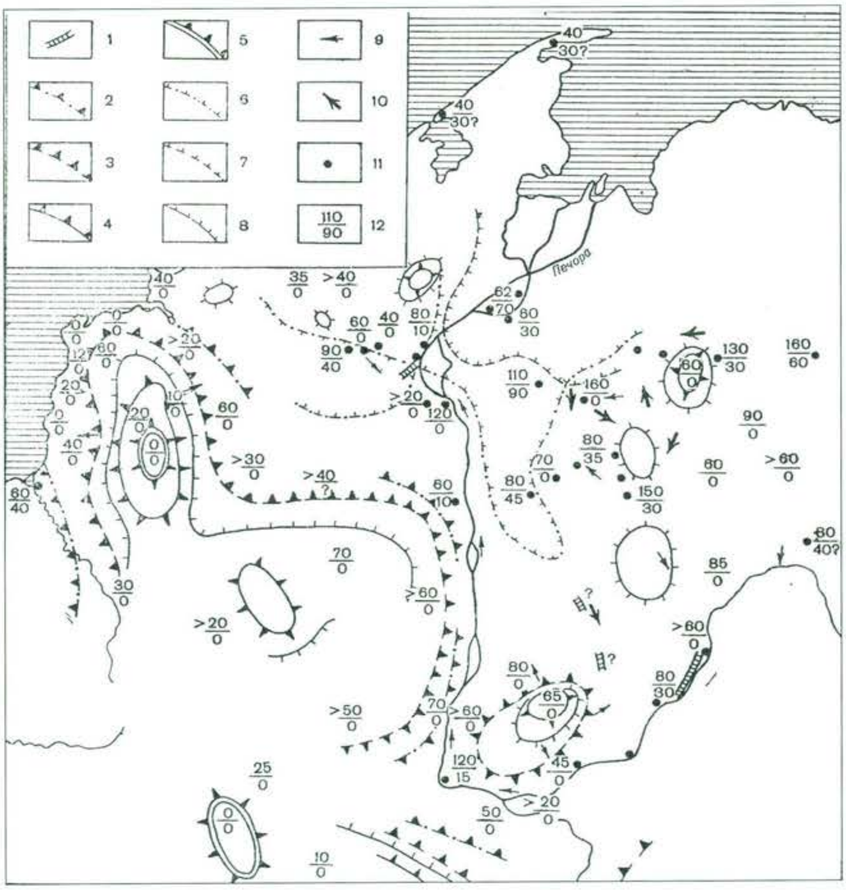


Figure 4.3
Distribution of Late Tertiary, Early and Middle Quaternary transgression sediments in the Timan-Pechora region.

Legend:
1 - Pre-Quaternary valley. Sea coasts during transgression cycles:
2 - Kamenskoe Sea, 0-20 m (N-An^1);
3 - Budrinskoe Sea, 40-60 m (An^{2}bd);
4 - Shapkinskoe Sea, 120-130 m (An^{2}schp);
5 - Salindeikoe Sea, 180-250 m (An^{2}sl). Sea coasts during regression cycles:
6 - Kamenskoe Sea, -20-0 m;
7 - Budrinskoe Sea, 10-20 m;
8 - Shapkinskoe Sea, 100-120 m;
9 - main river flow direction during the regression period of the Budrinskoe Sea;
10 - main coastal flow direction during the regression of the Shapkinskoe Sea;
11 - drilling holes;
12 - thickness of deposits: numerator - Middle Quaternary transgression period; denominator - Late Tertiary-Early Quaternary transgression period.

More often glacial tills are completely eroded or overlaid by fluvioglacial deposits (Liverovski 1987b) or redeposited marine sediments of the boreal transgression (Astakhov 1994). Along the northern border, in the coastal zone of the White Sea, the Barents Sea and the Kara Sea also marine deposits from the late-glacial and post-glacial sea transgression periods can be found, mainly sands. The geological diversity of glacial and interglacial deposits is additionally complicated by uplift and tilting after retreat of the ice sheets. Locally uplift is estimated at 150-200 m (Astakhov 1994) These values are in accordance with observations of the northern Siberian lowlands, where sand and loam of marine origin occur up to an absolute height of 120 m (Rosswall & Heal 1975).

The present structure of the landscape was also determined by climatic changes in geological time. During the climatic optimum the present tundra area was covered with boreal forest up to the northern seas, limiting water and wind erosion processes. In the following colder and dryer period the forest border was pushed southward, and although water erosion did not increase, eolian processes did, strongly influencing tundra relief. In the Late Holocene the climate became more moist, causing the revival of water erosion processes while eolian processes decreased.

Hydrology

The hydrological network of the lower Pechora region consists of a dense pattern of large and small rivers and streams and numerous small lakes. Streams with a maximum length of 10 km prevail. The Pechora river is the largest river, flowing in northern direction through the region. Near Nar'yan-Mar the Pechora river splits into a number of parallel large branches interconnected by numerous smaller streams, forming an elongated delta area with an average width of 30 km and a length of 70 km. The pattern of multiple branches and the complex of connecting streams is like a braided river (Pannekoek & van Straaten 1992). However, unlike a braided river, the location of stream branches in the Pechora Delta is typically very stable. This stability is conditioned by the sub-arctic climate, a well developed vegetation cover and frost processes hampering erosion processes. The Pechora river obtained its present course after the end of the last glaciation (Astakhov 1994). River levees in the Pechora Delta are poorly developed, mainly as a result of a low sediment load and a mainly fine-textured composition.

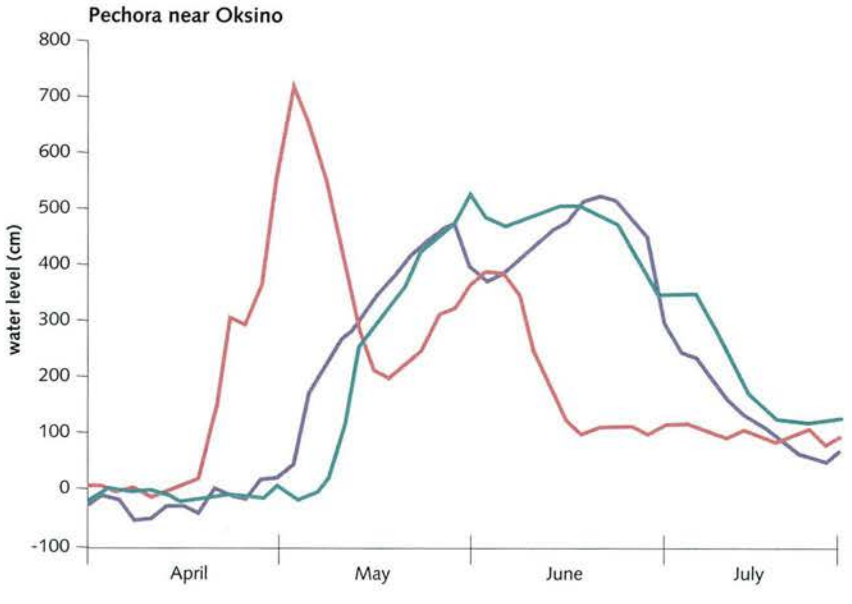


Figure 4.4
Variation in river discharge in Oksino (40 km upstream Nar'yan-Mar) in various years. 1995 was more wet, 1994 and 1996 dryer than average.

The river hydrograph shows a 2-month discharge maximum in spring, related with snow melt in the drainage basin. Near Nar'yan-Mar, on average the discharge starts to increase in the beginning of May and drops in the second half of June (Fig. 4.4). During peak discharges large areas in the Pechora Delta are flooded, the water level rising up to 8 m above the winter-early spring minimum. Large-scale flooding is conditioned by the typical flow direction of the river. Snow melt starts earlier in the southern upstream areas of the drainage basin, and results in a discharge peak at a moment when the the most downstream part of the river delta (especially the estuary zone of the Korovinskaya Bay and the Pechorskaya Bay) are still covered with ice, acting as a barrier which results in widespread flooding. After breaking of the ice in these northern regions at the end of June, and disappearance of snow and ice throughout the drainage basin, the river water level and discharge decrease. Due to widespread permafrost in the surrounding upland areas, the inflow of groundwater is limited during the summer season. The smaller streams discharging into the Pechora river or directly into the estuary or sea also show a large seasonal variation. Especially in the elevated uplands the smallest streams only intermittently discharge water in spring.

The low surface gradient together with tidal water level fluctuations in the Korovinskaya Bay and Pechorskaya Bay result in an alternating direction of water flow in the Pechora Delta coastal zone, extending up to 20 km inland. At Khabuika, located on the eastern shore of Ruskii Zavorot peninsula, the tidal difference is on average 1.4 m, strongly depending on wind speed and direction (Beekman *et al.* 1996).

In between river branches and streams in the Pechora Delta floodplain, as well as in the surrounding upland areas, a large number of rounded lakes occur. Most lakes are small, their surface rarely exceeds 2 km^2. Only a few lakes are larger than 10 km^2, while two lakes, lake Peschanka-To and Golodnaya Bay, are larger than 100 km^2. Most lakes develop as result of thermokarst processes, i.e. the local thawing of permafrost and subterranean ice. This thawing is either due to destruction of the vegetation cover or to development of standing water as a result of local heaving, related to cryogenic processes. Often lakes are not interconnected, embedded in a permafrost surrounding which hampers drainage. Typically these lakes are shallow, with a sludge/sandy bottom.

Another type of lakes occurring in the lower Pechora region are lakes formed by glacial erosion. Glacial erosion lakes mainly are formed by flowing glacier ice reworking the underlying mineral surface into a irregular rolling surface, in which depressions fill with melt water after retreat of the glacier. Glacial lakes also develop in end-moraine deposits due to the irregular oscillations of the ice front. Within the project area, this type of lake occurs only in the elevated Nenetskaya Ridge, because at lower topographical levels lakes were filled with post-glacial marine, glacial-marine or fluvioglacial sediments (Liverovski 1933, Pannekoek & van Straaten 1992). Glacial erosion lakes typically are deep, and often have a bottom of coarse-fragmented mineral material including gravel and stones.

Vegetation

The vegetation cover in the lower Pechora Delta consists mainly of communities typical for the southern or sub-arctic tundra zone, also referred to as shrub and tussock tundra (Chernov & Matveyeva 1997). Especially elevated areas within the region also include communities characteristic for the typical tundra zone. The southern tundra zone is the dominant subzone of the tundra in north-east European Russia stretched along the coast of the Arctic Ocean (Fig. 4.5).

Tundra communities thrive under conditions of a short and cool vegetative period with low soil temperatures; most of the species are cryophytes. The short vegetative period contributes to an extraordinary dynamics of the seasonal development of both flora and fauna. Often the vegetation height is limited, allowing species to be covered by snow, thus being protected against severe frosts and winds in winter, and to make use of the warmest layer in summer. Typically the relative cover of mosses and lichens is higher than in southern communities, and also surface-confined dwarf shrubs are common. Shrub species only occur on protected locations shielded from strong winds. Mosses have a significant effect on environmental conditions, especially on soil temperature regime and thus depth of seasonal thawing of the soil surface layer. Both factors also affect soil drainage conditions and fertility aspects. Lichens show a less direct effect on soil conditions (Chernov 1985).

Figure 4.5
Distribution of zonal tundra subzones in the European Arctic (source: Chernov 1985).

Legend :
1 - polar desert zone;
2 - arctic tundra subzone;
3 - typical tundra subzone;
4 - southern tundra subzone;

- - - - southern limit of the forest tundra transition zone.

Communities in the tundra zone can be separated into zonal, intrazonal, extrazonal and azonal communities. Zonal community types in southern and typical tundra subzone include: willow and birch stands, low shrub-dwarf shrub heath tundra, sedge-moss small hummock tundra, cotton-grass tussock-dwarf shrub tundra, dwarf shrub heath with frost boils. Extrazonal communities, communities occurring beyond the limits of their zonal occurrence, include e.g. forest islands on riverbank terraces (southern tundra), thickets of tall shrubs (southern and typical tundra subzones), slope and valley communities. Intrazonal communities, communities occurring only within the limits of the tundra zone but not resembling characteristic zonal types include e.g. polygonal mires with marsh vegetation in low centre depressions, snowbed vegetation. Floodplain communities represent azonal communities, which are not specific for any zone but are distributed within the limits of other physical-geographical zones (Chernov & Matveyeva 1997). At the highest level, zonation in the tundra zone depends on the summer radiation balance and related summer temperature, as well as the length of the frost-free period.
In general tundra ecosystems show a spatial mosaic pattern of several community types, one of which normally is dominant (Andreev & Aleksandrova 1981). The mosaic pattern of vegetation is strongly determined

by intensive cryogenic soil processes, which evidence on the surface in specific micro- and nano-relief forms (e.g. mounds, bare spots, sorted stone circles).

Sedge-moss small hummock communities show a characteristic continuous but mosaic cover of small hummocks 10-15 cm in height and 15-30 cm in diameter (occupying about 70% of the stand area) and troughs of 15-20 cm in width. In the southern and typical tundra zone the zonal frost-boil tundra, in Russian called the spotted tundra, creates a typical nano-relief with patches of bare soil 25-70 cm in diameter, rims 5-10 cm in height surrounding these patches, and troughs 15-30 cm in width and 10-15 cm in depth separating the rims of adjacent patches. This pattern of repeating elements occurs in different tundra subzones but the size and cover of the elements vary. From south to north the number and proportion of bare soil increase per unit area, while the average size decreases. In the southern tundra subzone, patches are not round, rims are not high and "troughs" are almost flat.

Environment

The distribution of flora and fauna in the tundra zone is shaped by environmental factors and processes. At the regional scale, climatic conditions and variation in relief are overriding environmental control factors. At the local scale, the regional environmental factors are strongly modified by local factors - parent material, snow cover, moisture, nutrients (Washburn 1980).

Throughout the tundra zone permafrost, perennially frozen ground, is present in the sub-surface. Only the uppermost surface layer thaws each summer, also referred to as the active layer. Other conditions being equal, the depth of thawing depends on the type of parent material involved (Chernov & Matveyeva 1997). For the Malozemelskaya Tundra the active layer averaged 30-40 cm for peat, 50-80 cm for fine-textured and 100-120 cm for coarse-textured material (Liverovski 1934). Additional factors which influence the depth of thawing include plant cover, slope exposure, local moisture status and the amount of ground ice in the upper soil layer. The largest part of thawing, 60-80%, takes place in the first month after snow melt (Bliss 1997). Due to climatic variations, the depth of thawing shows interannual variations of 10-20 cm (Chernov 1985).

Complex interrelationships exist between permafrost, freeze-thaw processes and vegetation. Permafrost exerts an adverse effect on the vegetation cover by impeding drainage and soaking of the ground and root development and by damaging the vegetation due to cryogenic processes. On the other hand, vegetation affects the depth of thawing of the active layer: a thicker, denser vegetation cover, more mosses, increase the heat-insulating properties and decrease summer soil temperatures, which leads to a rise in permafrost level and adverse conditions for plant growth (in particular vascular plants). Therefore, in contrast to temperate zones, the final stage of vegetation development in the Arctic there often comprises no stable equilibrium (Chernov & Matveyeva 1997).

Interacting with parent material, freeze-thaw processes in the active layer and upper part of the permafrost layer have a strong influence on local conditions, through modification of regional relief features. Permafrost and cyclic seasonal freezing and thawing determine cryogenic processes (e.g. frost cracking, frost wedging, heaving, sorting) which create a repeating pattern of micro- and nano-relief which differs from other physical-geographical zones. Examples of these patterned ground include hummocks, sorted and non-sorted circles, polygons, nets, steps, stripes (Washburn 1980, Tedrow 1977). In the Pechora Delta region, patterned ground is observed in the uplands and on the coastal plain. Patterns are absent in the Pechora Delta riverine floodplain, mainly due to the absence or deep level of permafrost. Typical patterned ground features occurring in the Pechora uplands include polygons, hummocks and bare spots. Polygons can be divided into polygonal (high centre) tundra and polygonal (low centre) mires (Fig. 4.6). Hummocks include small circular mounds separated by shallow trenches, with both mounds and trenches usually covered by a continuous moss layer. Bare spots (Fig. 4.7) develop in the southern and typical tundra subzone as a result of a break in vegetation cover, either due to the degradation of vegetation following swelling and frost cracking (Liverovski 1987a) or the expulsion of liquefied soil under hydrostatic pressure.

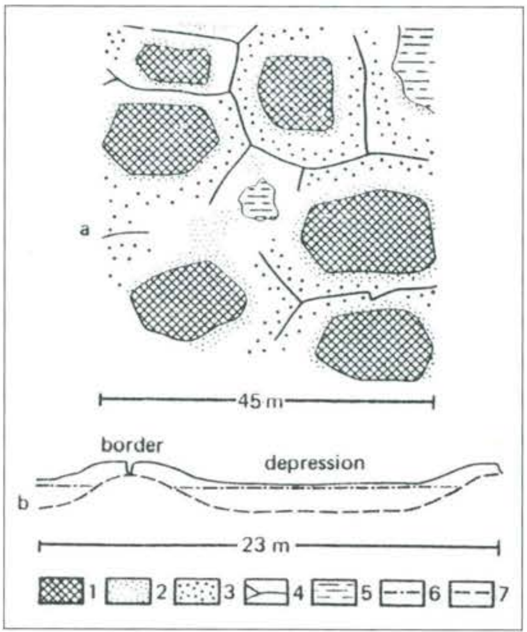


Figure 4.6
Schematic representation of low centre polygons (source: Chernov 1985).

Legend:
1 - polygonal depressions;
2 and 3 - raised borders and slopes;
4 - crack depressions separating adjacent polygons;
5 - small pond in depression;
6 - upper water level;
7 - upper level of permafrost.

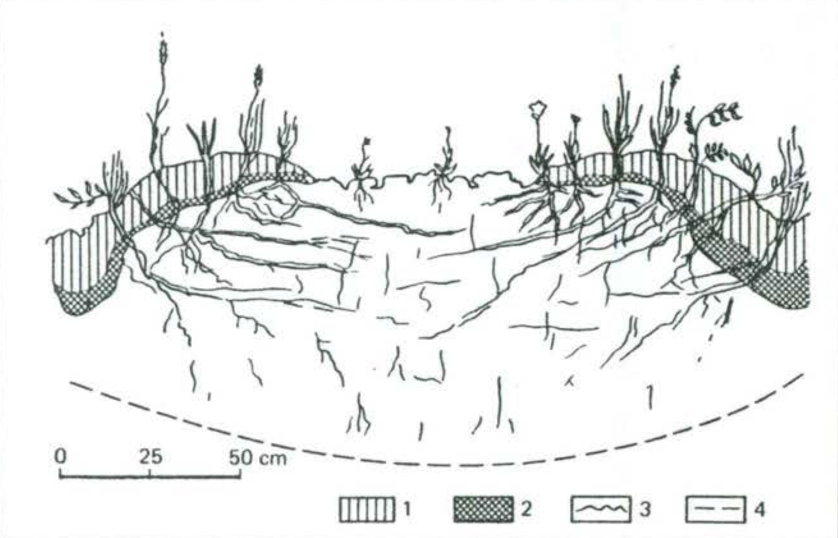


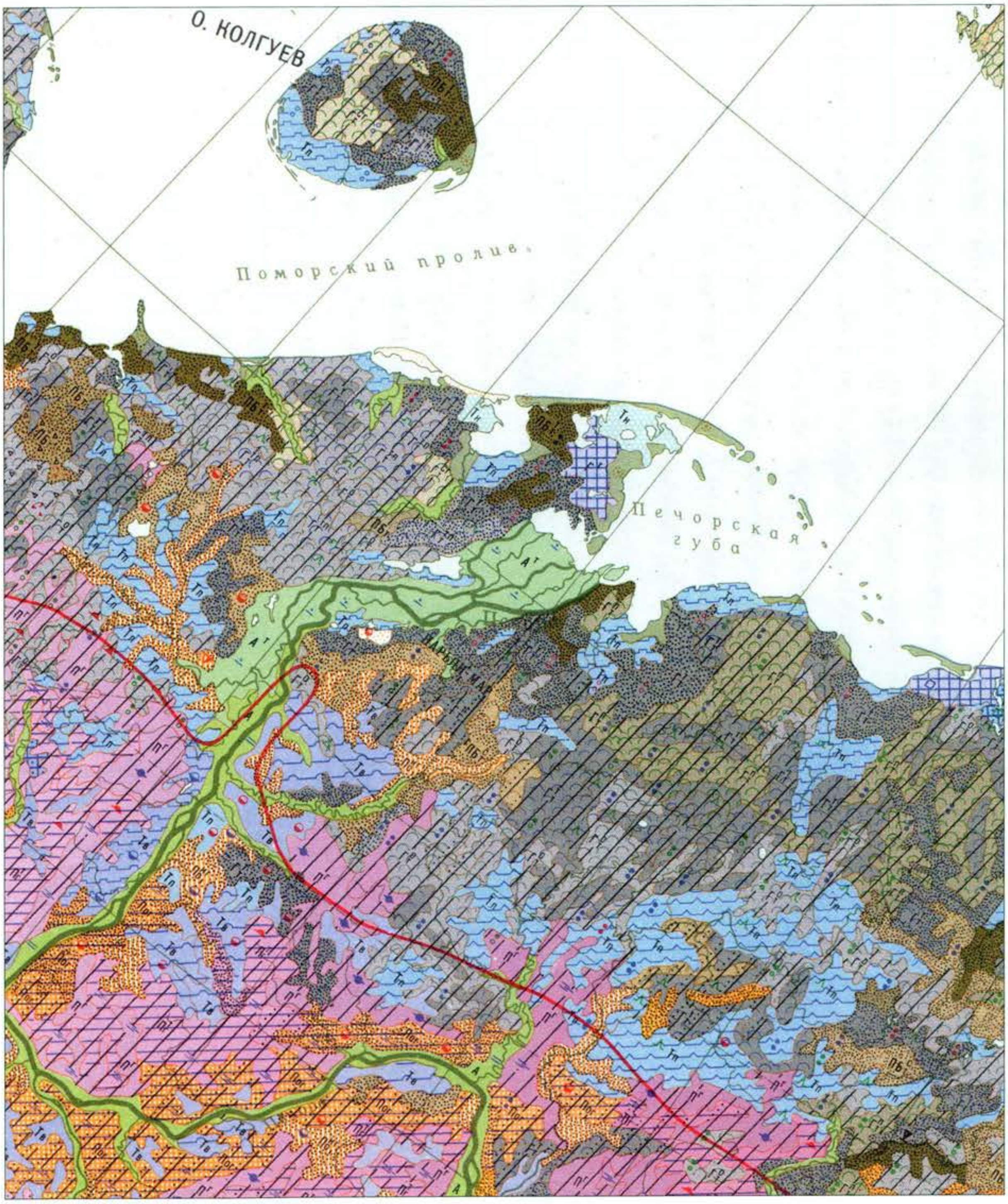
Figure 4.7
Schematic representation of a bare spot in the southern and typical tundra subzone (source: Chernov 1985).

Legend:
1 - moss sward;
2 - moss peat;
3 - surface of bare soil;
4 - level of permafrost.

Figure 4.8
Soil map fragment of the north-eastern part of European Russia.
(source: Authors collective MSU 1995).

Legend:

$\text{Т}_{\text{в}}$	oligotrophic peat marsh
$\text{Т}_{\text{п}}$	mesotrophic peat marsh
$\text{Т}_{\text{н}}$	eutrophic peat marsh
$\text{Г}^{\text{ст}}_{\text{т}}$	weak gleyic humus tundra gley soil, mul-type
$\text{Г}^{\text{п}}_{\text{т}}$	humus tundra gley soil, moder-type
$\text{Г}^{\text{т}}_{\text{т}}$	peaty tundra gley soil (variable thickness of peat layer)
$\text{Г}^{\text{т}}$	tundra gley soil
$\text{Г}^{\text{о}}_{\text{т}}$	surface-gleyic humus tundra gley soil, mor-moder type
$\text{Г}^{\text{тп}}_{\text{т}}$	humus tundra gley soil, mor-moder type
$\text{ПБ}^{\text{т}}_{\text{т}}$	dark tundra Podbur
$\text{П}^{\text{иж}}_{\text{о}}$	illuvial-Fe podzol
$\text{П}^{\text{г}}$	gleyic podzoluvisol
$\text{П}^{\text{т}}_{\text{г}}$	gleyic peaty podzoluvisol
$\text{П}_{\text{ог}}$	gleyic peaty podzoluvisol, mainly illuvial-humus
$\text{П}^{\text{о}}_{\text{о}}$	stagnic-gleyic podzol
А	alluvial soil
$\text{А}^{\text{т}}$	tundra alluvial soil



Soil profile at the coast near Khabuika showing cryogenic features and two A horizons. The profile was created making use of eroded coastal edge.

Natural cliff caused by erosion of peatlayer at larger lake of Site 2. Vertical scale 1.50 m.

The intensity of freeze-thaw processes strongly depends on the temperature regime in the active layer and the upper permafrost zone. The soil temperature regime is determined by a complex interaction of independent factors (climate, topography, parent material, time) and dependent factors (snow cover, moisture, vegetation). Soil freezing is a complicated thermodynamic process, involving mainly refreezing from the surface downward, although freezing upward from the permafrost table is also observed (Chernov & Matveyeva 1997). The specifics of freezing result in unfrozen material under hydrostatic pressure at depth, which may be squeezed to the surface forming "frost boils" (Bliss 1997).

Figure 4.8 shows a map of soil types in the north-eastern part of European Russia. Three main groups of genetic soils can be distinguished in the Pechora region: well-drained soils - imperfectly to poorly drained soils - very poorly drained soils (Tedrow *et al.* 1958, Targulian 1971).

Well-drained soils occur on elevated positions characterised by a deep thaw of the active layer, related with dry forms of permafrost, coarse-textured sandy parent material and a significant hydraulic drainage gradient. As a result of good drainage conditions, oxidation rather than reducing conditions prevail and soluble weathering products are redistributed within the soil profile or leached from the soil (Rieger 1974). Soils show a distinct soil profile differentiation in genetic horizons - a thin surface layer of organic material, underlain by a blackish humic A0A1, a blackish brown illuviation Bh and reddish brownish Bh, Fe, over sandy parent material. Sometimes the illuviation horizon is overlain by a thin greyish bleached eluvial E horizon. Important soil forming processes include cryo-coagulation of dispersed material, Al-Fe-humus eluviation-illuviation and cryoturbation (Rusanova 1996, Targulian 1971). According to the Russian soil classification (Anonymous 1997), soils belong to the Order of Podburs, comparable with either the Suborder Cryods (Great Group: Haplocryods) or Orthels (Great Group: Psammorthels), depending on the permafrost level, in the Soil Taxonomy (Soil Survey Staff 1999). In slightly worse drainage conditions, redoximorphic features develop in the subsoil (gleyic Podbur) displaying an increased intensity of eluviation-illuviation processes (Targulian 1971).

Imperfectly to poorly drained soils cover extended areas on flat plains and undulating landscapes from ridge top to valley. The standard soil profile distinguishes a Histic surface layer underlain by gleyic fine-textured mineral layers. The soil profile of this group shows considerable variation, depending on factors like relative wetness, parent material, plant cover, organic matter type and accumulation, regional and local topography. The Russian classification (Anonymous 1997) distinguishes two Suborders based on increasingly impeded drainage - surface gley soils (slightly sloping hummock landscapes) and tundra gley soils (almost flat hummock landscapes). These soil types correlate with the Gelisol Suborders of the Turbels (Great Groups: Histoturbels, Aquiturbels) and Orthels (Great Groups: Historthels, Aquorthels) in the Soil Taxonomy (Soil Survey Staff 1999). Typical for this group is the insignificant profile differentiation, although micro-morphological investigations show evidence of gleyic and cryogenic processes, as well as minimal humus, Fe and clay eluviation-illuviation and the accumulation of organic matter (Ivanova *et al.* 1970, Ignatenko 1979, Vasilyevskaya 1980, Rusanova 1996). The associated soil forming process is primarily gleization in low-temperature environments (Tedrow *et al.* 1958).

Very poorly drained soils occur in extended flat areas with little opportunity for surface runoff, while permafrost acts as an impermeable layer for vertical drainage. Soils therefore are wet throughout the warm season, frequently standing water occurs on the surface. Water logged conditions

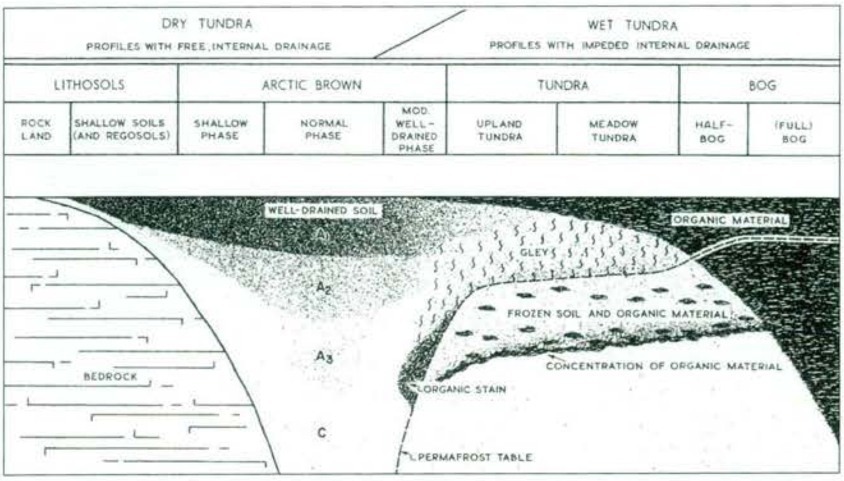


Figure 4.9
Major drainage sequence of soils in the tundra zone (source: Tedrow *et al.* 1958).

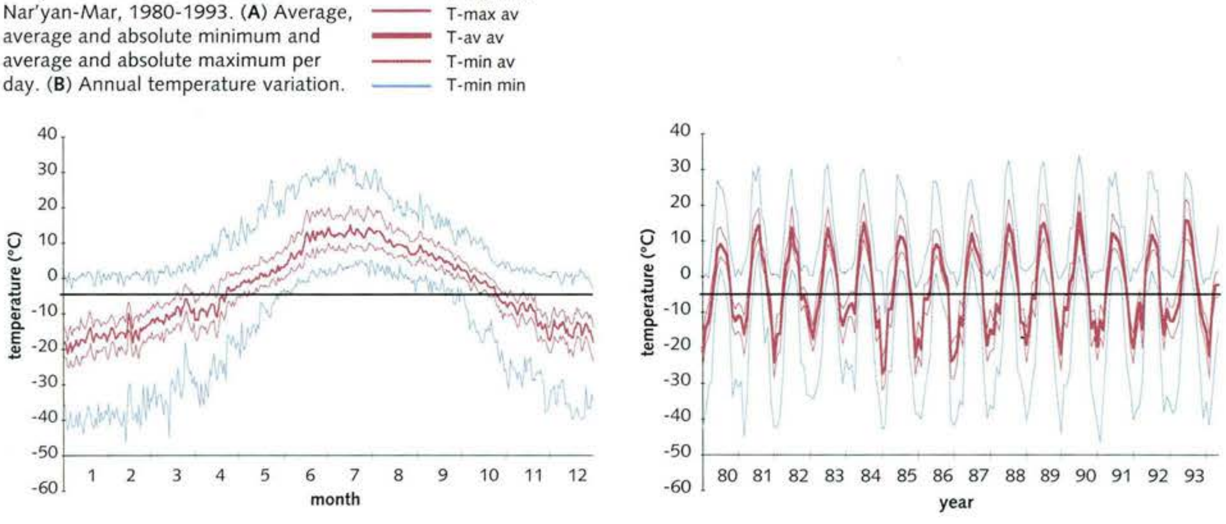
strongly limit organic matter decomposition, resulting in an accumulation of mainly fibrous peat of sedge-*Sphagnum* and graminoid vegetation communities. Micro-morphological investigations show a minimal decomposition of organic material in the upper 3-6 cm, as well as processes of mechanical disintegration of organic matter due to freeze-thaw processes (Rusanova 1996). Often this type of soils is associated with depressions of low centre polygons, occurring in a mosaic pattern with organic soils developed under well-drained conditions on surrounding elevated areas. In the Russian soil classification, the soils are characterised as tundra bog soils, comparable with the Gelisol Suborder of Histels (Great Group: Fibristels) in the Soil Taxonomy.

The drainage sequence of the major soil groups distinguished in tundra areas is summarised in Figure 4.9 based on investigations on the arctic slope of Alaska (Tedrow *et al.* 1958). Characteristically absent in the Pechora Delta region are the soils with bedrock shallow in the soil profile. The nutrient status of the soil, both in well-drained and very poorly drained conditions, depends on the release of nutrients from weathering, related with parent material, and decomposition of organic matter. Locally the nutrient status may be altered by fluxes of nutrients with drainage or flood water.

Climate

According to the climate map of the Nenets Autonomous Region the project area is located in the sub-arctic climate zone. Climatic conditions in this zone are determined by the amount of solar irradiation, the radiation balance, intensive air convection streams and a noticeable influence of the Arctic Ocean. The total solar irradiation in the tundra regions of Eurasia amounts to around 70 kcal cm^{-2} yr^{-1}, of which 40 kcal cm^{-2}, more than half, is received between June and August. An important indicator for the heat conditions and vegetation growth possibilities is the radiation balance, the difference between the total radiation reaching the surface and the part radiated back into the atmosphere. For the lower Pechora the radiation balance between June and August is 18 kcal cm^{-2} (Chernov & Matveyeva 1997). Most of the solar irradiation in arctic regions is reflected from the surface, but the albedo varies widely within the year, During

Figure 4.10
Temperature measured at station Nar'yan-Mar, 1980-1993. (**A**) Average, average and absolute minimum and average and absolute maximum per day. (**B**) Annual temperature variation.



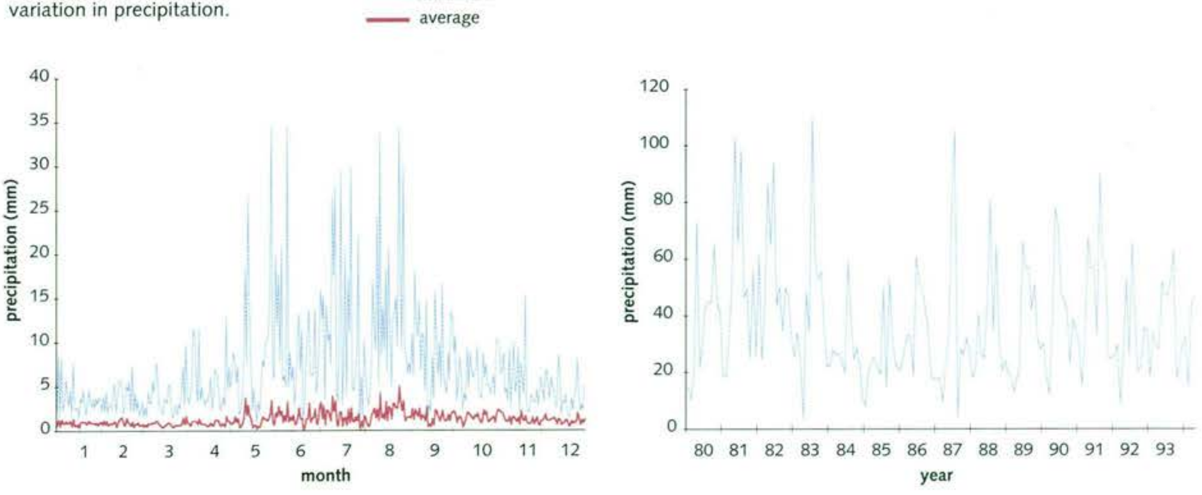
the summer period the albedo averages 20%, increasing up to 85-90% for a fresh snow cover.

The regional weather conditions are characterised by a year-round instability determined by interchanging atlantic cyclones and arctic air masses. Atlantic cyclone activity is especially high during winter, conditioning overcast weather, snow storms and blizzards. During summer cyclones bring cool rainy weather. In winter arctic air masses bring cold sunny weather, in summer they result in a significant decrease in temperature, often accompanied by frost on the ground surface.

The temperature regime in the project region shows large seasonal fluctuations. The long-term 24-hour average temperature varies from -20°C in January to 13°C in July (Fig. 4.10.A), with extremes varying between -40°C and 30° C. The 24-hour temperatures on average rise above zero in the first half of May, and fall below zero in the beginning of October. The average frost-free period lasts four months, although ground frost may occur throughout the summer season. Summer is conventionally the period when the 24-hour temperature exceeds 10°C, which in the Nar'yan-Mar area is a period 1-1.5 months between half June and the beginning of August. The length of the summer period is one of the most decisive factors for the development of organic life in the tundra zone. Of major importance for living organisms is the summer temperature more than the average yearly temperature. The variation in monthly temperature between 1980 and 1995 is presented in Figure 4.10.B.

The region is characterised by an excess moisture regime. The average long-term precipitation amounts to 450 ± 90 mm yr^{-1}, distributed over 211 ± 45 days during the year. The average amount of precipitation on a rain day is 1.98 ± 0.3 mm (Fig. 4.11.A). Monitoring data show that 65% of the precipitation occurs during the warm season, with a maximum in August, and 35% during the cold season, with a minimum in March. The highest variation in precipitation is observed in spring and summer (Fig. 4.11.B). During winter precipitation falls in the form of snow, which covers the surface for about 200-240 days. Snow cover in north-European Russia is about 50-60 cm, characterised by a large spatial variation due to redistribution by strong winds. Even the nano-relief is an important factor in this respect. The presence or absence of a snow cover is of utmost

Figure 4.11
Precipitation measured at station Nar'yan-Mar, 1980-1993. **(A)** Average and maximum per day. **(B)** Annual variation in precipitation.



importance for the vegetation, determining the level of protection against severe frosts. Mean annual humidity equals 80%, a minimum of 70% occurring in June. Due to low temperatures in summer and negative temperatures in winter, yearly evaporation is low and concentrated in the warm season.

The wind direction and strength are determined by the interaction of atlantic cyclones and arctic air masses. During the cold season southern and south-western winds prevail, during summer winds mainly blow from the North and North-East. In general wind speed is higher in winter. Average wind speed is 7 m sec^{-1}, during blizzards the wind speed can increase up to 25 m sec^{-1} (90 km h^{-1}).

The region is characterised by a strong seasonal variation in day length. During the arctic winter, between early December and half January, the sun does not rise above the horizon, while between half May and late July the sun does not set.

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5 Classification of main landscape units

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5.1 Satellite image analysis techniques

Landsat Thematic Mapper (TM)

For the study in the Pechora Delta Landsat (TM) data have been used. Landsat TM is a satellite with a multispectral scanning system which records reflected/emitted electromagnetic energy from the visible, reflective-infrared, middle-infrared and thermal-infrared regions of the spectrum (the thermal infrared was not used in this study). TM has a swath width of approximately 185 km and records information from an altitude of approximately 705 km. The spatial resolution of TM is 30x30 m^2 for all bands except the thermal (band 6) which has a spatial resolution of 120x120 m, but is resampled to 30x30 m^2 to match the other bands. Detectors record electromagnetic radiation in seven bands (ERDAS 1997):

(1) Blue 0.45-0.52 nm. Useful for mapping coastal water areas, differentiating between soil and vegetation, forest type mapping and detecting cultural features.

(2) Green 0.52-0.60 nm. Corresponds to the green reflectance of healthy vegetation. Also useful for cultural identification.

(3) Red 0.63-0.69 nm. Useful for discriminating between many plant species and also for determining soil boundary and geological boundary delineation as well as cultural features.

(4) Reflective-infrared 0.76-0.90 nm. This band is especially responsive to the amount of vegetation biomass present in a scene. It is useful for crop identification and emphasises soil/crop and land/water contrasts.

(5) Mid-infrared 1.55-1.74 nm. Sensitive to the amount of water in plants, which is useful in crop drought studies and in plants health analyses. This is also one of the few bands that can be used to discriminate between clouds, snow, and ice.

(6) Thermal infrared 10.40-12.50 nm. Useful for vegetation and crop stress detection, heat intensity applications and for locating thermal pollution. It can also be used to locate geothermal activity.

Sea fog coming in.
Site 6, August 1998.

(7) Mid-infrared 2.08-2.35 nm. Important for the discrimination of geologic rock formations and soil boundaries, as well as soil moisture content.

Image processing

The images are provided on Computer Compatible Tapes and CD Roms in the form of plain row-column images. Although the orientation of Landsat TM scenes roughly corresponds with map co-ordinate systems, a geometrical transformation improves the possibilities for visual interpretations since the images can be compared more easily with other sources of information. For the geometrical correction in this study topographical maps were used 1:100 000 and additionally GPS information was obtained in the field. The overall accuracy of the geometrical transformation is approximately 200-300 meters.

Unsupervised classification

A basal landscape map was obtained by "unsupervised" classification of a Landsat TM image of 9 September 1985. Unsupervised image classification extracts a predefined number of classes based on a multivariate statistical clustering of the intrinsic variation in spectral reflectance values in the seven wavelength bands. This procedure does not make use of any information on actual landscape conditions. The 20 extracted classes were grouped into eight unsupervised landscape classes (Beekman *et al.* 1996, Fraikin *et al.* 1996).

The results of the unsupervised classification identified four main landscape regions, being the Pechora Delta floodplain, the Nenetskaya Ridge uplands, the Ruskii Zavorot coastal plain and the Bolshezemelskaya Tundra uplands. A stratified sampling approach was applied to collect ground-truth information in each of the main landscape regions. In each landscape region a number of study areas was selected for detailed field work.

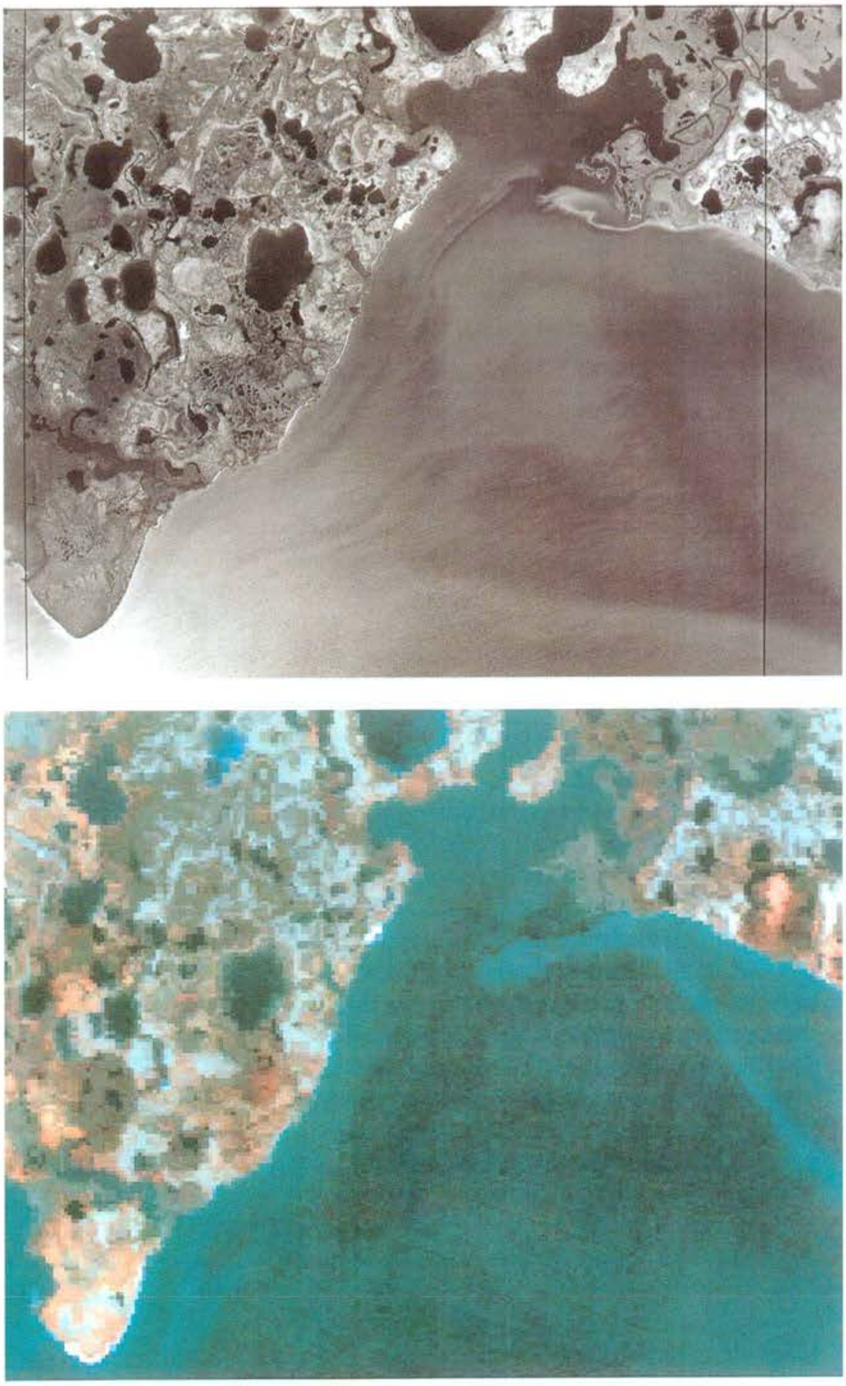
False colour composites

Bands 2, 3 and 4 of Landsat TM were used to create false colour composites. Areas with much green biomass are depicted red. Clear water is black whereas areas with a high reflection (bare sand, dead vegetation, lichens) appear whitish/bluish. Also suspended matter in water gives a lighter appearance. False colour images were used commonly to choose training sites (see below) and for orientation. Pixel size of Landsat limits the use to general, large-scale investigations. For reason of comparison, an aerial picture is shown to the same scale as the false colour composite (Fig. 5.1). Contours of smaller lakes and pools are sometimes difficult to see, as well as vegetation patterns within the size of a pixel, i.e. 30 m.

NDVI composites

To summarise intrinsic spectral information on biomass and Leaf Area Index (LAI), spectral data were also transformed into a Normalised Difference Vegetation Index (NDVI), using the red and near infra red bandwidths. Vegetation indices were considered useful to minimise the effect of varying view angles and illumination conditions (Hope & Stow 1996). Especially expressed micro-relief features typical in tundra regions may give rise to shadowing and bi-directional reflectance properties. Also images acquired at this latitude are associated with solar elevations less than 45° which is considered to be less than optimal for quantitative image analysis (Stow *et al.* 1989). NDVI classes were recoded in ten classes based on the internal variation within study areas. A disadvantage of vegetation indices is that mainly biomass is taken into account, a parameter which especially in an early season image is of limited use to charac-

Figure 5.1
Comparison of resolution of an aerial picture and Landsat false colour image, showing the same area at identical scale. The area is situated at the NW sector of Korovinskaya Bay, opposite the delta of the river Pechora (Spot 25).



terise the diversity of community types. In tundra landscapes, characterised by a relative low variability in vegetation structure, vegetation composition rather than biomass is a significant parameter determining the spectral reflectance properties (Hope & Stow 1996), as is spatial heterogeneity of community distribution.

Multispectral classification

This is the process of sorting pixels into a finite number of individual classes, or categories of data, based on their data file values. If a pixel satisfies a certain set of criteria, the pixel is assigned to the class that corresponds to that criteria. This process is also referred to as image segmentation.

Depending on the type of information one wants to extract from the original data, classes may be associated with known features on the ground or may simply represent areas that "look different" to the computer. An example of a classified image is a land cover map, showing vegetation, bare land, pasture, urban settlements, etc.

Pattern recognition This is the science - and art - of finding meaningful patterns in data, which can be extracted through classification. By spatially and spectrally enhancing an image, pattern recognition can be performed with the human eye; the human brain automatically sorts textures and colours into categories. In a computer system, spectral pattern recognition can be more scientific. Statistics are derived from the spectral characteristics of all pixels in an image. Then the pixels are sorted based on mathematical criteria. The classification process breaks down into two parts: training and classifying (using a decision rule).

Training First, the computer system must be trained to recognise patterns in the data. Training is the process of defining criteria by which these patterns are recognised. This is closely controlled by the image processor, which selects pixels that represent features, like land cover or vegetation type, that are recognisable or that can be identified with help from other sources, such as aerial photos, ground-truth data or maps. Knowledge about the data and about the classes desired is required before classification. For identifying patterns the computer system can be programmed to identify pixels with similar characteristics. If the classification is accurate, the resulting classes represent the categories within the data originally identified.

Signatures The result of training is a set of signatures that defines a training sample or cluster (see feature space). Each signature corresponds to a class, and is used with a decision rule to assign the pixel in the image to a class.

Feature space Many algorithms in image processing compare the values of two or more bands of data. The programs that perform these functions abstractly plot the data file values of the bands being studied against each other. An example of such a plot in two dimensions (two bands) is illustrated in Figure 5.2.A.
The pixel that is plotted has a measurement vector of 86/170. The graph implies physical dimensions, for the sake of illustration. Actually, these dimensions are based on spectral characteristics, represented by the digital image data. As opposed to physical space, the pixel above is plotted in a

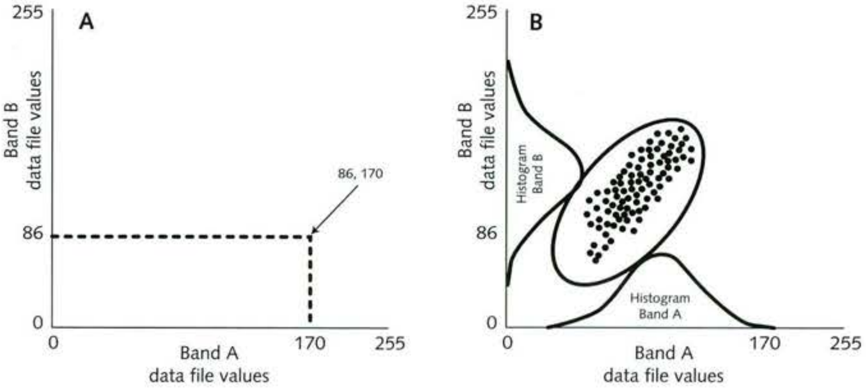


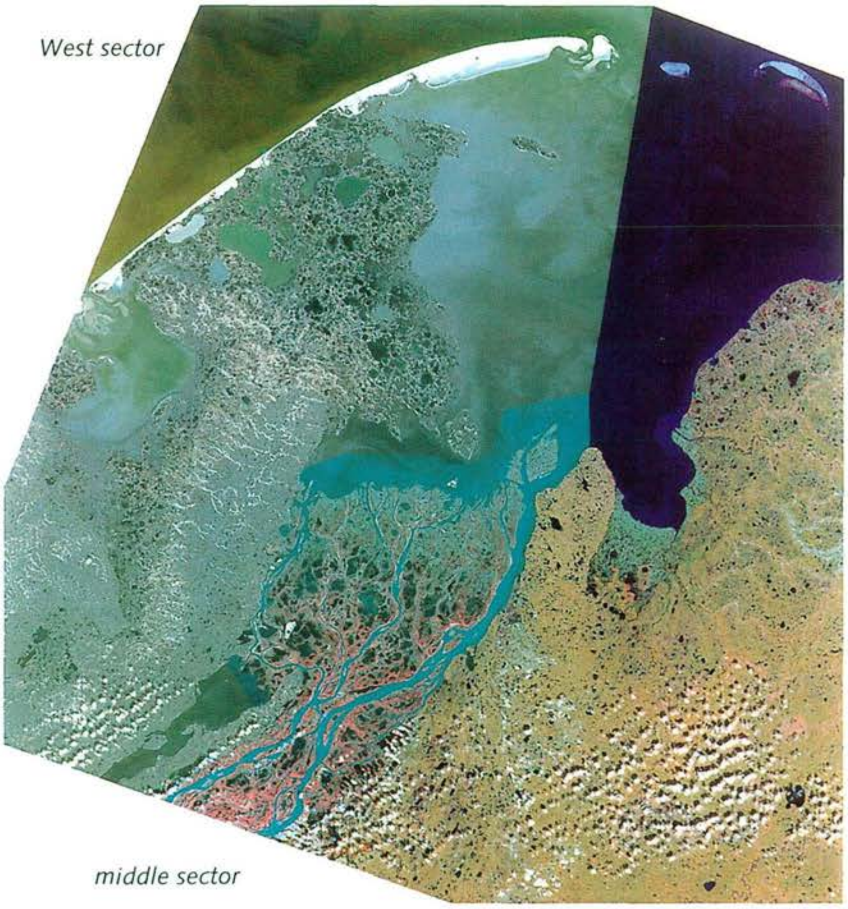
Figure 5.2
(A) Pixel plot showing spectral information of two bands. This procedure is used to characterise all pixels in the image.

(B) Histogram showing spectral characteristics of all pixels in the area under study.

so called feature space. This is an abstract space that is defined by spectral units (such as an amount of electromagnetic radiation).

Feature space images Several techniques for processing of multi-band data make use of a two-dimensional histogram, or feature space image. This is simply a graph of the data file values of one band of data against the values of another band. In Figure 5.2.B the histograms are shown to illustrate how they relate to the feature space image. When the values in the bands that are plotted jointly have normal distributions, as in the example above, then the feature space forms an ellipse. This ellipse is used in several algorithms, specifically for evaluating training samples for image classification.
In this study the Pechora Landsat TM has been split into three sectors because in each sector spectral features of different vegetation showed considerable overlap causing major problems when classifying (Fig. 5.3). The separation is made by digitising the sectors with help of the characteristics of the landscape itself. Also a separation is made of the land and water using Band 5 of Landsat TM which gives a low reflection so that a water mask can be made.

Figure 5.3
Three sectors used for classifying vegetation patterns in the study area. West sector includes Ruskii Zavorot peninsula and the Nenetskaya Ridge.
The middle sector, the floodplain of the Pechora river, shows the greatest deviation from the other two. The East sector comprises the western part of the Bolshezemelskaya Tundra.



Fieldwork 1995-1999

During the fieldword carried out in five consecutive years (1995-1999) information was obtained for the use of classification. Field work was executed with image prints, scale 1:35 000, with a standard pixel size of about 30x30 m². In the period 1995-1999 in total 252 detailed field descriptions were made, mainly in study sites but also at sites visited shortly by helicopter. Descriptions included all main landscape regions as follows: Pechora Delta floodplain - 54, Nenetskaya Ridge uplands - 44, Ruskii Zavorot coastal plain - 70, western Bolshezemelskaya Tundra uplands - 34. During field expeditions to selected study areas, unsupervised image classes, NDVI and false colour image prints were used as an aid to structure the observed landscape diversity. For each landscape type a number of sufficiently large representative spots was selected for detailed descriptions of vegetation and environmental conditions. The number of spots per landscape type depended on the relative occurrence of the unit in a study area, the average surface area of individual units as well as the internal variability. The latitude and longitude of spots was determined with a Global Positioning System.

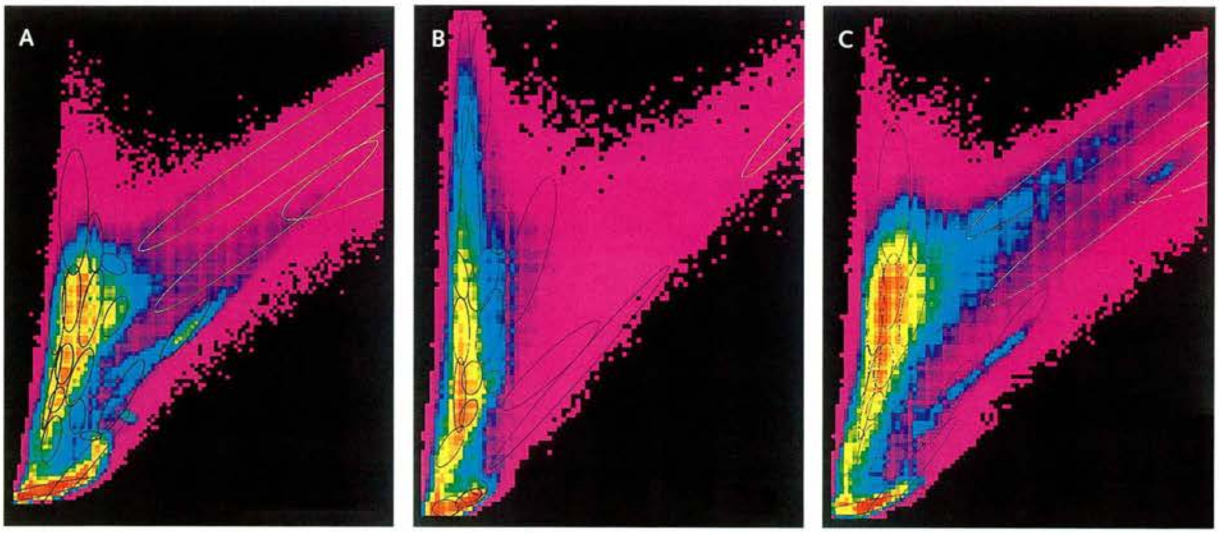
Detailed vegetation descriptions included the structure of the vegetation, the species composition and cover percentages as well as a reference to botanical community type according to the Russian classification system. Heterogeneous landscape types were characterised by multiple detailed descriptions.

Detailed descriptions of environmental conditions included drainage conditions, slope, topography, micro-relief and depth of frozen layer. The soil profile was characterised based on distinguished soil horizons, including information on colour, granulometric texture, redoximorphic features/mottling, type of organic matter and state of decomposition. On a number of spots samples for laboratory analyses were collected. Analyses include particle size distribution, organic matter content, carbonate content, N, P, K, CEC and exchangeable bases. On a limited number of spots organic layers or mineral layers with high organic matter content were sampled for future C^{14} dating.

Classification of the Pechora Delta

Based on the occurrence of landscape types observed during field expeditions separate supervised classification procedures were executed for three

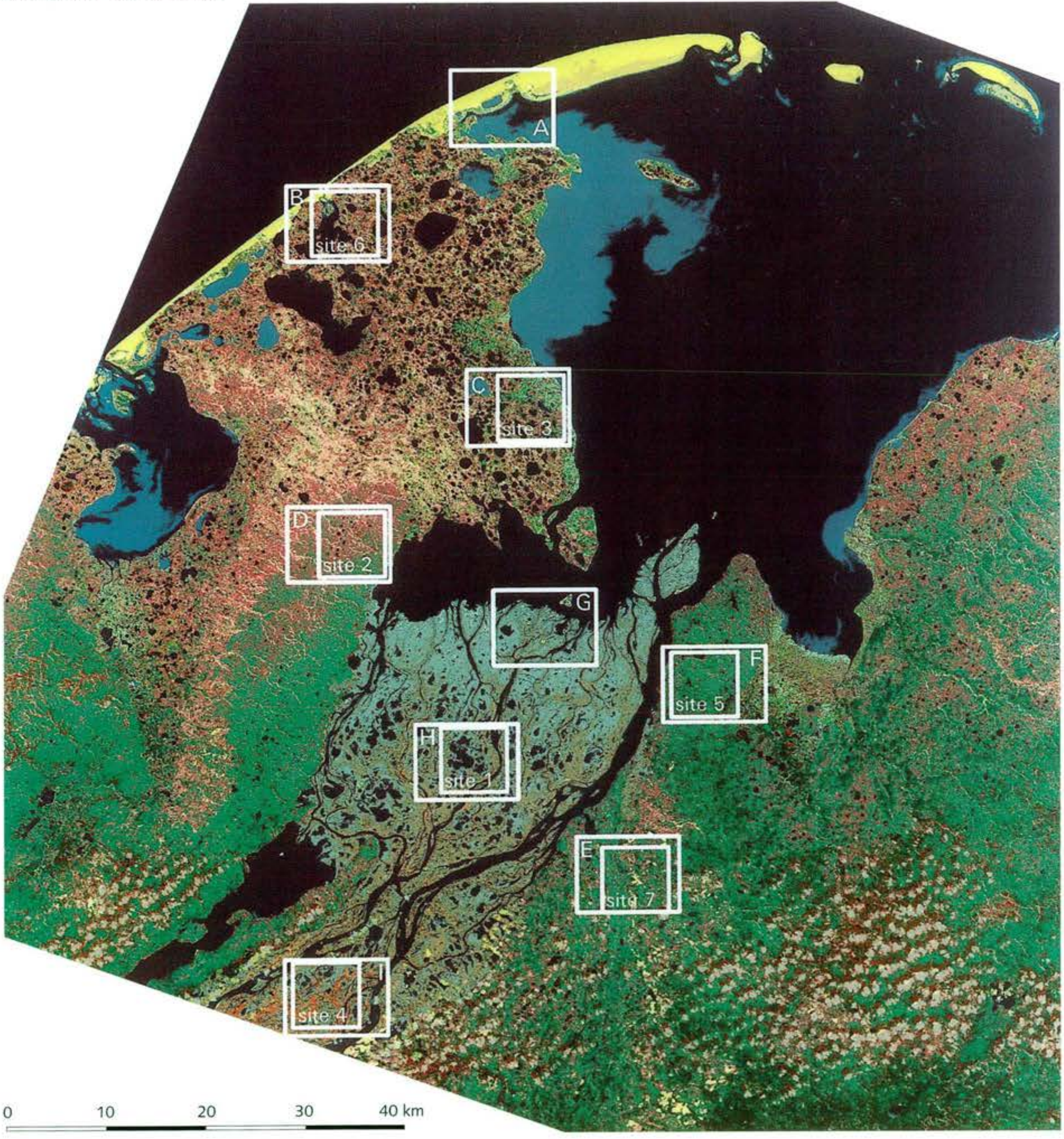
Figure 5.4
Feature space showing spectral characteristics of all pixels for three sub-areas **(A)** West, **(B)** Middle and **(C)** East. Signatures of training samples are shown.



defined sub-areas: (1) the Ruskii Zavorot coastal plain including the Nenetskaya Ridge (West), (2) the Pechora Delta floodplain (middle), (3) the western Bolshezemelskaya Tundra uplands (East). Figure 5.4 shows feature space plots with determined signature samples for these three regions.

In the West sector from 72 field samples a signature was made. Also nine samples were made by visual interpretation such as sand, mud flats and

Figure 5.5
Classified image of the entire study area showing the large scale vegetation patterns in three major landscapes being the floodplain area, the coastal plain and the uplands. Indicated are the seven study sites where expeditions were directed to in different years. See Fig. 5.6 - 5.8 for details.



inundated *Carex*. By using the feature space, a selection was made and eventually 20 classes where selected excluding water.

In the middle sector from 29 field samples a signature was made. Also five samples were made by visual interpretation. By use of the feature space analysis, a selection was made and finally 18 classes where selected excluding water.

For the East sector only 16 field samples were available initially, this information being too little for classification. For this reason we used signatures of the West sector because many of the class types are the same as in the East sector. In total 22 classes were defined excluding water.

A water classification was made resulting in seven classes. However, the spectral differences between these classes is minimal.

Class name
Clear water
Clear water with few algae
Clear water with algae
Water with abundant algae
Suspended matter low
Suspended matter medium
Suspended matter high

The seven water classes are shown here as two classes, although within a GIS environment these seven classes are available.

The final image classification of the Pechora Delta region resulted in 31 classes (24 landscape and vegetation classes, two water classes, six other such as clouds, snow, bare soil). An overview of the entire classified image is shown in Figure 5.5, also indicating study sites. More detailed selections from the image for the three landscape regions separately are shown in Figures 5.6 (uplands), 5.7 (coast) and 5.8 (floodplain). The classification units for both the uplands, the coastal plain and the Pechora Delta floodplain will be described below.

5.2 Legend descriptions

5.2.1 Uplands and coastal region

Unit name	**dry high centre polygons**	
Image colour	**light rose**	**1a** 🟥

Topography

Upland areas, on flat to convex upper slopes up to 5%, on all topographical levels. On the coastal plain this unit is never flooded by sea water, also not during storm surges or spring tides.

Surface expression

Micro-relief features show a structure of cryogenic high centre polygons (80% surface cover), surrounded by linear depressions (20% surface cover). Depressions developed following thawing of ice wedges formed after frost cracking. Polygons have an average size of 25-500 m^2. Height difference between the central part of polygons and depressions on average is 5-10 cm, with height differences within high centre polygons smaller than 5 cm. Bare spots cover 5-15%, maximum 25% of the surface.

Parent material and soil characteristics

Parent material consists of (medium fine, 200-300 m) sands of quaternary interglacial or post-glacial marine or fluvioglacial origin. Soils characteristically show weak podzolic profiles with thin eluviation and illuviation horizons. The dominant soil profile on high centre polygons distinguishes:

- a strong humic sandy or histic A horizon, thickness 1-5 cm, dark grey-brown to black, with well decomposed organic matter;
- a light (yellowish) grey sandy eluviation E horizon, deprived of Fe and organic compounds, thickness 1-3 cm;
- a (dark) red-brown, sandy illuviation Bh, Fe horizon, thickness 2-8 cm. Not in all profiles the illuviation horizon is easily recognised, while others distinguish separate illuvial horizons for organic compounds and Fe, Al (1-2 cm);
- a red yellowish brown sandy B2 horizon, thickness 5-25 cm. This horizon is clearly darker in colour but lacking the expressed evidence of illuviation;
- a yellowish brown to grey sandy C horizon, single-grain granular structure without clear stratification. Frozen deeper than 50 cm (early July). Maximum depth of thawing 100 cm (August). Includes irregular reddish and blackish spots typical for water-deposited sediments.

Influenced by cryogenic processes, boundaries in topsoil horizons are wavy to irregular, rarely broken. Podzolic features not necessarily result from actual processes, but may reflect an increased intensity of soil forming processes during warmer periods of the Holocene. The soil profile in depressions resembles the depression profile described for image class 1b. In the coastal zone, the topsoil may include wind-blown sand particles, while sometimes old profiles are covered by a thicker layer of wind-blown sand.

Moisture regime

Xeric. The unit is characterised by a deep penetration of seasonal thaw, a good to excessive drainage due to a high vertical and lateral hydraulic conductivity, and rather dry permafrost releasing limited amounts of water upon thawing. Surface water in linear depressions is absent.

Nutrient level

Oligotrophic. Limited amounts of nutrients are released by weathering. The inflow of nutrients with drainage water is negligible. Although organic matter decomposition is relatively favourable, amounts are limited, and a prevailing vertical downward water flux transports nutrients out of the root zone.

Vegetation characteristics

Total vegetation cover >75%, often 100%. Bare spots occur in different stages of regeneration, varying from bare sand to being covered with a thin crust of black algae and starting lichens. Vegetation composition includes 97 species, dominated by lichen species (>50%). Dominant lichen species include *Cetraria islandica, Flavocetraria nivalis, Cetrariella delisei.* Important aspect of the community are dwarf shrubs, with a typical high cover of *Empetrum hermaphroditum* (10-25%). Characteristic dwarf shrubs with a lower cover include *Arctous alpina, Vaccinium vitis-idaea, V. uliginosum and Salix nummularia.* Typical graminoids and herbs include *Carex arctisibirica, Armeria scabra, A. labradorica, Luzula confusa*. Sometimes either *Betula nana or B. tundranum* occurs. The spatial distribution of the vegetation cover is very irregular. Small irregularities in micro- or nano-relief create different environmental conditions (moisture, temperature) which result in a different species composition. In the depressions surrounding high centre polygons, vegetation communities are dominated by mosses and graminoids (see classification unit "moist high centre polygons"). According to the Russian vegetation classification this unit mainly resembles the "dwarf shrub-lichen and spotty dwarf shrub-lichen tundra on sands".

Uplands 1

1. Dry high centre polygon
2. Moist high centre polygons bordering a larger lake
   Spot 9, August 1998
3. Long-slope hummocks
   August 1998,
   Site 2
4. Dry hummocks
   August 1998,
   Site 2
5. Wet hummocks
   August 1998,
   Site 2
6. Low centre polygons
   Spot 22, July 1995

Unit name	**moist high centre polygons**	
Image colour	**bright rose**	**1b** 🟥

Topography

Upland areas, flat to almost flat plateaux or slight convex slopes up to 4%, on all topographical levels. On the coastal plain this unit is never flooded by sea water, also not during storm surges or spring tides.

Surface expression

The unit shows a structure of cryogenic high centre polygons (60%), surrounded by linear mossy depressions (40%). Depressions developed following thawing of ice wedges formed after frost cracking. Polygons have an average size of 25-300 m^2. Height difference between the central part of polygons and depressions is 20-40 cm, while height differences within high centre polygons on average are 10 cm. On micro-heights up to 5% of the surface area is not covered by higher plant vegetation.

Parent material and soil characteristics

- Parent material consists of medium fine sands of quaternary interglacial or post-glacial marine or fluvioglacial origin. The soil cover shows a large spatial heterogeneity, due to an irregular micro-relief and related differences in drainage and nutrient conditions. The soil profile of micro-heights resembles the profile described for the unit "dry high centre polygons", with sometimes a slightly thicker histic A horizon. The soil profile of depressions shows:

- a blackish O horizon with actual living mosses and roots of graminoids, thickness 5 cm;
- a dark brown to blackish, histic A horizon, thickness 5 cm, slightly to moderately decomposed organic material of mosses and lichens;
- a light red-brown to brown histic A horizon, thickness 10-20 cm, moderate to well decomposed organic material of mosses and grasses;
- a reddish grey sandy C horizon, single-grain granular structure without clear stratification, the parent material, maximum depth of thawing 45 cm.

Surface water in depressions is absent, but typically groundwater is observed not deep in the profile (July). Maximum depth of seasonal thawing varies between 40 and 80 cm, depending on the micro-relief position.

Moisture regime

Mesic-xeric. The unit is characterised by a moderately deep thawing of the active layer, a moderately good vertical and lateral drainage. Drainage conditions are worse than for the unit "dry high centre polygons", due to a slightly worse regional hydraulic gradient (less height differences, longer slopes), which results in more free water in the profile, more intensive freeze-thaw processes and a more expressed micro-topography.

Nutrient level

Micro-heights - oligotrophic; depressions - slightly mesotrophic. Nutrient conditions on micro-heights are characterised by a limited release of nutrients by weathering, relative fast decomposition of organic matter and removal of nutrients by drainage water. Although in depressions decomposition of organic matter is limited, and weathering does not provide significant amounts, the inflow of nutrients with drainage water from micro-heights provides for slightly mesotrophic nutrient conditions.

Vegetation characteristics

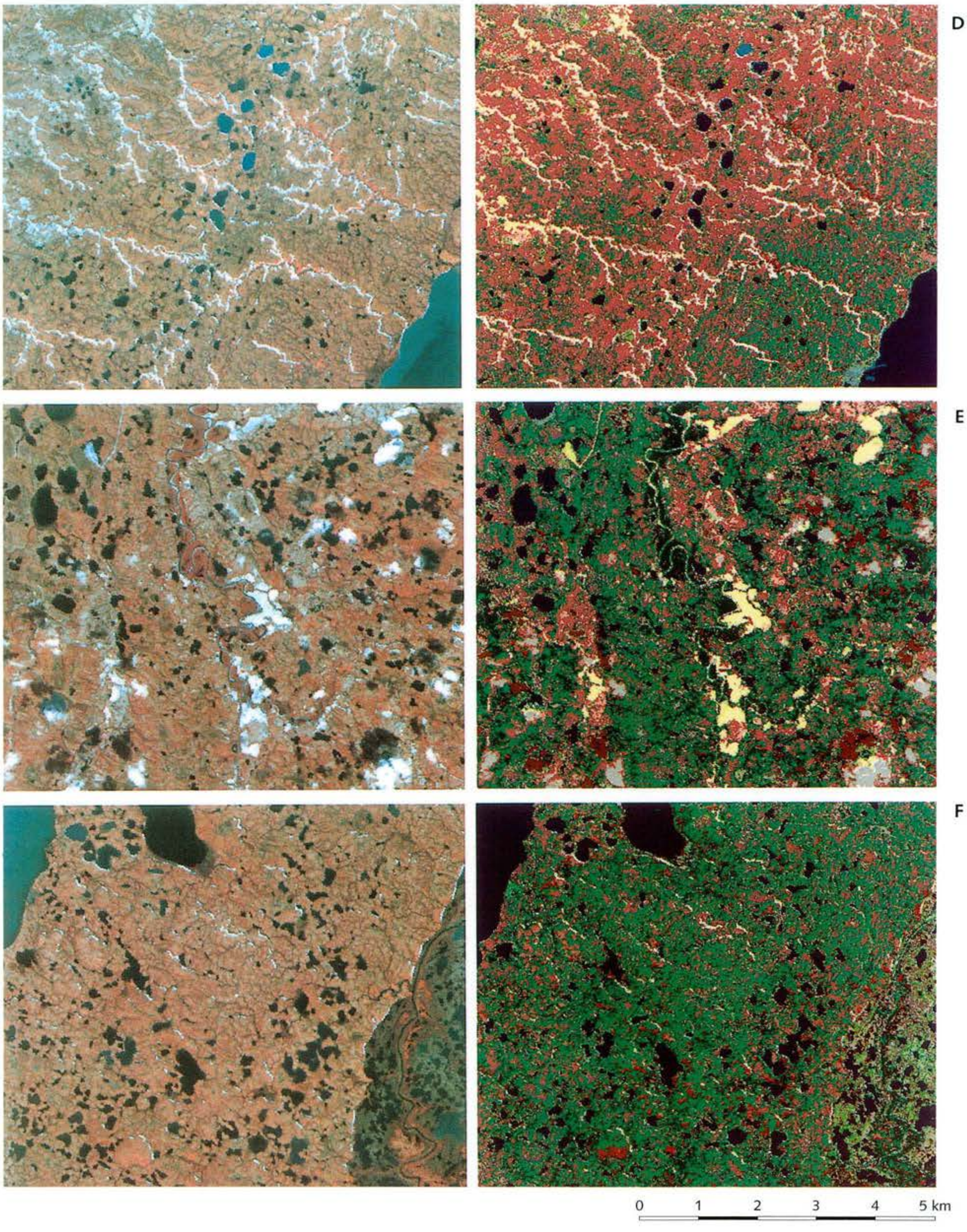
Micro-relief differences give rise to clear differences in vegetation communities, related to the described differences in drainage and trophic state. On micro-highs typically "dwarf shrub-lichen communities" occur, comparable with the vegetation described for "dry high centre polygons". Most open spots are covered with a thin crust of black algae. In depressions, within polygons and in trenches, vegetation communities are dominated by mosses (mainly *Sphagnum* spp., additional *Dicranum* and *Polytrichum*) and graminoids and herbs (*Eriophorum scheuchzeri, Carex aquatilis, C. rariflora, Luzula wahlenbergii* and *Rubus chamaemorus*). Dwarf shrubs include *Empetrum hermaphroditum, Vaccinium vitis-idaea* and *Andromeda polifolia*. Lichen species include *Cladonia* spp. and *Cetrariella delisei*.

Remarks

This unit may represent a successional phase following "dry high centre polygons". A mossy vegetation in depressions, developed due to progressive degradation of ice wedges, holds more water and has a different heat capacity (insulation). This changes the thawing speed and depth, which has consequences for sub-surface drainage properties (reduced drainage), which in turn results in more wet permafrost and more intensive frost processes.

Figure 5.6

False colour (L) and classified image (R) of typical landscapes in the upland area (see Fig. 5.5). **(D)** Higher territory in the Nenetskaya Ridge showing isolated lakes at the watershed area surrounded by open tundra. Small creeks have eroded small canyons in NW or SE direction (partly filled with snow at the time of the image). **(E)** Ortina river area with scattered spruce and birch stands. Large scale sandy areas with dunes and partly open hummocky, partly bushy tundra area. **(F)** Uplands near Bolvanskii Nos showing gently sloping, hummocky plateaux interspersed with lakes. Variation in these landscapes is larger because of micro-variation not detectable from Landsat TM images.



The detailed spot descriptions show that the classification unit includes a wide variety in field landscape types. This grouping partly is caused by poor classification for the Nenetskaya Ridge region, a result of insufficient stratification. A more detailed analysis of field descriptions reveals that partly the classification unit includes spots with comparable drainage conditions and vegetation composition, while the external landscape structure, which was primarily used for distinguishing field landscape types, varies widely. Variation in patch size is big and patches are sometimes small, which results in mixed pixels which are poorly classified.

Unit name **dry hummocks**

Image colour **dark rose** **1c** 🟥

Topography

Uplands with a rolling topography with short range variability - relatively short slope lengths and convex slope forms. Dry hummocks occur on convex upper slopes varying from gently sloping to sloping, 2-13%.

Surface expression

A complex spatial structure of hummocks and depressions. Hummocks develop as result of frost heave and cryoturbation processes in fine-textured parent material. Depending on local texture and drainage conditions, spots of bare soil cover 20-30% of the surface, in size from 0.09 to 4 m^2. Hummocks and depressions occur in about equal amounts, height differences between mounds and depressions vary between 5-20 cm. Depressions with surface water in the growing season do not occur.

Parent material and soil characteristics

The classification unit mainly occurs on loamy parent material of glacial end moraine, fluvioglacial or interglacial marine deposits. The typical soil profile distinguishes:

- an organic sod layer, average thickness 3 cm;
- a histic A horizon, thickness 5-8 cm, dark reddish brown to blackish, moderately to well decomposed organic matter of low shrubs, mosses, grasses and lichens, abrupt wavy to broken boundary;
- a transitional humic loamy AC horizon, thickness 2-3 cm, brown to grey-brown, clear wavy boundary;
- a clay loam, compact C horizon, brownish grey to grey, rarely blue-grey, with redoximorphic features, changing in depth into a permanently reduced layer.

Small amount of gravel and stones can be found on the surface on bare spots and in the clay loam subsoil. The average depth of thawing late June was 25 cm. Depressions show a thicker histic A horizon, up to 20-30 cm, the poorly decomposed organic material dominated by *Sphagnum*. Due to the limited depth of thawing early in the season, the presence of a loamy subsoil horizon could not always be confirmed. The maximum thickness of the active layer on average is 50-60 cm. The compact subsoil structure hampers rootability; the majority of the roots occurs in the upper 10-15 cm. Typically the topsoil separates easily from the subsoil, because only a limited amount of roots enter the subsoil.

Moisture regime

Mesic. Excess water in the topsoil rarely occurs, water is rapidly removed by lateral drainage. Short periods of wet conditions may occur due to low hydraulic gradients on moderate slopes. The upper layer of the subsoil shows mottling features, evidence of regular oxidation and reduction, conditioned by the release of significant amounts of water upon thawing, low vertical and lateral hydraulic conductivity, a compact structure and permafrost.

Nutrient level

Oligotrophic to mesotrophic. Nutrients are provided by weathering and organic matter breakdown. Addition of nutrients by seepage inflow is insignificant.

Vegetation characteristics

The diversity includes 130 species, the majority belongs to mosses and lichens, while shrub and dwarf shrub species are limited in diversity. Common lichen species include *Cladonia arbuscula, Flavocetraria cucullata, Peltigera aphthosa, P. membranacea, P. scabrosa and Thamnolia vermicularis*. In the shrub layer (which might be absent) dominate *Betula nana, Salix lanata, S. glauca* and *Ledum decumbens*. Dominant dwarf shrubs include *Empetrum hermaphroditum* and *Vaccinium vitis-idaea*, common dwarf shrubs include *Arctous alpina* and *Salix reticulata*. Common herbs include *Bistorta* spp., *Carex arctisibirica, Equisetum arvense, Festuca ovina* and *Petasites frigidus*. Mosses are dominated by *Aulacomnium palustre, Drepanocladus* spp., *Hylocomium splendens*, common *Polytrichum* spp. The classification unit resembles the Russian classes "dwarf shrub-moss tundra with spots". The unit includes spots with vegetation communities affected by anthropogenic activities (reindeer resting camps), which are classified as "graminoid-dwarf shrub-moss tundra".

Remarks

Image class 1c represents a landscape type with a complex structure of vegetation types. The combination of parent material and macrorelief features conditions a mesic moisture regime and the landscape type resembles those of the image classes 1d and 1f.

Unit name	**wet hummocks**	
Image colour	**red**	**1d** 🟥

Topography

Uplands, occurring on extended flat to almost flat plateaux, slope angles 0-6%.

Surface expression

A mosaic spatial structure of hummock elevations and depressions, lacking standing water characteristic for "low centre polygons". Hummocks are on average 0.25-1 m^2, and often are arranged in plateaux sized 100-600 m^2, surrounded by slightly deeper linear depressions. Height differences between hummock plateaux and depressions average 30 cm, within plateaux 10-15 cm. Bare "frost boil" spots occur only sporadically, <10%, mainly because the thicker histic topsoil is characterised by a high porosity as well as a good cohesion due to a dense root system. Depressions with surface water in the growing season cover a minor part of the unit.

Parent material and soil characteristics

The class developed on loamy parent material. The typical soil profile distinguishes:

- a blackish to dark red-brown sod layer, thickness 5 cm, including slightly decomposed peat of (dwarf) shrubs, mosses, lichens, with extreme roots;
- a dark red-brown to blackish, histic A horizon, thickness 5-15 cm, consisting of medium to well decomposed peat of (dwarf) shrubs, mosses, lichens with many to common roots, easily separated from the underlying mineral layer;
- an intermediate grey-brown, silty clay to clay loam AC horizon, thickness 5 cm, common to few roots, including some organic matter;
- a dark grey, silty clay to clay loam C horizon, overlying permafrost, compact, almost to completely reduced, some indications of cryoturbation activities, few to no roots.

The presence of the mineral subsoil was not always confirmed.
The typical profile in a depression distinguishes :

- a layer of 5 cm mainly with actual living mosses;
- a light red-brown to brown histic A horizon, thickness 10-20 cm, consisting of not to slightly decomposed peat of mosses and grasses, sometimes a more blackish brown topsoil layer of 5 cm can be distinguished. In depth bulk density increases, changing the colour intensity.

The thickness of the active layer on average is 30-50 cm, depending on the thickness of the histic topsoil and local drainage conditions.

Moisture regime

Hygric-mesic. Vertical drainage is limited due to the compact loamy subsoil and permafrost, lateral drainage is limited due to the lack of a significant hydraulic gradient (low slope angles) and irregular thawing of the active layer due to differences in heat capacity between different vegetation community types. The inflow of seepage water is no factor of importance.

Nutrient level

Mesotrophic. Nutrients are supplied by local weathering of mineral material and decomposition of organic material. No nutrients are removed by seepage outflow, while the inflow of nutrients is also insignificant.

Vegetation characteristics

Vague mosaic community structure - polygonal "*Carex*-moss communities" with hummocks, or clear separated structure of "*Carex-Eriophorum-Sphagnum* marsh" and small "*Betula nana*-dwarf shrub-moss communities" on hummocks. Open water up to 5%. No bare spots. *Betula nana* cover 0-25%, height 7-8 cm, graminoids and dwarf shrubs 5-30%, moss up to 75%, lichens <1%. Total species diversity includes 120 species, of which 80 mosses and lichens. Hummocks include *Betula nana*, the dwarf shrubs *Ledum decumbens, Andromeda polifolia, Empetrum hermaphroditum, Vaccinium vitis-idaea*, the herbs *Rubus chamaemorus, Carex* spp., *Eriophorum* spp. and others. Hummocks also include *Dicranum, Polytrichum* and *Sphagnum* moss species. Depressions on hummock plateaux are often covered by *Hyphnum* mosses. The lichen flora, limited to hummocks, shows a rather rich species diversity. Most typical species include *Cladonia arbuscula, C. amaurocraea, C. bellidiflora, Cetraria islandica, Ochrolechia frigida, Bryocaulon divergens, Sphaerophorus globosus*. The frequently wet conditions in depressions create a rather uniform vegetation cover including *Carex rariflora, C. concolor, Eriophorum* *medium, E. scheuchzeri, Sphagnum* mosses mixed with *Polytrichum* and *Hyphnum* species. Frequently occurring lichens include *Cetrariella delisei, Arctocetraria andrejevii, Cladonia crispata* and *Ochrolechia frigida*.

Unit name	**low centre polygons**	
Image colour	**purple**	**1e** 🟪

Topography

Flat to almost flat topography, large plateaux or valley areas with slopes <2%, on all topographical levels.

Surface expression

Mosaic spatial structure of wet depressions (60-70% surface cover) dissected by elevated hummocks (40-30%), referred to as low centre polygons. Hummocks on average are 0.25-1.0 m^2, grouping into larger polygons of 5x10 m to 20x20 m or elongated linear structures. Height differences within hummock polygons are 10-30 cm. Hummock plateaux and linear structures surround low centre polygons, size 50-400 m^2. "Low centre polygons" may include smaller individual hummocks. Height differences between hummocks and depression varying between 30-75 cm, average 50 cm.

Parent material and soil characteristics

Mineral parent material with variable granulometric composition is assumed but often not confirmed, due to early season visits and slow thawing of thick peat layers. The soil profile of hummocks distinguishes:

- a dark red-brown O/A sod layer, thickness 5-7 cm, consisting of slight to moderate decomposed peat of (dwarf) shrubs, mosses, lichens, with extreme roots;
- a blackish, histic A horizon, thickness 10-20 cm, consisting of medium to well decomposed peat of (dwarf) shrubs, mosses, lichens as well as grasses, with many to common roots, changing to brown in depth.

The soil profile in a depression distinguishes:

- a blackish sod layer, thickness 5-10 cm mainly with living *Sphagnum* mosses and slightly decomposed organic material of *Sphagnum* mosses and *Eriophorum* grass;
- an orange-brown histic A horizon, changing to orange-yellow-brown in depth, thickness 20-35 cm, consisting of slightly decomposed peat of mainly mosses and grasses;
- a grey reduced loamy to sandy C horizon, on top of permafrost layer, without organic material. The presence of the mineral subsoil was only observed during field work at the end of the growing season.

In hummocks the depth of thawing was maximal 25 cm, in low centre polygons 45 cm.

Moisture regime

Hummocks - xeric-mesic; depending on internal micro-relief structure and polygon size. Thaw water is rapidly removed by lateral drainage to depressions. Depressions - hydric; typically water occurs at or very close to the surface throughout the growing season. The level may drop below the surface near the end of the season.

Nutrient level

Hummocks - oligotrophic to mesotrophic. Depressions - mesotrophic. On hummocks nutrients are provided by decomposition of organic matter, which partly are removed by lateral drainage to depressions. In depressions the decomposition of organic matter is minimal.

Vegetation characteristics

Elevated hummocks are covered by "dwarf shrub-lichen communities", while depressions are covered by "*Eriophorum-Sphagnum* communities". Total species diversity includes 155 species, of which mosses and lichens cover 66%. In depressions mosses of *Polytrichum* and *Sphagnum* are most common, also occur *Dicranum* species, and representatives of the groups *Aulacomnium* and *Drepanocladus*. *Carex* spp., graminoids and herbs also are common in depressions - *Carex aquatilis, Geranium crylovii* and *Trientalis europaea*. On hummocks lichen species often include *Cladonia amaurocraea, C. arbuscula,* rarely *C. bellidiflora* and *C. rangiferina*. Typical shrubs are *Betula nana* and *Ledum decumbens*, dwarf shrubs include *Salix* spp., *Empetrum hermaphroditum* and *Vaccinium* spp.

Unit name	**long slope hummocks**	
Image colour	**dark green**	**1f** 🟩

Topography

Uplands, a rolling topography with long-range variability - mainly long slope lengths. The classification unit mainly occurs on elongated straight middle slopes, average slope 6-13%.

Surface expression

Micro-topography shows mostly hummocks separated by depressions, occurring as vague line structures perpendicular to the slope direction. Hummock size varies between 0.25x0.25 m to 0.5x0.5 m. Height differences between hummocks and depressions on average are 10-20 cm. Regular also vegetation tussocks develop, mainly of *Eriophorum* spp. Bare cryoturbation soil spots occur.

Parent material and soil characteristics

Mainly loamy parent material, of glacial, interglacial or post-glacial origin. The soil profile distinguishes three main horizons:

- a brown-black to dark red-brown sod layer, thickness 5 cm, including slightly decomposed peat of (dwarf) shrubs, moss, lichens, with many to extreme roots;
- a blackish, histic A horizon, thickness 5-15 cm, consisting of moderately well to well decomposed peat of dwarf shrubs, mosses, easily separating from the underlying AC;
- a transitional, (light)brown, loamy AC horizon, thickness 5-10 cm, with few roots;
- a brown-grey to dark grey, silty clay to clay loam C horizon, compact structureless, reduced with stagnic properties, no roots.

Depending on micro-relief position, the thickness of the peat topsoil varies between 2-20 cm, with more moss-peat in depressions. The transitional loamy AC was not always observed.

Moisture regime
Mesic-hygric. Although external characteristics resemble "dry hummocks", drainage conditions are slightly worse due to the inflow of lateral seepage water from upslope territories.

Nutrient level
Mesotrophic. Nutrients are provided by weathering and organic matter breakdown. An additional amount of nutrients enters the unit with seepage inflow.

Vegetation characteristics
A mosaic pattern of "dwarf shrub-moss-lichens" on hummocks and tussocks, and prevailing mosses in depressions. Species diversity includes 137 species - 48 vascular species, 57 lichens, 32 mosses. Although species diversity of shrubs and dwarf shrubs is limited, they determine the structure of the vegetation, including typical species like *Betula nana, Ledum decumbens, Salix glauca* and *Vaccinium uliginosum.* Typical lichens include *Cladonia gracilis, Stereocaulon paschale, Cetraria islandica, C. nivalis, Cladonia gracilis* and *Nephroma arcticum*. Dominant moss species include *Dicranum angustum, Drepanocladus uncinatus, Polytrichum commune, Sphagnum girgensohnii*, rarely *Sphagnum fuscum*. In depressions green mosses are dominant (*Sphagnum* spp.), other species include *Eriophorum vaginatum, Petasites frigidus* and *Rubus chamaemorus*.

Remarks
This classification unit is an important source for reindeer fodder during winter, spring and autumn migration. Although occurring at different landscape positions, the class shows a strong overlap with class 1d, due to comparable abiotic steering factors moisture regime and nutrient supply.

Unit name	**upland shrub thicket**	
Image colour	**very dark green**	**1g** 🟩

Topography
Upland areas, straight to convex lower toe slopes of drainage gullies, slope angle 6 to 25%, and elevated straight gentle slopes of the intermediate zones between elevated uplands and flat lake coastal zones, slopes angles 5-15%.

Surface expression
No specific cryogenic surface features, irregular surface due to preferential flow pattern following snow melt.

Parent material and soil characteristics
Parent material varies from loamy to sandy loamy. The typical soil profile distinguishes:
- a blackish histic A horizon, thickness 10-15 cm, composed of moderately decomposed peat of shrubs, graminoids and mosses, extreme to many roots, clear wavy boundary;
- a dark brown to brown histic to humic loamy AB horizon, thickness 8-12 cm, composed of well decomposed peat, many to common roots, few to common redoximorphic mottling features;
- a brownish to grey-brownish loamy to sandy loamy BC horizon, thick-

ness 5-10 cm, compact, with horizontal platy crumby layering structure of freeze-thaw processes, common distinct redoximorphic mottling features;
- a greyish loamy to sandy loamy C horizon, with stagnic redoximorphic properties due to a compact structure.

The AB horizon did not occur on all locations. The profile was frozen at 45 cm at the end of June, while the maximum depth of thawing reached in August is 80-90 cm. The relative deep thawing is a result of the deep snow cover, protecting vegetation and soil against extreme cold.

Moisture regime
Mesic. The classification unit is moderately well to imperfectly drained, excess water occurs only during a limited period of the growing season. Throughout the growing season a progressive thaw of the active layer in upland areas results in an inflow of drainage water.

Nutrient level
Mesotrophic to eutrophic. Nutrients are provided by weathering of mineral material and decomposition of organic matter and the constant inflow of nutrient-enriched drainage water from elevated uplands.

Vegetation characteristics
Dense cover of mainly shrubs, height 1-2.5 m, the occurrence of which is conditioned by deep snow cover in winter. The thickets differ in composition of the shrub layer from the thickets occurring in the floodplain subarea; dominant are *Salix lanata, S. glauca, S. phylicifolia.* Other shrub species can include *Salix hastata, S. lapponum* and *Betula nana.* The undergrowth layer includes species like *Chrysosplenium sibiricum, Equisetum arvense, Geranium krylovii, Geum rivale, Rubus* spp. and *Veratrum lobelianum*. Mosses include mainly *Drepanocladus* spp. and *Sanionia uncinata,* sometimes *Polytrichum* spp. The classification unit is a typical tundra representative of the Russian community type "medium high willows of *Salix phylicifolia* and *S. lanata*".

Unit name	**ombrotrophic inland bogs 1**	
Image colour	**sandy brown**	**2a** 🟫

Topography
Extended flat depressions - drained thermokarst lakes and degraded low centre polygon complexes.

Surface expression
Hummocks may occur on a minor scale in the depressions, covering 5-10% of the surface.

Parent material and soil characteristics
Parent material is a layer of organic material underlain by predominantly light-textured mineral marine, lacustrine or alluvial deposits. The soil profile distinguishes:
- an orange-brown to blackish histic A1 horizon, thickness 6-15 cm, composed of not to moderately decomposed peat of mosses and graminoids;
- a yellowish white to brown histic A2 horizon, thickness 5-10 cm, com-

posed of not to slightly decomposed peat of graminoids and mosses, including some remnants of dwarf shrubs;
- a light orange-brown histic A3 horizon, thickness 7-10 cm, composed of moderately decomposed peat of graminoids and moss;
- a grey to bluish grey sandy to silty C horizon, with organic matter of grasses.

Maximum depth of thawing in August is 30 cm. The distinguished C horizon was only observed in a few spots.

Moisture regime
Predominantly hydric. Very poor drainage conditions are the result of impeded drainage in depressions surrounded by uplands and widespread permafrost. Water occurs at the surface for a significant period of the growing season.

Nutrient level
Ombrotrophic, extremely poor in nutrients. Due to very wet hydrological conditions, almost no release of nutrients through decomposition of organic matter. The release of nutrients by weathering of mineral material is minimal due to the wet conditions and predominantly sandy parent material. No additional nutrients are supplied by seepage water or inundation.

Vegetation characteristics
A mainly closed vegetation cover dominated by graminoids and *Sphagnum* mosses, although a significant percentage open water is not rare. Species composition is dominated by *Sphagnum* mosses (*S. lindbergii), Polytrichum* spp. (*P. jensenii*), while *Calliergon stramineum* and *Aulacomnium palustre* also occur. Graminoids are dominated by *Carex* spp. (*C. aquatilis, C. rariflora, C. concolor*). Other typical graminoids include *Eriophorum scheuzeri.* Lichens play a minor role. The vegetation of hummocks include species like *Ledum decumbens, Andromeda polifolia, Luzula wahlenbergii, Empetrum hermaphroditum, Vaccinium uliginosum and Rubus chamaemorus.* Hummocks can both be old, the vegetation cover showing adaptation to better drainage conditions, and relatively young, the vegetation cover being dominated by species typically occurring in wetter conditions. The classification unit resembles the Russian community type "*Carex-(Eriophorum)-Sphagnum* marsh, sometimes very wet, locally including peat hummocks with dwarf shrub-lichen cover".

Remarks
The vegetation composition and environmental conditions of this classification unit strongly resemble those of the unit "ombrotrophic inland bogs 2". In false colour composite images, "bogs 2" seems to be slightly wetter than this unit. This might be related with a difference in relative cover of surface water between the classes, which results in differences in phenology visible in the early season satellite image. In a late season image spectral differences would be insignificant between the two units.
This classification unit occurs in a successional series following on the degradation of "low centre polygon" complexes.
The ombrotrophic nutrient status compared to the eutrophic nutrient status of other inland and coastal marshes causes a significant difference in vegetation cover, mainly with respect to the dominant *Sphagnum* species. The different vegetation compositions result in differences in spectral reflectance properties. In a false colour composite image, eutrophic marshes appear from light blue to dark greenish blue, while ombrotrophic bogs

appear brown or golden brown. Ombrotrophic bogs rarely occur in the Nenetskaya Ridge, which is a consequence of the overall short-range variability in altitude.

Uplands 2
1. Inland dune area
   Site 7, July 1999
2. Well-drained sandy plateau with depressions and patches of Birch
   Spot 10, August 1998
3. Upland shrub thicket
   Site 2, August 1998
4. Ombrotrophic bogs 1
   Spot 9, August 1998
5. Ombrotrophic bogs 2
6. Eutrophic inland marshes
   Spot 14, July 1999

Unit name	**ombrotrophic inland bogs 2**	
Image colour	**bright brown**	2b 🟫

Topography
Central parts of extended flat depressions, vicinity of open water surfaces of lakes.

Surface expression
Hummocks rarely occur, vegetation tussocks may develop, open water typically is present.

Parent material and soil characteristics
The soil profile shows a strong resemblance with the profile described for the unit "ombrotrophic inland bogs 1", a moderate layer of not to slightly decomposed peat underlain by a permanently reduced, light-textured mineral C horizon of marine, lacustrine or alluvial origin. The typical profile distinguishes:

- an orange-brown to blackish histic A1 horizon, thickness 6-15 cm, composed of not to moderately decomposed peat of mosses and graminoids;
- a yellowish white to brown histic A2 horizon, thickness 5-10 cm, composed of not to slightly decomposed peat of graminoids and mosses, including some remnants of dwarf shrubs;
- a light orange-brown histic A3 horizon, thickness 7-10 cm, composed of moderately decomposed peat of graminoids and moss;
- a grey to bluish grey sandy to silty C horizon, with organic matter of grasses.

Maximum depth of thawing in August is 30 cm. The distinguished C horizon was only observed in a few spots.

Moisture regime

Hydric. Slightly more wet than the unit "ombrotrophic inland bogs 1".

Nutrient level

Ombrotrophic nutrient level. Weathering and decomposition of organic matter are minimal due to the very poor drainage conditions. No additional nutrients are provided by seepage inflow.

Vegetation characteristics

Mainly the vegetation cover is dominated by species of *Carex (C. aquatilis, C. concolor, C. rariflora)* in depressions. Mosses, *Polytrichum jensenii, Calliergon stramineum* and *Aulacomnium palustre* also are common. On small elevated hummocks in addition to mosses also dwarf shrubs (*Empetrum hermaphroditum, Vaccinium uliginosum*) and lichens (*Cladonia* spp.), sometimes *Salix* spp. occur. The classification unit resembles the wet variant of the Russian community type "*Carex-(Eriophorum)-Sphagnum* marsh, sometimes very wet, locally including peat hummocks with dwarf shrub-lichen cover".

Remarks

Main spectral differences observed in the early July image with the classification unit "ombrotrophic inland bogs 1" probably are caused by phenological differences. Due to the slightly wetter conditions, vegetation development is slightly lagging behind in the beginning of the growing season. It is expected that a late season image will show less spectral differences between the ombrotrophic bog units. Also, differences in dominant *Sphagnum* species may cause spectrally differences.

Unit name **tidal marshes**

Image colour **blue green** **3a** 🟩

Topography

Almost flat coastal plains, mainly along the eastern and northern coast of the Ruskii Zavorot peninsula, as well as in some concentrations in other parts (Neruta Delta, Bolvanskaya Bay, Kolokolkovskaya Bay), extending inland in the vicinity of mouths of rivers and streams.

Surface expression

Excessive wetness, relative uniform vegetation cover and moisture distribution in a tidal environment.

Parent material and soil characteristics

Soils developed on stratified loamy to loamy sandy marine deposits. The profile is characterised by dull, predominantly greyish, colours, characteristic for soils in which redoximorphic features occur from the topsoil. Below the A horizon, the ratio of organic and mineral material varies between horizons. Pure layers of either mineral or organic material were not found. The continual flooding of this class is evidenced by the presence of an active layer of fine-textured mineral material.

Moisture regime

Hygric-hydric; water occurs near or on top of the surface throughout the growing season. Poor drainage conditions are the result of low drainage gradients and regular inundation during tidal currents.

Nutrient level

Mesotrophic-eutrophic. Nutrients are provided by weathering of mineral material, slight decomposition of organic matter and regular flooding with sea water. Depending on the location, sea water is very slightly brackish (Pechorskaya Bay) to saline (Barents Sea).

Vegetation characteristics

The classification unit groups two quite different communities which are rarely growing together. The aspect of regular flooding is reflected in the presence of *Hyppurus tetraphylla*, which can form almost uniform stands in very soft mud (5-30% cover). *Puccinellia phryganodes, Festuca richardsonii, Plantago schrenki* border the depressions which are flooded twice a day. Another type of vegetation which comprises this class is formed by an almost pure stand of *Arctophila fulva*. After snow melt these areas are flooded extensively and after retreat of the water the thick mat of dead leaves may appear bluish on false colour.

Coast

1. *Coastal dunes*
   Site 6, August 1998
2. Young dunes and sandflats
   Site 6, July 1997
3. Tidal mudflat Peschanka-To
   Site 6, August 1998
4. Coastal marsh
   Site 6, August 1998
5. Tidal marsh
   Site 6, August 1998
6. Coastal marsh inundated
   Khunavei, spot 21
   June 1997

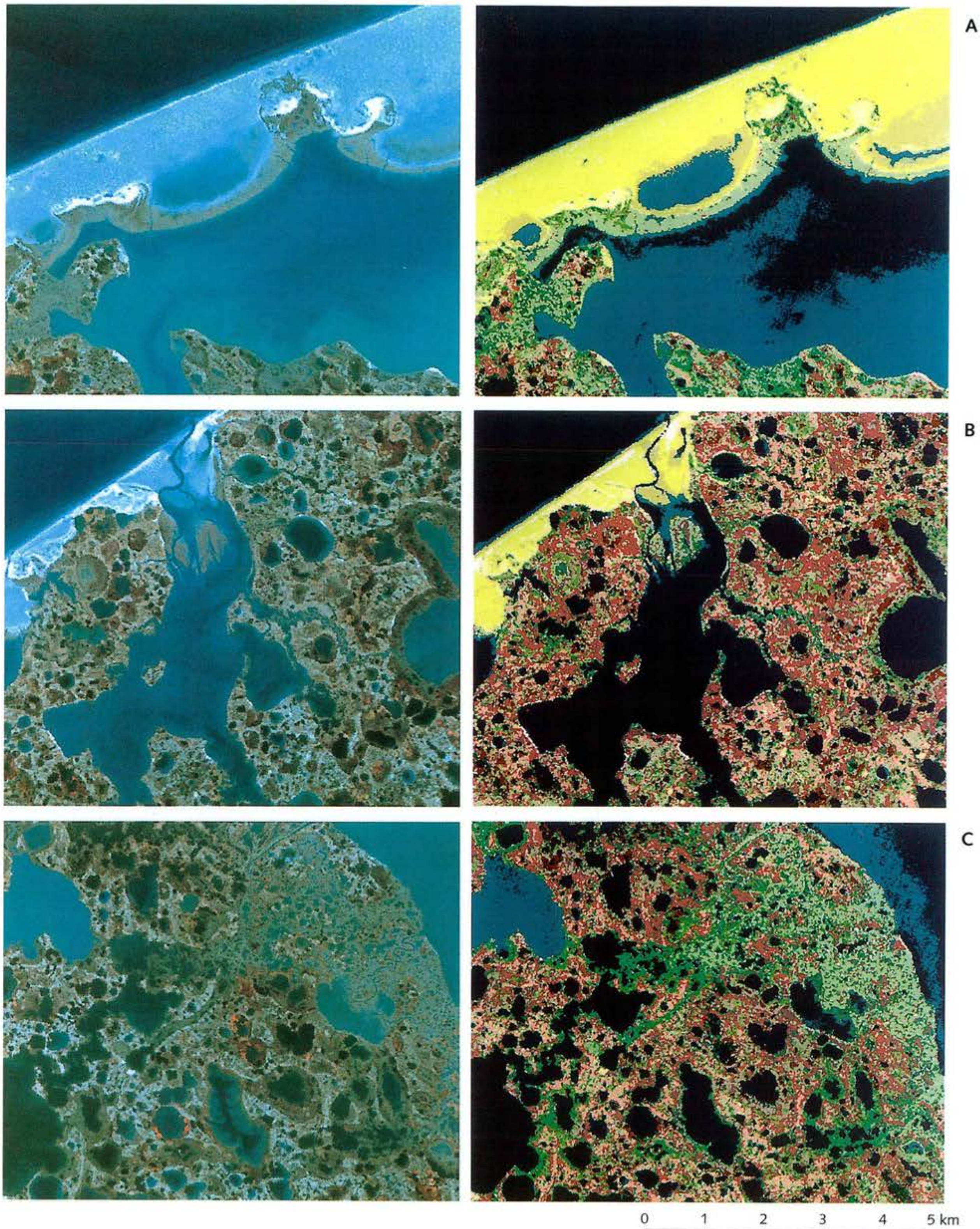
Unit name	**coastal marshes**	
Image colour	**light green**	**3b** 🟩

Topography

Almost flat coastal plains, mainly along the eastern and northern coast of the Ruskii Zavorot peninsula, as well as in some concentrations in other parts (Neruta Delta, Bolvanskaya Bay, Kolokolkovskaya Bay), extending inland in the vicinity of mouths of rivers and streams.

Figure 5.7

False colour (L) and classified image (R) of typical landscapes in the coastal area (see Fig. 5.5). **(A)** North coast of Ruskii Zavorot near Khodovarikha station showing young dune area near Barents Sea, vegetated beach areas and saltmarsh vegetation. **(B)** Dynamic seashore of the NW coast with tidal creek and extensive brackish water area of Peschanka-To lagoon. Inland water bodies are partly isolated and partly connected to the sea by channels. Saline meadows occur at the island whereas extensive bogs occur inland. **(C)** East coast of Ruskii Zavorot along Pechora Bay near Khabuicka. Because of the discharge of the Pechora river the water in summer is almost fresh. Freshwater tides move by channels several km inland giving rise to specific coastal meadows dominated by sedges and grasses. The water quality differs over a short range which leads to high biodiversity of aquatic and terrestrial organisms.



Surface expression

Characteristically no hummocks occur, most probably because of excessive wetness, relative uniform vegetation cover and moisture distribution.

Parent material and soil characteristics

Soils developed on stratified loamy to loamy sandy marine deposits.
The typical profile distinguishes:

- a dark grey-brown histic A horizon, thickness 4-8 cm, consisting of not to slightly decomposed peat of grasses, mixed with a small amount of loamy sediments deposited during irregular inundation;
- a grey-brown to brown histic/humic A2-AC1, thickness 6-10 cm, weakly to moderate decomposed peat of grasses, mixed with or dominated by a medium amount of sedimentary loam;
- a dark grey to blue-grey loamy AC2 horizon, few faint redoximorphic features in the upper part, changing into permanently reduced, including a high amount of not to slightly decomposed peat of grasses.

The profile is characterised by dull, predominantly greyish, colours, characteristic for soils in which redoximorphic features occur from the topsoil. Below the A horizon, the ratio of organic and mineral material varies between horizons. Pure layers of either mineral or organic material were not found. The active layer reaches an estimated average depth of 30-40 cm. The continuing regular flooding of this class is evidenced by the presence of fine-textured mineral material in mainly peaty (poorly decomposed) topsoils. This aspect of the profile structure is not observed in inland marshes.

Moisture regime

Hygric-hydric; water occurs near the surface throughout the growing season. Poor drainage conditions are the result of low drainage gradients and irregular inundation during storm surges.

Nutrient level

Eutrophic. Nutrients are provided by weathering of mineral material, slight decomposition of organic matter and irregular flooding with sea water. Depending on the location, sea water is very slightly brackish (Pechorskaya Bay) to saline (Barents Sea).

Vegetation characteristics

The classification unit groups two quite different "coastal plain graminoid-moss vegetation communities": non-saline and saline. The non-saline community includes *Comarum palustre, Festuca ovina, Rubus chamaemorus* and *Polytrichum* mosses. Also species like *Carex lachenalii, Salix glauca, S. polaris* and *Empetrum hermafroditum* occur. The aspect of irregular flooding is reflected in a very low cover of *Puccinellia phryganodes.* The saline community includes *Puccinellia phryganodes, Calamagrostis deschampsioides, Festuca richardsonii, Plantago schrenki, Carex subspathacea, C. glareosa, Arcanthemum hultenii* and *Stellaria humifusa*. The saline community resembles the coastal halophytic meadows of the lowest and medium level as characterised by Leshkov (1936) for the coastal zone of the Malozemelskaya Tundra.

Remarks

The classification unit probably represents an ancient terrace of marine origin, developed at sea level. The class has a slightly dryer moisture regime compared to the classes 3c and 3d, which is visible on a false colour composite image as lighter blue colours.

Unit name	**eutrophic inland marshes 1**	
Image colour	**bright green**	**3c** 🟩

Topography

Flat to almost flat lake shorelines, and rims of extended flat depressions in upland areas.

Surface expression

No typical cryogenic micro-relief structures. Often developing vegetation tussocks are present. Surface water occurs regularly.

Parent material and soil characteristics

Parent material strongly variable - sand, loam - of marine, lacustrine or alluvial origin. Sometime peat prevails. The typical soil profile of this class distinguishes:

- a reddish brown histic A horizon, thickness varying between 10-20 cm, composed of not to slightly decomposed peat of graminoids and mosses;
- an intermediate brown-grey mineral sandy/loamy AC horizon, thickness 5-7 cm, with a significant amount of slightly decomposed peat;
- a grey C horizon, varying in texture from sand to loam, permanently reduced, structureless.

The occurrence of the subsoil mineral layer was not confirmed on all control spots, due to the limited depth of thawing early in the season. Maximum depth of thawing is 30-40 cm.

Moisture regime

Hygric-hydric. Water occurs at or near the surface throughout the growing season. Poor to very poor drainage conditions result from the absence of a hydraulic gradient and inflow of drainage water from upland areas.

Nutrient level

Eutrophic. Nutrients are mainly provided by seepage water from adjacent upland areas, which is a major difference with "ombrotrophic bogs", which typically occur in central parts of extended flat depressions. In contrast to coastal marshes, the influence of a marine environment is absent, which probably results in a different composition of nutrients supplied.

Vegetation characteristics

This classification unit represents inland marshes, mainly composed of "*Carex*-graminoid-moss communities", sometimes including willow shrubs. The species diversity includes 54 species, mainly vascular species (36), of which most are graminoids (24). Characteristic species include *Carex aquatilis, Comarum palustre, Sphagnum* spp. The vegetation and environment of this unit mainly resembles the Russian class "homogenous graminoid-moss (*Hypnum*) marsh", which characteristically occurs in enriched environments under very wet conditions.

Remarks

In inland areas this classification unit often occurs in close association with "eutrophic inland marshes 2", which is considered to be slightly wetter, other factors being equal.

Unit name	**eutrophic inland marshes 2**	
Image colour	**green**	**3d** 🟩

Topography
Flat inland areas along lake shorelines and rims of upland areas. The classification unit does not occur in central parts of extended depressions.

Surface expression
No typical cryogenic micro-relief structures. Often developing vegetation tussocks are present. Surface water occurs regularly.

Parent material and soil characteristics
Parent material strongly variable - sand, loam - of marine, lacustrine or alluvial origin. Sometime peat prevails. The typical soil profile of this class strongly resembles the profile described for "eutrophic inland marshes 1". The profile distinguishes:

- a (light) reddish brown histic A horizon, thickness varying between 10-25 cm, composed of not to slightly decomposed peat of graminoids and mosses;
- an intermediate (reddish) brown-grey AC to horizon, thickness 5-10 cm, sandy to loamy mineral material with a significant amount of slightly decomposed peat;
- a (dark) grey C horizon, varying in texture from sand to loam, permanently reduced, structureless.

The occurrence of the subsoil mineral layer was not confirmed on all control spots, due to the limited depth of thawing early in the growing season. The observed maximum depth of thawing in August was 30-40 cm.

Moisture regime
Hydric. Water occurs at or very close to the surface throughout the growing season. This classification unit is slightly wetter than the unit "eutrophic inland marshes 1".

Nutrient level
Eutrophic. Nutrients are provided by seepage inflow from adjacent upland areas. Any influence of the marine/estuarine environment is minimal.

Vegetation characteristics
This classification unit represents inland marshes, mainly composed of "*Carex*-graminoid-moss communities", sometimes including willow shrubs. The species diversity includes 64 species, mainly vascular species (39), dominated by graminoids. Characteristic species include *Carex aquatilis, Comarum palustre, Sphagnum* spp. The vegetation and environment of this classification unit mainly resembles the Russian class "homogenous graminoid-moss (*Hypnum*) marsh", which characteristically occurs in enriched environments under very wet conditions.

Remarks
The occurrence of class 3d is strongly linked to the occurrence of class 3c.

Unit name	**sparse spruce forest**	
Image colour	**black green**	**4** 🟩

Topography

Upland areas. Stream banks and lower terraces along the Ortina river and further South on the Malozemelskaya Tundra.

Surface expression

No cryogenic micro-relief features were observed. Main micro-relief irregularities were caused by wind erosion or preferential flow paths on redeposited sediments.

Parent material and soil characteristics

Parent material is sand of marine and lacustrine origin. Possibly redeposited by wind or water erosion processes. The typical soil profile distinguishes:

- an O layer of fresh organic material of leaves and needles, thickness 3 cm;
- a brown-black sandy loamy A horizon, thickness 10-15 cm, including well decomposed organic matter peat, many to common roots, weak, very fine to fine crumb structure, clear smooth boundary;
- a dark brown to brown sandy loam to loamy sand B horizon, thickness 8-12 cm, common to few roots, weak fine to medium subangular blocky structure, clear smooth boundary;
- a dull yellowish brown sandy BC horizon, massive structureless.

The profile was frozen at 30 cm (half June). Maximum depth of thawing is estimated at 100-150 cm.

Moisture regime

Mesic. The soil profile is well-drained due to high hydraulic conductivity of the sandy parent material, the relative dry frost and significant hydraulic gradient and short distances to the mainly deeply incised streams.

Nutrient level

Mesotrophic. Nutrients are provided by weathering of mineral material and relative fast decomposition of organic matter.

Vegetation characteristics

This classification unit includes two community types according to the Russian classification: the relict spruce "islands", discussed in more detail in Chapter 6.1 and the sparse spruce forests on sandy well-drained deposits in the southern tundra zone. Sparse spruce forests, dominated by *Picea obovata*, have a well developed shrub and dwarf shrub layer with characteristic species like *Juniperus sibirica, Lonicera pallasii, Ribes rubrum, Betula nana, Salix glauca, S. lanata, S. phylicifolia, Vaccinium vitis-idaea, Empetrum hermaphroditum* and *Linnaea borealis*. Mosses include *Rhytidiadelphus squarrosus, Rh. triquetrus, Sanionia uncinata, Pleurozium schreberi* and *Hylocomium splendens.* Other species include *Sorbus gorodkovii, Orthilia obtusata, Avenella flexuosa* and *Equisetum pratense*. Lichens include mainly boreal species like *Cladonia rangiferina, Xanthoria polycarpa, Bryoria capillaris, Ramalina dilacerata, R. roesleri, Usnea lapponica, U. subfloridana, Tuckermannopsis sepincola, T. chlorophylla, Peltigera canina* and others.

Unit name	**coastal dune area**	
Image colour	**yellow**	5 🟨

Topography

Coastal range bordering Barents Sea in the entire West and North coast of Ruskii Zavorot.

Surface expression

No cryogenic micro-relief features were observed. Main relief caused by wind. Young dunes occur on upper part of beach and along the northern beach barrier. Erosion of higher dunes up to 15 m along West coast due to sea water.

Parent material and soil characteristics

Parent material is sand of marine origin, redeposited by wind or water erosion processes.

The profile was not frozen at 100 cm (end June). Maximum depth of thawing is estimated at 100-150 cm.

Moisture regime

Xeric. The soil profile is well-drained due to high hydraulic conductivity of the sandy parent material, the relatively dry frost and significant hydraulic gradient and short distances to the beach and coastal plain.

Nutrient level

Mesotrophic. Nutrients are provided by weathering of mineral material and relatively fast decomposition of organic matter, partly deposited by sea and wind.

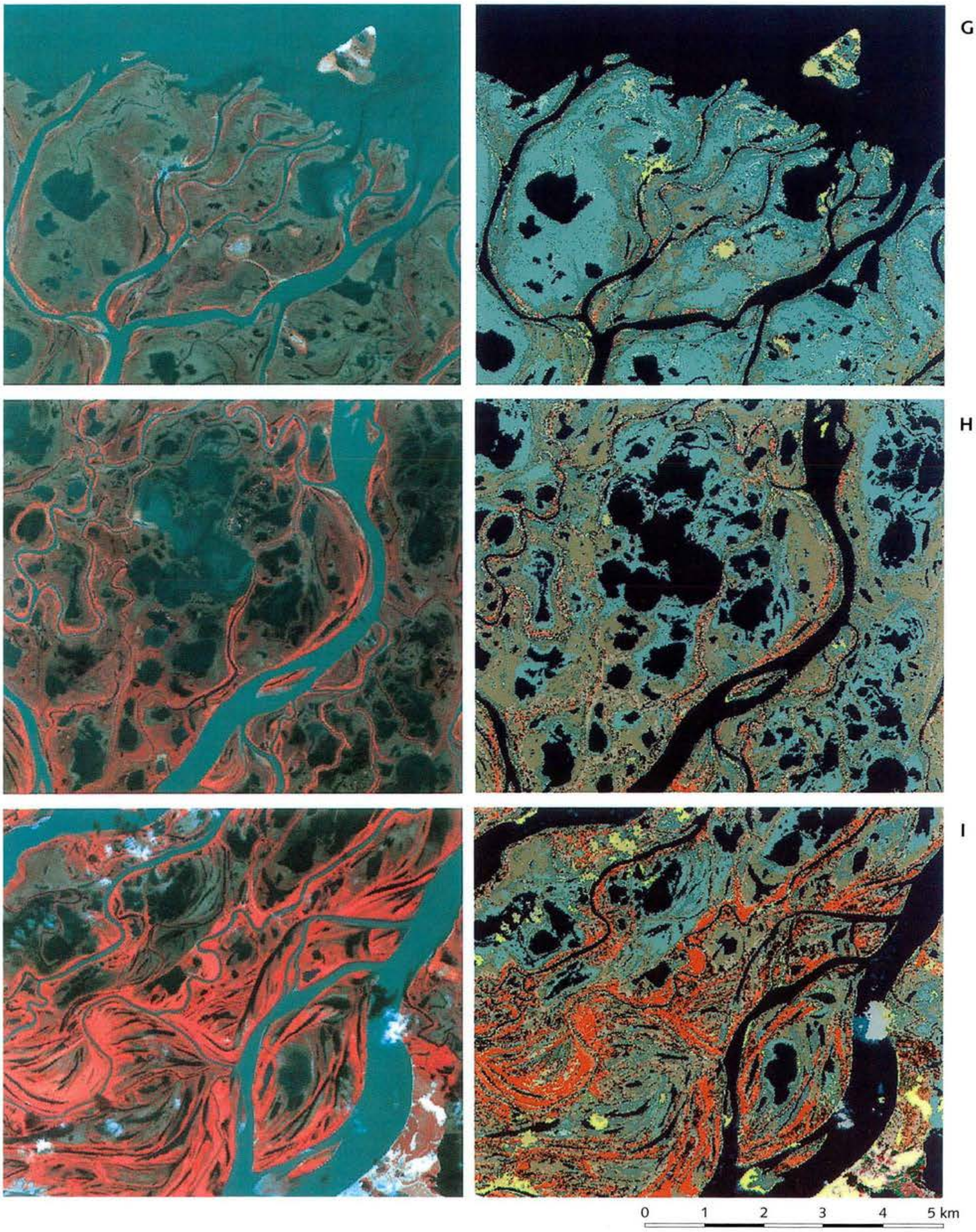
Vegetation characteristics

Partly bare, partly covered with specialised graminoids like *Leymus arenarius*. Inner parts of dunes sometimes contain isolated waterlogged quicksands on the edges of which dense stands of *Carex* may occur. Better protected places with a fixed soil have a lichen rich, xeric series of plants with small herb association like *Minuartia* sp., Honckenya oblongifolia

Lower floodplain
1. Northern floodplain meadow
   Site 1, August 1998
2. Sand bank in larger channel of Pechora
   Site 1, August 1998
3. Lower delta marsh
   Spot 17, July 1995

Figure 5.8

False colour (L) and classified image (R) of typical landscapes in the floodplain area (see Fig. 5.5). Notice the large difference in development of the vegetation at the time the image was taken (6 July 1996). **(G)** Mouth of the river Pechora into Korovinskaya Bay, near Kashin Island. Inundated sedge marshes and shallow areas in channels and in the bay have submerged vegetation. Low levees have willow thickets and some natural meadows. **(H)** Central part of lower floodplain showing large complex of lakes, surrounded by extensive sedge and willow thickets. Isolated areas develop into fen peat. Higher levees are covered by high willow and Duschekia riverine forest and both primary and secondary meadows occur. **(I)** Southern part of floodplain area near Nar'yan-Mar showing extensive hayfields and riverine forest. At the edge of the image the bare sand of riverine dunes is visible.



5.2.2 Pechora Delta floodplain region

Unit name	**lower delta marshes**	
Image colour	**light green**	**6a** 🟩

Topography

Pechora river delta near its mouth, gradually decreasing 40 km upstream.

Surface expression

Floodplain depressions between permanent streams, oxbows and younger stream bed depressions as well as shorelines of gullies.

Parent material and soil characteristics

Sandy and loamy deposits, changeable; no detailed information of profile.

Moisture regime

Hydric. Water occurs at or above the surface throughout the growing season. The very poor drainage conditions are the combined result of yearly flooding and zero to very low hydraulic gradients.

Nutrient level

Mesotrophic-eutrophic. Yearly flooding by the river and the Korovinskaya Bay because of wind effects provides an inflow of nutrients sufficient to create a eutrophic nutrient level at most places.

Vegetation characteristics

As this image class does not occur in the study areas visited in the Pechora Delta, no detailed field descriptions are available. The class mainly occurs in the coastal zone of the Pechora Delta and in the vicinity of the Kolokolkovskaya Bay. It is assumed that the class mainly resembles image class 6b, the riverine "freshwater marshes", of which vegetation phenology lags behind due to the delay in drainage of flood water in spring. This was confirmed by aerial surveys July 1999. *Carex aquatilis* is the leading species here, some isolated swamps having mesotrophic vegetation with *Comarum palustre* and *Equisetum fluviatile*. At low levees *Salix* shrubs (0.5-1.5 m) occur. Also it is expected that the coastal delta area might be flooded intermittently during storm surges, although salinity aspects are not considered to be of importance due to the almost freshwater quality of bay water.

Unit name	**freshwater marshes**	
Image colour	**green**	**6b** 🟩

Topography

Floodplain backswamp depressions between permanent streams, oxbows and former stream bed depressions as well as shorelines of thermokarst lakes.

Surface expression

No specific micro-relief features except small tussock formation of vegetation (mosses). Surface water covers up to 40% of the surface.

Parent material and soil characteristics

Parent material: peat deposits. The typical soil profile distinguishes:

- a grey-black to brown histic H1 horizon, thickness 10-30 cm, composed of not to slightly decomposed peat of graminoids, mosses and shrubs;
- a grey-black to grey histic H2 horizon, thickness 10-40+ cm, composed of not decomposed peat of graminoids and mosses;
- a grey silt loam to silty clay loam 2C horizon, reduced, occurred occasionally in the lower part of the profile, including a significant amount of not decomposed organic material of graminoids and roots.

Only occasionally oxidation processes proceed along root channels into the topsoil and upper part of the subsoil. Under all conditions the soil matrix remains reduced. The thickness of the topsoil histic horizons shows significant variation between locations, varying between 40 and 160 cm. Histic topsoil often includes an admixture of fine silty mineral material deposited during spring flooding.

Moisture regime

Hydric. Water occurs at or above the surface throughout the growing season. The very poor drainage conditions are the combined result of yearly flooding and zero to very low hydraulic gradients.

Nutrient level

Mesotrophic. Weathering and decomposition of organic material are depressed in conditions of permanent wetness. Yearly flooding provides an inflow of nutrients sufficient to create a mesotrophic nutrient level.

Vegetation characteristics

Vegetation is dominated by graminoids - average cover 70%, mainly *Carex aquatilis* with *Comarum palustre, Equisetum fluviatile* - and mosses - average cover 10-30%, dominated by *Sphagnum* species. Additionally communities include a cover <10% of shrubs and dwarf shrubs, height < 30 cm, mainly *Salix phylicifolia*, sometimes *S. lanata*. According to the Russian classification the classification class includes "*Carex*, herb-*Carex* and herb-moss communities".

Unit name	**freshwater shrub marshes**		
Image colour	**sandy brown**	**6c**	🟫

Topography

Floodplain backswamp depressions between permanent streams, oxbows and former streambed depressions as well as the lower slopes of levees and the shorelines of thermokarst lakes.

Surface expression

No specific micro-relief features except small tussock formation of vegetation. Surface water covers up to 15% of the surface.

Parent material and soil characteristics

Parent material: peat and alluvial deposits. The typical soil profile distinguishes:

- a brown histic H1 horizon, thickness 10-20 cm, composed of slightly decomposed peat of graminoids and shrubs;
- a grey-brown histic H2 horizon, thickness 10 cm, composed of not to

slightly decomposed peat of graminoids, mosses and shrubs;

- a grey silt loam to silty clay loam 2C horizon, reduced, including a significant amount of not decomposed organic material of graminoids and roots.

Oxidation processes prevail only in the upper part of the topsoil, occasionally penetrating in depth along root channels while the subsoil matrix remains reduced. Mineral material occurs often more shallow in the soil profile than in "freshwater marshes". The histic topsoil often include an stratification admixture of fine silty mineral material deposited during spring flooding.

Moisture regime

Hydric-hygric. Water occurs at the surface during a large part of the growing season, possibly dropping below the surface only at the end of the growing season. The poor drainage conditions are the combined result of long yearly flooding and very low hydraulic gradients.

Nutrient level

Mesotrophic-eutrophic. Weathering and decomposition of organic material are limited due to prevailing wetness, but together with the yearly flooding providing an additional inflow of nutrients sufficient to create a mesotrophic-eutrophic nutrient level.

Vegetation characteristics

The classification unit is dominated by a marsh community which includes a significant cover of shrubs. The species composition is dominated by graminoids - average cover 30-50%, including characteristic species like *Carex aquatilis, Equisetum fluviatile, Calamagrostis neglecta, Comarum palustre, Galium uliginosum, Myosotis palustris, Veronica longifolia.* Mosses mainly include *Sphagnum* spp., *Plagiomnium affine* and *Sanionia uncinata*, average total cover 20-30%. Shrub species include *Salix phylicifolia* and *S. lanata*, height 30-100 cm, cover 15-25%.

Unit name	**floodplain shrub thicket**	
Image colour	**dark green**	**7a** 🟩

Topography

The class mainly covers low levees or slopes of high levees along streams, oxbow lakes, former stream beds and around lakes.

Surface expression

Small height differences due to preferential flow, irregular erosion and depositioning processes.

Parent material and soil characteristics

Parent material: stratified alluvial deposits. The typical soil profile distinguishes:

- a blackish brown histic A horizon, thickness 10 cm, composed of not to slightly decomposed peat of shrubs, grasses and mosses;
- a dark brown silty clay loam BC horizon, thickness 10 cm, showing intensive fine-sized redoximorphic mottling features, common to few roots;
- a grey-brown silty clay loam C1 horizon, thickness 30 cm, intensive fine to medium-sized redoximorphic features, no roots;

- a grey-brown loam C2 horizon, thickness 30 cm, intensive fine to medium-sized redoximorphic features, no roots;
- a grey sandy loam C3 horizon, thickness 20+ cm, almost permanently reduced.

Oxidising conditions prevail only in the topsoil, although redoximorphic mottling features are a characteristic feature. In depth soil colours change within 50 cm to dull chromas and greyish colours, indicating limited drainage possibilities, while within 1 m the profile is permanently reduced. Occasionally a mineral admixture was observed in the histic A horizon, deposited during yearly flooding. The profile shows a fining-upwards structure typically for floodplain deposits.

Moisture regime
Hygric. Local drainage conditions are poor to imperfect, due to the slightly elevated topography compared to depressions. Although yearly flooded, flooding water is removed rather fast, but the substrate stays moist to wet for most of the growing season, groundwater typically occurs within 50-70 of the surface.

Nutrient level
Eutrophic.

Vegetation characteristics
The vegetation structure of the classification unit is determined by the dense shrub layer, dominated by *Salix phylicifolia* and *S. lanata*. The average height of the shrub layer is 1.5-2.0 m. The undergrowth includes herbs, grasses and mosses, like *Calamagrostis purpurea, Chrysosplenium alternifolium, Filipendula ulmaria, Ranunculus* spp., *Veratrum lobelianum* and *Drepanocladus* spp.

Remarks
The surface area of the classification unit is rather limited, which is not in accordance with field observations. Detailed research should indicate whether this unit shows some significant vegetation or environmental differences with the unit "tree/shrub thicket", or that these units better can be grouped into one classification unit.

Unit name	**tree/shrub thicket**	
Image colour	**red-brown**	**7b** 🟫

Topography
Upper middle slopes between levees and backswamp depressions.

Surface expression
Small height differences due to preferential flow, irregular erosion and depositioning processes.

Parent material and soil characteristics
Parent material: alluvial deposits. Oxidising conditions prevail in the topsoil, although redoximorphic mottling features are visible in the upper horizons. In depth soil colours change within 50 cm to dull chromas and greyish colours, indicating limited drainage possibilities, while at 1 m the soil typically is permanently reduced. The typical soil profile strongly

resembles the profile described for the classification unit "shrub thicket".

Moisture regime
Mesic-hygric. Local drainage conditions are imperfectly due to low hydraulic gradients. The class is yearly flooded for a medium long period.

Nutrient level
Eutrophic-mesotrophic.

Vegetation characteristics
This classification unit is interpreted as an intermediate between "shrub thicket" and the floodplain forest units, as appears from a qualitative evaluation of the class structure on the classified image. Dominant species of the shrub layer is *Salix lanata*, although other woody species like *S. phylicifolia, S. viminalis, Duschekia fruticosa* and *Lonicera pallasii* also occur. The height of the shrub layer is 2.5-3 m. The undergrowth layer includes species like *Equisetum arvense, Poa pratense, Adoxa moschatellina, Chrysosplenium sibiricum, Veratrum lobelianum* and *Veronica longifolia*. The moss layer is dominated by *Polytricum* and green mosses.

Unit name	**willow floodplain forest**	
Image colour	**brown**	**8a** 🟫

Topography
On upper slopes and top of levees along streams and oxbows.

Surface expression
Small height differences due to preferential flow, irregular erosion and depositioning processes.

Parent material and soil characteristics
Parent material: alluvial deposits. The profile shows a fining-upwards sediment sequence typically for floodplain deposits. The typical soil profile distinguishes:

- a blackish sodic O horizon, thickness 5 cm, consisting of a root mat and fresh organic matter;
- a brown to grey-brown loamy AC1 horizon, thickness 40 cm, stratified with loamy mineral and organic layers, consisting of moderately decomposed peat of trees, graminoids, few fine faint mottling, common to few roots;
- a grey-brown to grey loamy C2 horizon, thickness 40 cm, stratified with some sandy loamy interlayers, common fine to medium distinct mottling, no roots, in depth changing to permanently reduced.

The groundwater level occurs at a depth of 20-40 cm in the growing season. The topsoil is subjected to seasonal freezing and thawing, while the subsoil remains unfrozen.

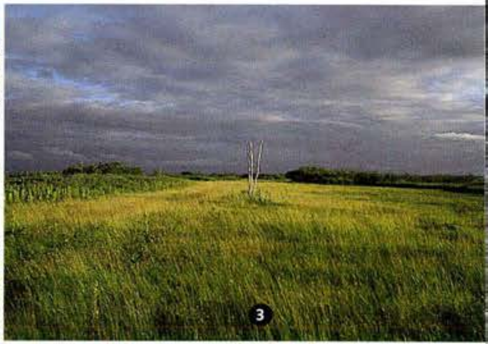
Moisture regime
Mesic. Regularly if not yearly flooded for a short period, as evidenced by stratified soil profile structure. Short range drainage conditions are moderately well, excess water is removed rapidly, but the profile is moist throughout the vegetative season.

Nutrient level

Eutrophic-mesotrophic. Nutrients are provided by weathering of mineral material as well as by the relatively fast decomposition of organic matter.

Vegetation characteristics

The structure of the vegetation community is dominated by tree willow species - *Salix viminalis, S. dasyclados*. Sometimes also *S. lanata, S. phylicifolia* or *Duschekia fruticosa* occur. The height of the trees exceeds 4 m, up to 7 m in the South parts. The undergrowth layer consists of large herbs, graminoids and mosses, including species like *Filipendula ulmaria, Veratrum lobelianum, Calamagrostis purpurea, Equisetum arvense, Lamium album, Myotis palustris, Ranunculus repens, Veronica longifolia* and *Drepanocladus* spp.



Floodplain

1. Duschekia forest, ice eroded
   Site 1, August 1998
2. Floodplain shrub thicket
   Site 1, August 1998
3. Southern floodplain meadow
   Site 1, August 1998
4. Freshwater marsh
5. Freshwater shrub marsh
6. Side channel of Pechora
   Site 1, August 1998

Unit name **Duschekia floodplain forest**

Image colour **black** **8b** ■

Topography

On upper slopes and top of higher levees along streams and oxbow lakes.

Surface expression

Small height differences due to preferential flow, irregular erosion and depositioning processes.

Parent material and soil characteristics

Parent material: alluvial deposits. The soil profile shows a fining-upwards sediment sequence. The typical soil profile distinguishes:

- a blackish brown sodic O horizon, thickness 5 cm, consisting of a dense root mat and fresh organic matter, sometimes including fine mineral sediments deposited during flooding;
- a reddish brown loamy AC horizon, thickness 20-25 cm, few fine faint

mottling, often showing stratification with thin more sandy interlayers, many roots;

- a brown loamy to sandy loamy C1 horizon, thickness 20 cm, common fine to medium faint mottling, common roots;
- a grey-brown sandy loamy C2 horizon, thickness 50 cm, common to many fine to medium distinct mottling, few to no roots.

The topsoil is subjected to seasonal freezing and thawing, while the subsoil remains unfrozen.

Moisture regime

Mesic. Regular if not yearly short flooding is a characteristic aspect of the hydrological cycle, resulting in a stratified profile build-up of interchanging mineral and organic layers. Short range drainage conditions are moderately well, excess water is removed rapidly, but the profile is moist throughout the vegetative season.

Nutrient level

Eutrophic-mesotrophic. Nutrients are provided by weathering of mineral material as well as by the relatively fast decomposition of organic matter.

Vegetation characteristics

The vegetation structure of this classification unit is dominated by tree species - mainly *Duschekia fruticosa*, sub-dominant *Salix viminalis*. Below the trees a well developed undergrowth layer occurs, characterised by species not hampered by the shadow rich environment. Typical species include *Calamagrostis purpurea, Veratrum lobelianum, Equisetum arvense, Anthriscus sylvestris, Filipendula ulmaria, Lamium album, Chrysosplenium sibiricum* and others. Height of the trees exceeds 5 m. In the Pechora Delta floodplain this unit often occurs in association with "willow floodplain forest". The unit resembles the Russian community type "herb-graminoid *Duschekia* forest". *Duschekia* occurs mainly in the southern part of the Pechora Delta floodplain, probably limited to slightly milder climatic conditions.

Remarks

The environmental conditions strongly resemble those described for the unit "willow floodplain forest", as well as those for the "northern floodplain meadows" and "southern floodplain meadows".

Unit name	**northern floodplain meadow (primary)**	
Image colour	**orange**	**9a** 🟧

Topography

Top of levees along streams and oxbow lakes in the northern part of the Pechora Delta floodplain.

Surface expression

Small height differences due to preferential flow, irregular erosion and depositioning processes.

Parent material and soil characteristics

Alluvial deposits. The profile shows a fining-upwards granulometric composition. The typical soil profile distinguishes:

- a blackish brown sod, thickness 5 cm;
- a dark brown sandy loamy to loamy A horizon, thickness 20-25 cm, almost no redoximorphic mottling, stratified with thin histic interlayers consisting of well decomposed peat, many roots;
- a grey-brown sandy loamy BC horizon, thickness 20-30 cm, few to common fine to medium faint mottling, common roots;
- a grey-brown to grey sandy loamy C2 horizon, thickness 40+ cm, common to many fine to medium distinct mottling to permanently reduced below 1 m, few to no roots.

The topsoil is subjected to seasonal freezing and thawing, the subsoil remains unfrozen.

Moisture regime

Mesic. Regular if not yearly short flooding is a characteristic aspect of the hydrological cycle, visible in the stratified soil profile structure. Short-range drainage conditions are moderately well, excess water is removed rather rapidly, but the profile is moist throughout the vegetative season.

Nutrient level

Eutrophic-mesotrophic. Nutrients are provided by weathering of mineral material as well as by the relatively fast decomposition of organic matter.

Vegetation characteristics

The classification unit includes both secondary and primary meadows. Secondary meadows, described for the unit "southern floodplain meadows", are dominated by short graminoids and herbs. Primary meadows often are characterised by a mixture of classification units, in accordance with the short-range heterogeneity of grasses and trees/shrubs. The vegetation community type of primary meadows is characterised by large graminoids and herbs, interchanging with trees and shrubs. Dominant species include *Alopecurus pratensis, Bistorta vivipara, Calamagrostis purpurea, Conioselinum tataricum, Equisetum arvense, Festuca rubra, Filipendula ulmaria, Galium boreale, Ranunculus propinquus, Tanacetum vulgare, Valeriana wolgensis, Veratrum lobelianum, Veronica longifolia.* Sometimes a small cover of *Salix phylicifolia* and *S. lanata* occurs, as well as *Poa alpigena*.

Remarks

With respect to the secondary meadows included in this classification unit, the difference with secondary meadow included in class 9b may be the phenological development stage, the biomass development slightly lagging behind in the "northern floodplain meadows". The main aspect causing spectral differences difference between this class and the image classes 8a-8b (floodplain forests) is the effect of regular anthropogenic mowing on the structure and composition of the vegetation.

Unit name	**southern floodplain meadows (secondary)**		
Image colour	**dark orange**	**9b**	🟥

Topography

Upper slopes of high levees along larger streams and oxbow lakes.

Surface expression
Small height differences due to preferential flow, irregular erosion and depositioning processes.

Parent material and soil characteristics
Alluvial deposits. The profile shows a fining-upwards granulometric composition. The typical soil profile distinguishes:
- a dark brown sandy loamy to loamy A horizon, thickness 20-25 cm, almost no redoximorphic mottling, sometimes stratified with thin histic interlayers consisting of well decomposed peat, many roots;
- a grey-brown sandy loamy BC horizon, thickness 20-30 cm, few to common fine to medium faint mottling, common roots;
- a grey-brown to grey sandy loamy C2 horizon, thickness 40+ cm, common to many fine to medium distinct mottling to permanently reduced below 1 m, few to no roots.

The topsoil is subjected to seasonal freezing and thawing, the subsoil remains unfrozen.

Moisture regime
Mesic. Regular if not yearly short flooding is a characteristic aspect of the hydrological cycle, as regularly evidenced by stratified soil profile structures. Short-range drainage conditions are moderately well, excess water is removed rather rapidly, but the profile is moist throughout the vegetative season.

Nutrient level
Eutrophic-mesotrophic. Nutrients are provided by weathering of mineral material as well as by the relative fast decomposition of organic matter.

Vegetation characteristics
Community types are dominated by short graminoids and herbs; trees and shrubs occur only very rarely. Meadow communities are mainly secondary; the observed vegetation structure and composition is a consequence of regular mowing. Species with a significant cover include *Alopecurus pratensis, Bistorta vivipara, Equisetum arvense, Ranunculus* spp. and *Veratrum lobelianum*. Additional species include *Rumex acetosa* and *Achillea millefolium*. Species diversity includes 73 species, mainly vascular plants.

5.3 Discussion

After elaboration of a supervised classification for the Pechora Delta it can be compared to the unsupervised image classification made as a first step. Ground-truth information collected during field expeditions confirmed at the regional scale the existence of four main landscape regions: (1) the Pechora Delta floodplain dominated by shrub-marsh communities, alternating with trees and meadows, (2) the Nenetskaya Ridge and other uplands with typical dwarf shrub-moss and dwarf shrub-lichen tundra communities, dissected by gullies with herb-shrub communities, (3) the Ruskii Zavorot coastal plain with coastal meadows in addition to dwarf shrub-moss-lichen tundra and heterogenous freshwater marshes and (4) the western Bolshezemelskaya Tundra uplands with a landscape structure resembling the Nenetskaya Ridge , but with a less dissected topography. The information obtained during field expeditions shows that at subregional level, within classification units, vegetation communities often occur in a typical short-range mosaic pattern, which results from the large variability of environmental conditions in tundra landscapes. In combination with the specific resolution of a Landsat TM image (pixel ground size 30x30 m^2) this results in supervised classification units often including multiple vegetation communities characterised by a set of environmental conditions. Several classification units are characterised by an identical set of vegetation communities, but differ in the relative occurrence of each community type. This gives rise to specific spectral reflectance properties which were identified in the classification procedure.

Table 5.1
Summary of characterisation of parameters for different units of classification in the Pechora Delta region.

Classification unit	Colour	Moisture regime	Nutrient level	Parent material	Vegetation characteristics
uplands and coastal plain					
Dry high centre polygons	light rose	Xeric	Oligotrophic	Sand	Lichen-dwarf shrub-moss
Moist high centre polygons	bright rose	Mesic-xeric	Oligo-mesotrophic	Sand	Moss-dwarf shrub-lichen-herb
Dry hummocks	dark rose	Mesic	Oligo-mesotrophic	Loam	Lichen-moss-dwarf shrub
Wet hummocks	red	Hygric-mesic	Mesotrophic	Loam	Moss-dwarf shrub-herb-lichen
Low centre polygons	purple	Xeric-hydric	Oligo-mesotrophic	Sand-loam	Moss-lichen-herb-dwarf shrub
Long slope hummocks	dark green	Mesic-hygric	Mesotrophic	Loam	Moss-lichen-dwarf shrub
Upland shrub thicket	very dark green	Mesic	Meso-eutrophic	Light loam-sand	Shrub-herb-moss
Sparse spruce forest	black green	Mesic	Mesotrophic	Mainly sand	Tree-moss-shrub-herb
Tidal marshes	blue green	Hygric-hydric	Eutrophic, tidal	Loam	Graminoid-herb
Coastal marshes	light green	Hygric-hydric	Eutrophic	Loam+peat	Herb-moss-shrub
Eutrophic inland marshes 1	bright green	Hygric-hydric	Eutrophic	Peat+sand/loam	Herb-moss
Eutrophic inland marshes 2	green	Hydric	Eutrophic	Peat+sand/loam	Herb-moss
Ombrotrophic inland bogs 1	sandy brown	Hydric-hygric	Ombrotrophic	Peat	Moss-herb
Ombrotrophic inland bogs 2	bright brown	Hydric	Ombrotrophic	Peat	Moss-herb
Coastal dune area	yellow	Xeric	Mesotrophic	Sand	Graminoid-lichen-herb
floodplain Pechora river					
Lower delta marshes	light green	Hydric	Mesotrophic	Peat	Herb-moss, late dev.
Freshwater marshes	green	hydric	Mesotrophic	Peat	Graminoid-herb-moss-shrub
Freshwater shrub marshes	sandy brown	Hydric-hygric	Meso-eutrophic	peat on loam	Graminoid-shrub-herb-moss
Floodplain shrub thicket	dark green	hygric	Eutrophic	Loam	Shrub-herb-graminoid
Tree/shrub thicket	light grey-brown	Mesic-hygric	Eutro-mesotrophic	Loam	Shrub-tree-herb
Willow floodplain forest	brown	Mesic	Eutro-mesotrophic	Loam-sandy loam	Tree-shrub-herb-graminoid
Duschekia floodplain forest	black	Mesic	Eutro-mesotrophic	Loam-sandy loam	Tree-shrub-herb-graminoid
Northern floodplain meadow	light orange	Mesic	Eutro-mesotrophic	Loam-sandy loam	Graminoid-herb-shrub-tree
Southern floodplain meadow	dark orange	Mesic	Eutro-mesotrophic	Loam-sandy loam	Graminoid-herb

Using detailed descriptions of environmental spot and soil characteristics, as well as the spatial structure and composition of vegetation, the abiotic and biotic characteristics of classification units were defined. Major parameters for each unit are summarised in Table 5.1. The applied ecological moisture regime classes are based on Didiuk & Ferguson (1997).

The legend description for classification units defined with the supervised classification procedure was compared with landscape types identified during field expeditions. Matrices were constructed showing the distribution of spots over both field landscape types and image classification units. Separate matrices were established for the Pechora Delta floodplain sub-area and for the uplands/coast sub-area (Table 5.2 and 5.3). The crosstabulation shows that in general a good fit exists. However, image classification identified sometimes more, sometimes less spectral signatures than there were landscape types distinguished during field expeditions. Table 5.2 and 5.3 show that the total group of spots which characterises a field landscape type often is dispersed over multiple classification units, the

Table 5.2
Correlation matrix uplands and coast sub-area.

Field landscape type		**Classification unit**												
	1a	1b	1c	1g	1d	1f	1e	2a	2b	3b	3c	3d	4	5
High centre polygons on sand	**3.22**, *8.11*, *8.12*, *9.1*, **9.3**, **9.8**, **9.21**, **10.3**,	**2.9**, *2.12*, **3.4**, **3.11**, **3.15**, **3.19**, **6.1**, **6.2**, **6.9/9.16**, **6.11**, *9.1*, **9.7**, **10.9**, **10.4**,	2.12											
Hummocks on loam		*2.7*, *2.27*, *5.2*, **5.3**, *5.11*, *8.2*	*2.7*, **2.8**, *2.27*, *5.16*, *8.2*, **8.7**	*5.17*,	*5.2*, *5.9*, *5.11*, *5.8*, **5.13**,	*2.15*, **3.3**, **5.4**, **5.7**, *5.8*, *5.9*, *5.11*, *5.16*, *5.17*, *9.6*, **10.14**,	*9.6*, *2.15*, *5.8*,							
Willow thicket		*2.16*,		**5.6**, *5.10*, *5.14*, **5.15b**	*2.24*,	*2.16*, *2.24*,	**2.5**, *5.10*, *8.5*, **8.16**	*5.14*,						
Low centre polygons		**2.4**, **2.6**, **2.10**, **2.13/8.6**, **6.5**, 8.1, *8.9*, **9.2**, **9.12**,			**5.18**	*8.9*	**3.6**, *3.7*, **3.9**, **3.23**, **8.3**, *10.10*, *10.11*, **10.12**	*3.7*, *10.10*, *10.11*, **10.13**						
Sphagnum marsh						**3.5**		**8.4**, **9.4**, **9.5**, *9.11*, **9.14**, *9.19*	**6.13**, **9.9**, *9.11*, *9.19*,		*6.6*,	*6.6*,		
Carex-Equisetum upland marsh						*9.6*	*9.6*	*5.5*, *6.10/9.17*, *6.14*, *9.10*, **10.8**,	*5.5*, *6.14*, *9.10*, **9.18**,	**3.12**, **3.13**, **3.14**, **3.16**, **6.3**	*2.11*, *2.17*, **3.10**, **6.4**, *6.10/9.17*,	*2.11*, *2.17*, **5.15a**,		
Coastal marshes										**3.1**, **3.18**, **3.20**, **3.25**, **9.20**, **9.23**	*3.24*, *9.15*	*3.2*, *3.24*, **6.16**, *9.15*		
Coastal dunes														**9.15**
Rare forest-Spruce													**10.1**	
Rare forest-Birch		**10.2**												
Meadow tundra			*5.1*,		*5.1*,	*5.1*,								

Notes:

- field spots which represented a too small area are excluded from the matrix, as are spots which in the final classification were assigned to a mosaic of more than two classification units, in total 18 spots.
- Abbreviations: 1a - dry high centre polygons; 1b- moist high centre polygons; 1c - dry hummocks; 1d - wet hummocks; 1e - low centre polygons; 1f - long slope hummocks; 1g- upland shrub thicket; 2a - ombrotrophic inland bog 1; 2b - ombrotrophic inland bog 2; 3c - eutrophic inland marsh 1; 3d - eutrophic inland marsh 2; 3b - coastal marsh, 4 - spruce forest, 5 - coastal dune area.
- field spot number and colour indicate the study area and the serial number, the location of study sites is indicated in Figure 5.5: 2, 8 - Nenetskaya Ridge uplands (1996, 1998 resp.); 3, 11 - eastern Ruskii Zavorot coastal plain (1996, 1999 resp.); 5, 10 - western Bolshezemelskaya Tundra (1997, 1999 resp.); 6, 9 - western Ruskii Zavorot coastal plain (1997, 1998 resp.);
- spot numbers printed large bold are characteristic for one classification unit, spot numbers printed small italic occur in two classification units.

"horizontal dispersion". Partly this is because the number of units defined during the image classification exceeds the amount of landscape types defined during the field expeditions. This explanation is valid when the additional classification units refer to differences in spectral characteristics as a result of subtle differences in land cover which were not observed during field expeditions. The explanation is not valid if additional classification units refer to landscape types which were not visited during field expeditions. It also needs to be noted that a statistical image analysis technique extracts as much classes as there are spectral signatures defined as input, which does not necessarily indicate that all resulting classification units have a significant meaning in explaining the observed landscape diversity.

An example indicating the increased level of detail in the image classification over the field landscape types is the ability to distinguish the classification units "dry hummocks", "wet hummocks" and "long slope hummocks", during field expeditions defined as one landscape type "hummocks on loam". Vegetation descriptions showed that the set of vegetation communities is identical, but that the relative occurrence and stage of development of individual communities differs between units. This may be the result of differences in environmental conditions in turn related to succession processes and differences in parent material. Cryogenic processes, micro-relief and drainage properties which determine growth conditions for plant species thus affect the local composition of species abundance and communities.

Another example is the distribution of the field landscape type "*Carex-Equisetum* upland marsh" over all identified marsh classification units in

Table 5.3
Correlation matrix Pechora Delta floodplain.

Field landscape type	**Classification unit**							
	7	**8a**	**8b**	**7**	**6c**	**6b**	**9a**	**9b**
Willow floodplain forest		*1.16,* **1.18,** *7.3,*			*1.16, 7.3,*			
Dushekia floodplain forest	*1.7,*	*1.7,*	*4.8,*		*1.7,* **1.10,**		*4.2, 4.8,*	*4.2, 4.8,*
Shrub thicket	*1.4,* **1.8**	1.4,		**4.11, 4.12**	*1.4,* **1.19,** *4.9,* **4.10, 4.13,** *7.10,*	*4.9, 7.10,*		
Carex-Equisetum floodplain marsh					**1.3, 1.5, 1.6, 1.11, 1.12, 1.13, 1.14, 4.7,** *7.4,* **7.5, 7.7,**	**1.9, 4.5, 4.6, 7.1,** *7.4,* **7.11**		
Floodplain meadow (primary, northern)		*7.2,*	*4.1,*		*4.1, 7.2,*		*4.1, 7.2,* **7.6**	
Floodplain meadow (secondary, southern)							**1.2, 1.15/7.9, 7.8,**	**4.3, 4.4, 4.14, 4.15,**

Notes:

- field spots which represented a too small area are excluded from the matrix, as are spots which in the final classification were assigned to a mosaic of more than two classification units, in total 13 spots.
- Abbreviations: 7 - flood plains shrub thicket; 8a - willow floodplain forest; 8b - Duschekia floodplain forest; 6c - freshwater shrub; 6b - freshwater; 9a - northern floodplain meadow; 9b - southern floodplain meadow.
- field spot number and colour indicate the study area and the serial number, the location of study sites is indicated in Figure 5.5: 1, 4, 7 - Pechora Delta floodplain 1996, 1997 and 1998 respectively.
- spot numbers printed large bold are characteristic for one classification unit, spot numbers printed small italic occur in two classification units.

the set of uplands legend classes. Although probably a landscape-related explanation is responsible for the classified differences in spectral reflectance properties, more detailed investigations of this field landscape type are required. For the Pechora Delta floodplain the supervised classification identified both a classification unit "freshwater marsh" as well as "freshwater shrub marsh", where only one field landscape type "*Carex-Equisetum* floodplain marsh" was distinguished. The heterogeneous field landscape type "erosion valleys", consisting of either willow shrubs or natural meadows was also distributed over a number of unrelated classification units, including snow. It can be successfully mapped in detail making use of topographical maps and Digital Terrain Models to determine slope angles. The resulting maps can be combined with the image classification in a Geographical Information System.

A less easy explained example is the distribution of the field landscape type "willow thicket" over a number of unrelated classification units, mainly for the uplands sub-area. The poor classification result is partly caused by the elongated structure of shrub thickets, partly by differences in phenological timing of leaf development during the time the image was taken. Mainly this landscape type covers small surfaces which are often rather narrow and elongated along drainage gullies, which means that establishing training areas on satellite images needs to be done with special care. It might also indicate that the pixel size of the Landsat TM image is too coarse to classify this landscape type with sufficient reliability. The classification of this type of landscape types, as well as mosaic landscape types in general, might be improved by mapping this landscape type using conventional techniques like aerial photographs or "new generation" satellite images like Ikonos2 having a 4 m resolution.

From Table 5.2 and 5.3 it also follows that one classification unit often includes spots of different field landscape types, the "vertical dispersion". Several explanations are possible: (1) an observed or inferred difference in vegetation or environmental conditions used to assign spots to different field landscape types was not sufficiently significant to result in differences in spectral reflectance values at the moment of image "snapping". When using an early season image differences between field landscape types are still limited but will be significant at the end of the growing season. Also wetness conditions may be identical at one moment but significant differences in drainage properties will result in quite large differences in wetness conditions at another moment in time. It is also possible that (2) an observed difference in dominant species composition does not cause any difference in reflectance values, which are determined by another parameter less visible in the field; (3) the defined classification unit groups too much spectral variation into one unit, thus ignoring variation of significance for explaining differences in landscape structure on the ground; (4) the defined spectral signature was not based on the variation in spectral reflectance values in all wavelength bands, but made use of a limited selection of bands only. An example is classification unit 9a, which includes both northern floodplain meadow communities and closed tree communities. Evaluating spectral characteristics shows that in band 1, which reflects mainly moisture status, spectral values for both field landscape types resemble each other, while NDVI values strongly differ: meadows are included in class 2-3, while tree communities are included in class 9-10. A combination of multiple bands needs to be used to define the spectral signature of field landscape types, because meadows on the other hand can only be distinguished from wet marsh communities in band 1, because NDVI values resemble.

From an overall comparison of field landscape types with classification units, one could conclude that the field landscape types described in some parts of the territory are not in complete accordance with the units. This is the result of the level of stratification applied during image processing. For example the Nenetskaya Ridge regional landscape region was processed together with the Ruskii Zavorot coastal plain, resulting in one set of legend units which afterwards were joined with the legend units defined for the Bolshezemelskaya Tundra to receive the final legend set for the uplands. The joint processing of the two landscape regions with very different landscape structure by means of one feature space representing the total variation in spectral reflectance values results in a compression of the internal variation observed in both regions separately. During the subsequent definition of spectral signatures this internal variation is grouped in fewer classification units than could be the case if the sub-area was processed separately. Locally this may result in erroneous classification. However, the original purpose of the classification procedure was to cover large land masses with enough detail and without too much stratification. Classification by Landsat TM is considered tool and not purpose in itself. Deviations from reality may inspire future work, but our general conclusion is that the final maps produced give the best achievable result possible, given the amount of time and tools available.

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6.1 Vegetation cover and productivity

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Introduction

Historical developments

The existing ecosystems, vegetation cover and species diversity in the Pechora Delta region are strongly related with the physical-geographical developments on the NE European plain throughout the Quaternary period. The absence of relict species from the Early and Middle Tertiary period suggests that the arctic flora and especially the tundra flora, compared to floras of other climatic regions, is relatively young, developed since the Late Pliocene period. Only the flora of the arctic polar zone developed earlier, under milder climatic conditions. In the northern regions decreasing temperatures related with global climate changes at the end of the Pliocene resulted in a gradual change from broad-leaved forest to increasingly shrub and sparse forest communities (willow, shrub birch, alder, tree-shrub bogs). New vegetation communities mainly developed as a result of the gradual adaptation of Pliocene non-arboreal species and communities to the new, more severe climatic conditions. Especially marsh communities are considered to have adapted to an increasing physiological dryness and low soil temperature (Gorodkov 1935). Due to the increasingly colder climate in the beginning of the Pleistocene and the development of permafrost the share of trees and shrubs in vegetation communities reduced further. A landscape developed which resembles the present-day forest tundra and southern tundra. The reduction of arboreal and shrub species was accompanied by the development of dwarf shrub and grass-moss communities. The newly developed arctic flora subsequently spread to southern areas during glaciation periods. As a result of the harsh climatic conditions the continuous vegetation cover gradually evolved into a spotty one. During this period the climatic conditions afforded alpine species to spread over the lowland areas, and to take part in the evolution of new tundra communities.

Vegetation mapping at Site 6, 1997.

The present vegetation of the lower Pechora region reflects the historical changes in environmental conditions as well as the evolution of autochtonous and alpine species. Therefore, two main groups of communities are distinguished in the actual tundra zone (Gorodkov 1935): (1) communities which existed already in the Late Tertiary period, and which now mainly occur in the forest and alpine belt (forest marshes, alpine meadows, shrub communities, floodplain-meadow-shrub communities, hydrophytic communities); (2) communities which developed during the Quaternary period, and which only occur in the tundra zone and alpine belt (mountain tundra).

The end of the last glaciation, the beginning of the Holocene 10 000 b.p., was caused by a rise of global temperatures. As a result the tundra vegetation in the Pechora Delta region was quickly invaded and replaced by spruce forest (Kremenetski *et al.* 1996). The forest expansion is linked with a deep or total thawing of permafrost during the Holocene climate optimum (the Boreal Period) between 9 000-4 000 b.p. (Shpolyanskaya 1997). The temperature in the region exceeded present-day temperatures with 5-6°C during the first part of the Boreal Period (9 200-8 000 b.p.), resulting in a extension of the forest area up to the Barents Sea coast and

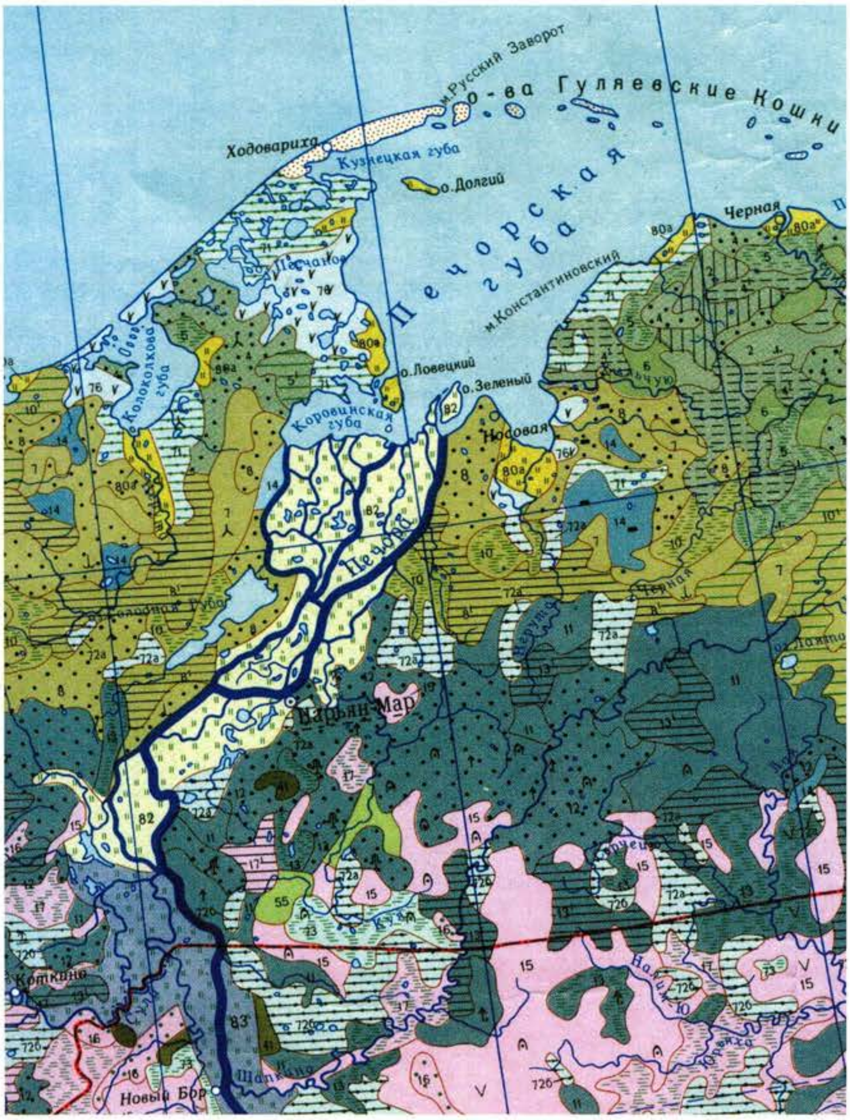

Figure 6.1.1
Part of geobotanical map showing the lower Pechora basin.

Tundra
Northern (typical) tundra

▨	4
▨	5
▤	5.1

Southern (shrub) tundra
Small *B. nana, few low shrubs*

■	7
▨	8
▤	8.1
▨	10

■	Large *B. nana, closed shrub layer* 11
■	14
■	**Forest & sparse forest** 15
▤	**Graminoid-lichen-moss marshes** 71
▤	72
▨	**Graminoid (& -**Hypnum**) marshes** 76
▨	**Meadows** 80
▨	**Floodplain meadows of tundra** 82

For full description see Appendix 7

beyond to some polar islands (Borzenkova 1990). Since the beginning of the Sub-boreal Period (4 500 b.p.) global temperature decreased and became increasingly unstable, resulting in at least five relatively cold periods during which the temperature was 2-3°C lower than today, and five periods during which the temperature was 1-2°C higher than today. Growth conditions for spruce deteriorated and the northern forest boundary receded southward, while isolated spruce "islands" stayed behind.

Biogeographical zonation

The actual spatial distribution of major vegetation types is summarised in a geobotanical map (Fig. 6.1.1). Along the downstream Pechora, the map shows a gradient in zonal biogeographical regions from forest tundra, characterised by inclusion of trees (spruce, low birch) in communities, via southern tundra to typical tundra. In addition extrazonal marshes and floodplain areas occur in all zonal regions, their structure and vegetation composition adapted to specific regional conditions.

Methods

Three of the distinguished biogeographical regions were studied within the framework of the Pechora Delta project: (1) floodplain: the riverine floodplains in the delta; (2) uplands: southern tundra in the undulating uplands; (3) coastal plain: azonal marshes interchanging with typical tundra on the coastal plains. In the three landscapes regions vegetation composition, spatial pattern and productivity was studied in detail in selected study sites (see Chapter 3).

Vegetation cover

The geobotanical descriptions have been collected using standard methods (Voronov 1973, Rabotnov 1983). Vascular plant species were identified using Tolmachev (1974-1977), Anonymous (1953-1966), Anonymous (1960-1987). Lichens species have been named in accordance with Hawksworth *et al.* (1995). Vascular plants species were named in accordance with the latest nomenclature list of Cherepanov (1995), lichens in accordance with Santesson (1993). Of most species samples were collected and included in the herbarium of the Komi Science Centre, Ural Divion, Russian Academy of Sciences. The most interesting species were also handed over for inclusion in the herbarium of the Komarov Botanical Institute (St. Petersburg).

Productivity

During the field expeditions in the period 1997-1999, biomass was sampled in the three landscape regions of the Pechora Delta. In August 1998 sampling occurred during the optimal period for biomass development. In that year it was possible to measure above-ground biomass in various upland communities and marsh complexes. Sampling was done in the floodplain region (Site 1), in the uplands (Site 2 - Nenetskaya Ridge; Site 7 - western Bolshezemelskaya Tundra), and in the coastal plain (Site 3 - Ruskii Zavorot plain near Khabuika; Site 6 - lake Peschanka-To).
Biomass samples were collected in tundra communities typical for this region. Biological production (above-ground biomass) was defined by weighting, excluding mosses and lichens. The soil surface was considered to be the plane where green (living) mosses were replaced by brown (dead) mosses. Because soil cover of tundra vegetation has a mosaic character, well-developed homogeneous vegetation communities were select-

Floodplain

Uplands

Coast

Floodplain
1. Delphinium elatum
2. Geum rivale
3. Caltha palustris

Uplands
4. Pedicularis oederi
5. Salix herbacea
6. Ledum decumbens
7. Nephroma arctica
8. Cladonia gracilis
9. Vaccinium uliginosum

Coast
10. Sphagnum fuscum
11. Carex subspathacea
12. Hippurus tetraphylla

ed, with an almost 100% cover, which could be easily identified on satellite images. Sampling was repeated 2-5 times on plots of 0.4x0.4 m^2, 1.0x1.0 m^2, or 3.0x3.0 m^2, depending on the structure of the vegetation community. The above-ground biomass was completely cut within the boundaries of the selected plots. In shrub communities the living parts of stems and branches, the herb undergrowth and the green leaves of shrubs were collected separately. In meadow communities the total living above-ground biomass was collected, while in lichen communities both living and dead lichen parts were collected together. After weighting of the fresh biomass, samples were pre-dried in the field in a microwave and dried to absolute dry weight at 105°C in the laboratory. Sometimes the biomass of a separate shrub layer was calculated based on the soil cover. Biomass is calculated in g m^{-2}. The data on biomass of multi-layered shrub communities are approximately, because their reliability is not confirmed by parallel methods.

Results

Vegetation communities

Floodplain Riverine communities form the major landscape types in the Pechora Delta. The region is characterised by a short-range variation in vegetation communities strongly related with drainage conditions. The highest topographical level is characterised by willow and alder communities as well as primary and secondary meadows, the occurrence of which is partly related to anthropogenic activities. The intermediate topographical level includes shrub thickets, wet meadows and medium high shrub marsh communities. The lowest topographical level includes low shrub marshes and sedge marshes. All levels are yearly flooded in spring.

Uplands Southern tundra uplands dominate West and East of the floodplain, in the Nenetskaya Ridge and in the western Bolshezemelskaya Tundra. Widespread zonal community types include dwarf shrub-lichen tundra on flat elevated areas and sandy soils changing to dwarf shrub-moss-lichen tundra on loamy soils. In both communities up to 20% of the surface may be covered by cryogenic spots of bare soil. Flat hummock-depression complexes develop in conditions of impeded drainage and peat. On gentle slopes hummock dwarf shrub-herb-moss communities prevail, on steep slopes, toe slopes and in stream valleys replaced by azonal herb, herb-willow, willow-moss and *Poa*-moss communities (Gribova & Lavrenko 1974, Anonymous 1985). Characteristic for the southern tundra zone is the occurrence of small *Betula nana* tundra (yernik tundra) on flat moderately well drained elevated plateaux. Mosses and lichens are community-forming elements. Mosses are dominated by cryophylic species: *Polytrichum piliferum, Rhacomitrium lanuginosum* and *Rhytidium rugosum*, less important are *Hylocomium splendens, Pleurozium schreberi, Ptilidium ciliare* and *Dicranum elongatum*. Lichens are dominated by frutiscent lichens of the genera *Cetraria, Cladina* and *Stereocaulon*. Often lichens do not develop a continuous cover, maximum up to 60%.
Diversity within the zonal group of plant communities is associated with a varying cover of lichens, which depends on the depth and stability of the snow cover (Anonymous 1980).
Bare spots in this region often show different stages of recolonisation. The first stage shows spots being invaded by small mosses and lichens of the families Stereocaulon, Baeomyces, Ochrolechia and Pertusaria. Later specific small flowering plants also appear (*Pinguicula alpina, P. vulgaris,*

Tofieldia pusilla, Saxifraga oppositifolia, S. hirculus, Juncus biglumis, Carex bicolor, C. capillaris, Silene acaulis, Pedicularis oederi). During the last stage cushions of lichens of the families Cladonia, Bryocaulon, Bryoria, Alectoria and Flavocetraria develop.

Coastal plain Coastal marshes dominate in the western and northern Malozemelskaya Tundra. Main community types include sedge-*Hypnum* and sedge-*Sphagnum* marshes in depressions. Marsh communities interchange with flat hummock-depression complexes characterised by dwarf shrub-moss-lichen communities on hummocks and cottongrass-sedge-*Sphagnum* communities in depressions. High centre polygons with dwarf shrub-lichen tundra are limited to elevated areas, occurring sporadically along the coast but increasing in surface coverage in inland regions. Characteristically a gradient of communities which are influenced more or less by regular flooding with saline and brackish water occurs along the coast of the Barents Sea and Pechorskaya Bay.

Flora composition

The complete list of species identified during the field expeditions beween 1996 and 1999 included 608 species (see Appendix 1) in six different groups: trees - 3, shrubs - 18, dwarf shrubs - 16, herbs - 265, mosses - 128 and lichens - 166. In addition two mushroom species were found in the western Bolshezemelskaya Tundra.

Figure 6.1.2
Composition of the vegetation in different study sites.

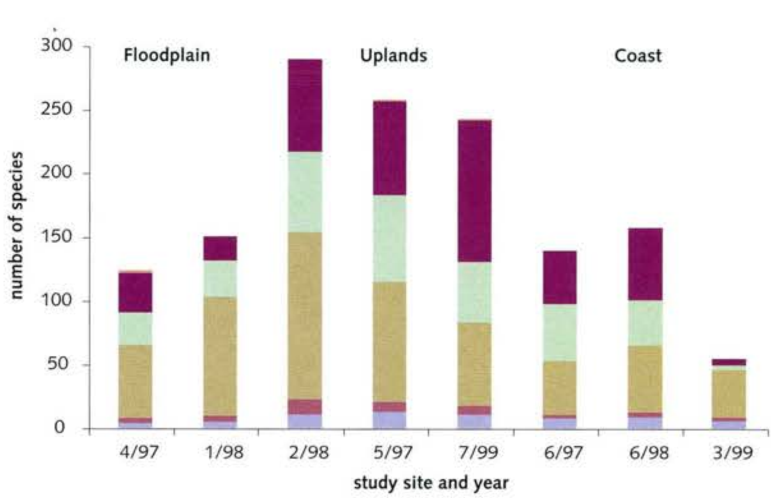

Table 6.1.1
Species diversity in different study sites.

	Major landscape region									
	Floodplain			Uplands		Coastal plain				
Year	96	98	97	96	98	97	99	96/99	97	98
Study site	1	1	4	2	2	5	7	3	6	6
Tree	0	0	2	0	0	1	1	0	0	0
Shrub	4	5	4	8	11	13	11	6	8	9
Dwarf shrub	2	5	4	4	12	8	7	3	3	4
Herb/grass	36	93	57	56	131	94	65	37	42	52
Moss	4	29	26	6	63	68	48	4	45	36
Lichen	10	19	31	25	73	74	111	5	42	57
Total	**56**	**151**	**124**	**99**	**290**	**258**	**243**	**55**	**140**	**158**

Figure 6.1.3
Composition of the vegetation for the three landscape regions.

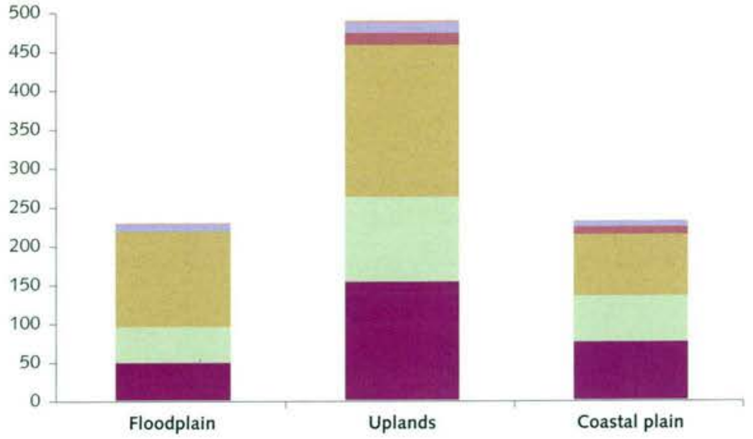

Figure 6.1.2 and Table 6.1.1 show the species diversity in the different study sites of the three landscape regions. The high number of moss and lichen species in 1997 and '98 compared to 1996 can be explained by the special attention paid to these groups since 1997. Differences in species diversity can also be explained by different sampling periods: in 1998 sampling took place late summer, in all other years early summer (see Table 6.1.1 Site 1, 2 and 6). Species diversity for the three landscape regions is presented in Table 6.1.2 and Figure 6.1.3. The highest species diversity is observed in the uplands with southern tundra vegetation, while both the floodplain and coastal marsh areas show a comparable lower number of species. Comparing Table 6.1.1 with Table 6.1.2 it is noted that the total species diversity of single study sites covers on average 59% of the total species diversity for the landscape region (floodplain - 60%; uplands - 54%; coastal plain - 64%), indicating a considerable spatial variation within the landscape regions. The study sites visited in 1996 were excluded from the calculation, for reasons indicated above.

Table 6.1.2
Species diversity in the three major landscape regions.

Species diversity	**Floodplain**	**Uplands**	**Coastal plain**
Tree	1	2	0
Shrub	10	14	8
Dwarf shrub	0	15	10
Herb	123	195	79
Moss	46	109	59
Lichen	49	153	75
Total	**229**	**488**	**231**

Dynamics and biodiversity of spruce "islands"

Although trees and especially coniferous trees have a limited distribution in the area under study, in some parts of the Bolshezemelskaya Tundra tree "islands" of Spruce *Picea obovata* occur. The existing spruce islands in the Pechora Delta region differ in their origin (Lavrinenko & Lavrinenko 1999). Some spruce stands are situated on high (4-5 m) sandy hills confined to the peripheral or central parts of vast sandy opens of the watershed territories. These stands can be considered as relics of the Holocene climate optimum preserved in tundra. Nowadays, spruce is not only preserved in such relics (where it is often suppressed) but has widely

"Spruce island" surrounded by dwarf shrubs with flowering cloudberry. Ortina river July 1999.

colonised the banks of the Ortina river and its tributary brooks. Separate spruce groups invade tundra communities as well. We can compare our data with the logbook of the expedition of A. Schrenk in 1837. On August 30, 1837, he passed the Severnaya river upstream in the Bolshezemelskaya Tundra (67°40'N, 51°00'E). A. Schrenk (1855) noted: «We found the first forest base in the wide flat valley of the Severnaya river... it consisted of a few low, distorted pitiful spruces». At present, spruce stands in the Ortina river basin occupy many hectares. They are mainly confined to the middle floodplain or to the elevated terraces of the Ortina river and its tributary brooks, above the floodplain. The trees in such communities are 10-12 meters high, their trunk at a height of 1 meter is 20-25 cm thick. There are healthy young trees of different age in these spruce stands.

The taxonomic and geographic structure of the spruce forests in the Ortina basin differ completely from the tundra floras (Lavrinenko & Lavrinenko 1999). They resemble forest communities of the forest-tundra. The flora of spruce stands includes 61 vascular species (26% of the whole regional flora) and 116 spore species (63%). So spruce stands considerably enrich the regional flora with spore species. Only spruce stands provide additional substrate for epiphyte and epixyle lichens (barks, branches and rotten wood of *Picea obovata*). Boreal and boreal-nemoral lichens such as *Alectoria sarmentosa, Bryoria capillaris, B. implexa, Cladonia bacilliformis, C. botrytes, Hypogymnia tubulosa, Ramalina dilacerata, R. roesleri, R. sinensis, Tuckermanniopsis chlorophylla, Usnea lapponica, U. subfloridana* are confined exclusively to spruce stands. As for vascular plants, boreal species such as *Sorbus gorodkovii, Ribes nigrum, Arctostaphylos uva-ursi, Orthilia obtusata* are only found in spruce stands. Exclusive boreal mosses are e.g. *Barbilophozia barbata, Rhytidiadelphus squarrosus*, and *R. triquetrus*. Thus, the relic spruce stands preserved in the tundra since the Holocene are nowadays refugia for many boreal and nemoral species.

Considering, on the one hand, the neighbourhood of the Pechora river which provides milder climate conditions in the region and the prevalence of sandy soils in the Ortina basin and, on the other hand, the high viability of spruce and accompanying boreal plants, favourable conditions exist for spruce open woods moving northward (e.g. to the Ortina river mouth) in the future.

Productivity

Floodplain

Site 1 (10-14 August 1998) Main types of plant communities defined in Site 1 include floodplain meadows, willow stands, alder stands, homogenous marshes and their different combinations on the micro-level. Samples were taken (1) in communities characterised by NDVI class 8-10. This group includes high willow and alder stands (up to 4 meters high), with a well-developed herb-graminoid undergrowth, and floodplain herb-graminoid meadow with a low cover of willows; (2) in communities characterised by NDVI class 4-9. This group includes willow thickets (height 1-2.5 m); (3) in communities with a varying vegetation cover and a certain percentage of open water, characterised by NDVI class 2-5. These communities mainly include sedge-swordgrass marsh complexes around lakes. Biomass data for different communities are presented in Table 6.1.3. The average above-ground biomass in herb-graminoid communities of the Bolshezemelskaya Tundra was determined at 3150 kg ha^{-1}, equal to 315 g m^{-2} dry weight (Bazilevich 1993). This biomass is comparable with our data presented for the floodplain region. Since data were collected on

Table 6.1.3
Above-ground dry biomass (excluding mosses and lichens) in different communities over three major landscape types

Landscape	Community type	NDVI class	Shrub living stems and branches (g m^{-2})	Shrub green leaves (g m^{-2})	Herb-grass green leaves (g m^{-2})	Total green biomass (g m^{-2})
Floodplain	Duschekia-herb floodplain forest	9	4200±800	190±31	46±4	236±35
	Willow-herb floodplain forest	9	n.d.	219	213	432
	Secondary meadow	9	-	-	164±55	164
	Primary meadow	9-10	-	-	370±46	370
	Tree-shrub thicket (2.0-2.5 m)	7-9	1900±430	212±40	70±16	282±60
	Shrub thicket (1.0-1.5 m)	4-5	n.d.	158±28	69±12	225±40
	Freshwater marsh (cover 50-80%)	3-5	-	-	240±45	240
	Freshwater marsh	2-3	-	-	285±50	285
Uplands	Shrub thicket (height up to 2 m)	9-10	3600±1200	164±30	104±25	268±55
	Herbs on a track through a willow stand	9-10	-	-	275±25	275±25
	Shrub thicket (height < 60 cm)	8-9	960±210	225±36	(Moss)	225±36
	Herbs on a track trough a low willow stand	8-9	-	-	170±25	170±25
	Herbs on slopes of a stream	10	-	-	225±22	225±22
Coast	Coastal meadow	3-4	-	-	126±24	126±24
	Sedge meadow (cover <20%)	1-2	-	-	28±6	28±6

Table 6.1.4
Air-dry biomass of different marsh communities in NE European Russia.

Geographical region	Community type	Dwarf shrub-shrub layer ($g\ m^{-2}$)	Graminoid layer ($g\ m^{-2}$)
Tundra on Yamal Peninsula	Graminoid-dwarf shrub-moss marsh	115.2 - 182.4	20.8 - 30.4
	Graminoid-*Sphagnum* marsh	-	68.8 - 97.6
	Sedge-*Sphagnum* marsh with dwarf shrubs	58.4 - 73.6	136.0 - 150.4
	Sedge marsh	-	130.8 - 155.6
	Sedge moor (*Carex aquatilis, Comarum palustre*)	-	295.0 - 350.0
	Cottongrass-sedge moor (*Carex aquatilis, Eriophorum polystachion, Comarum palustre*)	-	189.0 - 249.2
Bolshezemelskaya Tundra	Boggy sedge moors	-	353.0

plots with maximum vegetation, the data reflect the maximum productivity of primary meadows. The dry biomass of willow shrub communities (*Salix glauca, S. lanata*) in the Polar region near Baidaratskaya Bay was determined at 4245 g m^{-2}, including green parts of shrubs (116 g m^{-2}), the herb undergrowth layer (4 g m^{-2}) and wooden parts (153 g m^{-2}) (Bazilevich 1993). Table 6.1.4 includes literature data on the average above-ground biomass in marsh communities (Peshkova 1981, Bazilevic 1993), which show that the values measured in the floodplain region resemble biomass productivity for typical sedge and cottongrass-sedge moors.

Uplands

Site 2 (17-18 August 1998) Productivity was measured in community types characteristic for this landscape region - shrub communities and meadows developed on slopes of stream valleys. Some biomass measurements were done in plots where a track dissected an upland shrub thicket. Data on these plots show that the total above-ground green biomass of the nearby shrub thicket is almost comparable with the total above-ground green biomass of the herb community on the track, with average values of 275 and 268 g m^{-2} respectively. In other words, the herb community which developed due to anthropogenic activities shows an identical green biomass as the original shrub thicket. Only on locations where the anthropogenic herb community did not yet develop a closed cover, the total above-ground green biomass is lower (Table 6.1.3). The total above-ground green biomass of herbs on middle and toe slopes of stream valleys is slightly less compared with shrub communities (Table 6.1.3), although the spectral characteristics identify this type of meadows as being more productive. This is a consequence of the spectral image storing reflection values in horizontal surface pixels, which in case of sloping lands leads to distortions.

Site 7 (27 June-2 July 1999) Sampling was conducted in *Betula nana*-moss and *Betula nana*-lichen tundra communities in the Ortina river basin. The first community was sampled on the summit, middle and foot of a hill slope with north-eastern exposure on the left bank of the Ortina river. This transect of 60 m long has a *Betula nana* cover of almost 100%. Maximum shrub height reached 20 cm on the hill summit, on the foot slope increasing to about 70 cm. The undergrowth layer mainly includes moss litter. Biomass was sampled trice from plots sized 1 m^2 for shrubs 20 cm high to plots sized 4 m^2 for shrubs exceeding 50 cm (Table 6.1.5). It is observed that the dry and wet biomass of shrubs of 20 cm height almost does not differ from the biomass of shrubs with a height of 60 cm. Possibly the productivity of shrubs with different height occurring in an identical soil-climate environment is limited by the amount of solar irradiation per unit of surface. The lower biomass production of *Betula nana*-moss tundra shrubs on foot slope plots as well as of the *Betula nana*-lichen community type is probably related with a difference in environmental conditions.

Table 6.1.5
Absolute dry weight of *Betula nana* shrubs in different tundra community types.

Community type	Shrub height (cm)	Wet biomass* (g m^{-2})	Dry biomass* (g m^{-2})
Betula nana-moss	About 20	2300±290	1500±190
	About 60	2010±225	1600±180
	50-70 cm	2200±240	1280±140
Betula nana-lichen	About 50	1900*±240	1150*±145

*due to sampling early in the season, only the total biomass of stems and branches was determined

The second community was sampled on locations between vast sandy areas of the Ortina river, to the East gradually changing into floodplain structures of small lakes. The shrub layer in this tundra is formed by single bushes of *Betula nana*, with less than 30% cover. The undergrowth layer consists of a continuous (100%) lichen cover, the dominant species being *Cetraria nivalis* (90% soil cover). Measured dry biomass is 560±25 g m^{-2} (Table 6.1.6.).

Table 6.1.6
Lichen biomass in different communities in Site 7 (western Bolshezemelskaya Tundra) and Site 3 (Ruskii Zavorot coastal plain near Khabuika). In Site 3 lichen biomass was determined in different micro-relief elements of a flat hummock-lichen community.

Site	Community type	Micro-relief element	Lichen species	Projective cover (%)	Dry biomass (g m^{-2})
7	*Betula nana*-lichen	–	*Cetraria nivalis*	About 90	
			C. cucculata	5	560±25
			C. islandica	4	
			Cladina arbuscula	<1	
			Stereocaulon paschale	<1	
			Thamnolia vermicularis	<1	
3	Hummock-lichen	Slope	*Cetraria nivalis*		
			C. islandica	60	490±20
			Cornicularia spp.	20	
			Cetraria nigricans	10	
			Tamholia vermicularis		
			Sengiosorbus globularis	4	
				3	
				<1	
		Depression	*Cladina rangiformis*		
			C. rangiferina	95	740±80
			C. amaurocrea		
			C. arbuscula		
		Tussock	*Cetraria nivalis*	30	
			Cladina amaurocrea	40	
			C. arbuscula		1050±125
			Cornicularia spp.	20	

Samples from a typical *Betula nana*-pleurocia-polytrichum-dwarf shrub tundra in the southern tundra zone (the Vorkuta Tundra, height of *Betula nana* 60 cm, projective cover 60%), showed that the maximum air-dry above-ground shrub biomass was about 1080 g m^{-2} (Rakhmanina 1971). The presented data from the Ortina basin showed a higher biomass, but if we correct for the differences in cover, results for the spatially different areas are comparable.

Additionally, the above-ground biomass was sampled in a shrub complex dominated by *Salix lanata*, located on a terrace of the Ortina river floodplain. Height of *S. lanata* was 1.3-1.6 m, wet biomass 7300±960 g m^{-2} and dry biomass 2050±320 g m^{-2}. The undergrowth layer consisted of herbs, due to sampling early in the season still marginally developed.

Coastal plain

Site 6 (21-25 August 1998) In this study area we focused on measuring the gas exchange processes of plant communities, and therefore the available time for collecting biomass samples was limited. Both biomass and gas exchange were relative low compared with more southern locations. Biomass data are included in Table 6.1.3.

Site 3 (04-09 July 1999) Lichen biomass was sampled in a spotty flat hummock dwarf shrub-lichen tundra. Sampling was conducted on the coast of the Pechorskaya Bay, near the mouth of the Khabuika river. The site was located in a typical spotty flat hummock lichen tundra, with almost continuous cover, including a low share of shrubs. Samples were collected on a hummock, on a micro-relief slope and in a depression between hummocks, on spots with a lichen cover of 100% (Table 6.1.6). In addition, biomass of lichens on cryogenic spots with a 100% cover measured on Bolvanskii Nos showed an average value of 1300-1500 g m^{-2} (dominant species included *Cladina* and *Cornicularia*) or 1100 g m^{-2} (dominant species *Cladina*). The presented data show that measured lichen biomass in the collected samples is relative high. A first explanation is that in order to avoid errors due to the separation of living and dead parts, the total weight of living and dead parts was determined. A second explanation is that samples were collected on plots of only lichens, including just a minimal amount of dwarf shrubs.

Table 6.1.7
Above-ground and underground biomass of plots with varying projective shrub cover within a flat hummock-depression complex.

Community type	Dominant species	Projective cover (%)	Dry above-ground biomass of shrubs (g m^{-2})	Dry biomass of root system (g m^{-2})
Shrub-moss	*Rubus chamaemorus* Mosses	About 30	30	610
Shrub-moss	*Rubus chamaemorus* Mosses	About 90 Continuous cover	175	825
Shrub-moss	*Betula nana*	About 50	245	855
Shrub-moss-lichen	*Rubus chamaemorus* Lichens, mosses	About 70 About 10	110 100	570

Above-ground and underground biomass were sampled on a typical flat hummock-depression complex covered by a dwarf shrub-moss tundra community type. Dominant dwarf shrubs include *Betula nana, Rubus* *chamaemorus, Ledum decumbens*; additional dwarf shrub species include *Vaccinium vitis-idea, Empetrum nigrum* etc. Dominant mosses include *Polytrichum, Dicranum, Sphagnum*; additional species include *Peltigera rufesens* and *P. malacea*. Samples are taken on sites with different dwarf shrub cover. In Table 6.1.7 the results of extreme variants are presented. The table shows a considerable variation in dry above-ground biomass on different plots, which is explained by the spatial heterogeneity of soil cover. Compared to above-ground biomass the root system shows significantly higher values. According to Bazilevich (1993), total biomass in a comparable community type sampled in the Bolshezemelskaya Tundra was 1694 g m^{-2}, including 67 g m^{-2} green parts of shrubs and dwarf shrubs, 355 g m^{-2} mosses, 323 g m^{-2} wooden above-ground parts and 929 g m^{-2} underground parts. These results are slightly higher than ours, as they refer to more southern regions.

Discussion

Species diversity was highest in the upland area (southern tundra zone). Both herbs, mosses and lichens showed a considerable higher number of species recorded than in any of the other major landscape types investigated. This is partly due to the effect that in the upland area also elements occur that are typically constituting the other main areas. Small creeks and rivers have species typical for floodplain and mesotrophic marshes. Eroded inland dune areas share xerophilic species of the coast. The richness in micro-habitats as well as the occurrence of a number of southern species (Site 7) and species occurring at higher altitude (Site 2) add to the above mentioned main reason. Mosses and lichens constitute an important part of the floral composition which is a well known phenomenon in alpine and tundra communities. It is difficult to say what proportion of the actually present number of species is covered by our investigations. The study sites were chosen such as to represent major differences in landscape and vegetation characteristics. This choice was based on reflective properties as well as topographical information. Large areas of the region are more monotonously covered as was confirmed by aerial scans by helicopter surveys. During stops at areas where information of the vegetation could be obtained we noticed that the pattern of composition of vegetation units might differ, less so the plant species they contained. Some areas have not been visited and may contain species which add to our list. First this is true for the coastal areas. The saltmarshes around Kolokolkovskaya Bay, Kuznetskaya Bay and Bolvanskaya Bay are interesting in this respect. Also the dune area along the West coast may contain species that remain undetected. Aquatic macrophytes form a group that is not studied well during this study. The period of year was too early to detect this group properly. The channels in the floodplain of the Pechora river and the shallows near its mouth into the Korovinskaya Bay form important growing places as shown by aerial scans in August 1998 and work by others (Beekman *et al.* 1996, B. Nolet pers. comm.). Another interesting point is the possible occurrence of eelgrasses *Zostera* spp. This important food for waterfowl might be present along the northern shore of Kuznetskaya Bay as well as in the mouth of the Kolokolkovskaya Bay.

The sampling of biomass showed that the maximum standing stock (living above-ground biomass, excluding mosses and lichens) occurred in shrub communities of the Pechora floodplain. In the alder stands, above-ground biomass reached 4400 g m^{-2}. In willows dominated by *Salix lanata* and *S. glauca* biomass was 2180 g m^{-2} in floodplain communities and significantly higher on upland slopes of the Nenetskaya Ridge - 3860 g m^{-2}. In the *Betula nana*-moss communities in the Ortina basin biomass amounted to about 1400 g m^{-2}. In herb-graminoid meadow communities of the Pechora floodplain, the maximum biomass reached 370 g m^{-2}. It is clear that there is a significant difference in above-ground biomass between these communities, while on satellite images these communities cannot be differentiated and are recognised as communities with the highest biomass production. At the same time there is no significant difference in green biomass between the alder, willow and sedge-marsh communities of the Pechora Delta floodplain region and the shrub communities in the Nenetskaya Ridge, on average 260 g m^{-2}. A significantly higher above-ground green biomass per unit of surface was only observed in high willows (up to 4 m) - 432 g m^{-2} -, due to the well-developed crown and herbal undergrowth. Also higher biomass values occurred in the herb meadow communities in the floodplain region.

Extreme low values of total above-ground biomass were obtained for spotty hummock dwarf shrub-moss-lichen tundra - on average 0.21 g m^{-2} (excluding mosses and lichens). At the same time the spectral characteristics of the community are rather comparable with those of shrub communities. It is possible that the spectral reflectance is greatly influenced by green parts of mosses, the share of which in dwarf shrub-moss communities may be 50-93% compared with vascular plants, while in depressions their biomass may exceed the biomass of vascular plants up to 15 times (Rakhmanina 1971).

Sampling in different lichen communities showed that the lichen biomass was relatively high, 490-1550 g m^{-2}. In the spectral classification these communities are assigned to low-productive (non-green) communities. It is concluded that the productivity of lichens is not a factor correlating with the NDVI, and that correlation with other spectral bands needs to be investigated.

Thus, the differentiation of tundra communities by spectral classification (NDVI) shows the best correlation with the total green above-ground biomass. Assessment of the total above-ground biomass (excluding mosses) is by no means an adequate reflection of the productivity of tundra communities. To establish a more reliable relation between spectral properties and production in tundra ecosystems, broader and more detailed sampling is needed. Repeated sampling should be executed in the period of optimal vegetation development such as to measure annual production. For mosses and lichens specific measurements should be carried out.

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6.2 Phytoplankton

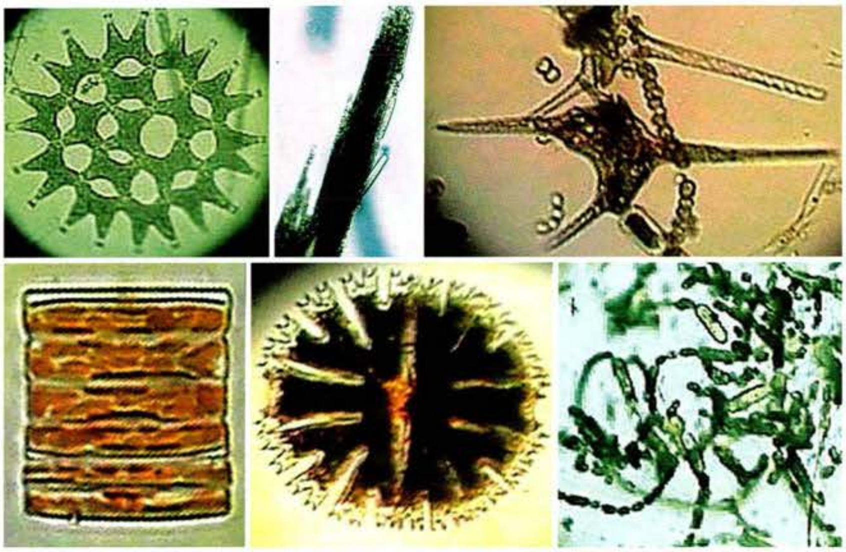
A.S. Stenina, E.N. Patova & R. Noordhuis

Introduction

Up to the present study, little information was available on the algae of the waters of the Pechora Delta and adjacent tundra. A study by Keselyov (1930) on phytoplankton of the Pechora estuary did not include the delta and coastal tundra water bodies. Information on the phytoplankton in water bodies of the Kolokolkovskaya Bay region is incomplete (Getsen *et al.* 1994). In the present study, the phytoplankton in 100 waters in the delta as well as in the adjacent tundra areas has been investigated, including 93 stagnant waters, four Pechora flows, two bays and connected channels. Specific information on phytoplankton in all waters sampled and lists of diatom species with abundancy values as well as maps showing the sampling locations are given in Appendix 2

Methods

Phytoplankton samples were collected by Ruurd Noordhuis in June and July 1996-1997, August 1998 and June 1999 during implementation of the project "Structure and Dynamics of the Pechora Delta Ecosystems". The diatoms in the samples were identified by A.S. Stenina, with a focus on the dominating species complexes. Identification was conducted in slides (magnification 1500x), prepared with Elyashev's medium after boiling in concentrated sulfuric acid (Diatoms of the USSR 1974). Abundance was estimated using a 6 point scale; taxa with values of abundance of 3-6 are referred to as belonging to the dominating complexes (DC, Getsen *et al.* 1994). Species identification was conducted with the use of the basic literature (Diatoms of the USSR 1992, Cleve-Euler 1952-1955, Hustedt 1961-1966, Krammer & Lange-Bertalot 1986) and separate articles. Ecological and geographic characteristics of diatoms are based on literary data (Proshkina-Lavrenko 1953, Hustedt 1937, Foged 1966, Meriläinen



Phytoplankton as seen through microscope.

1967, Salden 1978, Whitmore 1989). For the samples collected in the water bodies of the Barents Sea coast (Site 6) in 1998 mostly DC species were determined. The material was technically prepared by S.V. Vavilova. Algae species belonging to the taxonomic divisions Chlorophyta, Chrysophyta, Cyanophyta, Dinophyta and Xanthophyta were determined by E.N. Patova in the fixed samples. For a number of taxonomic groups belonging to these divisions (these are mostly small one-celled Chlorococcales and yellow-green algae) it turned out to be impossible to determine species. This is associated with the fact that the identification was conducted in the fixed material, which made it impossible to observe reproduction stages that are necessary for identification. Several algae were determined only up to genus level. For identification mostly Russian and a few foreign keys were used (Gollerbakh *et al.* 1953, Korshikov 1953, Kosinskaya 1960, Matvienko 1954, Moshkova & Gollerbakh 1987, Palamar-Mordvintseva 1982, Tsarenko 1990, Ettl 1978, Hindák 1990).

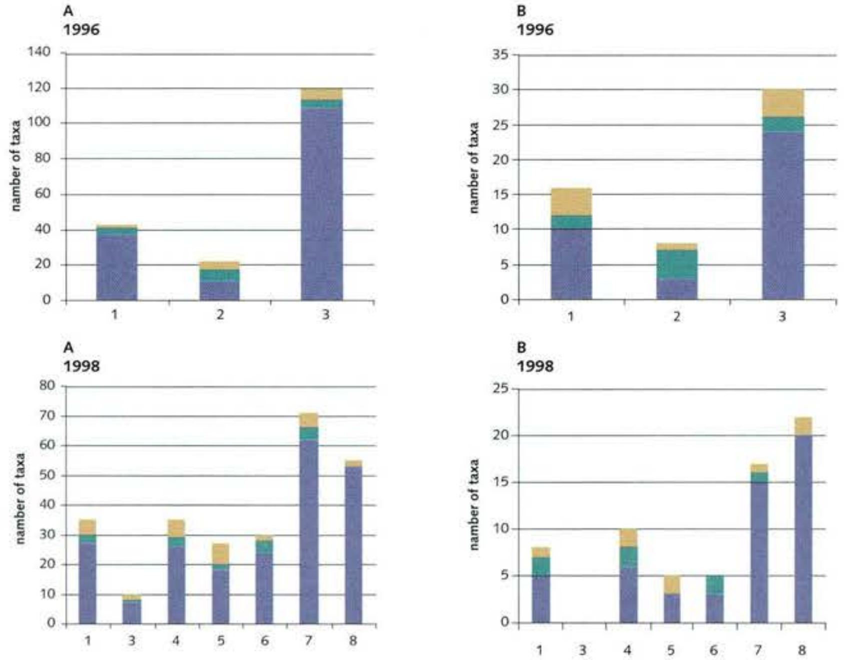
Results

Pechora delta (Site 1 and 4)

The water bodies studied in the delta are chosen to represent different origins, landscape positions and hydrological features. Water bodies in the lower part of the Pechora delta (Site 1) have been studied during two years (June 1996 and August 1998), the more upstream situated Site 4 was visited in June 1997. In two of the waters of Site 1 (A, C) samples were collected in both years, so algae development in both spring and summer is represented.

Comparative analysis of the Pechora delta water bodies demonstrates that phytoplankton is not homogenous in species richness, in species development level and in composition of the dominant complexes. General species richness was low. Richest in species was the relatively large lake 1.3 in 1996 (40 ha; Fig. 6.2.1; App. 3, Tab. 1) between the river channels. The dominant complexes of this lake also included the highest number of species. As for the rest of the water bodies, there was no relationship

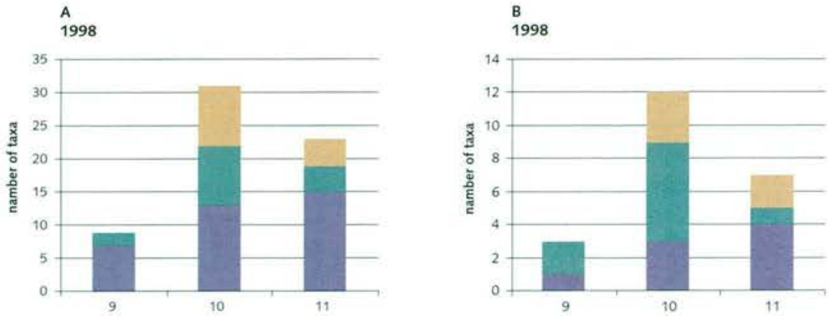
Figure 6.2.1
Number of phytoplankton taxa in the lakes of the Pechora delta (Site 1). **(A)** All taxa, **(B)** dominant taxa (abundancy 3 and higher in Appendix 3, Tab. 1).



🟨	others
🟩	Cyanophyta
🟦	Bacillariophyta

Figure 6.2.2
Number of phytoplankton taxa in river channels of the Pechora delta (Site 1). **(A)** All taxa, **(B)** dominant taxa (abundancy 3 and higher in Appendix 3, Tab. 1).
9 = second order side channel 1.9,
10 = first order side channel 1.10,
11 = main channel 1.12

🟨 others
🟩 Cyanophyta
🟦 Bacillariophyta



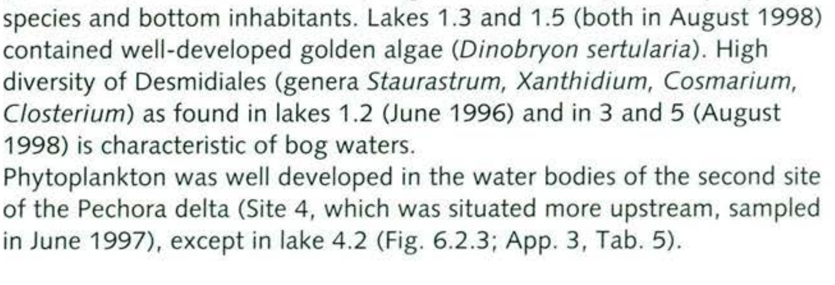
between species richness and the typical features of the waters. Most species were found in the littoral zone of lakes, at a sampling depth of 0.2-0.3 m. The samples from the lakes were dominated by non-plankton groups, which is explained by the shallowness of the lakes and the fact that the samples were taken from the shore. Typical plankton complexes, including diatoms and blue-green algae, are represented in the samples from the river channels.

Not all the water bodies of the lower Pechora delta (Site 1) were favourable for mass development of algae. Mass development of diatoms, blue-green and yellow-green algae was registered in the river channels and in the largest lake of Site 1 (800 ha lake 1.4; Fig. 6.2.1; App. 3, Tab. 1), which was sampled in August 1998 and had a pH of 8.2. The blue-green alga *Aphanizomenon flos-aquae* was blooming in this lake and in a connected channel (second order lateral channel, location 1.9 in August 1998; Fig. 6.2.2; App. 3, Tab. 1) with a silt bottom, rich in organic matter (under condition of slow flow). The main channel and a first order lateral channel (locations 1.11 and 1.9, respectively, both August 1998; Fig. 6.2.2; App. 3, Tab. 1), which both had a sandy bottom, showed a less abundant development of *Aphanizomenon flos-aquae*, but favoured the development of *Aulacosira italica* var. *subarctica*, and species from genera *Tribonema* and *Anabaena*. Diatom abundance was registered in lakes 1.3 (June 1996) and in 1.7 and 1.8 (August 1998), mainly due to periphyton species and bottom inhabitants. Lakes 1.3 and 1.5 (both in August 1998) contained well-developed golden algae (*Dinobryon sertularia*). High diversity of Desmidiales (genera *Staurastrum, Xanthidium, Cosmarium, Closterium*) as found in lakes 1.2 (June 1996) and in 3 and 5 (August 1998) is characteristic of bog waters.

Phytoplankton was well developed in the water bodies of the second site of the Pechora delta (Site 4, which was situated more upstream, sampled in June 1997), except in lake 4.2 (Fig. 6.2.3; App. 3, Tab. 5).

Figure 6.2.3
Number of phytoplankton taxa in the waters of the Pechora delta (Site 4). **(A)** All taxa, **(B)** dominant taxa (abundancy 3 and higher in Appendix 3, Tab. 1).

🟨 others
🟩 Cyanophyta
🟦 Bacillariophyta



Four euplanktonic species - *Asterionella formosa* and *Aulacosira italica* var. *subarctica* (especially in lake 4.1) and *Aulacosira italica* var. *italica* and A. islandica (in the channel, location 4.4) - were most abundant. Sometimes they reached mass development. Abundance of diatoms is characteristic of spring, in these cases with a dominance of *Asterionella formosa* (dead river arm, channel) and subdominance of golden and blue-green algae. Blue-green algae are more frequent in spring, although with different levels of abundance in various water bodies.

The species composition of diatoms found in the water bodies of the Pechora delta is characteristic of almost neutral, low-alkaline and alkaline freshwater reservoirs (Site 1, pH 6.77-9.42; Site 4, pH 5.89-7.04). As for the salinity level, all water bodies are dominated by indifferent species (Table 6.2.1, 6.2.2) which corresponds to the type of water in the study lakes (21.8-171.2 µS cm^{-1}). Nevertheless, if we register only the indicator species at Site 1 in 1996 (Table 6.2.1), we can see that the small peat lake (lake 1.2) is distinguished by the presence of halophobic species which are absent or rare in the dead river arm (location 1.1). The latter is dominated by halophylic diatom species. The large lake between the channels (lake 1.3) is also dominated by halophylic diatoms, although it also contains halophobes of no cenotic value. This lake had low conductivity values (41.3 µS cm^{-1} in 1996, 73.5 µS cm^{-1} in 1998), but seems to be influenced by low-saline sea water, or by sea sediments, judged by the presence of *Pseudoholopedia convoluta* which is typical for saline waters. According to Keselyov (1970), accidental invasions of saline species may occur, in spite of the fact that the phytoplankton community of the bay and the delta lakes is formed under the impact of the river runoff and has a freshwater character.

Table 6.2.1
Proportion of ecological groups of diatoms in the phytoplankton of the lower Pechora delta lakes, Site 1, June 1996. Non-euplanktonic species include bottom, littoral and epiphytic species. The table does not include species with an unknown ecology.

Location	**1.1**	**1.2**	**1.3**
According to habitat			
Euplanktonic	9	0	10
Partly euplanktonic	2	1	5
Mainly non-euplanktonic	26	10	94
According to salinity			
Indifferent	28	8	73
Halophylic	7	0	19
Meso-halobic	1	0	1
Halophobic	0	3	11
According to acidity			
Indifferent	12	3	29
Alkaliphylic + Alkalibionts	24	5	67
Acidophylic + Acidobionts	0	3	4

Table 6.2.2
Proportion of ecological groups of diatoms in the phytoplankton of the lower Pechora delta lakes, Site 1, August 1998. Non-euplanktonic species include bottom, littoral and epiphytic species. The table does not include species with an unknown ecology.

Location	**1.1**	**1.3**	**1.4**	**1.5**	**1.6**	**1.7**	**1.8**	**1.9**	**1.10**	**1.11**
According to salinity										
Indifferent	21	4	18	11	15	40	34	4	11	11
Halophylic	4	3	5	2	6	13	10	2	2	2
Meso-halobic	0	0	0	0	0	1	1	0	0	0
Halophobic	1	0	2	2	2	5	7	1	0	0
According to acidity										
Indifferent	10	1	7	6	7	17	12	1	3	4
Alkaliphylic + Alkalibionts	16	6	16	8	14	39	35	6	10	9
Acidophylic + Acidobionts	0	0	0	1	2	1	3	0	0	0

Concerning acidity, all water bodies (Tables 6.2.1, 6.2.2), especially the channels and the larger lakes, are dominated by alkaliphylic species and alkalibionts. Some of the smaller lakes (1.2, 1.5, 1.6 and 1.8) may be characterised as bog waters by the presence of acidophilic and acidobiontic species, e.g. the diversity of Desmidiales of the genera *Staurastrum, Xanthidium, Cosmarium* and *Closterium*, which is confirmed by their relatively low pH values (max. pH 7.6).

Asterionella formosa, Aulacosira italica var. *italica, Aulacosira granulata, Stephanodiscus hantzschii, Aphanizomenon flos-aquae, Closterium acerosum* and a number of other species are typical inhabitants of mesotrophic and eutrophic lakes and rivers. Increasing organic content from the river going downstream contributes to the development of such species in the delta (Vlasova 1988). Strong eutrophication of the river during the study period was not observed, judging from the absence of mass development of centric diatoms like *Stephanodiscus hantzschii*, that dominated in the downstream areas of the Danube and the Rhine (Ivanov 1977). Mass development of the eutraphents *Melosira varians* that had been recorded previously in the downstream parts of the Pechora (Vlasova 1988) and that of *Fragilaria crotonensis* was not observed either.

Nenetskaya Ridge (Site 2)

Lakes and temporary water bodies were examined in June 1996 and in August 1998. Eight lakes were sampled in both years.

In 1996, the water bodies of the Nenetskaya Ridge displayed low species richness and differences in the development of algae. Most of the lakes studied (11) did not have diatoms in the plankton except for some single findings. At the same time, diatoms were relatively abundant or had even developed in mass in five water bodies (2.4, 2.26, 2.28, 2.30, 2.31; Fig. 6.2.4;

Figure 6.2.4
Number of phytoplankton taxa in the lakes of the Nenetskaya Ridge (Site 2), separated in waters with low (I) and high (II) algal abundance.
(A) All taxa, **(B)** dominant taxa (abundancy 3 and higher in Appendix 3, Tab. 2).
Location numbers as used in 1998. (For corresponding numbers used in 1996, see App. 2)

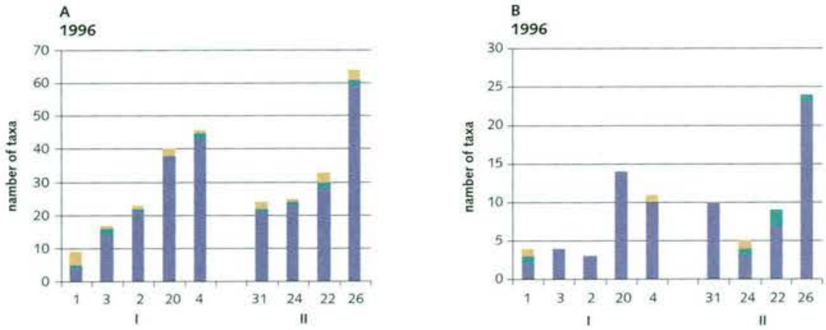
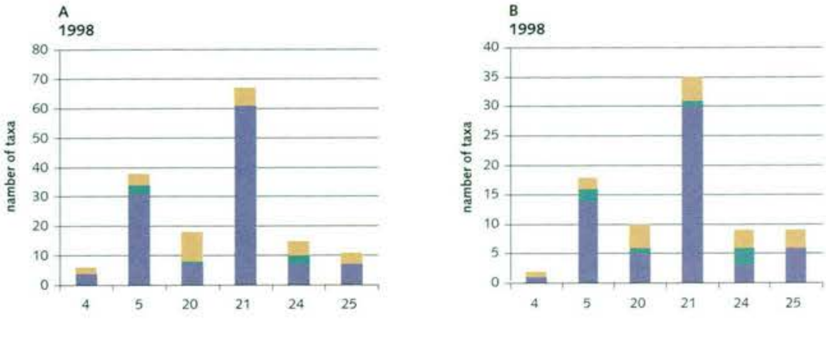


Figure 6.2.5
Number of phytoplankton taxa in the lakes of the Nenetskaya Ridge (Site 2).
(A) All taxa, **(B)** dominating taxa (abundancy 3 and higher in Appendix 3, Tab. 3).



🟨 others
🟩 Cyanophyta
🟦 Bacillariophyta

App. 3, Tab. 2). These were mainly species from non-plankton communities, euplanktonic diatoms were found in lakes with a low abundance index. Most water bodies have one plankton species in common - *Asterionella formosa*. The lakes 2.20 and 2.26 also share *A. gracillima*. Only one lake (2.24) had an abundant development of euplanktonic species of the genus *Aulacosira*. Mass development of these species can be an indicator of meso-eutrophic water conditions, i.e. intermediate or high productivity.

The abundance of algae belonging to other taxonomic groups was low in most of the lakes. However, in lakes 2.22 and 2.24 blue-green and yellow-green algae were frequent. As a rule, euplanktonic species had low abundance.

In 1998 planktonic diatoms were abundant or frequent in three lakes of this area (2.4, 2.5, 2.25; Fig. 6.2.5; App. 3, Tab. 3). Two other lakes (2.21, 2.24) had diatoms in mass, although they are mainly represented by epiphytic and benthic forms. Other lakes were poor in diatoms. The algae from other taxonomic divisions were abundant in lakes 2.4, 2.5, 2.20, 2.24. Some lakes had a phytoplankton composition typical for boggy water bodies. Very abundant pikoplankton (in lake 2.20, which had the lowest pH of 7.45 at this site in 1998) and mass development of *Ceratium hirundinella* were specific features of these lakes.

Table 6.2.3
Proportion of ecological groups of diatoms in phytoplankton from the Nenetskaya Ridge water bodies, 1996.

Locations	**2.1**	**2.2**	**2.3**	**2.4**	**2.14**	**2.20**	**2.21**	**2.22**	**2.24**	**2.25**	**2.26**	**2.31**
According to salinity												
Indifferent	8	11	9	29	18	25	14	19	17	19	33	15
Halophylic	1	4	2	10	8	7	4	8	4	4	7	4
Meso-halobic	0	2	0	1	1	1	0	1	1	0	0	0
Halophobic	2	3	1	1	2	3	2	0	1	3	12	2
According to acidity												
Indifferent	4	7	1	10	5	11	8	7	6	10	22	6
Alkaliphylic + Alkalibionts	6	10	11	29	20	20	11	21	16	11	22	12
Acidophylic + Acidobionts	1	2	0	0	2	4	1	0	1	4	7	1

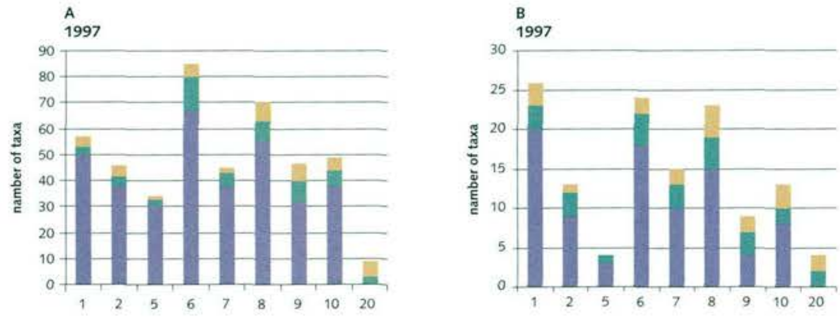
According to the results, the studied water bodies have a typical freshwater phytoplankton, shown by the dominance of species indifferent to salt content in the water (Table 6.2.3). This type of community is common in oligotrophic and mesotrophic lakes of average depth. Halophylic species tended to be the second most important group, except in lake 2.26 (1996; Table 6.2.3), in which halophobic species clearly came second. With 18.7 μS cm^{-1}, conductivity in this lake was among the lowest values recorded. Like the Pechora delta water bodies, the waters in the Nenetskaya Ridge are dominated by alkaliphylic species. Lakes 2.25 and 2.26 were exceptions in 1996: they include an equal number of alkaliphyles and indifferent species (Table 6.2.3).

Bolvanskii Nos (Site 5)

The water bodies of this site are situated mainly on the elevated relief, similar to those in the Nenetskaya Ridge, but with a slightly higher connectivity to the river. Their phytoplankton was studied only during a spring expedition (end of June, 1997).

The results show unequal development of algae in the water bodies of this site. Phytoplankton was characterised by a relatively poor species composition, with somewhat higher species numbers in lakes 5.1, 5.8 and 5.6 (50-67 species; Fig. 6.2.6; App. 3, Tab. 6). Most lakes displayed an intensive phytoplankton development, except lake 5.10. Diatoms were abundant or frequent in the plankton of lakes 5.1, 5.2A and 5.7. At the same time, the plankton was mostly dominated by the blue-green (lakes 5.1, 5.2, 5.5-9, 5.20), green (5.8, 5.9, 5.10) and yellow-green algae.

Figure 6.2.6
Number of phytoplankton taxa in the waters of Bolvanskii Nos (Site 5). **(A)** All taxa, **(B)** dominating taxa (abundancy 3 and higher in Appendix 3, Tab. 6).



Among diatoms, *Asterionella formosa* showed the highest abundance and frequency, followed by *Aulacosira islandica*. The species from genus *Anabaena* were often abundant and dominant. A peculiar dominating complex with *Woronichinia naegeliana* was registered in lake 5.7. Accompanying species complex in most lakes included *Tabellaria fenestrata* and *T. flocculosa*, in lake 5.8 *Cyclotella radiosa*, but most frequent were *Fragilaria construens* and *F. pinnata*, even dominating in lake 5.10. Certain lakes contained *Opephora martyi* (lakes 5.1, 5.8), *Nitzschia dissipata, Fragilaria vaucheriae* (lakes 5.6, 5.10), *Eucocconeis lapponica* (lakes 5.2B, 5.8) as accompanying species. Some lakes even included *Achnanthes linearis, Cymbella ventricosa* and other non-planktonic species. Four lakes (5.1, 5.2B, 5.10, 5.20; App. 3, Tab. 6) demonstrated high abundance of Desmidiales, characteristic of boggy lakes. As for the salt content, the diatom community was dominated by indifferent species (Table 6.2.4). Apart from these, the numbers of halophylic species was usually slightly higher than those of the other indicators, but lake 5.8 was dominated by halophobes. Concerning acidity, alkaliphylic diatoms dominated the species composition, except in lake 5.7, which had an equal ratio of halophyles/halophobes.

Table 6.2.4
Proportion of ecological groups of diatom in the water bodies of the Bolvanskii Nos area, 1997.

Location	5.1	5.2	5.5	5.6	5.7	5.8	5.9	5.10
According to salinity								
Indifferent	43	24	24	48	28	36	27	29
Halophylic	4	7	3	10	4	7	2	5
Meso-halobic	0	0	0	0	0	0	0	0
Halophobic	1	5	3	8	5	10	2	3
According to acidity								
Indifferent	16	11	10	19	15	16	12	15
Alkaliphylic + Alkalibionts	30	21	18	39	16	32	18	19
Acidophylic + Acidobionts	1	3	2	4	4	2	1	1

Ortina river basin (Site 7)

This site was visited in spring (28 June-2 July) 1999. Development of phytoplankton was poor due to the fact that the ice on river branches and lakes melted relatively late. In connection to this, there was a considerable shift in phytoplankton composition during the sampling period.

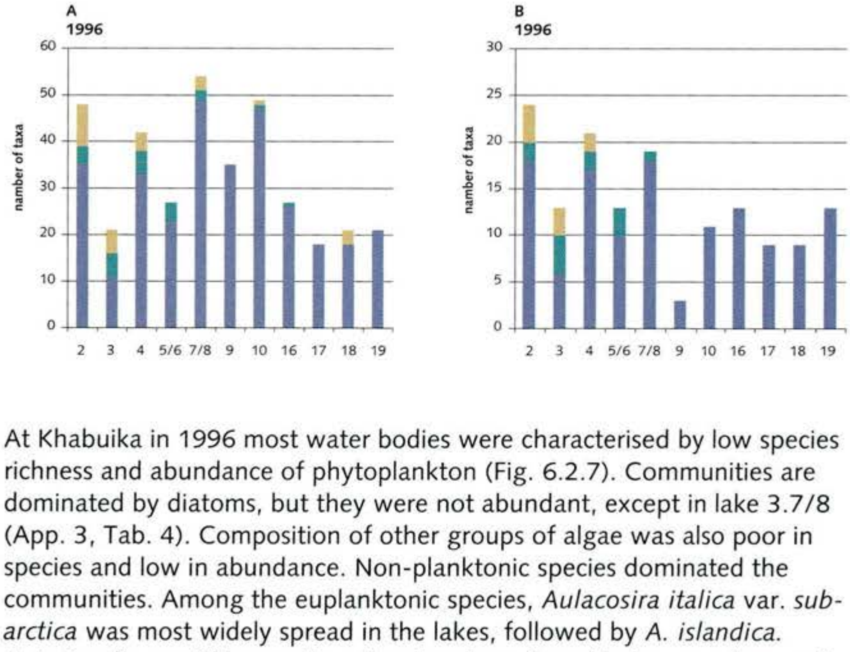
In most water bodies there were low amounts of algae, except for Desmidiales, which were diverse and represented by species of the genera *Staurastrum, Closterium, Euastrum, Xanthidium, Micrasterias* and *Cosmoastrum*. Filamentous algae of the genera *Hyalotheca, Desmidium, Spondilosium* were also frequent.

Diatom abundance was low. Only a few species were found in lakes 7.4, 7.7 and 7.10, while in lake 7.4 (App. 3, Tab. 8) they were more frequent. Among all registered species, only one euplanktonic species, *Asterionella formosa*, had a considerable abundance. Not rare was *Tabellaria flocculosa*, a typical periphyton species. Other species were single finds. Blue-green algae were abundant in lakes 7.5, 7.7, 7.8 and 7.13, dominant were *Oscillatoria lacustris, Anabaena cylindrica* and *A. variabilis*. In lake 7.8 *Stigonema ocellatum* and *Fischerella muscicola* were also abundant, typical for *Sphagnum*-bogs. A higher diversity of blue-greens was found in lake 7.13, in which phytoplankton was dominated by *Aphanizomenon flos-aquae*. The presence of *Nodularia spumigena* indicates low salinity in this lake.

Barents Sea coast (Site 3 and 6)

Two sites on the coastal plains were studied; Site 3 near Khabuika on the coast of the Pechora bay and Site 6 near lake Peschanka-To near the Barents Sea coast. Khabuika was visited in early July, 1996 and 1999, Site 6 in early July, 1997 and in August 1998.

Figure 6.2.7
Number of phytoplankton taxa in the lakes of Khabuika (Site 3).
(A) All taxa, **(B)** dominant taxa (abundancy 3 and higher in Appendix 3, Tab. 4).



🟨 others
🟩 Cyanophyta
🟦 Bacillariophyta

At Khabuika in 1996 most water bodies were characterised by low species richness and abundance of phytoplankton (Fig. 6.2.7). Communities are dominated by diatoms, but they were not abundant, except in lake 3.7/8 (App. 3, Tab. 4). Composition of other groups of algae was also poor in species and low in abundance. Non-planktonic species dominated the communities. Among the euplanktonic species, *Aulacosira italica* var. *subarctica* was most widely spread in the lakes, followed by *A. islandica. Asterionella gracillima* on the other hand was found in low numbers and only in lake 3.16. Mass development of blue-green algae was observed only in the plankton of lakes 3.2 and 3.5/6. The proportions of non-planktonic and euplanktonic species were about the same.

In most lakes the composition of diatoms (especially in the dominating complexes) reflects the alkaline conditions (Table 6.2.5) and increased water mineralisation under the impact of brackish water from the Pechora bay. *Cyclotella striata, Synedra tabulata, Lyrella pygmaea, Navicula crucicula, N. gregaria, Anomoeoneis sphaerophora, Nitzschia hungarica,* *N.levidensis, N. sigma* and a few valves of *Thalassiosira* sp. indicate such conditions and in some lakes (3.3, 3.5/6, 3.7/8) so did certain blue-green algae.

Table 6.2.5
Proportion of ecological groups of diatoms in phytoplankton from the Khabuika area water bodies, 1996.

Location	3.2	3.3	3.4	3.5/6	3.7/8	3.9	3.10	3.16	3.17	3.18	3.19
According to salinity											
Indifferent	15	8	13	11	22	13	23	10	7	8	7
Halophylic	11	1	9	6	13	8	7	2	0	0	0
Meso-halobic	6	1	8	3	6	3	3	0	0	0	0
Halophobic	0	0	0	1	2	5	8	11	8	8	10
According to acidity											
Indifferent	4	2	2	2	7	6	8	6	4	4	5
Alkaliphylic + Alkalibionts	25	2	24	18	33	18	20	4	2	0	0
Acidophylic + Acidobionts	0	0		0	1	4	8	13	9	11	12

The diatom community in four lakes (3.16-19), on the other hand, included species preferring low mineralisation and pH, often inhabiting bogs. Examples are *Fragilaria constricta, F. constricta* f. *stricta, Frustulia rhomboides* var. *saxonica, Eunotia bigibba* var. *pumila, E. faba, E. fallax, E. tenella* and a few other species. That these waters may be characterised as boggy (dominance of acidophylic species shown in Table 6.2.5) is also indicated by the development of Desmidiales and is in accordance with the relatively low pH values measured (see Chapter 7.1).
In 1997, some of the water bodies in the vicinity of the Peschanka-To lake (lakes 6.3, 6.6, 6.10A, 6.10C and 6.11B; App. 3, Tab. 7) showed mass development of various types of algae. Most common as dominant species were eurytopic species from the genus *Tribonema*. Euplanktonic species also reached relatively high abundance in some of the samples, especially *Pediastrum, Oscillatoria, Microcystis* and *Dinobryon*. Halophylic and meso-halobic euryhaline species were found in lakes 6.10A, 6.10C and 6.11B which are situated near the sea coast. The development of these species reflects the impact of sea water with increased mineralisation. Diatoms were low in abundance and diversity in most coastal water bodies (Fig. 6.2.8) due to blue-green algae developing in some of them; zooplankton mainly developed in lake 6.10B. Euplanktonic species were not very abundant here. Species from genera *Asterionella, Aulacosira* (forming the core of plankton communities in the water bodies of Sites 4 and 5) were rare here. They are substituted by *Diatoma tenue* var. *elongatum* and *Chaetoceros wighamii*, albeit with low abundance, in relation with

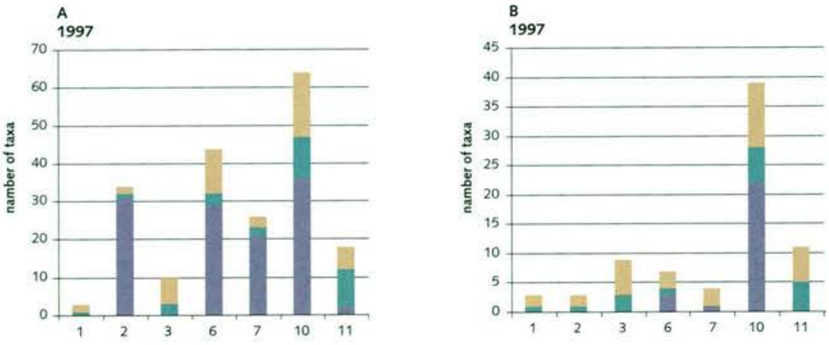


Figure 6.2.8
Number of phytoplankton taxa in the lakes of Peschanka-To (Site 6). **(A)** All taxa, **(B)** dominant taxa (abundancy 3 and higher in Appendix 3, Tab. 7).

- 🟨 others
- 🟩 Cyanophyta
- 🟦 Bacillariophyta

high mineralisation levels in some waters. In 1998 too, the share of diatoms in the plankton of most water bodies was small. The basic species composition characterised these water bodies as oligotrophic and even distrophic with signs of bogging-up (except lakes 6.E and 6.10A). Ecological analysis showed the dominance of species indifferent to salt content (Table 6.2.6), except one channel connected to the sea which included a larger share of halophylic/meso-halobic species. Alkaliphylic species dominated the diatom communities in most water bodies. Littoral species had the main share in composition and structure of communities. Dominant and subdominant species were *Fragilaria construens* var. *venter* and *F. pinnata*. The plankton of the water bodies is also enriched by periphytonic diatoms: *Tabellaria flocculosa, Fragilaria constricta, Achnanthes kryophila, A. sublaevis,* by *Eucocconeis lapponica* in lake 6.10A and by *Berkeleya rutilans* in the bay. Benthic species are found in samples as well, but most of them are single finds.

Table 6.2.6
Proportion of ecological groups of diatoms in the water bodies of the Barents Sea coast, 1997.

Location	Lake 6.10	Channel 6.2	Channel 6.7	Bay 6.1
According to salinity				
Indifferent	23	21	5	44
Halophylic	4	5	8	15
Meso-halobic	0	3	14	13
Halophobic	8	2	2	10
According to acidity				
Indifferent	16	9	3	7
Alkaliphylic + Alkalibionts	12	18	12	14
Acidophylic + Acidobionts	5	2	2	0

Discussion

The analysis of the samples resulted in 440 identified species of algae (or 523 with varieties and forms included), belonging to 107 genera, 61 families and six divisions, while 24 taxa remained unidentified. Diatoms prevailed according to taxonomic diversity (Table 6.2.7). The levels of species richness are similar to that of other northern areas: to the Bolshezemelskaya Tundra, some Yakutian rivers (Stenina & Getsen 1975, Getsen 1985, Gabyshev 1999), although they are higher than those of the Taimyr peninsula and the Ob Delta water bodies (Ermolaev *et al.* 1971, Solonevskaya 1972). However, it should be noted that the species rich-

Table 6.2.7
Number of taxa identified in phytoplankton samples taken during the project.

Division	Number of taxa		
	Family	**Genera**	**Species (with variations and forms**
Bacillariophyta	19	44	285 (360)
Cyanophyta	18	26	73 (79)
Chlorophyta	21	34	70 (72)
Xanthophyta	1	1	10 (10)
Chrysophyta	1	1	1 (1)
Dinophyta	1	1	1 (1)
Totaal	**61**	**107**	**440 (523)**

ness of the phytoplankton is not formed by euplanktonic species, but primarily by representatives of phytobenthos/periphyton communities. These species mostly have low abundance, although some bottom planktonic and eurytopic species take up dominating or sub-dominating positions in the plankton. A large share of tychoplanktonic algae in the littoral/pelagic phytoplankton is a common feature of most tundra water bodies (Stenina & Getsen 1975, Stenina 1978, Getsen 1985). This feature results from their hydrologic characteristics and from intensive mixing by wind (which lifts the bottom species up and washes epiphytic species from substrates into the water).

Table 6.2.8
Number of taxa of algae identified per site.

Site	1	2	3	4	5	6	7
Bacillariophyta	166	181	135	150	142	95	15
Other	50	48	28	38	52	55	47
Total	**216**	**219**	**163**	**188**	**194**	**150**	**62**

Comparative analysis of the samples from the various sites shows that algae diversity and abundance (Table 6.2.8) in the phytoplankton of studied water bodies are not homogeneous, but vary in a broad range. The highest number of species was found in the Pechora delta water bodies (Site 1 and 4) and the Nenetskaya Ridge (Site 2), the lowest in the Ortina river basin. These values, nevertheless, do not reflect the real situation, because the sampling frequency and sampling terms were different. To a certain extent, these data can reflect the level of knowledge available for these regions. The presence of particular species in the plankton and the level of their development depend upon the time of sampling and upon biotic and abiotic factors. Some of these factors can be explained. Comparison of the results with data on other northern rivers (the Ob Delta being the best studied region) shows similarities (Solonevskaya 1972). The plankton in the Pechora Delta and in the Ob Delta shows comparable numbers of algae taxa (150-166 and 192 respectively), if we account for the fact that certain species are registered in the Obskaya Bay while in the Pechorskaya Bay these groups are not studied yet. The phytoplankton of the Ob Delta was also dominated by diatoms, but green algae had a considerable share of species composition as well. Blue-green algae came third as far as the number of taxa was concerned. If we compare the results of sampling that was carried out during the similar time of year, a comparable composition of the dominating complexes may be noted. These complexes include *Asterionella* and *Aulacosira* species in the Ob Delta (in the northernmost sites), *Aphanizomenon* and *Anabaena* in the sub-delta sites and chlorococcal algae in the southernmost parts of the bay. Composition and species proportion in different years depended upon water level, water current speed and temperature. Under conditions of low current and low water level and at 18°C an increase in the number of blue-green algae, including the number of "blooming" taxa, was observed (Solonevskaya 1972).

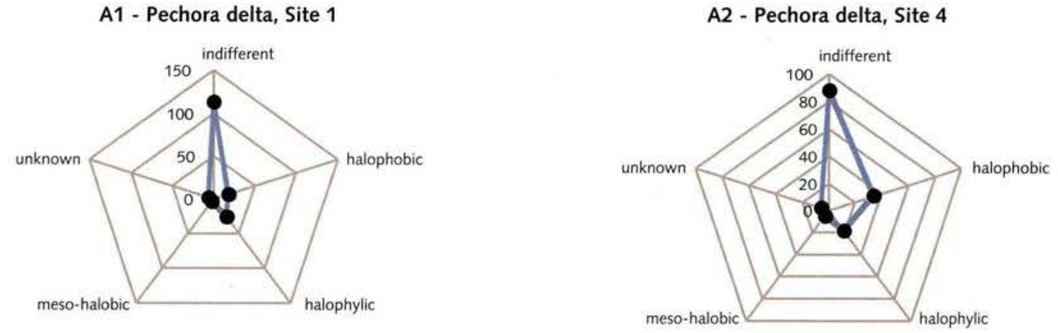
An increased content of biogenic (N, P) and organic matter (i.e. of animal origin) promotes mass development of algae in the delta water bodies (Vlasova 1988) as a result of their accumulation in this part of the river bed. Abundant development of blue-green algae is confined to stagnant or slowly-flowing waters. The photosynthetic activity of blue-green algae and their decomposition leads to considerable water alkalisation.

Low productivity of algae in most investigated lakes of the Nenetskaya

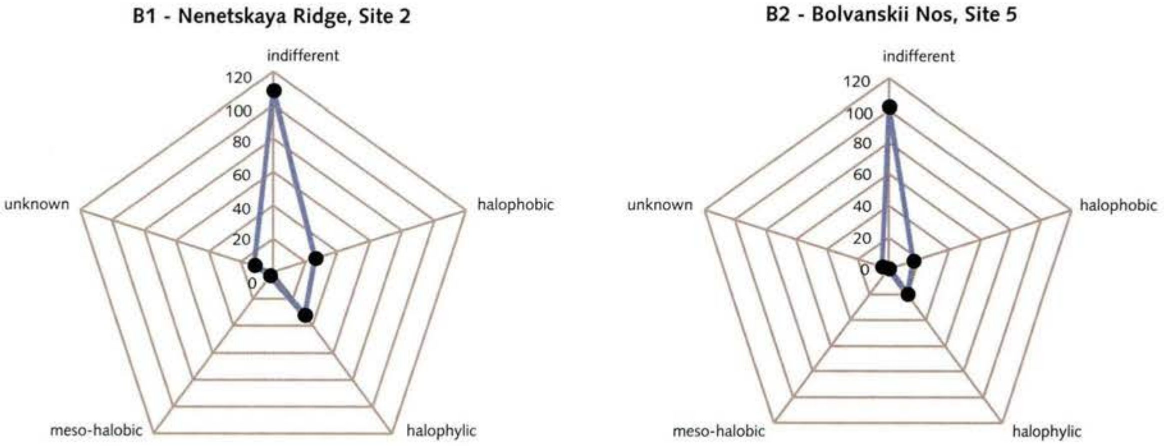
Ridge area are typical for the water bodies of elevated landscapes. Abundant development of phytoplankton is observed not only in depressions but in different parts of the relief, due to the income of biogenic and organic matter with the river runoff (Stenina 1996).

Relatively low development of algae in the seashore water bodies is explained not only by the origin of these water bodies, by specific features of morphometry and hydrochemical regime during the study period, but also by grazing of algae by zooplankton (as well as in other study regions). Mosaic distribution of algae is a specific feature of tundra water bodies.

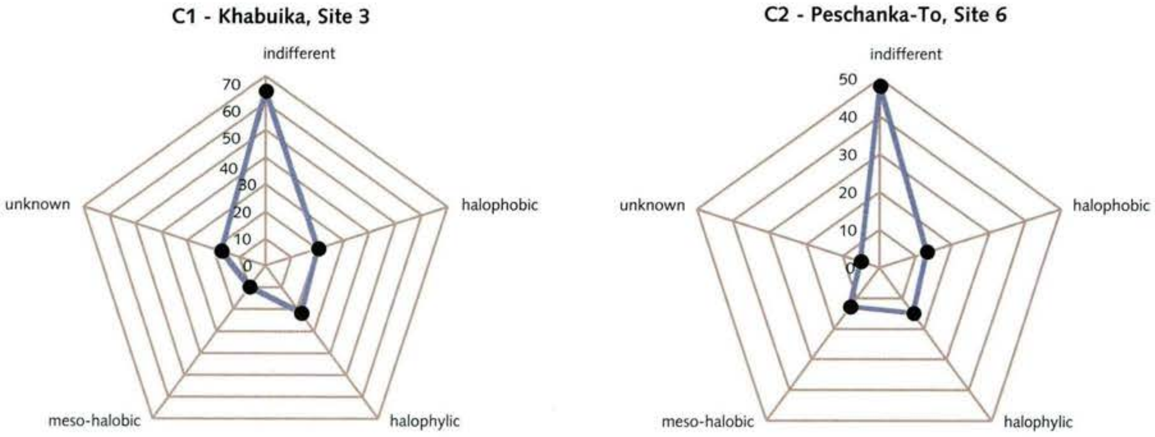
Figure 6.2.9
Distribution of diatom species according to preference for salinity levels. **(A)** Pechora delta, **(B)** uplands, **(C)** coastal plain.


A1 - Pechora delta, Site 1

A2 - Pechora delta, Site 4


B1 - Nenetskaya Ridge, Site 2

B2 - Bolvanskii Nos, Site 5


C1 - Khabuika, Site 3

C2 - Peschanka-To, Site 6

Most studied water bodies belong to the freshwater type according to their phytoplankton composition, as is shown by the dominance of indifferent species among the diatoms (Fig. 6.2.9). Nevertheless, the presence of halophylic and even euryhaline meso-halobic species in the communities reflects the impact of increased mineralisation. Comparing two sites in the river delta according to the proportion of halobic groups of diatoms, it must be noted that the share of halophylic/meso-halobic species is larger in the lower part of the delta than in its upper part. The number of these indicator species increases in the coastal water bodies, especially in the open coastal areas, bays and channels. This is obviously the result of sea water impact (which is different) and by salting-up of the coastal tundra soils.

Alkaliphylic species prevail in the water bodies of all the study areas (Fig. 6.2.10). The second place is taken up by indifferent species. The share of acidophylic species increases in the boggy sites of the upper delta and coastal tundra.

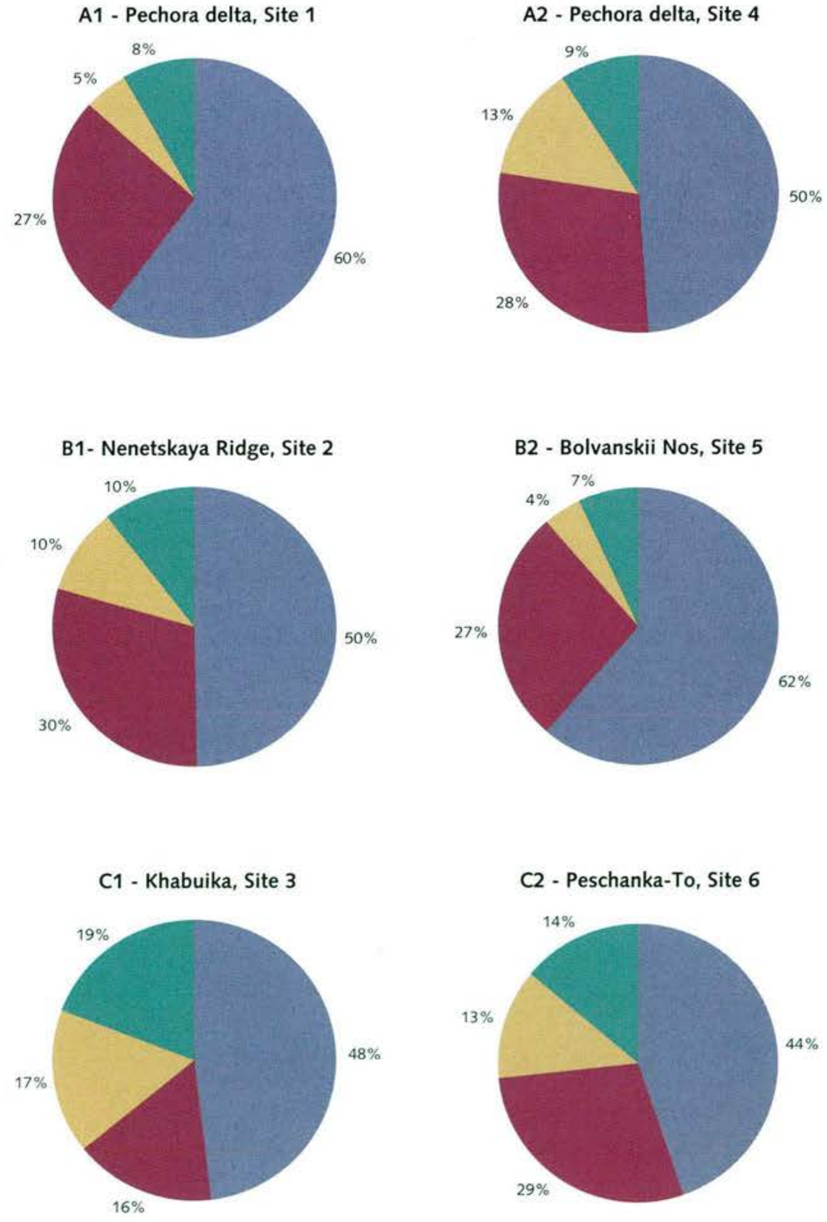
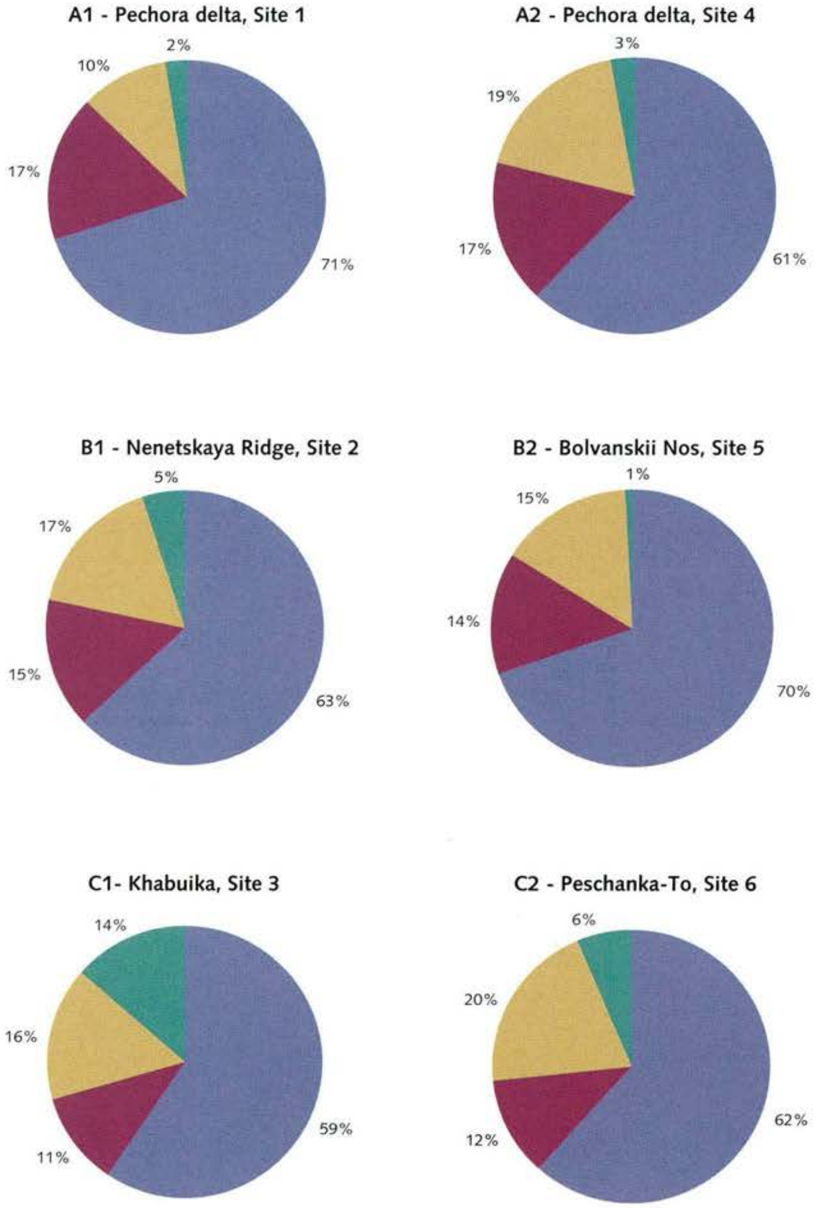


Figure 6.2.10
Distribution of diatom species per site, according to preference for pH range. **(A)** Pechora delta, **(B)** uplands, **(C)** coastal plain

🟦 Alkaliphylic
🟥 Indifferent
🟨 Acidophylic
🟩 Unknown

According to the leading species composition of their phytoplankton, most lakes can be characterised as typical northern water bodies. Nevertheless various groups of diatoms and all the algae in general are dominated by cosmopolitan species (Fig. 6.2.11). The dominance of cosmopolitan species is also recorded in other tundra lakes and ponds of the Russian Arctic (Stenina 1978, Getsen 1985), in Alaska and in the Arctic and sub-Arctic lakes and brooks of north-west Canada (Sheath & Steinman 1982). The share of Arctic-Alpine diatoms species varies in different areas between 10% (lower Delta) and 20% (sea coast). However, the absolute number of these species is highest in the waters of the Nenetskaya Ridge, followed by the waters on the sea coast and in the upper Delta.

Figure 6.2.11
Distribution of diatom species according to biogeographical distribution. **(A)** Pechora delta, **(B)** uplands, **(C)** coastal plain



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6.3 Zooplankton

V.M. Sadyrin

Methods

Zooplankton samples were taken in waters in the Pechora Delta area during four expeditions in 1996-1999. Samples from three years were analysed so far: 27 samples taken in the period 30 June-8 July 1996 (Sites 2 and 3), 33 samples from 24 June-7 July 1997 (Sites 4, 5, 6) and 39 samples from 9 August-24 August 1998 (Sites 1, 2, 6). The quantitative/qualitative analysis of the samples of 1996 and 1998 was carried out in the laboratory of the Institute of Inland Waters Biology, RAS. The samples of 1997 were processed by V.M. Sadyrin at the Laboratory of Animal Ecology of the Institute of Biology, Komi Science Center RAS. The species belonging to the Harpacticoida sub-division (collected in 1997) were identified by E.B. Fefilova (Laboratory of Water Organisms Ecology, Komi Science Center RAS). The zooplankton was processed according to current methods in the Institute of Inland Waters Biology RAS (Mordukhai-Boltovskoi 1975).

Results

Pechora Delta floodplain (Site 1), 1998

Samples were collected on 9-12 August. The sampled water bodies were shallow, their maximal depth varied between 0.5-2.8 m. Average water temperature in the water bodies was 12.1°C, pH was relatively high and ranged from 7.1-9.4.

Species diversity 55 species and forms of freshwater invertebrates of five taxonomic groups have been found. There is a large number of littoral and phytophylic species, especially among the Cladocera. Rotatoria and Cladocera dominate in numbers, which is typical for a well-developed

Plankton daphnia.

oligotrophic/mesotrophic zooplankton community in summer (Appendix 4, Table 6). *Arcthodiaptomus ulomskyi, A. niethammeri* (Calanoida), representatives of the Asian warm-water fauna, were recorded earlier in the south of West Siberia and the vicinity of Orenburg town. Brackish water species were absent at Site 1.

Quantitative values Average zooplankton density per site was rather high at 92 specimen l^{-1}, average biomass was 0.84 mg l^{-1}. Average values are higher than at Site 4 in 1997. This can be explained by the later collection period in 1998. Rotatoria dominate in number, in some water bodies they dominate in biomass as well (Appendix 4, Table 6), which is unusual for lake zooplankton in summer. Average mass of one zooplankton item in Site 1 lakes was 0.008 mg.

Nenetskaya Ridge (Site 2) and Khabuika (Site 3), 1997

Sites 2 and 3 were examined in June and July 1996, Site 2 was investigated again in 1998. The water bodies in these sites are situated in different landscapes and vary in abiotic factors. The waters of Site 2 are not influenced by spring floods, they are situated in a hilly area. They have a lower pH and lower conductivity than the waters of Site 3. Aquatic macrophytes were found in the littoral zone of some of the lakes of Site 2. All lakes had similar mineralisation levels. Water temperature was ca. 10.6°C. The water bodies of Site 3 are situated in the open coastal plain. Some of the water bodies are connected to the sea. Almost all lakes have higher pH and conductivity than at Site 2 as a result of a higher level of water mineralisation due to the sea water impact. There were no aquatic macrophytes in the lakes of Site 3. Water temperature was ca. 12.5°C.

No clear relationship was found between biotic and abiotic characteristics of the separate water bodies and the species diversity or quantitative values of zooplankton. For this reason the two sites are described together.

Species diversity The number of samples taken at Site 2 and Site 3 in 1996 was about the same (Appendix 4, Tables 1 and 2). In the samples from the Nenetskaya Ridge 25 species belonging to five different taxonomic groups were found. In the samples from Khabuika we identified twice as many (51) species, also out of five taxonomic groups. All three basic zooplanktonic groups (Rotatoria, Cyclopoida, Cladocera) were richer in species at Khabuika. This is partially due to the presence of low-saline water species like *Keratella cruciformis* and *Trichocerca heterodactyla* (Rotatoria). *T. heterodactyla* is known only from the saline and low-saline waters of the northern part of the Kaspian Sea (Kutikova 1970). The rotifer *Notholca cinetura* is known only from large cold-water lakes, but during our study it was found in small shallow-water lakes.

Copepoda Species from the sub-division Harpacticoida have not been identified yet. Many Harpacticoida are low-saline water species. The Calanoida are represented by a few boreal species in both sites. The most abundant Cyclopoid was the warm-water species *Thermocyclops oithonoides* (Alekseev 1995), which was found in lake 3.4. Its discovery in this high-latitude water body testifies to the expansion of the distribution area of this species beyond the Polar Circle.

Cladocera In the waters of Site 3 representatives of the cladoceran families Cliydoridae and Macrothricidae were found. These families consist of phytophylic and benthic species. So the zooplankton communities represented in the samples are littoral rather than pelagic. Many of the lakes were small and shallow and perhaps lack real pelagic zooplankton communities.

Quantitative values In the Khabuika samples (Site 3) on average 204 specimen and 1.23 mg l^{-1} were present (Table 6.3.1). Six lakes which are hardly affected by floods, with low pH and conductivity (3.9, 3.10 and 3.16-19), lacked rotifers and on average had only 47 specimen or 0.51 mg l^{-1}, while five lakes in the floodplain at lower altitude, with higher pH and conductivity, were much richer (lakes 3.2, 3.3, 3.4, 3.5 and 3.7) with on average 413 specimen and 1.79 mg l^{-1}. The density of zooplankton in the waters of the Nenetskaya Ridge (Site 2) was on average about 70 specimen l^{-1}. Average mass per zooplankton item was similar (0.006 mg at both sites). Productivity in the waters of the Nenetskaya Ridge is low as compared to Khabuicka. It must be noted, however, that the water temperature at Site 3 was considerably higher than at Site 2. Zooplankton development was probably more rapid for this reason, which may partly account for the high numbers of species and specimen and high biomass in the floodplain lakes of Site 3.

Table 6.3.1
Mean densities of main zooplankton groups per site per year (N l^{-1} and biomass in mg l^{-1}).

Site **Year**	**1** **98**	**2** **96**	**2** **98**	**3** **96**	**5** **97**	**4** **97**	**6** **97**	**6** **98**
Density:								
Rotatoria	55.4	7.4	17.4	91.5	18.7	6.6	1.4	31.1
Cyclopoida	26.9	54.1	6.9	73.0	9.9	52.4	17.5	3.8
Calanoida	0.9	0.4	4.1	35.2	0.7	8.5	0.4	5.4
Cladocera	9.2	7.9	1.8	3.9	1.3	6.8	2.1	19.5
Phyllopoda	0	0	0	0	0.1	0.3	0.6	0.0
Total	**92.4**	**70.1**	**30.3**	**203.8**	**30.8**	**74.7**	**22.0**	**59.9**
Biomass	**0.84**	-	**1.26**	**1.23**	**0.71**	**1.59**	**0.68**	**1.65**
Locations	**10**	**12**	**11**	**14**	**12**	**5**	**11**	**13**

Nenetskaya Ridge (Site 2), 1998

Samples were collected on 16-19 August. Most waters were considerably deeper than those of Site 1; maximum depth was 2.0-9.8 m. Average water temperature was 10.6°C, pH was considerably higher than in 1996 and ranged from 7.3-8.6.

Species diversity 57 species of freshwater invertebrates of five taxonomic groups were found (Appendix 4, Table 7). There were many benthic and phytophylic species, especially among the Cladocera. Rotatoria and Cladocera dominated in number of species. Brackish water Rotatoria species found were *Platias guadricornis* and *Keratella cruciformis*. The find of *Hemidiaptomus amblyodon* (Calanoida) is of interest because so far it was recorded only in Siberia (Rylov 1930). *Camptocercus rectirostis* (Manujlova 1964) (Cladocera) and *Arcthodiaptomus nietammeri* (Calanoida) can be considered as South Polar species.

Quantitative values Average density of zooplankton per location was 30 specimen l^{-1}, average biomass 1.26 mg l^{-1}. Rotatoria dominate the Site 2 water bodies in number but not in biomass as in many lakes of Site 1. Biomass is dominated either by Cladocera or by Calanoida. Average mass of one zooplankton item in Site 2 lakes is 0.03 mg.

Pechora Delta floodplain (Site 4), 1997

Site 4 was visited in 1997; samples were taken on 24-26 June, at the end of phenologic spring and beginning of summer. Average water temperature in the water bodies was 13.1°C. Aquatic macrophytes were present but not very well developed yet. pH at Site 4 was 5.9-7.0. The share of Rotatoria species is relatively low. There were no species that tolerate low-saline conditions. Several northern and circumpolar species were found.

Species diversity We identified 34 species of water invertebrates of eight different taxonomic groups. There were Phyllopoda larvae in the samples, as well as Chydoridae, representatives of the littoral and phytophylic fauna. No single species dominated, the share of the main groups of zooplankton is comparable (Appendix 4, Table 3).

Quantitative values The average number in all the water bodies was ca. 75 specimen l^{-1}, average biomass ca. 1.6 mg l^{-1}. Average mass of one zooplankton item in Site 4 lakes is 0.01 mg.

Bolvanskii Nos (Site 5), 1997

Site 5 was visited only in 1997, samples were collected on 28 June-1 July. Average water temperature in the water bodies was 13.1°C. Aquatic macrophytes (*Potamogeton, Lemna, Nitella*) were present in many of the lakes. pH in the water bodies of Site 5 was 5.3-7.0, somewhat lower than at Site 4. Four water bodies get warm slowly. Water temperature rose from ca. 9°C on 28 June to ca. 15°C on 1 July.

Species diversity 37 species of aquatic invertebrates of eight different taxonomic groups were found. The share of the main zooplankton groups was comparable (Appendix 4, Table 4). The share of Rotatoria species is larger than at Site 4. Part of the species were phytophylic. The crustacean *Caenesteria salbergi* was till now only found in northern water bodies of Asiatic Russian. *Attheyella nordenskjöldi* is a species that prefers low-saline water.

Quantitative values Average number in all the water bodies of Site 5 was 30.8 specimen l^{-1}, average biomass 0.71 mg l^{-1}. Average mass of one zooplankton item in Site 5 lakes was 0.02 mg.

Peschanka-To (Site 6), 1997

The samples were collected on 5-7 July. Average water temperature in the water bodies of Site 6 was 6.8°C, pH 5.6-7.7. There were no aquatic macrophytes in the lakes. Water bodies 6.2, 6.7, 6.11b and 6.1 are connected to the bay and had high conductivity.

Species diversity 34 species of freshwater invertebrates of zeven taxonomic groups were discovered (Appendix 4, Table 5). Species composition is equally distributed between the groups. There are a few Rotatoria species. Five species of Harpacticoida were found, a rather high value for this taxon. Three species - *Tachidius littoralis, T. discipes* and *Mesochra rapiens* - are species of brackish waters. Phyllopoda were represented in relatively high numbers. The two most common *Anostraca, Polyartemia forcipata* and *Branchinecta paludosa*, are arctic species.

Quantitative values Average zooplankton density in the waters of Site 6 in 1997 was 22 specimen l^{-1}. Average biomass was 0.68 mg l^{-1}. These values are not unlike those of the waters that are not affected by floods at

Site 3 (1996), that also largely lacked rotifers. Calanoid copepods on the other hand, that were almost absent in these waters at Site 3, were present in all waters at Site 6. Both sites are situated in the coastal plain. Average mass of one zooplankton in the waters of Site 6 was 0.04 mg.

Peschanka-To (Site 6), 1998

Samples were collected on 2-24 August. Lake depth is not registered in the water bodies, but all of them were very shallow (<0.5 m). Average water temperature was 11°C, pH ranged from 5.5-8.8.

Species diversity 38 species and forms of aquatic invertebrates of five taxonomic groups were found (Appendix 4, Table 8). There were considerably less dithophylic species than in Sites 1 and 2. Rotatoria and Cladocera were highest in species number at Site 6, like in Sites 1 and 2. *Keratella cruciformis* (Rotatoria) prefers brackish waters. The waters of Site 6 had the highest number of species of Phyllopoda of all sites. Three species were only present with one or two specimen in one particular sample from location 6.3 (Appendix 4, Table 8). These were *Branchinecta minuta* and brackish water species *B. tolli* and *B. querneyi.B. tolli* is an arctic species, the two other species have a distinctly southern distribution; *B. minuta* inhabits temporary puddles of the forest-steppe zone of Europe, *B. querneyi* was recorded in the low-saline water bodies of the lower Wolga and near the Caspian Sea (Alexeev 1995). *B. paludosa* was much more common in the samples, it inhabits tundra water bodies of Euro-Asia (Alexeev 1995) and is even abundant in the water bodies of Novaya Zemlya (Vekhov 1999).

Quantitative values Average density of zooplankton was 59.9 specimen l^{-1}. Average biomass was 1.65 mg l^{-1}. Rotatoria dominate in number (some lakes are dominated by Calanoida or Cladocera as an exception). Calanoida and less frequently Cladocera dominated the zooplankton biomass. Average mass of one zooplankton item at Site 6 was 0.02 mg.

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