

# Arctic Rivers

## John E. Brittain

*Norwegian Water Resources and Energy Directorate, PO Box 5091 Majorstua, 0301 Oslo, Norway*  
*Natural History Museum, University of Oslo, PO Box 1172 Blindern, 0318 Oslo, Norway*

## Jim Bogen

*Norwegian Water Resources and Energy Directorate, PO Box 5091 Majorstua, 0301 Oslo, Norway*

## Ludmila G. Khokhlova

*Institute of Biology, Komi Science Centre, UrD RAS, 167982 Syktyvkar, Komi Republic, Russia*

## Kjetil Melvold

*Norwegian Water Resources and Energy Directorate, PO Box 5091 Majorstua, 0301 Oslo, Norway*

## Angelina S. Stenina

*Institute of Biology, Komi Science Centre, UrD RAS, 167982 Syktyvkar, Komi Republic, Russia*

## Gísli M. Gíslason

*Institute of Biology, University of Iceland, Askja-Natural Science Building, 101 Reykjavík, Iceland*

## Sturla Brørs

*Directorate for Nature Management, 7485 Trondheim, Norway*

## Sergej K. Kochanov

*Institute of Biology, Komi Science Centre, UrD RAS, 167982 Syktyvkar, Komi Republic, Russia*

## Jón S. Ólafsson

*Institute of Freshwater Fisheries, Keldnaholt, 112 Reykjavík, Iceland*

## Vasily I. Ponomarev

*Institute of Biology, Komi Science Centre, UrD RAS, 167982 Syktyvkar, Komi Republic, Russia*

## Arne J. Jensen

*Norwegian Institute for Nature Research, 7485 Trondheim, Norway*

## Alexander V. Kokovkin

*Institute of Social and Economic Problems of the North, Komi Science Centre, 167982 Syktyvkar, Komi Republic, Russia*

## Lars-Evan Pettersson

*Norwegian Water Resources and Energy Directorate, PO Box 5091 Majorstua, 0301 Oslo, Norway*

### 9.1. Introduction

- 9.1.1. Geology
- 9.1.2. Landscape
- 9.1.3. Climate
- 9.1.4. Hydrology
- 9.1.5. Water Chemistry
- 9.1.6. Biota

### 9.2. The Altaelva River

- 9.2.1. Physiography, Climate and Land Use
- 9.2.2. Geomorphology, Hydrology and Biogeochemistry
- 9.2.3. Biodiversity
- 9.2.4. Management and Conservation

### 9.3. The Tana River

- 9.3.1. Physiography, Climate and Land Use
- 9.3.2. Geomorphology, Hydrology and Biogeochemistry

- 9.3.3. Biodiversity

- 9.3.4. Management and Conservation

### 9.4. The Komagelva River

- 9.4.1. Physiography, Climate and Land Use

- 9.4.2. Geomorphology, Hydrology and Biogeochemistry

- 9.4.3. Biodiversity

- 9.4.4. Management and Conservation

### 9.5. The Varzuga River

- 9.5.1. Physiography, Climate and Land Use

- 9.5.2. Geomorphology, Hydrology and Biogeochemistry

- 9.5.3. Biodiversity

- 9.5.4. Management and Conservation

### 9.6. The Onega River

- 9.6.1. Physiography, Climate and Land Use

- 9.6.2. Hydrology and Hydrochemistry

- 9.6.3. Biodiversity
- 9.6.4. Management and Conservation
- 9.7. The Northern Dvina River**
  - 9.7.1. Physiography, Climate and Land Use
  - 9.7.2. Hydrology and Hydrochemistry
  - 9.7.3. Biodiversity
  - 9.7.4. Management and Conservation
- 9.8. The Mezen River**
  - 9.8.1. Physiography, Climate and Land Use
  - 9.8.2. Geomorphology, Hydrology and Hydrochemistry
  - 9.8.3. Biodiversity
  - 9.8.4. Management and Conservation
- 9.9. The Pechora River**
  - 9.9.1. Physiography, Climate and Land Use
  - 9.9.2. Geomorphology, Hydrology and Hydrochemistry
  - 9.9.3. Biodiversity
  - 9.9.4. Management and Conservation
- 9.10. The Geithellnaá River**
  - 9.10.1. Physiography, Climate and Land Use
  - 9.10.2. Geomorphology, Hydrology and Biogeochemistry
  - 9.10.3. Biodiversity
- 9.11. The Laxá River**
  - 9.11.1. Climate and Land Use
  - 9.11.2. Geomorphology, Hydrology and Biogeochemistry
  - 9.11.3. Biodiversity
  - 9.11.4. Management and Conservation
- 9.12. The Vestari Jökulsá River**
  - 9.12.1. Physiography, Climate and Land Use
  - 9.12.2. Geomorphology, Hydrology and Biogeochemistry
  - 9.12.3. Biodiversity
- 9.13. The Bayelva River**
  - 9.13.1. Physiography, Climate and Land Use
  - 9.13.2. Geomorphology, Hydrology and Biogeochemistry
  - 9.13.3. Biodiversity
  - 9.13.4. Management and Conservation

#### Acknowledgements

#### References

## 9.1. INTRODUCTION

Arctic regions of the world cover a substantial portion of the Earth's land mass and constitute one of the major biomes. Although annual precipitation is often low, streams, rivers, lakes and wetlands are particularly common and widespread due to low evaporation rates, widespread permafrost, and extensive melt water from snowfields and glaciers. Arctic river ecosystems (Figure 9.1) increase and decrease in tact with the Ice Ages and are therefore young in geological

terms. Since the last Ice Age many glacier-fed rivers have been replaced by snowmelt and rainfall dominated rivers; a change reflected in channel morphology, water quality and biota.

Arctic rivers are generally among the most pristine ecosystems worldwide. However, they are under increasing threat from global and regional anthropogenic impacts. Although often far removed from centres of industrial activity, they are subject to the long-range transport of persistent organic pollutants in addition to local sources of pollution. For instance, freshwaters in northern Norway have been severely affected by acidification as a result of emissions from smelters further east. The poor nutrient status of many arctic ecosystems makes them particularly vulnerable to uptake of contaminants. Rivers along the northern coastlines of Eurasia are also key transport pathways, carrying pollutants from contaminated land areas, such as those associated with weapons production, out into the continental shelves of the northern oceans (AMAP 2004a,b, 2005a). The fish resources of Arctic rivers have been exploited by man for centuries, and catches of migrating salmonids have been important for many indigenous peoples. However, the introduction of exotic species and stocking with genetically foreign strains has been widespread. Recreational fishing is now becoming an important industry in many Arctic rivers.

Climate change is also impacting the Arctic and current climate change scenarios indicate proportionally greater impacts at high latitudes (AMAP 2005b). In non-glacial rivers water, temperatures are expected to rise. In addition, increasing air temperatures may also disrupt permafrost leading to changes in runoff characteristics and favouring formation of groundwater storages. In contrast, increased glacier ablation will, at least in the short term, result in decreased water temperature and therefore a downstream expansion of the kryal fauna (McGregor et al. 1995).

Arctic areas also contain major water resources that have been extensively exploited. The construction of dams and reservoirs for hydropower development has impacted many arctic rivers (Dynesius & Nilsson 1994), often leading to changes in water flow and temperature. The construction of dams also interrupts the river continuum and has been responsible, at least in part, for the decline of many migratory fish populations. Arctic rivers have also been used for transport of timber from forested inland areas, resulting in dam construction and canalisation. Flood protection measures, although less widespread than elsewhere in Europe, have also been instigated in some arctic rivers where infrastructures are at risk.

The Arctic Circle (66°N 32'W) inadequately represents the Arctic region due to the effects of ocean currents and land mass topography influencing climate. Northwestern Europe is strongly influenced by the warm waters of the Gulf Stream, making the climate relatively mild in

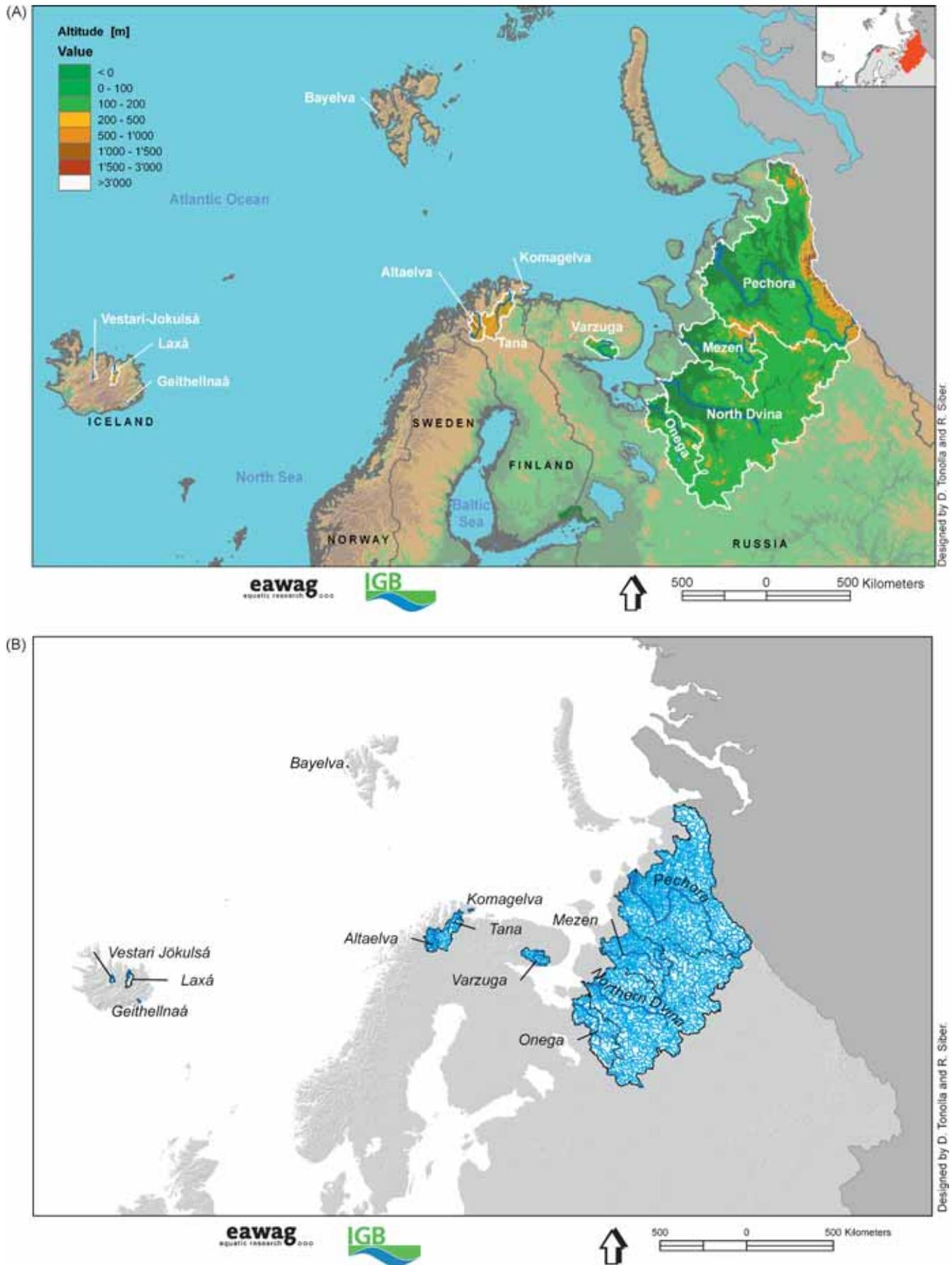


FIGURE 9.1 Digital elevation model (upper panel) and drainage network (lower panel) of Arctic Rivers.

winter. Hence, the Arctic is better defined as areas north of the treeline, typically approximating a mean July isotherm of 10 °C. The Arctic can be divided into the High and the Low Arctic. The High Arctic typically refers to various islands lying within the Arctic Basin, such as the Svalbard archipelago. Deforestation in much of Iceland has created treeless areas that are often classed as subarctic as they possess many characteristics in common with the true arctic. The subarctic also includes a transitional zone between the continuous closed canopy woodlands of the boreal forest and the treeless arctic tundra. This transitional zone is wide in Eurasia where it can extend for 300 km.

### 9.1.1. Geology

The geology of the European Arctic is varied. Norway's northernmost area, the county of Finnmark, has a complex geology. In the south and eastern parts eroded Precambrian bedrocks give rise to gentle slopes and rounded terrain forms. To the northwest, including the Varanger Peninsula, these bedrocks are overlain by sedimentary rocks, while further west hard gabbros characterize an alpine landscape. Glacial deposits are extensive and there are substantial gravel and sand deposits in the main valleys and on the Finnmarksvidda. Further east on the Kola Peninsula the bedrock is dominated by granite and gneiss of the Baltic Shield, although there are again extensive Quaternary deposits. The Dvina and Mezen basins are characterized by Permian, Triassic and Jurassic sandstones overlain by extensive Quaternary deposits. Further east the Pechora basin, bordered by the Timansky Ridge to the west and the Urals to the east, is known for its oil, gas and coal deposits. During the last major glaciation the major rivers of northwest Russia were blocked by the continental ice shelves of the Barents Sea, forming a huge inland sea, Lake Komi, which probably had its outlet into the Baltic Sea, although the final emptying of the lake occurred through the Pechora valley and the White Sea (Maslenikova & Mangerud 2001).

Iceland is almost entirely of volcanic origin, and its bedrock is 80–85% basalt lava. The island straddles the Mid-Atlantic Ridge, marking the boundary between the North American and Eurasian tectonic plates. The active volcanic zones run through the island from southwest to northeast giving rise to lava flows, geysers and hot springs. Glaciers cover approximately 11% of the island (Einarsson 1994; Saemundsson 1979). Svalbard is a mountainous archipelago dominated by snow and ice and some 60% is covered by glaciers and icefields. The geology is varied, Precambrian, Cambrian and Ordovician basement rocks predominating along the west coast and in the northeast, while much of the archipelago is dominated by sedimentary rocks, Devonian, Carboniferous–Cretaceous and Tertiary strata. The latter contains layers of

coal that form the basis of the coal mining industry on Svalbard.

### 9.1.2. Landscape

Landscape forms are very different throughout the European Arctic. The western parts of Finnmark reach altitudes >1000 m asl and are characterized by deep valleys, steep slopes and glaciers. In contrast, the central parts of Finnmark and the Kola Peninsula have much more gentle terrain forms and are characterized by thousands of small lakes and pools, birch forest and extensive lichen heaths. Several fjords, Altafjord, Porsangerfjord, Laksefjord, Tanafjord and Varangerfjord, cut deep into this plateau-like landscape. To the southeast there are large tracts of open pine forest. These are the western outliers of the Taiga forests that stretch eastwards in a band across Russia all the way to the Pacific. Out towards the coast, on the Nordkinnhalvøya and the Varangerhalvøya birch forests give way to arctic tundra.

Further east inland there are extensive undulating plains with a mosaic of rivers, lakes and bogs that stretch all the way to the Urals. Most of the plains are forested, but towards the coast in the east the forests give way to arctic tundra. There are extensive areas of permafrost in the lower part of the Pechora basin, notably in the northeast.

About 60% of Iceland is a highland plateau >400 m asl. Coastal lowlands generally extend for only a short distance inland. Fjords cut deep into the plateau in the west, north and east, whereas these are extensive lava flats and alluvial plains in the south (Landmǫlingar Íslands 1993). Cultivated land is limited to 1.4% of the island (Upplýsingathjonusta landbunadarins 1994), while urban areas cover only 0.07%. After 1100 years of human activity, birch forest (*Betula pubescens*) now only covers about 1% of the island (Steindorsson 1964), although the treeline is around 400 m asl.

### 9.1.3. Climate

Although located at 69–70°N, the coastal areas of Finnmark, especially in the west, are influenced by the Atlantic, giving rise to milder winters and cool summers. The inner parts of the fjords and the inland areas have a much more continental climate, with colder winters, warmer summers and lower precipitation. Further east the climate gets progressively cooler as the Atlantic influence decreases and this trend continues through the Northern Dvina, Mezen and Pechora basins. Winters are cold, although summers are warm in the more inland areas to the south.

Iceland, situated at 63°25'–66°32'N, has a cool temperate maritime climate and average temperatures of the warmest month exceed 10 °C only in the lowlands of the south and west, while in winter the coastal lowlands have a mean temperature close to 0 °C. Annual precipitation varies from <600 mm in the north to in excess of 4000 mm over the highest icefields.

The Svalbard Archipelago, located between 76 and 80°N and only 1000 km from the pole, has long winters with several months of constant darkness and short summers with midnight sun. The islands are influenced by the Gulf Stream and low pressure weather systems that track into the North Atlantic, and even during winter the western parts can experience periods with rain and temperatures over 0 °C. However, summers are short, even in coastal areas. Snowmelt takes place during May and June and subzero temperatures usually return in September. During winter, extensive sea ice forms in the fjords and along many coastal areas.

#### 9.1.4. Hydrology

Three main types of running water ecosystems have been identified between the permanent snowline and treeline (Steffan 1971; Ward 1994): the kryal, or glacier-melt dominated system; the rhithral, or seasonal snowmelt-dominated system; and the krenal, or groundwater-fed system. Snow and ice cover varies significantly over small spatial scales, and different stream and river reaches will display characteristics that reflect the relative proportions of the three principal runoff sources (Brown et al. 2003). In High Arctic areas such as Svalbard, groundwater is limited by the widespread distribution of permafrost, but in areas further south it may be extensive. The proportion of these three water sources explains much of the spatial and temporal heterogeneity of biotic communities in Arctic rivers (Milner et al. 2001).

In Arctic regions there is a close and interactive relationship between streams and their catchments. The significance of these interactions varies with changes in terrestrial vegetation and the extent of permanent snowfields and glaciers (Power & Power 1995). The input of allochthonous terrestrial plant material to aquatic ecosystems is greatest in sub-arctic areas, but may also be significant above the treeline where riparian vegetation, frequently of willows, can be extensive. Rivers in the European Arctic vary considerably in size, from the large rivers of northern Russia to the multitude of small and medium-sized rivers typical of northern Scandinavia. The rivers of Iceland and the Svalbard archipelago are typically short, but may seasonally display high flows as a result of snow and ice melt. Huge glacial outburst floods (Jökulhlaup) may occur in glacial rivers, notably in Iceland, often completely reforming river channels and transporting huge amounts of sediments downstream. Significant freshwater discharges into coastal marine areas arise from tundra regions of northern Russia many of these rivers also carry considerable amounts of sediments into estuarine and marine environments.

Icelandic rivers have been divided into three categories (Kjartansson 1945, 1965): glacial rivers with high summer discharge, extensive sediment transport, high turbidity and unstable substrates (Pálsson & Vigfusson 1991); direct runoff rivers found in catchments with bedrock of low permeability, with increasing influence of groundwater in the low-

lands and highest discharge during the spring thaw; and spring-fed rivers, the most common type close to the edges of the permeable bedrock within the neo-volcanic zone, particularly emerging under edges of post-glacial lava, often connected to fissure systems formed by tectonic movements (Sigurdsson 1990), and characterized by low annual fluctuations in discharge and relatively stable river beds.

Many arctic rivers in northern Europe originate in temperate and boreal forests and, in contrast to most rivers, environmental conditions, such as water temperature and ice conditions often become more severe as they flow northwards towards the sea. Hydrological regimes are typified by the contrast between extremely low winter flows and the high discharges associated with spring snowmelt and the summer glacial melt season (Table 9.1, Figures 9.2 and 9.3).

#### 9.1.5. Water Chemistry

The chemistry of European arctic waters varies considerably, depending on geology, although nutrient levels are generally low throughout the region. The rivers in northern Norway and the Kola Peninsula that lie on the Baltic Shield have low levels of dissolved solids. Further east, several rivers originate in karst areas, giving much higher concentrations. The same is true of the rivers on Svalbard that lie on sedimentary rocks. Icelandic rivers vary in their chemical composition, largely depending on whether they originate from or flow through volcanic areas. In volcanic areas total dissolved solids (TDS), as well as phosphate and/or nitrate concentrations are naturally high.

#### 9.1.6. Biota

Water temperatures in arctic rivers are invariably low and fall with increasing altitude and latitude, although there are major differences between kryal and rhithral streams; often as much as 10 °C during summer. Low temperatures combined with high sediment load and channel instability serve to make glacier-fed rivers amongst the most inclement of habitats for aquatic biota (Brittain & Milner 2001). Snow and ice is a particular feature of arctic rivers, creating unique environmental conditions that have led to the development of many adaptive mechanisms among the biota (Füreder 1999; Prowse 2000), although winter conditions inevitably cause high mortality, especially in reaches susceptible to formation of frazil and anchor ice. The lack of nutrients, limited allochthonous inputs, low temperatures and the long period of ice and snow cover limits species richness, biomass and productivity. In general, species richness and ecosystem productivity decrease with increasing latitude (Castella et al. 2001). The extensive glaciation and the isolation of Svalbard and Iceland has also hindered colonisation and thereby limited biodiversity, both of fish and invertebrates (Milner et al. 2001; Gíslason 2005). On Iceland there are only one species each of Plecoptera and Ephemeroptera, 11 species of

TABLE 9.1 General characterization of the Arctic Rivers

	Pechora	Mezen	Northern Dvina	Onega	Varzuga	Komagelva	Tana	Altaelva	Geithellnaá	Laxá	Vestari-jökulsá	Bayelva
Mean catchment elevation (m)	161	137	143	135	158	293	330	462	625	436	679	243
Catchment area (km <sup>2</sup> )	322 000	78 000	357 000	56 900	9510	321	16 380	7389	187	2385	840	33
Mean annual discharge (km <sup>3</sup> )	138.0	27.1	109.0	16.9	2.4	0.3	6.4	3.1	0.6	1.8	0.7	0.04
Mean annual precipitation (cm)	52.8	56.9	59.9	62.9	55.3	64.9	54.0	56.4	138.6	47.8	40.8	74.3
Mean air temperature (°C)	-3.5	-0.9	0.9	1.7	-0.5	-0.9	-3.1	-3.8	2.48 <sup>a</sup>	2.2 <sup>a</sup>	-0.1	-6.3
Number of ecological regions	3	1	2	1	1	2	2	2	1	1	1	1
Dominant (≥25%) ecological regions	51; 60	60	60	60	60	44; 62	60; 62	60; 62	38	38	38	5
Land use (% of catchment)												
Urban	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Arable	0.1	6.4	7.2	19.4	0.5	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Pasture	0.3	24.8	0.0	11.3	20.2	30.9	26.6	66.7	0.5	1.6	1.0	0.0
Forest	53.1	56.5	90.6	51.9	49.9	0.8	33.1	16.9	3.3	3.9	0.0	0.0
Natural grassland	42.5	0.0	0.5	0.0	0.0	0.0	22.1	1.4	16.2	34.5	8.0	0.0
Sparse vegetation & barren	0.5	0.0	0.0	0.0	0.0	51.7	10.2	4.8	68.0	55.7	77.9	52.4
Wetland	1.4	11.9	0.0	14.7	26.2	16.6	6.1	7.8	0.0	0.5	1.0	0.0
Freshwater bodies	2.1	0.4	1.6	2.6	3.2	0.0	1.9	2.3	0.4	3.8	1.3	0.3
Glacier	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.6	0.0	10.8	47.3
Protected area (% of catchment)	12.2	6.2	5.2	6.1	23.7	93.5	33.0	1.0	0.0	8.4	0.0	0.0
Water stress (1–3)												
1995	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2070	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Fragmentation (1–3)	2	1	1	1	1	1	1	2	1	2	1	1
Number of large dams (>15 m)	2	0	0	0	0	0	0	1	0	0	0	0
Native fish species	35	27	34	28	20	4	17	14	1	5	1	0
Non-native fish species	2	1	6	4	1 <sup>b</sup>	1 <sup>b</sup>	4 <sup>c</sup>	2 <sup>b</sup>	0	0	0	0
Large cities (>100 000)	1	0	3	0	0	0	0	0	0	0	0	0
Human population density (people/km <sup>2</sup> )	2	0	5	3	0	0	0	2	0	1	0	0
Annual GDP (\$ per person)	2928	2929	2873	2929	2929	34 076	30 710	33 981	31 325	31 325	31 325	n.d.

Precipitation and mean annual temperatures for the Laxa and Vestari-jökulsá are based on data from the Icelandic Meteorological Office, Reykjavik. Land use for Geithellnaá, Laxá and Vestari-jökulsá based on information from G. Gudjonsson, Institute of Natural History, Reykjavik. Data on forest cover in Iceland: Iceland Forest Research Station data base.

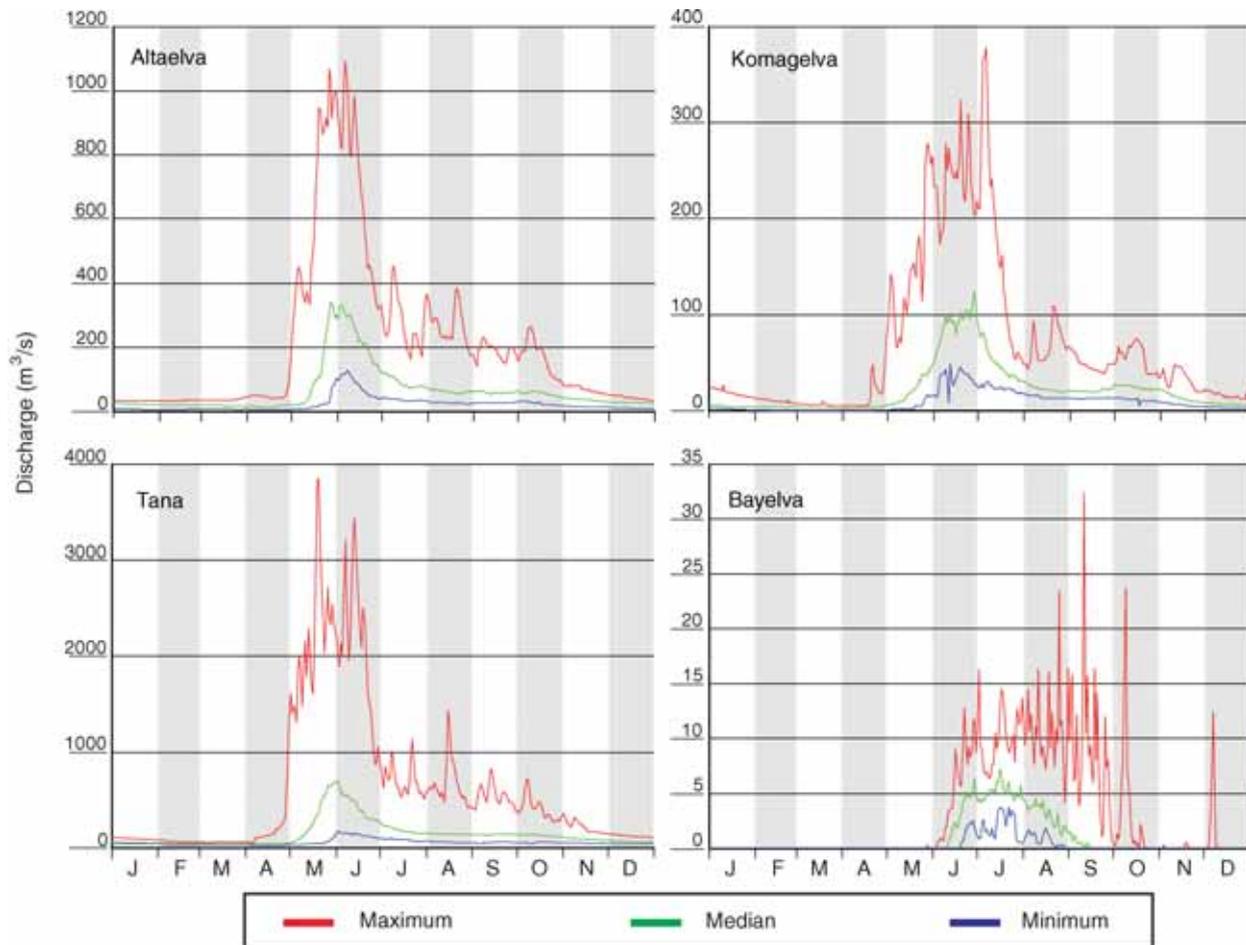
<sup>a</sup> Mean for whole catchment.

<sup>b</sup> One species is not reproducing.

<sup>c</sup> Three species are not reproducing.

For data sources and detailed explanation see Chapter 1.

n.d.: no data



**FIGURE 9.2** Annual discharge patterns for selected Arctic rivers: Altaelva (1971–2004), Komagelva (1980–2003), Tana (1911–2004) and Bayelva (1990–2004). The discharge patterns for Komagelva are based on discharge data from the gauging station at Båtsfjord in a neighbouring catchment to the north.

Trichoptera, 4 Simuliidae, 80 species of Chironomidae and 5 species of Coleoptera. Of these, only Plecoptera, 5 species of Trichoptera, all Simuliidae species and 41 species of Chironomidae occur in running waters (Tuxen 1938; Peterson 1977; Gíslason 1981; Lillehammer et al. 1986; Hrafnisdóttir 2005). Svalbard has only a single trichopteran, *Apatania zonella*, a dubious record of an ephemeropteran and no Plecoptera (Coulson & Refseth 2004). In the arctic rivers of mainland Europe the biota becomes progressively more diverse as one moves eastwards and inland, with the lowest number of taxa along the Atlantic coast and the highest diversity in the continental Russian river catchments such as the Pechora. Grazers, notably chironomids, but also mayflies and caddisflies, are the dominant functional feeding group in alpine and arctic rivers owing to the lack of riparian vegetation, although in the low alpine/arctic the presence of riparian vegetation alongside the streams gives rise to a significant allochthonous input that is utilised by shredders, such as stoneflies (Peterson et al. 1995).

In many European Arctic rivers salmonids (e.g. Atlantic salmon, brown trout, whitefish, grayling and Arctic char) are the most important fishes, both in terms of the number of species and in terms of their significance in sport and

commercial fisheries (Figures 9.4 and 9.5). The number of fish species is greatest in the large Russian rivers to the east and least in the islands of Svalbard and Iceland. There are six freshwater fish species in Iceland, all occurring in running waters: Atlantic salmon (*Salmo salar*), brown trout (*Salmo trutta*), Arctic charr (*Salvelinus alpinus*), the three-spined stickleback (*Gasterosteus aculeatus*), European eel (*Anguilla anguilla*) and its hybrid with the American eel (*A. rostrata*) and the European flounder (*Platichthys flesus*) (Gudbergsson & Antonsson 1996; Albert et al. 2006; Bjarni Jonsson, personal communication). Many salmonid fish populations undergo upstream migrations into arctic rivers from the sea which can represent a substantial input of marine derived nutrients to nutrient poor systems (Kline et al. 1997; Stockner & Macisaac 1996).

## 9.2. THE ALTAELVA RIVER

The Altaelva River is the third largest river in northern Norway, and the sixth in Norway. It is a sixth order river and the catchment covers 7389 km<sup>2</sup>. The official name of the catchment is Alta-Kautokeinovassdraget, while the lower

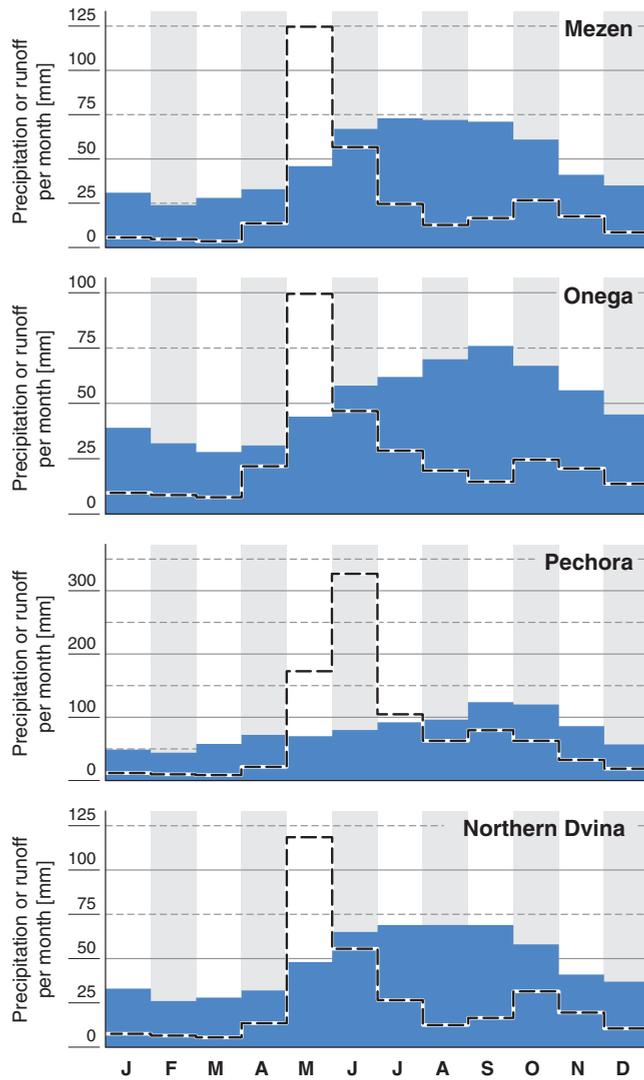


FIGURE 9.3 Seasonal patterns in precipitation and runoff in selected Arctic rivers.

47 km of the river, as far as Atlantic salmon migrates, is called Altaelva. Further upstream, the river is known as Kautokeinoelva, but in this context the entire river is called the Altaelva River. The river originates near the Finnish border, flows primarily in a north direction, and empties into the innermost part of the Alta Fjord (70°N 23°E). The extensive plateau, Finnmarksvidda, at 300–500 m asl forms a large part of the drainage.

The catchment is within the core area for the Sami people in Norway, and hence also a central area for reindeer husbandry. Remains of a 10 000 year old culture, called the ‘Komsa’ culture, after the initial finds at Alta, are the oldest traces of ancient people in Norway. It has not been proven that these people were ancestors of the Sami people (Anon. 1994). In Alta, >5000 rock carvings, the oldest dated around 4200 BC, have been uncovered in later years (www.alta.museum.no) and are listed on the UNESCO’s World Heritage List.

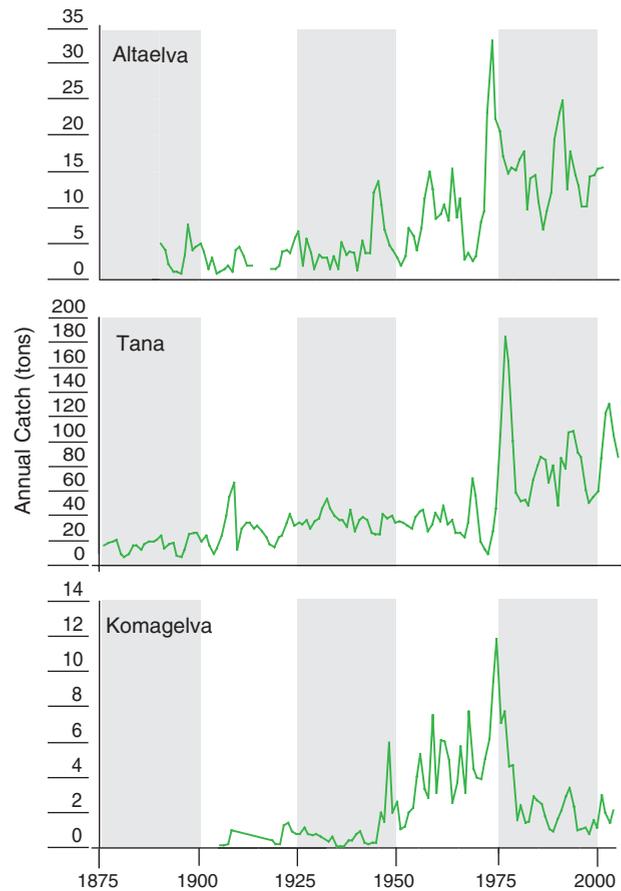


FIGURE 9.4 Annual catch of anadromous salmonids in selected northern Norwegian rivers.

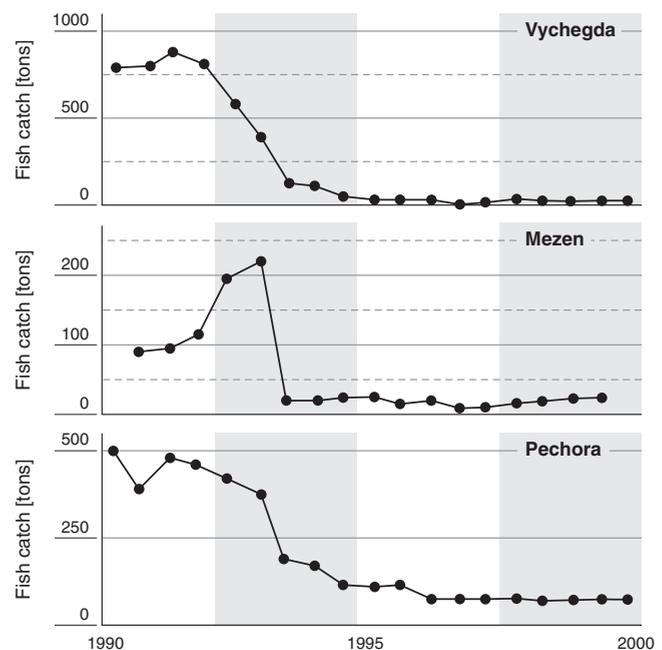


FIGURE 9.5 Annual fish catch between 1990 and 2005 in selected Arctic rivers. Vycheгда is a tributary of the N. Dvina.

The Altaelva is one of the most important salmon rivers in Norway. Written information about the Altaelva salmon exists from the 16th century, when the salmon fishery was owned by the king. In the middle of the 19th century, British people introduced sport fishery for salmon, and the river is now internationally famous for its sport fishery (Eikeset et al. 2001). After much controversy, especially with regard to the rights of the Sami people and the Altaelva salmon, a hydro-power station was built on the river in 1987. The outlet of the power station is located at the top of the anadromous reach, 47 km from the sea. As a result, the temperature and flow regimes have been somewhat altered downstream, and the Atlantic salmon catches decreased in the area below the dam during the first 10 years of impoundment. However, in later years there are indications of recovery.

### 9.2.1. Physiography, Climate and Land Use

About 30% of the catchment is covered by birch forest with treeline at 450–500 m asl and the rest by lichen heath, bed-rock, bogs and numerous lakes. Agriculture is concentrated in the lower part of the river and around the communities of Kautokeino and Masi and covers only 0.03% of the catchment. About 17 000 people live within the catchment, most in the communities of Alta (pop. 9000) and Kautokeino (pop. 2000). There is little pollution, except some sewage downstream of Kautokeino (Traaen et al. 1983).

The climate is influenced by the Gulf Stream, especially near the coast, with higher temperatures and more precipitation than inland areas, which have a more continental climate. At Alta, at the river mouth, annual mean precipitation is 420 mm, while the upper part of the catchment is among the driest areas of Norway, with an annual precipitation of 360 mm in Kautokeino (Norwegian Meteorological Institute). Most precipitation occurs in summer (June–September), especially in inland areas. The mean July temperature is 12.4 °C in Kautokeino and 13.5 °C in Alta. The mean January temperatures are –15.9 and –9.02 °C, respectively.

Finmark County is the main area for reindeer husbandry in Norway. In the West Finmark Reindeer District, of which the Alta–Kautokeino drainage is a major part, more than 1000 people are involved in reindeer husbandry, and in 2003 about 79 000 reindeer were present in this district. Almost the entire catchment, except the lower part of the valley near the main river, is used for reindeer grazing (Størset et al. 2004). Use of the natural resources, and other kinds of outdoor recreation, has a long tradition in the area and includes fishing, hunting, and berry picking, especially cloudberries.

### 9.2.2. Geomorphology, Hydrology and Biogeochemistry

The geology of the catchment is varied. The lower part is characterized by Eocambrian metamorphosed sedimentary rocks, especially gneiss near the coast. In the upper part there

are largely crystalline basement Pre-Eocambrian rocks, admixed with some basic rock types, giving circumneutral waters (Traaen et al. 1983). Much of the inland plateau is overlain with moraine deposits, while there are substantial glacial and marine deposits near the fjord.

Two main branches of the river, one from northwest and the other from south, have their confluence 7 km downstream of Kautokeino. The headwaters of the northwest branch are ~750 m asl. The first 20 km are rather steep (1.8%), but the river levels off on the Finnmarksvidda at ~400 m asl. The south branch has its headwaters at ~400 m asl in the interior of the plateau. The drainage from thousands of small lakes and ponds scattered throughout the plateau flows into the Kautokeino River. From the village of Kautokeino to the hydropower dam at Virdnejavri, a distance of ~80 km, the fall is only 35 m. This part of the river is characterized by an almost continuous row of lakes, interrupted by riffles. The Virdnejavri dam was built across the valley in the upper part of the largest canyon in northern Europe (Photo 9.1). The outlet of the hydropower station is located at the limit for anadromous salmonids, 47 km from the sea. From here, the river flows rather rapidly to the sea, with an average gradient of <0.2%.

The hydrological regime of the Altaelva River is characterized by high flows in early summer (May–June) and low flows in winter (Figure 9.2). The highest floods always occur during snowmelt and floods of more than 1000 m<sup>3</sup>/s are common (Magnell 1998). Rain-caused floods in late summer or autumn are rare and relatively small. At the outlet into the fjord (catchment area 7389 km<sup>2</sup>), the mean annual discharge is 99 m<sup>3</sup>/s (specific discharge 13.4 L/s/km<sup>2</sup>). The highest observed floods were in late May 1920 and in mid-June 1917 with daily discharges of 1302 and 1225 m<sup>3</sup>/s, respectively. After the hydropower regulation in 1987, the annual flow regime changed, with higher discharge during winter and slightly lower discharge during the spring flood.

The main river is covered with ice from November to May, although 5–7 km of the river downstream of the outlet of the power station is usually ice-free throughout most of the winter. The ice run in spring is now earlier than before regulation. Water temperatures are near zero from mid-November until late April, increasing during May/June, and reaching a maximum of about 14 °C in August. After regulation, water temperatures downstream have decreased during June and July, but have increased in late summer and early autumn due to the moderating effect of the hydropower reservoir. Just below the power station, temperatures have increased somewhat during winter. The tributary, Eibyelva, entering into the main river in the lower part of the catchment shows a similar temperature pattern as in the main river, except in the autumn. River waters are characterized by rather high alkalinity (200–400 CaHCO<sub>3</sub><sup>-</sup> μeq/L), and pH is usually above 7.0 (Traaen et al. 1983). Nitrate and phosphate concentrations are low throughout the catchment.



**PHOTO 9.1** Looking up the famous canyon on the Altaelva River (Photo: R. Pytte Asvall).

### 9.2.3. Biodiversity

In connection with the creation of the hydropower reservoir, there was an increase in the green alga, *Microspora amoena*, as a result of increased phosphorous concentrations (Ugedal et al. 2005). This effect has now decreased and algal communities are now dominated by the green alga *Ulothrix zonata* and the diatom *Didymosphaenia geminata*.

In connection with hydropower development, invertebrates have been thoroughly investigated in the lower part of the river. Densities were rather high for the region, with Chironomidae, the predominant group, followed by Ephemeroptera, Trichoptera and Plecoptera (Bergersen 1989; Ugedal et al. 2005). A correlation between algal biomass and invertebrate density has been shown (Koksvik & Reinertsen 2008) and after the initial increase in benthic densities as a result of increased algal growth, benthic densities have now decreased to pre-regulation densities. In total, 16, 21 and 18 species of Ephemeroptera, Trichoptera and Plecoptera, respectively, have been recorded in the lower part of the river. *Baetis rhodani*, *Ephemerella aurivillii*, *E. mucronata*, *Diura nansenii*, *Leuctra fusca*, *Rhyacophila nubila* and *Arctopsyche lagodensis* are the most numerous species (Ugedal et al. 2005; Koksvik & Reinertsen 2008). The stonefly fauna of the catchment is well documented (Lillehammer 1974, 1988) and in the upper part of the catchment 27 species have been recorded. *Asellus aquaticus* has been recorded from the upper part of the catchment (Walseng & Huru 1997).

The freshwater snail, *Valvata sibirica*, classified as rare in the Norwegian Red List, has been recorded near Kautokeino (Walseng & Huru 1997). The stonefly, *Nemoura viki*,

considered as rare in the Red List, is known from the Kautokeino area (Lillehammer 1972).

There are 14 native fish species in the river (Jensen et al. 1997). These species can be divided into two groups based on their immigration history. Atlantic salmon, brown trout, Arctic char, eel, three-spined stickleback and flounder immigrated from west and north, through marine waters. The other group, called the Finnmark species (whitefish, pike, minnow, burbot, perch and nine-spined stickleback), spread from the southeast from the Ancestral Sea in the Baltic area after the Ice Age (Huitfeldt-Kaas 1918).

Atlantic salmon is the most important species in the anadromous section of the river (46 km), both economically and socially. The organisation of the sport fishery for salmon in this river is distinct. The fishing rights are owned by an organisation called 'Alta Laksefiskeri Interessentskap (ALI)'. All people possessing or leasing agricultural land in the Alta valley sufficient to feed at least one cow can be members. The profit is divided equally between all members independent of property size. The fishing season lasts from 1 June to 31 August. Fishing permission is based on a combination of exclusive letting and selling of licenses on a daily or weekly basis. The number of fishing licenses is limited. Most daily and weekly based licenses are sold through a lottery to local people. There is also a sea trout fishery in the river, with annual catches of 1–2 tons.

The Alta salmon is famous for its large size, with an average weight up to 10 kg in some years. Based on the annual catch, the Alta is one of the five best salmon rivers in the Arctic region (Figure 9.4). From 1891 to 2003, the mean annual recorded catch of anadromous salmonids

(Atlantic salmon, brown trout and Arctic charr) was 7.8 tons. Atlantic salmon comprised 86% of the catch since 1983. The average annual catch from 1974 to 2004 was 15 tons. Females are usually larger than males in the river because they stay longer at sea before they return to the river to spawn. Most males return after only 1 year at sea, while most females stay 3 years at sea before they mature and return to the river. The mean weight of 1-sea-winter (1SW) salmon in the period 1993–1997 was 2.0 kg. For 2SW, 3SW and 4SW fish in the same period, mean weights were 6.5, 10.5 and 14.5 kg, respectively (Jensen et al. 1998). The largest salmon ever caught weighed 27.1 kg.

Thousands of lakes with good fishing in both summer and winter are located on the Finnmarksvidda. The main species are brown trout, Arctic charr and whitefish.

Grayling was introduced to the river basin from the River Tana during the 1920s (Berg 1964). Pink salmon are also occasionally caught in the river, but reproduction has not been documented. This species has penetrated westwards from the Kola Peninsula, Russia, where it has been introduced on several occasions since the 1960s (Berg 1977).

Only one amphibian, the common frog, is present in the watershed.

### 9.2.4. Management and Conservation

The Altaelva River has been exploited for hydropower since 1987, with an annual production of ~700 GWh. A 110-m high dam was constructed across the main river 5 km downstream from the original outlet of Lake Virdejavri, 50 km from the sea. The lake surface has been raised 15 m. The length of the reservoir is ~18 km, with a total regulation height of 20 m and a volume of  $135 \times 10^6 \text{ m}^3$ . The power station is near the dam, and the outlet at the upper end of the salmon producing area, 2.5 km downstream of the dam. The power station has an upper and a lower inlet, and because of reservoir stratification, water temperature in the river downstream can be modified. Just downstream of the dam, in the Sautso area, catches of Atlantic salmon have decreased after regulation, although not in other parts of the river (Ugedal et al. 2005). The regulation scheme is being revised to reduce the effects of temperature and flow changes on ice conditions and fish. The river has recently been designated a National Salmon River, giving the salmon population and its habitat additional focus in the management of the river.

There are 19 km of flood protection embankments along the lower river, many built in connection with hydropower development. Recently, work has started to improve the quality and lessen the environmental impact of these embankments. Above Virdejavri, the catchment is protected against further exploitation for hydropower by the National Protection Plan for River Systems (Anon. 1976). Eibyelva and other tributaries from the west below the dam are also protected. The outflow into Altafjord is on the monitoring list of river deltas compiled by the Norwegian

Directorate for Nature Management. The delta is an important transit site for wetland birds (Nordbakke 1983).

The catchment has several plant species with distinct eastern distributions, notably the protected *Oxytropis deflexa* (Pall), not found elsewhere in Europe and represented by an endemic subspecies, *O. deflexa norvegica*. One of the two populations of this endemic subspecies has been reduced by the damming of the Alta River to form Virdejavri reservoir (Elvebakk 2006).

## 9.3. THE TANA RIVER

The sixth order subarctic border river between Norway and Finland, the Tana (Tenojoki in Finnish), has a catchment area of 16 380 km<sup>2</sup>, of which 5092 km<sup>2</sup> is in Finland (Siirala & Huru 1990). The Tana flows northwards to the Tana Fjord on the Barents Sea at 70°47'N, 28°25'E. The name Tana comes from the Sami word, *Deatnu*, meaning 'big river', and is actually the name of the river from the junction of the major tributaries Kárásjohka and Anárjohka (Inarijoki in Finnish), that drain a large part of the plateau, Finnmarksvidda. The river forms the border between Norway and Finland for 283 km, but the lowermost 77 km of the river is solely in Norway (Siirala & Huru 1990) and the last 18 km are tidal. Iesjávri, 390 m asl, the largest lake in the catchment with an area of ~55 km<sup>2</sup>, drains to the major tributary Iesjohka.

The Tana probably supports one of the largest stocks of Atlantic salmon in the world (Niemelä 2004), as well as the world's highest annual Atlantic salmon catch at an estimated 70 000–250 000 kg (Figure 9.4). The river valleys and aquatic habitats are virtually pristine, and the only human impact affecting the salmon is fishing (Niemelä 2004). However, long stretches of the main stem have sandy substrate and low gradient, making them unsuitable for salmon production. Erosion is significant and huge sand banks build up in the river mouth, providing suitable habitat for up to 30 000 male goosanders during the moulting period in late summer and autumn (Svenning et al. 2005). The valleys of the Tana and its tributaries represent a core area for Sami culture and language. The catchment is sparsely populated (0.5/km<sup>2</sup>), with a total of ~7000 people, of which ~5500 live in Norway ([www.ssb.no/fob/kommunehefte](http://www.ssb.no/fob/kommunehefte)). Most people live in the villages of Utsjoki, Nuorgam and Karigasniemi on the Finnish side, and Karasjok and Tana Bru in Norway.

### 9.3.1. Physiography, Climate and Land Use

Bedrock in the lower 50 km of the river is little altered Eocambrian sedimentary rocks, while in the greater part of the catchment Precambrian rock complexes dominate. The river valley and much of the catchment is covered by Quaternary Ice Age deposits. Marine sediments, clay and silt, occur largely up to Storfossen (Alakongäs), but reach up to 90 m asl at Utsjoki. Glacio-fluvial deposits with coarse sand and gravels dominate upstream, although there are also areas

with fine glacio-lacustrine sediments (Fergus & Rönkä 2001).

The climate, especially in the southernmost part of the catchment, is continental, characterized by long winters and relatively warm summers (Fergus & Rönkä 2001). The lowest air temperature ever recorded in Norway,  $-51.4^{\circ}\text{C}$ , was in Karasjok in 1886, while the lowest recorded monthly mean temperature was  $-27^{\circ}\text{C}$  in February 1966, also in Karasjok (Fergus & Rönkä 2001). There is a climatic gradient from the coast, with long-term January/July mean air temperatures of  $-12.2/12.3$  and  $-17.1/13.1^{\circ}\text{C}$  at Rustefjelbma (10 m asl at the river mouth) and Karasjok (169 m asl), respectively (Norwegian Meteorological Institute). The climate is dry with an annual precipitation of 350–450 mm, most falling during summer and especially in inland areas.

The highest mountains are the Gaissat ( $\sim 1000$  m asl) in the western part of the catchment, although most of the catchment lies at 200–400 m asl (Fergus & Rönkä 2001). Forest and alpine tundra each cover about 40% of the catchment and wetlands 10% (Fergus & Rönkä 2001). The tree-line is 20–30 m asl at the coast increasing to 400 m asl further inland. Most of the forest is birch, but along Utsjoki, Kárásjohka, Anárjohka and the main stem down to Levajok, open pine forests dominate. A mosaic of wetlands, lichen heaths and birch forest is typical in much of the southwestern catchment, especially along Iesjohka.

Stone walls to gather and lead wild reindeer towards and over cliffs have been found in or near the river valley (Vorren 1958), and have been dated to  $>4000$  years BP (Furset 1995). Until the 17th century, the Sami people were almost the only inhabitants and they administered the fisheries themselves (Steinar Pedersen, personal communication). Salmon was a valuable resource, attracting traders from countries such as Holland (Pedersen 1986). The present national border, at that time between Denmark and Sweden, was drawn up in 1751, but the Sami people continued to fish more or less as before (Pedersen 1991).

The Sami people of the river valleys developed the nomadic way of reindeer husbandry during the second part of the 17th century, probably because of reduced game stocks (Siirala & Huru 1990). Through an annex to the border treaty in 1751, the Sami people in the border area could use land and water resources on both sides of the border, still making it possible for the people living in, for example Utsjoki, to bring their reindeer to the fjords in summer (Pedersen 2006). In 1852 the border was 'closed', creating serious consequences for reindeer husbandry and to a lesser extent salmon fishing (Siirala & Huru 1990).

Reindeer husbandry is still important and about 99% of the area in the region of Karasjok is used for reindeer grazing (Siirala & Huru 1990), supporting up to  $\sim 50\,000$  reindeer in winter, spring and autumn (Anon. 2006). Even though the general trend has been a reduction in numbers, many people are still full or part-time employed in reindeer husbandry.

A fishing arrangement closing the entire or part of the river with birch branches or similar material placed between wooden poles, a precursor of the still used 'barrier' was in use in earlier centuries (Pedersen 1986). This required co-operation between the people on both sides of the river, and was used in the upper part of the main stem and in Iesjohka and Kárásjohka (Pedersen 1986). Those who now have fishing rights for nets are allowed to use different types of gear for salmon fishing, although this is now strictly regulated.

Presently, it is possible to travel by car on both sides of the main stem and even to Angeli on the Finnish side of upper Anárjohka, but roads suitable for cars were not completed along the main stem until 1979. Earlier the river played a major role in transportation and people were obliged to go by river boat in summer and on the river ice in wintertime. There is also a track for snowmobiles along the main stem. The river was previously used for transportation of timber, mainly along Kárásjohka and Anárjohka.

### 9.3.2. Geomorphology, Hydrology and Biogeochemistry

The valleys of Anárjohka and the main stem downstream have a typical U-shaped formed by Ice Age glaciers. The valley floor is 200–300 m lower than the mountain plateau and lichen heaths above. Along the river valley there are substantial deposits of gravel and sand, forming eskers, terraces and deltas (Siirala & Huru 1990). These deposits are the main source of sediment in the river and most of their erosion is a result of natural processes (Fergus & Rönkä 2001). Extensive unstable sandbanks are a characteristic feature of the lower parts of Tana (Eie et al. 1996). At Storfossen and much of the lower stem, sand underlies the surface layer while in Utsjoki and Leavvajohka there is more gravel. Transport of suspended material is relatively low and in 1999 a specific sediment yield of 4800 tons/year was measured. However, large amounts of sand are transported along the river bottom and also in suspension during major floods (Fergus & Rönkä 2001).

River water quality has been classified as good or very good in the later years (Traaen 2003), although previously the river was significantly polluted with sewage downstream of Karasjok. After 1993, the situation improved with the installation of a new sewage treatment plant. The river has high levels of dissolved salts (calcium 2–9 mg/L) due to calcareous rocks and extensive moraine deposits. The waters are circumneutral with a pH of 6.8–7.6 and conductivity 31–79  $\mu\text{S}/\text{cm}$  (Traaen 2003; Johansen et al. 2005). Natural levels of phosphorus in the Tana are relatively high (4.5–7.5  $\mu\text{g}/\text{L}$  in 2002) and contribute to good productivity. Episodes with increased erosion and ensuing high turbidity give increased levels of total phosphorous, especially in the lower reaches (Traaen 2003).

The hydrology of the Tana is characterized by high flows in early summer (May–June) and low flows in winter



**PHOTO 9.2** The Tana River is ice-covered from October to May and experiences major ice runs in most years. (Photo: R. Pytte Asvall).

(Figure 9.2). The highest floods always occur during snowmelt. Rain-induced floods in late summer or autumn are rare and relatively minor. At the outlet into the fjord, the mean annual discharge is  $203 \text{ m}^3/\text{s}$ , giving a specific discharge of  $12.4 \text{ L/s/km}^2$ . The highest observed floods were in late May 1920 and in mid-June 1917 with daily discharges of  $3844$  and  $3429 \text{ m}^3/\text{s}$ , respectively.

From October to May the river is ice-covered, with water temperature of  $0.1\text{--}0.4 \text{ }^\circ\text{C}$  (Niemelä 2004). The Tana River has amongst the most spectacular ice runs in the country (Photo 9.2). Since the uppermost tributaries are to the south and have a more continental climate, maximum temperatures in spring tend to be higher. This gives rise to earlier ice melting than in the more coastal areas downstream, sometimes leading to major ice jams in narrow rapids such as around the Storfossen area. The ice runs give rise to substantial erosion and sediment transport (Fergus & Rönkä 2001). There is often extensive local flooding due to ice jams, especially in the upper reaches. Late ice runs, in late May and early June, give the most extensive flooding as discharge is usually greater at that time.

Water temperature is measured at Polmak (50 km from the mouth) in the lower part of the river and in the tributary Kárásjohka some 250 km from the mouth. During winter (late October until late April) water temperatures are close to  $0 \text{ }^\circ\text{C}$ , rising to about  $15 \text{ }^\circ\text{C}$  in summer. Mean water temperatures in the Utsjoki area reach  $12.9 \text{ }^\circ\text{C}$  in July. In the tributary streams summer temperatures vary mostly between 10 and 15, although some streams are cooler (Johansen et al. 2005).

### 9.3.3. Biodiversity

In general, information about freshwater invertebrates is sparse (Walseng & Huru 1997). Johansen (2005) recorded 17 mayfly species, 20 stonefly species and 21 caddisfly taxa from tributary streams. *E. aurivillii*, *Baetis muticus*, *B. subalpinus* and *B. rhodani* were the most widespread mayflies. *D. nansenii*, *Arcynopteryx compacta*, *Taeniopteryx nebulosa*, *Protonemura meyeri*, *Leuctra* spp. and *Capnia atra* were the most common stoneflies. The stonefly, *Nemoura viki*, considered as rare in the Norwegian Red List, is known from the Tana catchment (Lillehammer 1972; Johansen 2005).

The pearl mussel was previously widely distributed in the Tana, but in 2004 it was only found in a few locations (Paul Eric Aspholm, personal communication), probably due to excess harvesting. *Pisidium amnicum* recorded near Kárásjohka is classified as rare in the Norwegian Red list (Walseng & Huru 1997). The freshwater snail, *Valvata sibirica*, classified as rare in the Norwegian Red List, has also been recorded from the catchment (Walseng & Huru 1997). The crustacean, *Lynceus brachyurus*, is recorded from Máskejohka (Walseng & Huru 1997). The copepod, *Heterocope borealis*, restricted to the county of Finnmark in Norway, is found in pools and tarns in the catchment. *Mysis relicta* has been recorded from Polmakvatn, south of Tana Bru.

Seventeen native fish species have been recorded in the Tana, including the bullhead, which is probably introduced. More than 1200 river km are accessible for anadromous salmonids (Niemelä 2004). In addition to the main stem, there are more than 20 spawning tributaries with distinct salmon

strains (Elo et al. 1994; Vähä et al. 2007). Tributary streams with dense riparian vegetation have been shown to be of major importance for food and cover for salmon parr (Johansen et al. 2005). During the period 1972–2006 the annual catch of Atlantic salmon usually varied between 100 and 200 metric tons, with a mean of 135 tons. The salmon population is dominated by grilse and 2-sea-winter fish and the mean weight from 1990 to 1999 was 3.6 kg.

The salmon show diverse life history traits. The freshwater phase is between 2 and 8 years, whereas the marine phase varies from 1 to 5 years before returning for the first time to spawn (Niemelä et al. 2000). Many salmon survive spawning at an increasing rate, and since 2000 previous spawners have represented up to 25 % of the total spawning stock of multi sea winter salmon (Niemelä et al. 2006). In total, virgin and previous spawning salmon give rise to nearly 100 smolt and sea age combinations, which is the greatest in any single river system throughout the distribution area of Atlantic salmon (Niemelä 2004, Jaakko Erkinaro personal communication). According to Berg (1964), there has also been a stock of the so-called ‘autumn salmon’ that ascend the river in autumn but do not spawn until the next season, as in a large proportion of the salmon in White Sea rivers such as the Varzuga (Jensen et al. 1998; Section 9.5). There are indications that these ‘autumn salmon’ have become rare of late.

Pink salmon have been introduced into the Barents Sea and White Sea basins from the Pacific Ocean since 1956 (Bjerknes & Vaag 1980), and they have been recorded in the catches in Tana each year since the 1970s. Spawning has not been documented. Since the 1970s, the bullhead has been recorded in the large Finnish tributary Utsjoki (Pihjala et al. 1998). It is frequent in areas with low salmon density but is seldom found in areas with a high salmon density (Gabler 2000). In 2000, the bullhead was found for the first time in the main stem of the Tana near the confluence with the tributary Utsjoki (Niemelä 2004). Despite being on the Norwegian Red List, it has probably been introduced into Utsjoki.

The viviparous lizard probably has its northern limit in the river system, but its distribution is not mapped in detail (Siirala & Huru 1990). There is a small population of the harbour seal, registered in the Norwegian Red List as in need of monitoring, in the Tana estuary. In the 1800s, the population was much larger. Grey seals and harp seals also occur in the Tana Fjord. The Anárjohka and Lemenjoki National Parks in the upper catchment are important areas for brown bears. Elk seem to be increasing in number and are common in the river valleys.

### 9.3.4. Management and Conservation

The Atlantic salmon is economically the most important fish species, and up to 45 000 daily fishing licenses are sold to tourists annually. Sea trout, grayling, whitefish and pike are also economically important. Today salmon are caught by

several methods, such as ‘barriers’, fixed gill nets, drift nets, and rod and line. Barriers consist of a fence made of wood or metal bars and a gill net which is attached to the outer edge of the fence. The nets are set in a hook-like position to drive the fish into a narrow corner. Gill nets and barriers probably take about half the catch, rod and line accounting for the other half (Erkinaro et al. 1999). Besides the main stem of the Tana between Storfossen and Levajok, Iesjohka and Kárásjohka are known to produce the largest salmon in the river system (Niemelä 2004). A male salmon weighing 36 kg was caught below Storfossen in 1928, probably a world record for this species (Berg 1964).

The conservation of the salmon stocks of the Tana is based completely on natural production. The catchment is protected against hydropower exploitation (Anon. 1976) and there are no dams or power stations on the river. Furthermore, through a bilateral agreement between Norway and Finland, fish stocking is not allowed. The river has recently been designated as a National Salmon River, giving the salmon population and its habitat additional focus in the management of the river. Even if the stocks seem to be relatively healthy, some symptoms of over exploitation have been reported (Berg 1964; Niemelä 2004; Moen unpublished data). Some of the weakest tributary stocks seem to be extinct and important tributaries like Iesjohka were found to have below optimal salmon parr densities in the 1970s (Bjerknes 1978). In 2001, catches were almost at the level of the mid 1970s, even though low densities of spawning salmon have been reported in Kárásjohka and Iesjohka in several years after 2000.

More than 30 km of erosion protection have been built along the river by Finnish and Norwegian authorities since the mid-1970s, but this is unlikely to be extended in the future (Fergus & Rönkä 2001). Nevertheless, most of the Tana is a dynamic system little affected by human impact. The large natural sediment sources and the natural erosion and sedimentation processes remain active and make it unique in Norway and more akin to the large Russian rivers further to the east. The river mouth (‘Tanamunningen’) is a Nature Reserve and a Ramsar site. An unspoiled river estuary of this size is rare in Europe. The site is particularly important for the goosander *Mergus merganser*, with up to 13.5% of the Northwest–Central European population resting there during moulting in autumn. In Austertana, on the east side of the river mouth, there has been mining for quartzite that is shipped out directly. The discharge of ballast waters from these ships represents a potential threat to local biodiversity.

In Anárjohka National Park in the south, and in many other areas along the river valleys further downstream, reindeer husbandry is widespread, especially in winter, and there have been problems with overgrazing in recent years (Anon. 2006). There are some cabins associated with reindeer husbandry, fishing and hunting. Along some of the tributaries there are tracks for snowmobile and ATV vehicles, and sea planes are allowed to land at certain sites. Apart from these activities, there is little human impact in the catchment.

## 9.4. THE KOMAGELVA RIVER

The Komagelva is a fourth order river that begins on the plateau of the Varanger Peninsula and flows eastwards to the Varangerfjord at Komagvår. The 321 km<sup>2</sup> catchment has a maximum altitude of 633 m asl. The few lakes in the catchment are small. The river mouth is about 30 km from the easternmost town in Norway, Vardø. In fine weather you can see over to Russia on the other side of the Varangerfjord. The region has an arctic climate, with a mean July air temperature of only 9.2 °C in Vardø and the entire Komagelva catchment lies north of the treeline. Komagelva is an attractive salmon and Arctic charr river. The catchment has an interesting geology, flora and fauna and the river was included in the first National Protection Plan in 1973. The municipality of Vardø and the surrounding region has a long history. The precursor of Vardøhus fort was built in the 1300s (Willoch 1960). The marine resources in the Barents Sea have given rise to an extensive fishing industry, although in recent years there has been a decline in local land-based processing and unemployment has been high.

### 9.4.1. Physiography, Climate and Land Use

Bedrock of the catchment consists of Eocambrium sedimentary rocks, mainly sandstones. The Trollfjord–Komagelv fault zone runs more or less along the river course. The river valley itself has been formed by running water and not by glacial erosion (Sørbel & Tolgensbakk 2004). The inland ice in this area was polar in nature and thus

frozen permanently to the bedrock. In the bottom of the valleys and along the sides there are deposits of moraine material and meltwater channels. Almost circular deposits or rings of moraine material are unusual, but are more common in this region than in any other part of the world (Sørbel & Tolgensbakk 2004).

The river bed is composed predominantly of gravel and stones and appears fairly stable (Power 1973). Below the ravine, Bjørneskardet, there are no waterfalls or rapids to prevent ascending anadromous fish. In the lower part of the valley, the river has cut through a flat plain and flows in a wide shallow channel between steep banks (Power 1973). The river waters are circumneutral (pH 6.95–7.45) and ionic content increases downstream (conductivity 20–50 µS/cm) (Eie et al. 1982).

Climatically, the Varanger Peninsula is at the border of permanent permafrost (Sørbel & Tolgensbakk 2004), with a mean annual temperature in Vardø of 1.3 °C (Norwegian Meteorological Institute). Precipitation is low with an annual mean in Vardø of 563 mm for the period 1961–1990. The maritime influence gives a mean January temperature in Vardø of –5.1 °C. The uppermost reaches of the catchment are practically without vegetation, although further downstream grasses and heath vegetation occur (Photo 9.3). Below Bjørneskardet, where the river becomes slower flowing and meandering, there are dense riparian stands of willow (Eie et al. 1996). In general the river and the river valley are little influenced by human activity. The catchment is used for reindeer husbandry, largely in summer. Less than 10 persons live permanently around the river mouth, although the lowermost part of the catchment has ~150 recreational cabins.



**PHOTO 9.3** The upper reaches of the river, Komagelva, Varangerhalvøya National Park. (Photo: A. Bjordal).

A road open for vehicles reaches about 7 km into the valley, serving anglers and grouse hunters together with cabin owners. The road is closed in winter, but there is a snowmobile track. In summer, the reindeer herdsman use ATV vehicles in the catchment.

### 9.4.2. Geomorphology, Hydrology and Biogeochemistry

The catchment is susceptible to erosion and frost action is probably a major source of river sediment. In a nearby catchment, Julelva, the specific sediment yield was estimated at 23 tons/km<sup>2</sup>/year (Jim Bogen, personal communication). There are no discharge records from Komagelva. However, data from neighbouring rivers show that the hydrological regime in the area is characterized by high flows during snowmelt (mid-May to mid-July) and low flows in winter. The highest floods always occur during snowmelt. The lack of lakes in the Komagelva catchment usually limits the duration of high flows in spring to about 3 weeks (Berg 1964). Rain-induced floods in late summer or autumn are rare and relatively small. At the outlet into the fjord, the mean annual discharge is calculated at 8.3 m<sup>3</sup>/s (specific discharge 25.8 L/s/km<sup>2</sup>). The mean lowest annual discharge and the mean annual flood discharge, estimated on data from neighbouring rivers, are 0.7 and 66 m<sup>3</sup>/s, respectively (Figure 9.2).

There are few observations of water temperature from Komagelva (Eie et al. 1982). However, data from other rivers in the area show that from early November to late May the water temperature remains close to 0 °C, increasing rapidly to ~12–16 °C in July/August. The river is ice covered from November to May and ice runs in spring can be relatively severe. In some years there may be temporary ice runs during autumn (Berg 1964).

### 9.4.3. Biodiversity

In general, the flora and fauna of the Varanger region is of considerable interest because of its location between western and eastern biogeographical elements. Among the eastern plant species typical of the area are *Allium schoenoprasum* ssp. *sibiricum*, *Dianthus superbus*, *Oxytropis campestris* ssp. *sordida* and *Veronica longifolia* (Anon. 2004). The willow stands along Komagelva are considered of international interest (Anon. 2004).

Benthic densities are low above 300 m asl. In the lower river below Bjørneskardet, benthic densities are unusually high for the region, probably due to the high allochthonous inputs from dense riparian willow stands. The high benthic biomass provides the basis for good salmonid production. Chironomids and mayflies dominated the benthos during July and August, and 8 species of mayfly, 11 species of stonefly and 4 species of blackfly have been recorded (Eie et al. 1982). The fauna is typical of the

northern and eastern parts of Scandinavia. The small water bodies along the floodplain of the river have a rich and varied zooplankton fauna and 18 taxa have been recorded (Eie et al. 1982).

The fish community in the Komagelva consists of the species moving in from the west after the Ice Age: Arctic charr, Atlantic salmon and brown trout, as well as three- and ten-spined sticklebacks (Huitfeldt-Kaas 1918). The anadromous reach is only 33 km, but relative to its size, the Komagelva is an attractive salmon and sea charr river; giving annual catches of more than 6000 kg salmon in the 1970s (Figure 9.4). The river has never been stocked with salmon or other fish species. After the 1970s, the salmon catches have been relatively stable at a significantly lower level than before, although the reason for this is unknown. From 1905 to 2003, the mean annual recorded catch of anadromous salmonids (Atlantic salmon, brown trout and Arctic charr) was 2.5 tons. Since 1983, Atlantic salmon have constituted 78% of the catch. The salmon population is dominated by grilse and the mean weight from 1990 to 1999 was 2.3 kg. They are known to be especially shy and difficult to catch, probably due to the crystal clear water and low discharge (Berg 1964). Pink salmon have been stocked in the Barents Sea and White Sea basins from the Pacific Ocean since 1956, and from year to year some of these fish reach the Komagelva. They may also have come from some of the Norwegian salmon rivers where they seem to spawn regularly, such as the river Neiden on the south side of Varangerfjord. Spawning of pink salmon has not been documented in the Komagelva.

The marshes and wetlands along the river valley are important ornithological sites for among others red-necked phalarope, red-throated diver and whooper swan (Systad et al. 2003). The endangered Arctic fox has one of its last outposts on the European mainland in the heart of the Varanger Peninsula. The wolverine has always been present in the Varanger Peninsula, but is seen as a constant threat to the reindeer husbandry.

### 9.4.4. Management and Conservation

The Komagelva was among the first group of Norwegian rivers protected against exploitation for hydropower in 1973 (Kontaktutvalget Kraftutbygging – naturvern 1971). Most of the catchment is now included in the recently established 1804 km<sup>2</sup> Varangerhalvøya National Park (Anon. 2004). The area is highly pristine, and contains a suite of different biogeographical regions, special biotopes for protection of plants and animals, river valleys, valuable coastal areas and cultural relics. The shoreline of the Varangerfjord south of the river mouth is a nature reserve because of its sand dunes and several 'eastern' plant species growing at the extreme western edge of their distribution. In 2003, the Norwegian Parliament included Komagelva as one of the



**PHOTO 9.4** The Varzuga River with Varzuga village in the background. (Photo: B. O. Johnsen).

‘National Salmon Rivers’, the only one wholly in the Arctic (Anon. 2001).

## 9.5. THE VARZUGA RIVER

The Varzuga River is on the Arctic Circle in the southern part of the Kola Peninsula in northwest Russia. It flows southeast from Varzugskoie Lake and drains into the White Sea. It is one of the largest rivers on the Kola Peninsula with a length of 254 km and catchment area of 9510 km<sup>2</sup>. The primary tributaries are the Pana, Arenga, Serga and Kitsa Rivers (Photo 9.4).

### 9.5.1. Physiography, Climate and Land Use

Bedrock of the Kola Peninsula is dominated by granite and gneiss of the Baltic Shield, although there are extensive Quaternary deposits. The catchment area consists of ~50% wetlands and ~50% forest. It is mainly low gradient marshy tundra. The vegetation is dominated by lichen heath, birch trees and willow scrub. In some locations, primarily on hills, conifers grow. Surface soils are peaty or sandy, but occasionally rocky.

The climate is characterized by long winters and cool summers. The mean annual air temperature in the nearby Umba village is 0.5 °C, with means of –11.0 °C in January and 14.3 °C in July. Mean annual precipitation is 498 mm, with greatest amounts in summer (Anon. 2003). Most of the catchment is unpopulated, but there are two small villages, Kuzomen and Varzuga, near the mouth of the river and 24 km upstream, respectively (Photo 9.4).

### 9.5.2. Geomorphology, Hydrology and Biogeochemistry

The headwaters are ~200 m asl and the river has a mean gradient of about 0.8 m/km. In the upper reaches, runs and small riffles of 25–40 m predominate. In the middle reaches, large pools are more common, in addition to some major rapids, being especially frequent in the lower reaches. In the headwaters, the river is 2–6 m wide, increasing to 20–40 m in the upper reaches, 60–150 m in the middle reaches and up to 200 m in the lower reaches. In the lower 20 km, which is tidal, the river can be up to 800 m wide. The mean discharge near the village of Varzuga is 76.5 m<sup>3</sup>/s. The annual discharge regime is characterized by a spring flood, low discharge during summer, smaller floods during autumn and low water levels in winter. The spring flood, lasting for 15–40 days, normally occurs in May and June. The lowest water level during summer is usually observed in July. The river freezes in October–November and ice-break occurs in May. Riffles and runs become ice-covered 20–40 days later than pools, while major rapids freeze only during the most severe winters. Anchor ice may form in riffle reaches. Water temperature rises rapidly during May, and increases to a maximum of about 17 °C in July. In general, the waters of the Varzuga have low ionic concentrations due to low dissolution of crystalline minerals in the catchment, and its water chemistry has remained essentially unchanged for more than 50 years (Ziuganov et al. 1998).

### 9.5.3. Biodiversity

Twenty native fish species occur in the River Varzuga (Jensen et al. 1997). Atlantic salmon is the predominant fish

species, but brown trout, grayling, whitefish, pike, roach, minnow, perch and three- and nine-spined sticklebacks are also common. The salmon stock in the Varzuga is one of the largest in the world, and on average 70 000 spawners ascended the river annually during the last 15 years of the 20th century (Kaliuzhin 2003). The Varzuga has two distinct salmon runs. The summer run fish arrive in June to mid-August and spawn that autumn. In contrast, the autumn run fish arrive from mid-August onwards and continue upstream until ice formation. They do not spawn in the year they arrive, but wait until the following autumn before spawning (Jensen et al. 1998). Most salmon are grilse (1-sea-winter fish). Introduced pink salmon occasionally enter the river. Pink salmon have been introduced into the Barents Sea and White Sea basins from the Pacific Ocean since 1956. They are now established in some rivers on the Kola Peninsula and enter other rivers in the region (Berg 1977). The Varzuga River has the world's largest population of freshwater pearl mussels, estimated to exceed 100 million specimens (Ziuganov et al. 1994).

#### 9.5.4. Management and Conservation

The catchment has not been subject to any major economic developments. However, the salmon population has become the target of harvesting, providing an important source of income for local communities. Before 1958, nets operated in the lower reaches were used to fish for salmon. After 1958, the river has been blocked by a barrier fence with a trap ('Ruz'), which is installed annually at a site located 12 km upstream from the river mouth. Usually, all ascending fish were caught for commercial purposes each second day, while on alternate days they were allowed to migrate freely. From 1987 onwards, the fence has been operated every third day or less frequently. From 1961 to 1989, the catch of Atlantic salmon varied between 33.4 and 161.2 metric tons, and averaged 72.5 tons (Jensen et al. 1997). In later years, several camps for recreational sport fishery have been established in the river, mainly practising a catch and release fishery. Recent genetic studies (Primmer et al. 2006) indicate that there is a significant degree of isolation between the salmon populations of individual reaches and tributaries, suggesting that the preservation of a number of spawning sites spaced throughout the tributary system is recommendable for ensuring sustainable fishing tourism in the river.

## 9.6. THE ONEGA RIVER

The Onega catchment is situated in the northern part of the East European Plain and bounded by the Vetreniy Poyas and Andoma Uplands in the west, and the Onega–Dvina, Ozersk–Lebshina, and Sukhona–Dvina Uplands in the east. The Onega, a fifth order river, originates in Lake Lacha and flows north through the Vozhe–Latchensk and Onega lowlands and discharges into Onega Bay on the White Sea. The

Onega has a catchment area of 56 900 km<sup>2</sup> and a river length of 416 km. There are more than 3000 lakes within the river catchment. The Onega catchment is entirely within the Arkhangelsk Region. Over the centuries the river has served as one of the main trade routes towards the White Sea. Before the port of Arkhangelsk was built at the mouth of the Northern Dvina, Onega was the only large port in northern Russia. The waters of the Onega catchment are used for domestic and municipal services as well as for the timber industry.

### 9.6.1. Physiography, Climate and Land Use

The relief of the Onega catchment is a result of successive glaciations, with undulating plains and hilly moraines. In the south, the glacial plains are at an altitude of 100–150 m asl. The river flows along an undulating, forested plain and forms a delta where it flows into Onega Bay. Rapids are frequent and in the upper reaches of the river the most difficult rapids to pass have always been Kargopolski Rapids (388–370 km from the mouth), in the mid-channel the Biryuchevski Rapids (212–190 km from the mouth), and in the lower reaches the Kokorinski Rapids (25–18 km from the mouth). The spring flood in the upper reaches of the Onega lasts for 3 months and discharge remains high during most of the summer. Numerous cold springs discharge into the upper and middle reaches of the river, and the groundwater contribution to the Onega is 30–40%, the highest among comparable rivers in the region.

The catchment area has a temperate-continental climate with short cool summers and long cold winters. The average annual temperature in the south of the catchment at the town of Kargopol is 1.5 °C, and in the north at the town of Onega it is 1.3 °C. The average temperature of the warmest month ranges from 16.4 °C (Kargopol) to 15.9 °C (Onega). Mean temperatures usually are >0 °C in April, and temperatures fall <0 °C in the latter part of October. The duration of the frost-free period at the mouth of the Onega River is on average 107 days (Pylnikova 1989). The Onega catchment belongs to the zone of high humidity. The annual precipitation is about 600 mm, with highest rainfall from July to September. The landscape is usually snow covered from late October until late April, with a normal snow depth of 60–70 cm. The catchment is situated in the podzol soils zone of the north and middle Taiga. The primary soils originate from Quaternary deposits: moraine and top-soil loams, and fluvio-glacial and ancient alluvial sand deposits. The Severo–Onezhsk bauxite deposits are associated with Carboniferous karst limestones. The catchment is covered with coniferous forest, mainly pine.

### 9.6.2. Hydrology and Hydrochemistry

The widest ranges in water level recorded in the Onega River are 3.4 m in the upper reaches, 9.7 m in the mid-channel and 6 m in the lower reaches. The largest recorded river

discharge was 4930 m<sup>3</sup>/s, the lowest 82.6 m<sup>3</sup>/s. The average annual river discharge at the mouth is 535 m<sup>3</sup>/s. The mean specific catchment runoff is 9.8 L/s/km<sup>2</sup> (Figure 9.3). As a rule, the average discharge of the spring flood is approximately six-fold larger than mean discharge. However, the seasonal unevenness of the flow in the Onega is reduced by its lake source and the karst structure of the river catchment. The density of the hydrographic network is 0.39 km/km<sup>2</sup>. The ice regime of the river is complex, and the Onega River has one of the shortest ice cover periods of the larger northern rivers on account of rapids. At rapids and ground-water inflows, the ice cover is temporary. Freezing of the Onega River begins at its mouth in the north and spreads upstream. In the upper reaches of the Onega, ice break usually proceeds quickly and does not cause any problems, although lake ice remains longer. In the mid-channel and lower reaches there are usually two ice runs, the main one from the Onega and another from its tributaries.

Water chemistry of the Onega is strongly influenced by the 90+ highly mineralized springs in the upper reaches. The proportion of groundwater in the upper reaches of the river amounts to 40–50%. During winter the mineral content is 181–354 mg/L, decreasing during the spring flood and increasing again to 225 mg/L during low flows in summer. At the river mouth the mineral content is on average 20 mg/L lower. Bicarbonate and calcium are the predominant components. Up to 25% of the Onega catchment is boggy, resulting in high humic levels and high colour values (60–200°). The average concentration of iron is 0.5 mg/L, but sometimes it exceeds 1.0 mg/L. The content of ammonia nitrogen lies within the range 0.04–0.30 mg/L. Oxygen deficiency (down to 49%) occurs during winter, but in summer, the average saturation is 70 to 90%. The waters are predominantly alkaline (pH 6.9–7.4) (Filenko 1974; Olenicheva 1990–1991).

### 9.6.3. Biodiversity

Data on aquatic biodiversity are scarce and fragmentary and to a large extent refer to animal populations.

In the Onega catchment, species of the genera *Potamogeton*, *Sparganium*, *Stratiotes*, *Hydrocharis*, *Typha*, and rarely *Petasites*, have been recorded (Tolmochev 1974–1977; Potokina 1985). The following aquatic species are protected: *Subularia aquatica*, *Lobelia dortmanna*, *Batrachium dichotomum*, *Typha angustifolia*, *T. latifolia*, *Spirodela polyrrhiza*, *Zostera marina* and several species of sedge (Andreev 1995).

The planktonic fauna of the Onega includes 72 species, mostly Cladocera, but also Copepoda (Cyclopidae, Calanoida) and Rotifera (Gordeeva 1983). The composition is similar to that of the Northern Dvina, the main part consisting of widespread species of *Bosmina*, *Chydorus*, *Mesocyclops* and *Euchlanis*. The fauna of the upper reaches consists predominantly of limnophilous species. The average density of zooplankton is 483 000/m<sup>3</sup>, giving a biomass of 3.7 g/m<sup>3</sup>. Due to high current speed and sediment load in the middle

reaches, zooplankton here are mostly bottom-dwelling species in areas near banks. Zooplankton diversity increases in the lower reaches due to the slower current.

Sixteen macroinvertebrate groups have been recorded in the drift (Shubina et al. 1990). Mayflies, blackflies and chironomids were the most numerous, although caddisflies were also an important part of the biomass. The zoobenthos is mainly composed of chironomids, mayflies, stoneflies, blackflies, beetles, molluscs and worms (Gordeeva 1983). In summer, the average density is 968/m<sup>2</sup>, giving a biomass of 6 g/m<sup>2</sup>. On sandy-silty substrates, molluscs (*Pisidium*) make up 70% of the biomass. On clay-sandy substrates the community is characterized by a predominance of chironomids and oligochaetes constituting the main part of the biomass. The numbers of molluscs is limited by high current speed. In the stony bottom community, *Cryptochironomus*, *Pisidium* and hydropsychid Trichoptera are frequent.

There are 32 species of fish from 13 families in the Onega, including pink salmon, Atlantic salmon, brown trout, vendace, northern whitefish, powan, inconnu, and grayling (Novoselov 2000). Sterlet, northern whitefish and pink salmon are among the introduced species. Ten species of amphibians and reptiles have been recorded within the limits of the Onega catchment (Kuzmin 1999). The majority of the species are widely distributed from the headwaters to the river mouth, but the crested newt is restricted to southern areas of the catchment.

There are 182 species of breeding birds in the Onega catchment within the limits of the Arkhangelsk and Vologda regions (Dementiev & Gladkov 1951–1954; Ivanov & Shtegman 1978; Sviridova & Zubakina 2000). The song birds have the greatest number of species, followed by sandpipers, waterfowl, birds of prey and owls. The majority are migrating species and only 45 species inhabit the catchment throughout the whole year. The avifauna is dominated by species widespread in the Palearctic, followed by species of European and Siberian origin. There are few Arctic species. In the catchment, 52 species of mammals have been recorded (Geptner et al. 1961, 1967; Dinets & Rotshild 1996), with 51 species recorded in the southern part of the catchment and 44 species in the lower reaches. The southern area forms the northern limit for several species of mammals (hedgehog, bat, harvest mouse, common vole, European polecat and roe deer). In contrast, arctic foxes only occur in the northern part during their autumn–winter migration.

### 9.6.4. Management and Conservation

The Arkhangelsk Region Red Book (Andreev 1995) includes the fish species inconnu and bullhead. As they are at their northern limit and low in numbers, four amphibians (*Anguis fragilis*, *Lacerta agilis*, *Natrix natrix* and *Vipera berus*) are also included in the Arkhangelsk Region Red Book. Twenty-one species of birds are included in the Red Book of the Russian Federation. An additional 53 species on



**PHOTO 9.5** The Sysola River, Northern Dvina basin, looking downstream (Photo: V. Ponomarev).

the decline or at the northern limit are included in the Red Book of the Arkhangelsk Region. Among the introduced mammals are representatives of the American muskrat and American mink, and Far Eastern raccoon dog. At the beginning of the 20th century, beaver were reintroduced. Many mammals that are at their northern limits in the catchment are included into the regional Red Book due to low numbers. The Kenozersky, Vodlozersky and Russian North National Parks are located in the Onega catchment. The main aim is protection and promotion of the recreational use of northern mid-taiga forests and a number of historical and cultural sites. In 2005, the Kenozersky National Park was included in the list of UNESCO biosphere reserves. The Kozhozerskiy Reserve and seven game preserves are also in the catchment (Yermolin 1991; Kulikov 1995).

## 9.7. THE NORTHERN DVINA RIVER

The Northern (Severanaya) Dvina, a seventh order river, has the largest catchment in Europe and discharges into the Arctic Ocean (Photo 9.5). It has the second highest discharge after the Pechora. The catchment is located in the northern part of the East-European Plain. It is bounded in the west by the Onega–Dvina Plateau and in the east by the Dvina–Mezen Plateau and the Timansky Ridge in the Vychegda River catchment, which forms the border with the catchment of the Pechora River. The southern part the catchment is located in the high areas of the Northern Ridges that form the main watershed of the Russian Plain and separates the catchment from the rivers flowing north from the Volga catchment. The Northern Dvina catchment comprises 357 000 km<sup>2</sup>, and it is 744 km from the junction of the Sukhona and the Yug Rivers to the sea.

The geographical position of the Northern Dvina, with its proximity to the Volga catchment and its relief, has given it a vital role in the history of Russia. The river network and lakes of the catchment's southern border (including the Sukhona River and Kubenskoe Lake) form a part of the Northern Dvina waterway, constructed in 1825–1828, connecting the catchments of the White Sea and the Caspian Sea. It starts on the Sheksna River near the community of Topornaya and ends on the Sukhona River at the well-known Znamenity Lock. The total length of the system is 127 km. The Sukhona River is one of the Russian rivers where people have always tried to improve navigation conditions, and even in 1278 Russian princes attempted to regulate various difficult bends in the river channel.

### 9.7.1. Physiography, Climate and Land Use

The relief of the Northern Dvina catchment was formed as a result of glaciation that caused topography of undulating surfaces and hilly moraines. In the south of the catchment (in the Vologda Region), glacial valleys reach around 100–150 m asl. The Dvina–Mezen Plain slopes gently north towards the White Sea. The plains are forested and mainly boggy. In the north, it gradually changes to the Primorskaya coastal plain at 5–75 m asl. In the east and northeast, the Mezen–Vychegda plain meets the Northern Ridges at 250–270 m asl. In the northeast, the Timansky Ridge separates the catchment from the Pechora catchment. Towards the Onega–Dvina divide is an undulating plain at 100–200 m asl, with hills up to 250 m asl and where the lower parts are boggy. In the southeast there is a plateau with altitudes up to 150–200 m asl. The southern part is formed by the Sukhona–Volga watershed, while in the east it

stretches along the western slopes of the Northern Ridges. In the Timan Range there are karst formations.

The climate of the region is characterized by a low number of sunshine hours in winter due to the influence of the northern seas and intensive western movement of air masses from the Atlantic. This also leads to changeable weather throughout the year. The short, cool summer lasts for 2–3 months, with a mean monthly temperature of 16–17 °C, but with frosts possible in any month. Autumn starts during early September with temperatures down to –2 to –4 °C. The common autumn weather pattern is rainy with frequent thaws (Kobysheva & Narovlyansky 1978). In October, cold arctic winds are followed by a decrease in temperature to –10 to –15 °C. Winter starts in late October and lasts for 5–6 months. The mean temperature in January is –20 °C. Snow cover is stable and blizzards frequent. Winter precipitation is 110–200 mm, while summer rainfall is 400–500 mm.

The main soil-forming strata in the Northern Dvina catchment include overburdens of drift clay and blanket clay, fluvio-glacial sediments and fossil alluvial sand sediments. The catchment is located in the area of podzolic soils of the northern, sub- and southern taiga. The terrain is mainly covered with coniferous forests and peat bogs. Sparse timberlands are characteristic of the northern taiga, while to the south there are large areas of dense, fast growing coniferous forest.

### 9.7.2. Hydrology and Hydrochemistry

The smaller river valleys are up to 10–50 m deep and several hundreds metres wide, while the large rivers have a trapezoid valley profile with a wide flat bed. In the lower reaches of the Northern Dvina the valleys are shallow with gently sloping sides. The Northern Dvina River is formed by the junction of the Yug River (catchment area 35 600 km<sup>2</sup>) and the Sukhona River (50 300 km<sup>2</sup>), in whose estuary there is the historic town of Veliky Ustug. The Vycheгда River (121 000 km<sup>2</sup>) flows into the Northern Dvina 74 km downstream. The Vycheгда River is the largest tributary on the river. Downstream of the confluence, the Northern Dvina is called the ‘Big’ Northern Dvina. Kotlas, at the mouth of the Vycheгда River, is the second largest city in the Arkhangelskaya Region. It is an important river port and railway junction in the European North of Russia, established in 1899. The hydrographic network frequency of the Yug River is 0.72 km/km<sup>2</sup>, that of the Sukhona is 0.52 km/km<sup>2</sup> and that of the Vycheгда 0.62 km/km<sup>2</sup>. At 362 km from the mouth, the Vaga River (catchment 44 800 km<sup>2</sup>) flows into the Northern Dvina from the left bank. From here, the river flows through gypsum strata almost down to the mouth. At 137 km, the right bank tributary, the Pinega River (42 000 km<sup>2</sup>), flows into the Northern Dvina just upstream of the estuary. The river is 600–800 m wide, increasing to 2.0–2.5 km at the estuary. In general, the density of the hydrographic network is 0.58 km/km<sup>2</sup>; and the total length of all waterways in the catchment is more than 206 000 km.

The river is mainly fed by precipitation and snowmelt (Figure 9.3). Groundwater is insignificant and patchy, although in the southeast mineral springs play some role in groundwater supply. The river carries a high sediment load that contributes to forming the vast multi-channel delta. Extensive floodplains with terraces are typical of most tributaries. There are long reaches with sandbanks, although most rivers, except for the Vycheгда, do not meander. River water solute concentrations are usually 200–450 mg/L, but sometimes fall to 100 mg/L. Bicarbonate, calcareous waters dominate. In the Northern Dvina estuary, solute concentrations reach 13 000 mg/L due to intrusion of saline water up to the Mekhrenga and Kuloy Rivers. In such cases, the concentration of chloride can reach 5.6 mg/L and that of sodium up to 3100 mg/L. Water colour varies from 30 to 250°, dichromate oxidation is about 13–80 mg/L, but in the estuary it can reach 188 mg/L. Iron concentrations vary widely (130–3570 g/L), as does ammonium (70–2200 mg/L). The waters are saturated in oxygen for most of the year, but during winter ice cover values may fall to 12–27%. The pH is in the region of 6.5–7.8 (Olenicheva 1990–1991; Filenko 1974).

### 9.7.3. Biodiversity

The Northern Dvina phytoplankton is typical of lowland rivers (Bryzgalo et al. 2002), mainly consisting of diatoms and green algae, with *Asterionella* and *Aulacoseira* being dominant, and *Cyclotella* and *Stephanodiscus* occurring in some areas. In warm periods, *Anabaena* increases in number. In the estuary, phytoplankton includes *Fragilaria*, *Diatoma*, *Nitzschia*, *Scenedesmus* and *Pediastrum*. Cyanobacteria are represented by species of *Microcystis*, *Anabaena* and *Merismopedia*. Their densities change from 400 to 6 000 000/L according to locality and season. At pulp and paper mill discharges the density of algae decreases.

According to Korde (1959), Vycheгда River phytoplankton includes 110 algal taxa and 13 Cyanobacteria. Most diversity and highest densities are in diatoms, followed by Cyanobacteria (*Anabaena* and *Aphanizomenon*). In some lakes, algal blooms have been recorded. The density of algae varies from 84 to 503 000/m<sup>3</sup>. In upstream reaches there are 150 taxa with diatoms having the greatest diversity (Getsen & Barinova 1969). The main genera are *Epithemia*, *Cocconeis*, *Synedra*, *Achnanthes*, *Fragilaria*, *Diatoma*, *Gomphonema*, *Melosira*, *Cymbella* and *Rhoicosphenia*. In hilly reaches, *Ulothrix*, *Cladophora*, *Spirogyra*, *Oedogonium* and *Chantransya* are common and stones are often covered with the Cyanobacteria, *Nostoc*.

Characteristic genera for the Northern Dvina catchment are *Potamogeton*, *Sparganium*, *Equisetum*, *Sagittaria*, *Ceratophylla* and *Petasites* (Tolmachev 1974–77; Zvereva 1969; Potokina 1985; Vekhov 1990). In the Northern Dvina delta, subject to brackish water, *Triglochlin*, *Mertensia* and *Zannichellia* occur. The downstream ecosystems have changed due

to human use of the floodplain (Vekhov 1990, 1993) and *Utricularia*, *Myriophyllum*, *Potamogeton*, *Nuphar*, and *Butomus* are becoming rare. In enclosed channels *Hydrocharis*, *Stratiotes*, *Sparganium* and *Lemna* are present, while in coastal zones *Caltha*, *Alisma*, *Polygonum*, *Carex*, *Equisetum* and *Typha* are found. In places showing anthropogenic impacts, *Elodea canadensis* is often dominant (Postovalova 1966; Teteryuk 2003).

The Northern Dvina zooplankton is rich in *Bosmina*, *Chydorus*, *Mesocyclops* and *Euchlanis* species (Gordeeva 1983). *Holopedium*, *Daphnia*, *Pleuroxus*, *Podon* and *Ectocyclops* are also common. In the area near the estuary, there are 122 species of macroinvertebrates (Semernoy 1990), including sponges, oligochaetes, leeches, molluscs and chironomids. Oligochaetes and chironomids are most diverse, while *Isochaetides*, *Orthocladus* and Mollusca are the most numerous. Mean zoobenthos density and biomass is 6800/m<sup>2</sup> and 11.3 g/m<sup>2</sup>, respectively. Typical genera among molluscs are *Planorbis* and *Valvata*, and among Chironomidae, *Limnochironomus* and *Procladius* (Yepishin & Yelsukova 1990). In polluted areas, *Rotifera* dominate, in particular, *Brachionus* (Bryzgalov et al. 2002), while zoobenthos densities increase due to higher numbers of oligochaetes.

In the Vychegda River, zooplankton includes 44 taxa of Rotifera and 31 taxa of Cladocera (Korde 1959). On average, rotifers constitute 96% of numbers. Zooplankton is similar to that of the Northern Dvina. Densities vary from 10 000 to 253 000/m<sup>3</sup> (Zvereva 1969). Zoobenthos includes 17 groups, dominated by Chironomidae, and Oligochaeta and molluscs in some areas (Zvereva 1969; Leshko 1998). There are 51 species of molluscs, with the genera *Anisus*, *Lymnaea* and *Sphaerium* most numerous (Leshko 1998).

The fish fauna includes 41 species from 14 families (Solovkina 1975; Novoselov 2000) such as Atlantic salmon, vendace, powan, inconnu and grayling. As a result of introductions, river fishes also include Danubian bream, asp, spined loach, northern whitefish, zander and pink salmon. In the Northern Dvina, there are 11 species of amphibians and reptiles (Anufriev & Bobretsov 1996; Kuzmin 1999). Many species are at their northern limit, and *Triturus vulgaris*, *T. cristatus*, *A. fragilis*, *N. natrix* and *V. berus* are common only in the southern taiga and sub-taiga zones, while the other species are recorded north towards the estuary. The Northern Dvina is the western border for *Salaman-drella keyserlingii*.

At present, breeding birds in the Northern Dvina catchment, including territories from the southern taiga to shrub tundra include 16 orders (Yestafiev et al. 1995, 1999; Sviridova & Zubakina 2000). The northern border of 88 breeding bird species lies within the catchment. The highest bird diversity, 195 species, is typical of the headwater and mid-reaches. Further north, the avifauna is poorer, and in the lower reaches there are 107 species. There are 56 non-migratory species in the Northern Dvina catchment. In the southern and central parts of the Northern Dvina, birds common for the Palaearctic region are most usual, although

species of European and Siberian origin are also typical. In the north, birds of Siberian and Arctic origin are common, including waterfowl and sandpipers. In the south, there are many birds of prey, owls, pigeons, doves, woodpeckers and song birds. Since the beginning of the 20th century, populations of some 40 species, mainly European or common Palaearctic species have moved northwards. In contrast, partridges have moved south, while they were earlier typical in zones up to the sub-taiga (Kochanov 2001).

There are 56 species of mammals recorded in the Northern Dvina catchment (Geptner et al. 1961, 1967; Anufriev et al. 1994; Polezhaev et al. 1998). In the southern, middle and partially in the northern taiga, there are 51 species compared to 38 species in downstream areas. The borders of the sub-taiga and northern taiga form the limit of species such as water shrew, hedgehog, polecat, bats, raccoon dog, wild boar and roe deer. Lemming, narrow-headed vole and Arctic fox all inhabit the tundra. In the middle of the 20th century, new species were introduced: muskrat, American mink and raccoon dog, and European beaver were reintroduced.

#### 9.7.4. Management and Conservation

For many centuries, the Northern Dvina has served not only as the main waterway of Russia, connecting its centre to the North, but also to Europe. At present, the main industries in the Northern Dvina catchment are timber, wood processing, pulp and paper, mechanical engineering, ferrous metallurgy, light industry and food production.

The macrophytes, *Oenanthe aquatica*, *Nymphoides peltatum*, *Elatine hydropiper*, *Mertensia maritima*, *S. aquatica*, *Nuphar pumila*, *S. polyrrhiza*, *Zannichelia pedunculata*, *T. angustifolia*, *L. dortmanna*, *Ranunculus lingua* and *Eleocharis quinqueflora* are among the protected species (Andreev 1995; Taskaev 1998). *Triglochin*, *Potamogeton* and *Veronica anagallis-aquatica* are classified as vulnerable.

The Pinega Reserve, created in 1974, and 16 reserves aimed at preserving and enhancing rare species and lake ecosystems are in the Northern Dvina catchment (Yermolin 1991). In the Komi Republic, there are three specially protected water bodies, six ichthyological reserves in the catchments of the Vym, Sysola and Vychegda and complex reserves like the one on Sindor Lake (Taskaev et al. 1996). The fishes, inconnu and bullhead, are listed in the Red Books of the Arkhangelskaya and the Vologodskaya regions. Due to a limited and sporadic distribution and low numbers, five species of reptiles and amphibians have been included in the Red Books of the Arkhangelsk region and the Komi Republic (Taskaev 1998). Some 22 species of birds are listed in the Red Book of the Russian Federation. Due to low population size, around 60 species located in the northern areas are listed in the Red Books of the Komi Republic, the Arkhangelsk Region and the Vologodskaya Region. Many mammalian species inhabiting the northern borders of their distribution also have small populations and have been entered into regional Red Books.

## 9.8. THE MEZEN RIVER

The Mezen, a sixth order river, is one of the longest and largest in northeast Europe with a length of 966 km and catchment area of 78 000 km<sup>2</sup>. It originates at Chetlassky Stone (500 m asl) in the North Timan and enters the Mezen Bay of the White Sea. The Vashka River is the largest tributary with a length of 605 km and catchment area of 21 000 km<sup>2</sup>. It enters the Mezen 192 km from the estuary (Zhila 1965). Administratively, 400 km of the Mezen is situated in the Komi Republic (43.5% of the catchment), and the rest is within the Nenets National District of the Archangelsk Region. The main part (75% of the area) of the Vashka River flows through the Komi Republic. The main communities are the towns of Koslan and Usogork and the 16th century town of Mezen at the estuary (Ilyina & Grakhov 1987).

### 9.8.1. Physiography, Climate and Land Use

The springs that form the source of the Mezen River are situated between the bogs near Chetlassky Stone. The river runs first south and then northwards, flowing along the western slope of Timan Ridge. Much of the catchment is flat, mostly at altitudes of 130–180 m asl. The river catchment is underlain by Permian, Triassic and Jurassic rocks, and overlain by Quaternary deposits up to 20 m deep. The soils are mostly podzolic and boggy, although humus soils occur in Timan Ridge area. The Mezen catchment lies mainly within the sub-zones of the central and northern taiga, forests constituting 87% and bogs 12% of the area.

Frequent changes of air masses characterize the climate in the Mezen catchment. Proximity to the ocean also has an impact on climate. From south to north, mean annual temperature decreases from 1.2 °C (Kotlas) to –1.1 °C (Mezen). Throughout most of the catchment, January is the coldest month, but February is the coldest in the Mezen estuary. Mean daily temperature falls to –44 °C during extremely severe winters on the coast of the White Sea. In contrast, an absolute maximum temperature of 35 °C has been recorded in July. Spring usually starts in early April, while summer begins in early June. By the end of September, the mean daily temperature falls to 5 °C. Winter starts at the end of October and lasts until the beginning of May. Runoff is 50–55% of the annual precipitation of ~600 mm. About 200 mm precipitation is stored in the snow pack before being released in the spring thaw (Zhila & Alyushinskaya 1972; Anon. 1989).

### 9.8.2. Geomorphology, Hydrology and Hydrochemistry

The Mezen catchment covers a considerable part of northeast European Russia. The mean annual discharge to the White Sea is 858 m<sup>3</sup>/s (Table 9.1, Figure 9.3), which gives a total yearly freshwater volume of >27 km<sup>3</sup>. The Mezen River is a typical northern river, characterized by high flows

during the spring thaw, low flows during summer, interrupted by flash floods, as well as by very low winter flows. Widespread karst systems in the Timan Ridge provide much of the source water for the Mezen River and its tributaries and reduce variation in discharge. In upstream areas, the Mezen River is 0.5–1 km wide, but when it turns north its width increases to 2–5 km. At the town of Mezan, the river is 3–4 km wide. Floodplain terraces, often complex and up to 200 m wide, are noticeable along the river valley. In the estuary, water levels have an amplitude up to 7.6 m and the river is tidal >60 km upstream (Ilyina & Grakhov 1987).

The hydrochemistry of the Mezen system was studied from 1987 to 1990 by Khokhlova (1997). The waters are characteristically rich in calcium carbonate, with TDS concentrations of 2.8–200 mg/L, depending on season. In the tributaries of the Vashka River (Evva River), the concentration of major ions reaches 300 mg/L. There are also increased concentrations of sulphates and sodium ions due to underground karst sources. Rivers of the Mezen catchment vary in content of organic and inorganic compounds. Colour, permanganate and dichromate values vary between 10 and 168°, 3.7–23.0 and 7.6–59.1 mg/L, respectively. High concentrations have been recorded for ammonia (up to 1.78 mg/L) and iron compounds (up to 0.90 mg/L). Pollutants such as phenol (2–28 mg/L) from forestry and copper (2–17 mg/L) from natural sources exceed maximum permissible levels in fishery areas.

### 9.8.3. Biodiversity

Most of the available information on biodiversity is from the upper and middle reaches of the Mezen and some of its tributaries.

A total of 168 diatom taxa have been recorded in non-planktonic communities in the Mezen River and its tributaries, such as the Vashka, Ertom, Evva and Pozh. Epilithon is abundant, with *Fragilaria*, *Achnanthes*, *Epithemia* and *Cocconeis* most common. Tributaries are rich in *Melosira* and *Gomphonema* and other genera. *Cocconeis placentula* and *Melosira varians* are commonly recorded. Most of the dominant species are considered to be indicators of high nutrient content (Stenina 1997). Their development is favoured by macrophytes present in the slow-flowing river and the alkaline waters.

The most common genera in the Mezen River are *Potamogeton*, *Sparganium*, *Sagittaria*, *Batrachium*, *Stratiotes* and *Hydrocharis* (Tolmachev 1974–1977; Shmidt & Sergienko 1984; Leshko 1998). The estuary is rich in *Triglochin martimum*. *Potamogeton* and *Petasites* are widespread in slow-flowing reaches with sand-silt substrata *Myriophyllum*, *Eleocharis*, *Sagittaria* and *Utricularia* are also present. Aquatic mosses such as *Fontinalis* and *Dichelima* cover stony and silty bottom (Shubina & Zheleznova 2002). River banks are colonised by *Carex*, *Equisetum*, *Comarum*, *Alisma* and *Butomus*. *Allium*, *Pinguicula* and *Aster* are found in the moist and stony towpaths and stony headlands (Lashenkova 1970).

Zooplankton consists of rotifers, cladocerans and copepods (Leshko et al. 1990). Numbers and biomass are extremely low, with maximum values of 790/m<sup>3</sup> and 0.006 g/m<sup>2</sup>, respectively (Zvereva & Ostroumov 1953). *Euricercus*, *Simocephalus*, *Polyphemus*, *Scarpholeberis* and *Acroperuus* dominate the near shore zone and slow-flowing reaches of the river. The zoobenthos includes Hydra, Nematoda, Oligochaeta, Mollusca, Araneina, Hydracarina, Harpacticoida, Cladocera, Ostracoda, Copepoda, Collembola, Odonata, Ephemeroptera, Plecoptera, Coleoptera, Trichoptera, Simuliidae, Chironomidae Heleidae and Diptera (Zvereva & Ostroumov 1953; Leshko 1996; Leshko et al. 1990; Sidorov et al. 1999). Chironomids are abundant, up to 2300/m<sup>2</sup>. The biomass in the slow-flowing middle reaches is dominated by Mollusca (up to 3.2 g/m<sup>2</sup>). A study carried out in 1997 (Sidorov et al. 1999) showed that Chironomidae and Ephemeroptera dominated the biomass in upstream reaches. Chironomidae on stony substrates include 87 taxa (Kuzmina 2001), the most common being *Orthocladius*, *Microtendipes*, *Thienemanniella*, *Tanytarsus* and *Cladotanytarsus*. The benthos in the tributaries has a similar composition (Martynov et al. 1997), although Chironomidae are more numerous; from 1700 to 9700/m<sup>2</sup>. Coleoptera, Trichoptera and Chironomidae are major contributors to the zoobenthic biomass. There are 57 species of molluscs (Leshko 1998), the most important are in the genera *Cincinna*, *Anisus* and *Lymnaea*. Leeches are widespread, especially the genera *Pisciola* and *Helobdella* (Lukin 1954).

The fish fauna of the Mezen consists of 28 species from 11 families (Solovkina 1975). The most important are the native species, Atlantic salmon, powan, inconnu and grayling, as well as the non-native pink salmon. One reptilian species (*Lacerta vivvipara*) and three amphibians (*S. keyserlingii*, *Rana arvalis*, *Rana temporaria*) are recorded from the catchment (Anufriev & Bobretsov 1996; Kuzmin 1999). The fauna of nesting birds is represented by 156 species (Yestafiev et al. 1995, 1999), compared to 30 species wintering in the region. Bird communities are composed of widespread Palearctic taiga species, as well as Siberian and European species. There are 45 mammal species in the Mezen catchment (Geptner et al. 1961, 1967; Polezhaev et al. 1998; Anufriev 2004), most of which are widespread across the entire catchment.

#### 9.8.4. Management and Conservation

A number of protected areas (zakazniks) have been created in the Mezen catchment, primarily for protection of the landscape and bogs/forests (Yermolin 1991; Taskaev et al. 1996). In terms of the fishery, the Mezen River and its tributaries is one of the most valuable river catchments in NW Russia. *Nymphaea candida*, *N. pumila*, *Spirodela polyrrhiza* are protected species (Andreev 1995). The vascular plants, *Triglochin maritimum* and *Sparganium microcarpum* as well as the moss, *Dichelima falcatum*, have decreased due

to anthropogenic impact (Taskaev 1998) and are vulnerable. The fishes, inconnu and bullhead, are listed in the regional Red Book of the Komi Republic and Archangelsk region (Andreev 1995; Taskaev 1998). The Siberian salamander, *S. keyserlingii*, is included in the Red Book of the Archangelsk region and Komi Republic. This species occurs sporadically in the middle reaches of the Mezen, mainly in the higher wetlands.

The natural taiga landscape, plentiful forage and the absence of human disturbance help to preserve rare and protected birds. The Red Book of the Russian Federation includes 12 species, while the regional Red Book of the Komi Republic and Archangelsk region lists an additional 18 threatened or decreasing bird species. Naturalized mammals include the muskrat and raccoon dog, while the beaver has been reintroduced. The list of protected mammals includes six species from the northern areas (taiga shrew, Northern bat, Russian flying squirrel, Siberian chipmunk, European mink and badger) in the regional Red Books of the Archangelsk region (Andreev 1995) and Komi Republic (Taskaev 1998). The Mezen River catchment is little developed economically, but in the long-term there is potential for forestry and agriculture. Nevertheless, intensive deforestation has caused impoverishment of zoobenthos in some reaches (Leshko 1996, 1998).

### 9.9. THE PECHORA RIVER

The Pechora, a 12th order river, has the highest mean discharge of European rivers flowing into the Arctic Sea. Its occupies the vast Pechora lowlands bordered by the Ural Mountains in the east and by the Timansky Ridge in the west and southwest, dividing the Pechora from catchments of the Northern Dvina, Mezen and Volga Rivers. The Pechora catchment covers 322 000 km<sup>2</sup> and the river is 1809 km long (Photo 9.6). The original colonization of the region started in the Palaeozoic around 300 000 years ago. The earliest archaeological remains are at the Mamontova kurya site in the middle reaches of the Usa River, the largest right-hand tributary of the Pechora. The Finno-Permian tribes, ancestors of the present-day Finnish people, appeared in the region in the Late Stone Age (3000–4000 BC). The ancestors of Komi people, the present-day indigenous people, appeared in this area in the first millennium BC. The far northern regions (tundra, forest tundra) were populated by the Ugro-Samodian tribes in the Middle Ages. They engaged in deer hunting, fishing and hunting marine animals (Stolpovsky 1999; Spiridonov 2001).

#### 9.9.1. Physiography, Climate and Land Use

The catchment of the Pechora River is in the northeast part of the East European Plain and also partly in the Ural Mountains. The catchment is divided into three main orographic provinces: the Pechora lowlands, the Timansky



**PHOTO 9.6** Valley of the Pechora River, middle section (Photo: V. Ponomarev).

Ridge and the Urals. The northeast part of the catchment is within the borders of Bolshezemelskaya tundra which is a hilly plain with numerous moraines and ridges at 200–350 m asl. Between the moraines and ridges are many lakes, mostly of thermokarst origin. The northwest part of the Pechora River is occupied by the Malozemelskaya tundra. The Timansky Ridge, with an average altitude of about 190 m asl and peaks of around 400 m asl (Chetlassky Kamen at 463 m asl), forms the west and southwest part of the catchment (Zhila & Alyushinskaya 1972). The east part of the catchment is formed by the Ural Mountains with maximum altitudes of 1600–1800 m asl (Gora Naroda 1895 m) and small glaciers in the highest parts. The Urals in the Pechora River catchment are 20–50 km wide in the north and 60–100 km wide in the south. The Ural Mountains capture the moisture-laden air, giving rise to high flows in the rivers flowing from the western slopes. The main mountain rivers (Upper Pechora, Ilych, Shugor, Kosyu) flow in broad valleys. The mountains are mainly composed of metamorphic and igneous rocks, although as in the Timansky Ridge, karst structures are widely developed in the Ural foothills, influencing the hydrology of smaller rivers.

The central part of the Pechora catchment is occupied by the Pechora Lowlands, a flat area overlain with 100 m or more moraine material (Rykhter 1966; Efimov & Zaitsev 1970). The topsoil of the catchment's largest part, from 60° latitude southwards, is podzol, loam and sand, while in tundra areas waterlogged gleysol soils dominate. Vast peat bogs are widely distributed throughout the catchment. The largest European wetlands are situated in the catchment: the Usinsky wetland between the Usa and Pechora Rivers and Martoshevsky wetland between the Pechora and Mylva Rivers.

The vegetation is mainly coniferous forest, the forest coverage increasing from 60% in the north to the 90% in the south. In tundra and forest tundra that cover <30% of the catchment, the forests are thin and trees scattered. About 20% of the Pechora catchment is in the permafrost region (Bolshezemelskaya and Malozemelskaya tundra). In the extreme northeast, permafrost is continuous, its thickness reaching 250–300 m. The degree of intermediate permafrost increases southwestwards. On the left-bank of the Pechora River catchment, permafrost is either absent or only found in a few areas (Efimov & Zaitsev 1970).

The large size of the Pechora catchment, both longitudinally and latitudinally as well as differences in relief, results in considerable climatic heterogeneity. The average annual air temperature is always below zero, decreasing from the southwest (−1.0 to −1.3 °C) to the northeast (−3.5 to −5.0 °C). The warmest month is July, the coldest is January or February. The absolute minimum temperature has been recorded in the Urals (−55 °C) and in the southern part of the catchment (−54 °C). The absolute maximum for the main part of the catchment is 34–35 °C, in the northern part 31–33 °C. The earliest daily average air temperature above 0 °C is in the southern part of the catchment (14–18 April), the latest in the Polar Urals (28 May). In autumn, the average air temperature falls below 0 °C in southern parts of the catchment between 10 and 15 October, and in the north and in the mountains between 1 and 10 October. The average duration of the period with above 0 °C temperature varies from the south to the northeast from 160–180 days to 125–150 days (Anon. 1989).

The highest annual rainfall occurs on the slopes of the Urals (800–1000 mm), increasing with altitude (Kemmerikh 1961; Taskaev 1997). In the lowlands, precipitation increases from north to south, from 550 to 700 mm. About

30–35% of the annual precipitation falls in winter, with a minimum in February and a maximum in October. The average date for snow cover is 7–10 October in the north, 28–30 September in the Polar Urals and 5–13 October in the rest of the region. The snow cover remains for about 190 days in the southwest and 230 days in the extreme northeast. Snowmelt starts in the middle of May in the southwest and at the beginning of June in the northeast (Anon. 1989).

The oldest settlements in the catchment, including the communities of Pustozersk, Ust'-Tsylma and Izhma, were founded between the end of the 15th century and the middle of the 16th century. Until the 1930s, economic activity in the Pechora catchment was restricted to agriculture, deer ranching, logging, hunting and fishing. When major coalfields were discovered in the northern part of the Usa River catchment at the beginning of 1930s, the coal-mining industry was developed (Chernov 1989). In the coal mining areas, the cities of Vorkuta and Inta were founded, together with associated industries. At the same time, the first oilfield (1932) and gas field (1935) were discovered and industrial development started in the Timano–Pechorsky oil and gas bearing province in the Izhma River catchment. The most intensive development took place in the 1970s, based on the discovery of major oil and gas fields in the Bolshesemelskaya tundra, and Ukhta and Sosnogorsk in the Izhma catchment received new impetus for their development. In addition, new centres developed, including Naryan–Mar at the mouth of the Pechora River, Usinsk at the mouth of the Usa River and Vuktyl on the right bank of the middle Pechora River. At present, the energy industry plays a leading role in the regional economy. There are large thermal plants operating in Pechora, Vorkuta and Inta using local raw materials. The main railway in the Pechora region was built in the 1940s and connected the central Russian cities with the cities of the Komi Republic. A system of oil and gas pipelines was also developed. More traditional branches of the economy, the timber industry, agriculture and fishing, deer ranching and shipping developed simultaneously with these other industries.

### 9.9.2. Geomorphology, Hydrology and Hydrochemistry

The Pechora River originates from a small spring near the mountain of Pechor-Ya-Talyakh-Sekhal ('The mountain which gave birth to the Pechora River') in the northern Urals at 897 m asl. In the Urals, the Pechora is a typical mountain river with rapid flowing waters and stony substrates. The montane character of the Pechora continues until its confluence with the Ilych. Afterwards, and down to the estuary, it is a typical plains river. In the mountains, it flows west; then as it emerges from the mountains, it turns north. The Pechora then crosses the subzones of the middle and northern taiga, where forest cover is 85%, and bogs and wetlands comprise 10% of the area. Below the confluence with the Usa River, the Pechora turns west. Below the confluence with the Izhma

River, the Pechora again turns north and flows in this direction until it reaches the sea. In the area from the Usa confluence and to the estuary, the left tributaries are typical taiga plains rivers, while the right tributaries originate in the Bolshesemelskaya tundra region. This part of the Pechora is called the Low Pechora (Stolpovsky 1999; Ilyina & Grakhov 1987).

In montane and submontane parts of the catchment, the river flows in a narrow valley with steep sides. Lower down, from Rkm 1643, the river valley extends up to several kilometres forming vast floodplains covered with forests and meadows. In some places there are multiple channels, but when crossing hilly terrain it flows in narrow twisting valleys. Below the Usa confluence, the volume of water is almost doubled, and the watercourse is 2 km wide, with large numbers of channels and islands and floodplains of several kilometres in some places. At 130 km from the estuary, the river splits into two arms that down-river form the 45 km wide delta. The lower reaches of the Pechora are characterized by channel instability, wide floodplains and vast areas covered with shifting sand. The river is tidal up to 140 km from the sea (Stolpovsky 1999). The Pechora network consists of 34 570 streams and 62 140 lakes. The average stream frequency in the catchment is 0.48 km/km<sup>2</sup>, varying from 0.20 in the karst areas (Timansky Ridge) to 1.0 km/km<sup>2</sup> in other regions. The total length of all streams in the catchment is 155 800 km, although 99% of the rivers are <50 km in length. There are 20 rivers >200 km in length.

The largest lowland tributaries of the Pechora are:

- *Severnaya Mylva* – left bank tributary, enters the Pechora at Rkm 1360 from the estuary; 213 km in length, catchment area 5970 km<sup>2</sup>, average altitude 174 m asl. In the catchment, forest coverage is 92%, wetlands cover 6%. The valley is 2–5 km wide, with a floodplain ~1 km. The average slope is 0.00036 ppm.
- *Kozhva* – left tributary, enters the Pechora at Rkm 868; 194 km in length, catchment area 9560 km<sup>2</sup>. Forest coverage 95%, wetlands 4%; valley width 3–6 km, floodplain 1.0–1.5 km; average slope 0.00025 ppm.
- *Izhma* – the largest left bank tributary rises from the eastern slopes of the Timansky Ridge and enters the Pechora at Rkm 455. River length 531 km, catchment area 31 000 km<sup>2</sup>, mean altitude 141 m asl, average slope 0.00044 ppm. The river valley consists of several terraces; the width increasing from 2 to 12 km towards the confluence. The floodplain is discontinuous, 0.2–2.0 km in width. The catchment area is 90% forest and 6% wetland.
- *Tsylma* – the second largest left bank lowland tributary that rises on the eastern slopes of the Timansky Ridge and enters the Pechora River at Rkm 415. The river length is 374 km, catchment area 21 500 km<sup>2</sup>, average altitude 137 m asl, and average slope 0.00040 ppm. The valley consists of several terraces, broadest towards the confluence. The floodplain width is 0.2–3.0 km. The

catchment is 73% forest and 14% wetlands, while in the north forest-tundra and tundra landscapes are prevalent.

- *Sula* – the lowest large left bank tributary of the Pechora, originating from Sul'skoye Lake situated in the Northern Timan. The river catchment is almost completely situated in the Nenets Autonomous Area within the Malozemellskaya tundra region. It runs into the Pechora at Rkm 41. The river length is 353 km, catchment area 10 400 km<sup>2</sup>, average altitude 92 m asl and average slope 0.00069 ppm. Forest covers 40% of the catchment, while 55% is tundra. The river valley is indistinct, reaching 10 km in width. The downstream floodplain is up to 2–5 km wide.

All the major right bank tributaries from the western slope of the Ural Mountains until the Usa River flow into the Pechora.

- *Ilych* – originates from a swamp in the Tima-Iz foothills (593 m asl) and flows into the Pechora at Rkm 1400 from the estuary. The river length is 411 km, and catchment area equals 16 000 km<sup>2</sup>. The upper reaches are between spurs of the Ydydparma with maximum altitudes of 1195 m asl (Kozhymis) and 1096 m asl (Listovka). Near the catchment of the Pechora headwaters the river turns sharply west and crosses the mountains at the confluence. The average slope is 0.00058 ppm and the average altitude is 274 m asl. The major part of the catchment is hilly and 91% is covered in forest, much of which is boggy in the lowlands. The Ilych valley varies in width from 2 to 5 km, and the floodplain in middle and lower reaches is from 0.6–1.0 to 4–6 km wide. The larger part of the Ilych catchment is in the Pechoro-Ilychsky Nature Reserve.
- *Shugor* – originates in the slopes of the Yaruta Mountains at 720 m asl, and flows into the Pechora at Rkm 1037. The river length is 300 km, watershed area 9660 km<sup>2</sup>, and average slope 0.0024 ppm. The highest mountains in the catchment are Tel'posoz (1617 m asl), Khoriaz (1326 m asl) and Pedy (1001 m asl). The upper reaches flow from the south to the north; near the Pedy Mountains it turns sharply west. The upper reaches are characterized by high gradient and rapid flows and there are many rapids. After turning west, it is split into several minor channels in some places. Here the river flows in a broad (up to 10 km) mostly forest-covered valley; the floodplain is discontinuous. The Shugor River is protected as a part of the National Park 'Yugyd Va'.
- *Usa* – the largest right bank tributary of the Pechora rises at the junction of the Malaya and Bolshaya Usa, flowing from the Polar Ural spurs and runs into the Pechora at Rkm 754. The river length is 565 km, catchment 93 600 km<sup>2</sup>, and the average river gradient decreases downstream from 0.0048 to 0.0011 ppm. The left bank Usa tributaries are mostly mountain rivers. The largest are the Lemva (9650 km<sup>2</sup>), the Kosyu (14 800 km<sup>2</sup>) and the Bolshaya Synya Rivers (4040 km<sup>2</sup>). The highest peak of the Urals, Gora Narod (1895 m asl) is in the catchment

of the Kosyu River. The right bank tributaries rise in the Bolshezemelskaya tundra region. The largest are the Vorkuta (4550 km<sup>2</sup>), the Bolshaya Rogovaya (7290 km<sup>2</sup>), the Adz'va (10 600 km<sup>2</sup>) and the Kolva Rivers (18 100 km<sup>2</sup>). The tundra rivers originate in areas of permafrost, whose thickness reaches 250–300 m (Cherny 1970). The forests in the Usa catchment cover ~10% of its area. The remainder is tundra, forest tundra, alpine areas and wetlands.

The typical discharge regime of the Pechora and its tributaries include a high spring flood, with 60–68% of annual runoff in most rivers, low winter flows (5–7% of annual runoff) and a summer–autumn low flow period interrupted by relatively high rainwater floods (25–30% of annual runoff). The discharge pattern of rivers draining permafrost areas is rather different, with 71–80% of annual runoff occurring in the spring, only 1–3% during winter and 20–25% in the summer–autumn season. A more even discharge pattern is typical of karst rivers. A unimodal spring flood peak is typical of the lowland rivers of the Pechora catchment, in contrast to the mountain rivers where there are normally several peaks. The mean date for the onset and termination of the spring flood varies. In the south it begins around 15 April and ends around 31 May. In the north, the flood starts on about 15 May and ends on 1 July. Maximum water levels and discharge are recorded in most rivers during the period 20 May–5 June, although in mountane and tundra rivers the peak is 10–15 days later. Ice jams occur during the high water period in large and minor rivers as well as in the Pechora estuary that lead to water level rises of 1–3 m and flooding of adjacent areas (Zhila & Alyushinskaya 1972; Taskaev 1997). For most lowland rivers, the maximum specific runoff values are 70–120 l/s/km<sup>2</sup>, and for mountain rivers 300–400 L/s/km<sup>2</sup>.

There are many gauging stations on the Pechora and its tributaries, between 66 and 75 have been in operation over the last 30 years, and 45 stations have representative data (Filippova 1985, Figure 9.3). The duration of the low water period decreases northeast from 120 days in Timan to 60 days in the subpolar Ural and Bolshezemelskaya tundra (Kokovkin 1988). In this period, groundwaters are the main water source. Typical winter runoff values vary from 3.5 to 4.0 L/s/km<sup>2</sup> in the southern and central part of the Pechora catchment and the Urals to 0.1–0.2 L/s/km<sup>2</sup> in the central part of the Bolshezemelskaya tundra (Kokovkin 1988). The winter low water period is 150–180 days in the southern part of the Pechora basin and 200–220 days at its northeast edge. The rivers are covered with ice 60–110 cm thick and small tundra rivers freeze to the bottom (Kokovkin 1997).

The surface water chemistry and mineralization of the waters of the Pechora catchment vary considerably both with season and region (Vlasova 1988; Khokhlova 1994a). During winter, the chemistry is strongly influenced by the composition of the groundwater as this is the only water source. The general chemical characteristics for all rivers of the region include low mineralization of river waters in the

spring floods (30–50 mg/L), summer and winter low-water periods (to 100–200 mg/L), predominance of bicarbonate and calcium ions, low water hardness during the whole year, high iron concentrations in most Taiga rivers (up to 2.2 mg/L), relatively high concentrations of phosphorous and nitrogen, as well as phenols, low iodide and fluoride concentrations, and pH varies between 6.0 and 8.0 during the year (Zhila & Alyushinskaya 1972; Vlasova 1988).

The sources of right bank tributaries of the Pechora (Ilych, Podcherem, Shugor, upper Usa) are on the western slopes of the Urals. They have low mineralization levels (in the low water period <100 mg/L), favourable oxygen levels ( $\geq 100\%$  saturation), and circum-neutral pH. Organic substances and nutrients are quite low. The right bank downstream tributaries of the Pechora River (Laya, Shapkina), as well as the Usa tributaries (Bolshaya Rogovaya, Adz'va, Kolva), flow through permafrost areas. Here mineral content is up to 250 in summer and 450 mg/L in winter, and even up to 1000 mg/L in the Vorkuta and Seida Rivers (Khokhlova 1994b). Higher levels of mineralization lead to an increasing share of sulphate and sodium ions. Boggy areas increase the concentrations of humic substances.

The Pechora left bank tributaries (Velyu, Kozhva) and the Izhma right tributaries (Verkhny Odes, Nizhny Odes, Ayuva) crossing the Pechora lowlands also have moderate mineralization (73–100 mg/L), and a favourable oxygen regime. However, they have more humic substances and colour reaches  $140^\circ$  or more, permanganate values 20 mg/L and dichromate 80 mg/L. Ammonium nitrogen concentrations are also greater here (up to 1.8 mg/L) as well as iron compounds (up to 1.7 mg/L) (Vlasova 1988; Leshko & Khokhlova 2003). The left bank Timan tributaries of the Izhma (Sedyu, Ukhta, Kedva) are characterized by high water mineralization levels (up to 600 mg/L), with increased sulphate ions, and in the Ukhta also chloride (Kuchina 1955). TDS in the Pechora River vary from 15.2 (spring) to 630.6 mg/L (winter). The level of mineralization is relatively high in the section Troitsko–Pechorsk–Vyktyl, where it is dominated by calcium and bicarbonate ions. The Pechora River lies between the right and left tributaries level in terms of organic and biogenic substances. In the forest and swamps areas, as well as in the estuary, water colour increases up to  $48^\circ$ , permanganate up to 19.3 and dichromate up to 44 mg/L. Ammonium nitrogen concentrations vary from 0.14 to 1.83 mg/L and iron from 0.16 to 0.61 mg/L. During the open water period oxygenation is near saturation. In winter, however, there is lack of oxygen (21–59%), especially in downstream reaches. The pH varies from 6.1 to 7.9, but is mostly close to neutral.

### 9.9.3. Biodiversity

Research on the biota of the Pechora River has taken place over a long period and there is considerable information on the biodiversity of the river and its catchment (Zvereva 1969; Taskaev 1997; Ponomarev et al. 2004a,b).

In the montane areas of the upper Pechora River benthic algae are characterized by a diversity of diatoms (204 taxa), dominated by *Cymbella*, *Achnanthes*, *Hannaea* and *Nitzschia* (Stenina 2005). In tributary streams, the rheophilic taxa, *Diatoma*, *Meridion*, *Didymosphenia*, *Gomphonema* and *Fragilaria* occur. Filamentous red, green, yellow–green algae and Cyanobacteria are also common on stony substrates. In the river, its tributaries and floodplain lakes of the Middle and Lower Pechora there are more than 700 algal and cyanobacterial species (Chernov 1953; Getsen 1973; Shubina 1986; Patova & Stenina 2004); diatoms, green algae and Cyanobacteria are particularly diverse. In the phytoplankton, the predominant taxa are the diatoms, *Aulacoseira*, *Asterionella*, *Melosira*, *Fragilaria* and *Nitzschia* as well as the Cyanobacteria *Aphanizomenon* and *Anabaena* (Getsen 1971; Yenikeeva 1983). Mass algal and cyanobacterial blooms have been recorded in the river delta (Stenina et al. 2000; Stenina & Khokhlova 2004).

In spite of high currents, the upstream areas of the Pechora are characterized by rich aquatic vegetation on account of stable bottom conditions. The main components are *Petasites* and aquatic mosses (Zvereva 1969; Shubina & Shubin 2002). In the reaches where water velocities are low, *Sparganium*, *Potamogeton*, *Scirpus*, *Hippuris* and *Caltha* thrive, in addition to horsetails and sedges (Zvereva 1969; Teteryuk 2004). The Middle Pechora is characterized by high diversity and abundance of macrophytes due to deep silty substrate (Zvereva 1971a). *Batrachium*, *Butomus*, *Cicuta* and *Alisma* grow near the river banks and aquatic mosses on the stony bottoms. The Lower Pechora is poor in macrophytes because of unstable channels, although individual stands of *Potamogeton*, *Hydrocharis* and *Myriophyllum* are present. Most macrophytes are concentrated in the backwaters and floodplain lakes (Zvereva 1969; Vekhov & Kuliev 1986). The banks of small shallow streams in the Pechora catchment are often colonised by sedges and willows, and 69 macrophyte species have been recorded from such streams (Rebristaya 1977; Teteryuk 2004).

Zooplankton of the Upper Pechora is low in diversity and density (Tyutyunik 1983; Baranovskaya 1991; Shubina 1997; Fefilova 2002; Bogdanova 2004; Shubina 2004) due to high water velocity and stony substrata. Zooplankton is restricted to bank areas where low numbers of *Biapertura*, *Acroperus*, *Alonella* and *Euchlanis* are present. When stream velocities slow and macrophytes develop, the fauna becomes more diverse especially near the banks (77 species and forms). The key groups are Rotatoria, Cladocera, Copepoda, with *Bosmina*, *Chydorus*, *Ceriodaphnia*, *Euchlanis*, *Sida* and *Eucyclops* predominating. The Middle Pechora is characterized by higher zooplankton diversity (93 taxa) and abundance (Baranovskaya 1971). The most favourable areas are the floodplain lakes, where *Bosmina*, *Chydorus*, *Euchlanis* and *Cyclops* juveniles dominate. The average density in the Upper and Middle Pechora varies from 200 to 33 200/m<sup>3</sup>, and biomass varies from 0.05 mg/m<sup>3</sup> to 91.0 mg/m<sup>3</sup>. The zooplankton community is heterogeneous, depending on

the part of the Pechora watercourse and the flow (Zvereva 1969, 1971b; Shubina 2004). In the Lower Pechora, densities are up to 86 000/m<sup>3</sup> and biomass up to 12.7 g/m<sup>3</sup>, with Copepoda and Cladocera dominant.

Zoobenthos of the Pechora River catchment consists of many taxa, (Shubina 2004), the montane streams being especially rich in species. In the Upper Pechora, aquatic insects are numerous with Trichoptera, Ephemeroptera, Plecoptera and Diptera predominant (Shubina 1997; Shubina & Shubin 2002). Stony substrata and river banks are rich in molluscs, leeches, caddisflies, chironomids and other invertebrates. Zoobenthos of the Middle Pechora is dominated by chironomids, oligochaetes, benthic crustaceans, nematodes and mayflies (Zvereva 1969; Shubina 1997). The most developed invertebrate communities are found on stable stony substrata and macrophytes. The communities of the Lower Pechora and floodplain biotopes are most diverse in silty areas, where chironomids, oligochaetes and nematodes dominate (Zvereva 1969; Shubina 2004). Zoobenthos densities range from 100 to 26 900/m<sup>2</sup> in different river sections, and biomass from 0.02 to 11.7 g/m<sup>2</sup> (Shubina 1997; Shubina & Shubin 2002; Shubina 2004). A total of 55 molluscs species have been recorded from the Pechora (Leshko 1998), the genera *Lymnaea* and *Anisus* being dominant.

The Pechora River is traditionally of great significance in terms of fisheries (Figure 9.5). A total of 33 fish species in 15 families form relatively sustainable populations, several undertaking migrations within the Pechora River and its tributaries (Ponomarev et al. 2004a,b). Siberian sturgeon, flounder, pink salmon and the taimen are also occasionally recorded in the Pechora River. The special value of the Pechora River fish population is a result of the dominant salmonids. These include migratory species (pink salmon, Atlantic salmon and pollan), semi-migratory species that never migrate to sea or even to the main channel of the Pechora or its main tributaries (vendace, powan, inconnu and smelt) and common non-migratory species that live only in one local region of the catchment (Arctic charr, broad whitefish, northern whitefish, grayling and Arctic grayling). Practically all European salmonids (12 species) are known from the river. Sterlet and pink salmon are non-native species in the Pechora River.

One reptile and four amphibian species have been recorded in the Pechora catchment (Anufriev & Bobretsov 1996; Kuzmin 1999). Of these, four species are widespread in the catchment, while the European common toad is restricted to the plains of middle taiga. The fauna of nesting birds in the Pechora catchment contains representatives of 15 orders (Morozov 1987, 1989; Morozov & Kuliyevev 1990; Yestafiev et al. 1995, 1999). Within the upper and middle reaches there are 171 nesting bird species. In the lower reaches, species diversity decreases, with 104 species in 8 orders found, and 40 species spend the winter in the region. The bird fauna is diverse and many species, including black-throated accentor, lanceolate warbler, yellow-browed warbler, black-throated thrush, Siberian rubythroat, red-flanked

bluetail, white's thrush, and Indian tree pipit are at the limits of their European range. Since the end of the 19th century, the range of >30 bird species has extended northwards (Kochanov 2001; Yestafiev 2005).

There are 54 mammal species in the Pechora catchment (Geptner et al. 1961, 1967; Anufriev et al. 1994; Polezhaev et al. 1998; Bobretsov et al. 2004). Within the southern and middle part of the northern taiga there are 48 species, compared to only 26 species in the downstream reaches. The upper catchment forms the northern limit for bats, field voles, roe deer; and the middle and northern taiga form the northern limit for water shrew, pigmy shrew, raccoon dog and wild boar. In contrast, lemmings and arctic foxes inhabit the tundra areas. In the northern and subpolar Urals mountains, there are several colonies of the northern pika, *Ochotona hyperborean*. The western limit for the sable lies within the catchment. In the middle of the 20th century the muskrat was introduced and the non-native American mink and raccoon dog colonised the area from the south. At the beginning of the 20th century, beaver were reintroduced. The roe deer has not been recorded since the middle of the last century.

#### 9.9.4. Management and Conservation

The western slope of the Ural Mountains from the Ilych River to the Kozhim River (the Kosyu catchment) is a part of the Yugyd Va National Park. Recreational activities are being developed in the Park. In recent years the water quality of the Pechora River has been negatively affected, either as a result of insufficient waste-water treatment or due to industrial accidents. The continued development of the extensive energy resources of the region poses a continuing challenge for management, as well as being a potential threat to the pristine nature of much of the catchment. The macrophytes, *Ranunculus pallasii* and *E. quinqueflora*, are protected (Taskaev 1998). *N. candida*, *N. tetragona*, *T. maritimum*, *Potamogeton filiformis*, *Ranunculus hyperboreus*, *R. pygmaeus* and *V. anagallis-aquatica* are registered in the Pechora River catchment as potentially endangered species affected by anthropogenic activities (Tolmachev 1974–1977). Zoobenthic species diversity has also been reduced due to anthropogenic activities (Leshko & Khokhlova 1999).

The fishes, Arctic grayling, Arctic charr, inconnu, taimen and bullhead are listed in the regional Red Books of the Komi Republic and Arkhanglesk region. In recent years negative changes in salmon species populations connected to anthropogenic impacts, such as industrial, agricultural and household pollution as well as poaching have been registered. The only species among the reptiles and amphibians in the Red Book of the Arkhanglesk region (Andreev 1995) and the Komi Republic (Taskaev 1998) is *Salamandrella keyserlingii*, a widespread species, but uncommon and present in low numbers. A total of 14 bird species are listed in the Red Book of the Russian Federation (white-billed diver, lesser white-fronted goose, Berwick's swan, osprey, spotted eagle, golden

eagle, white-tailed eagle, gyrfalcon, peregrine falcon, osprey, curlew, ivory gull, eagle owl and great grey shrike). An additional 39 species, which are declining in numbers or at the limits of their range north, are listed in the regional Red Books of the Komi Republic and Arkhangelsk region. Numerous species within the northern borders of the catchment are low in numbers and are listed in these regional Red Books. The American mink has attracted a great deal of attention with regard to endangered species. It has spread north and an increase in numbers threatens many native species.

The Pechoro-Ilychsky Biosphere Nature Reserve, founded in 1930, is at the confluence of the Pechora and Ilych Rivers (Bobretsov et al. 2004). In 1994, the nearby Yugyd Va National Park, situated on the western slope of the Urals, was created. The main objective is to undertake research and protect the typical and unique flora and fauna of taiga-montane ecosystems of the region (Anufriev 2000; Ponomarev 2001). The nature reserve and National park are incorporated into the UNESCO Nature Heritage list. The Pechora Delta forms part of the Nenets State Nature Reserve founded in 1997, and borders on the Nenetsky State Nature Sanctuary founded in 1985. The key activity of these protected areas is the protection and study of endangered animal and plant species in the typical ecosystems of the eastern European tundra and the Barents Sea coastal waters. In addition, there are nine fish sanctuaries and four aquatic nature reserves in the Pechora catchment (Taskaev et al. 1996).

## 9.10. THE GEITHELLNAÁ RIVER

### 9.10.1. Physiography, Climate and Land Use

The Geithellnaá is a third order direct runoff river in eastern Iceland at 64°35'N, 14°45'W. The catchment is characterized by Tertiary bedrock (Johannesson & Símundsson 1998). As a runoff river, it collects water from the highlands east-northeast of the Vatnajökull Ice Sheet and flows along a 25 km long and narrow valley Geithellnadalur, excavated during the last Ice Age. The majority of the water in the highlands comes from a small icecap east of Vatnajökull, the Thorisjökull.

The mean air temperature in the upper reaches is 1.1 °C and at sea level 3.9 °C. The coldest month in the highland catchment is February with a mean temperature of -7.8 °C, while at sea level it is -0.1 °C in January. The warmest month is July in the highland catchment with mean temperature 7.8 °C and August at sea level with mean temperature 9.1 °C. Precipitation data are only available for the lower reaches, averaging 1312 mm, with May being the driest month and October the wettest. Only 54.5% of the total catchment is covered with vegetation, with 2% coverage in the upper reaches and 11% in the middle reaches. Agricultural land is limited and covers only about 0.5% of the lower reaches, although the area of farm land was much greater

prior to the 20th century. Today, only six people live on a farm in the lower reaches, giving a population density here of 0.03 persons/km<sup>2</sup>.

### 9.10.2. Geomorphology, Hydrology and Biogeochemistry

The river partly originates from a glacier and runs down a U-shaped valley formed during the last Ice Age. The size of the catchment is 187 km<sup>2</sup> (Adalsteinsson & Gíslason 1998). The Tertiary bedrock is impermeable and most runoff flows directly into the river along the bottom of the valley. Discharge varies from day to day depending on precipitation, especially during autumn, as well as seasonally. Discharge is greatest in spring, summer and autumn, with discharge of 30–50 m<sup>3</sup>/s, while winter discharge ranges from 5 to 15 m<sup>3</sup>/s. There is also variation in annual mean discharge, from 10 m<sup>3</sup>/s in 1971 to 25 m<sup>3</sup>/s in 1976, reflecting annual precipitation. Conductivity is low, between 17 and 30 µS/cm, lowest in the upper reaches and highest in the lower reaches. pH varies from 7.4 in the upper reaches to 8.0 in the lower reaches. Nutrients are low as the river is on an ancient bedrock formation (>10 million years old). In September 1995 PO<sub>4</sub>-P was 11.2–15.8 µg/L in all reaches and total N was 62.6 µg/L, 47.0 µg/L and 4.0 µg/L in upper, middle and lower reaches, respectively. NO<sub>3</sub> was by far the highest constituent, 55.9 µg/L, 40.7 µg/L and 40.0 µg/L in the upper, middle and lower reaches, respectively.

### 9.10.3. Biodiversity

Chironomids are most abundant of all invertebrates (Lárusdóttir et al. 2000), with densities ranging from 8000 to 36 000 /m<sup>2</sup>, with lowest numbers in the upper reaches. The proportion of Chironomidae larvae in the benthos varies little, between 97.5% in the upper reaches to 99.9% in the middle and lower reaches. The blackfly, *Simulium vittatum*, has been recorded in window traps in all reaches. The number of chironomid species in window traps (Jonsson et al. 1986) was 12, 15 and 16 in the upper, middle and lower reaches, respectively. They all belonged to *Diamesa* and *Orthoclaadiinae*, except a single specimen of *Tanytarsus gracilentus* recorded in the upper reaches (Olafsson et al. 2002). Although no catch statistics are available for fish, Arctic charr (*S. alpinus*) have been caught in the river by electro-fishing.

## 9.11. THE LAXÁ RIVER

The River Laxá is a third order river. It drains Lake Mývatn and flows 58 km northwards to the sea. Mývatn is located in the northeastern part of Iceland at around 65°35'N, 17°00'W and 277 m asl. It is fed by many cold and warm springs containing high levels of phosphorous



**PHOTO 9.7** (a) The Bruarfossar waterfalls in the River Laxá in 1912 (Photo: W.H. Lamblon, District Museum, Husavik). (b) The Bruarfossar waterfalls in the River Laxá 2006. Power plants were built here during the period 1939 to 1973 (see text) (Photo: G. Gudbergsson).

and nitrogen. Subsided lava and a lava dam form the basin of lake Mývatn, and lava also partially forms the bed of the Laxá. Both Lake Mývatn and the Laxá have been extensively studied (Photo 9.7).

### 9.11.1. Climate and Land Use

The climate of Iceland is oceanic, but inland, especially in the northeast, it is more continental in character (Einarsson 1979). The annual mean air temperature is 1.7 °C at Mývatn, 2.3 °C in the middle reaches of the Laxá and 2.6 °C at sea level. The average temperature for July, the warmest month, is highest at Lake Mývatn, 10.4 °C, compared to 10.1 °C in the middle reaches of the Laxá and 9.9 °C at sea level (Icelandic Meteorological Office).

During the coldest month, January, the mean temperature at Mývatn is  $-4.4$  °C, in the middle reaches  $-3.2$  °C of the Laxá and  $-2.7$  at sea level. The Mývatn area is in the part of Iceland with the lowest precipitation (Einarsson 1979), largely due to being in the rain shadow of the Vatnajökull Ice Sheet. The average annual precipitation at Lake Mývatn is 435 mm, but increases to 563 mm at sea level. At Mývatn, the lowest precipitation is in May and highest in October, but at sea level it is lowest in April and highest in June. The human population is mainly restricted to the area around Lake Mývatn, with a small village on the north shore of the lake. Farms are also located on the shores of Mývatn and on the shores of Lake Grīnavatn, in the lower reaches of the tributary River Kráka and along the banks of the Laxá. The population density at the upper reaches of the Laxá is

0.3 persons/km<sup>2</sup>, compared to 1.3 persons/km<sup>2</sup> in the middle and lower catchment areas.

### 9.11.2. Geomorphology, Hydrology and Biogeochemistry

The Laxá River flows out of Mývatn, a shallow lake with an area of 37 km<sup>2</sup> in the volcanic zone of northeast Iceland. Mývatn is fed by warm and cold springs on its eastern shores and by Lake Gr̄navatn, a short distance to the south. Its theoretical retention time is 27 days with a mean outflow to the Laxá of 33 m<sup>3</sup>/s (Olafsson 1979a; Rist 1979a). The warm spring water is rich in nitrogen and the cold spring waters are rich in phosphorus (Olafsson 1979b). High solar radiation and nutrients in the spring water render Lake Mývatn as one of the most productive lakes in northern Europe (Jonasson 1979a). The Laxá River can be divided into two parts, the upper 33 km from Mývatn to the Bruafossar waterfalls (Photo 9.7), and the lower 26 km from the waterfalls to the Arctic Ocean. The Bruafossar waterfalls in the Laxárgljufur canyon are impassable to fish. The mean discharge of the Laxá where it enters the sea is 55 m<sup>3</sup>/s (Rist 1979a).

The river bed consists of lava with boulders (diameter 20–50 cm), stones (10–20 cm), gravel and sand (<10 cm). The 1359 km<sup>2</sup> catchment of Mývatn has only 17% vegetation cover. The catchment of the Laxá (including the catchment of Mývatn) covers 2385 km<sup>2</sup>, 39% of which is covered with vegetation. The Laxá's tributaries have higher vegetation cover, ranging from 25% to 88% (Gíslason 1994), increasing at lower altitudes. The discharge of the Laxá is stable and floods rarely occur. In the spring thaw in May, discharge increases by about 35% and occasionally (about every 6–7 years) as much as 100% (Hydrology Department of the National Energy Authority, Gíslason 1994). Lake Mývatn is usually covered with ice from October or November until May, or sometimes to early June, with average duration of 189 days a year (Rist 1979b). Conductivity in the Laxá is high. In the outlet in 1977–1978, it was 151–193  $\mu\text{S}/\text{cm}$ , although slightly lower downstream (141–166  $\mu\text{S}/\text{cm}$ ). The pH of the Laxá varies between 7.7 and 9.3. Nutrients, originating in spring water in the source Lake Mývatn, fluctuate seasonally, mainly due to production in the lake (Table 9.2). They are high

in winter, and low or almost depleted during summer due to uptake by algae.

### 9.11.3. Biodiversity

A total of 52 invertebrate taxa have been identified from the Laxá, (Gíslason 1994; Olafsson et al. 2004; Thorarinsson et al. 2004). The blackfly, *S. vittatum* (Simuliidae), is the most abundant benthic invertebrate in the outlet from Mývatn. The stomach contents of blackfly larvae reflect the seston composition in the river, mainly drifting algae and detritus from the lake (Gíslason & Johannsson 1991). Further downstream, chironomid larvae are the most abundant benthic invertebrate group (Gíslason 1994). Chironomidae account for 27 of the 52 benthic species in the river. In the upper reaches of the river, 19 chironomid species have been recorded from window traps, compared to 23 and 25 species in the middle and lower reaches, respectively (Gíslason et al. 1995). The density of invertebrates in August 1978 was estimated at 132 500 /m<sup>2</sup> near the outlet, falling to 97 700 /m<sup>2</sup> in the middle reaches and increasing to 195 500 /m<sup>2</sup> further downstream (Thorarinsson et al. 2004), after the river had flowed through a wide channel that reduced the water velocity to about 0.4 m/s (Jonasson 1979b). The vertebrate fauna of the upper river is characterized by a landlocked brown trout (*S. trutta*) population and two duck species, Barrow's goldeneye (*Bucephala islandica*) and the harlequin duck (*Histrionicus histrionicus*) (Einarsson et al. 2006). In the upper part, *S. vittatum* constitutes about 60% of the diet of the brown trout regardless of fish size (Steingrímsson & Gíslason 2002). The relative contribution of *S. vittatum* to the diet declines downstream from Mývatn. The seasonal variation in stomach contents of brown trout reflects the different number of generations of *S. vittatum* in the upper and lower parts of the river (Gíslason & Steingrímsson 2004). *S. vittatum* has two generations per year in the upper part, whereas only one generation per year emerges in the lower river. In the lower reaches of the Laxá, Atlantic Salmon (*S. salar*) is the most common fish species caught, with anadromous brown trout being nearly as abundant, together with a small number of anadromous Arctic charr (*S. alpinus*). The Harlequin duck is also common in the lower reaches of the river (Gardarsson 1979).

**TABLE 9.2** Nutrients (PO<sub>4</sub>-P, NO<sub>3</sub>-N and SiO<sub>2</sub>-Si) in the River Laxá, at the outlet of Lake Mývatn, in the middle reaches (33 km from outlet) and lower reaches (58 km from the river mouth)

	PO <sub>4</sub> -P ( $\mu\text{g}/\text{L}$ )	NO <sub>3</sub> -N ( $\mu\text{g}/\text{L}$ )	SiO <sub>2</sub> -Si (mg/L)
Outlet	3.10–45.22	0.14–38.52	1.12–10.78
Middle reaches	2.17–19.82	0.84–47.34	2.53–10.45
Lower reaches	3.41–11.37	0.98–5.04	3.00–6.88

Data from Ólafsson (1979b) and Eiríksdóttir et al. (2008).

#### 9.11.4. Management and Conservation

In 1939, a power station (5 MW) was built by the town of Akureyri on the Laxá 30 km downstream from Lake Mývatn. It uses the upper part of the 39 m high Bruar waterfalls. A dam diverts the water to the station's intake, but there is no storage reservoir above the dam. Another power station (9 MW) became operational in 1953, and uses the lower part of the waterfalls, with a head of 29 m. There is also a small dam to divert the water to the intake of the station. Construction of a third power station began in 1970 and was intended to be 25 MW. It was to use the same inflow as the initial station, but be hidden inside the mountain, and with a 56 m high dam on the river that would have inundated about 15 km of the valley. This led to a dispute between farmers and environmentalists, on the one side, and the Akureyri Power Company and the government on the other. The dispute ended up with a settlement that led to a 13.5 MW power station below the existing dam for the initial power station and using the same head of water.

Limnological research on lake Mývatn and the Laxá (Jonasson 1979a) gave rise to the legislation embodied in the Mývatn and Laxá Conservation Act (1974), covering the entire Lake Mývatn catchment and the Laxá with 200 m buffer zones on each bank. In accordance with the Act, the Mývatn Research Station was established in 1974 on the banks of the Mývatn. The station has formed the basis for further research on the lake and the Laxá. In 1977, Mývatn-Laxá was the first wetland in Iceland to be designated on the Ramsar list (Convention on Wetlands of International Importance especially as waterfowl habitat) for its diverse biota and wealth of waterfowl (Gíslason 1998). The size of the designated area is 200 km<sup>2</sup> and covers lake Mývatn and the Laxá, all wetlands in the catchment and a large area around lake Mývatn, and a 200-m buffer zone on each side of the Laxá ([http://www.ramsar.org/profile/profiles\\_iceland.htm](http://www.ramsar.org/profile/profiles_iceland.htm)). In 2004, the protected area was reduced by revision of the Mývatn and Laxá Conservation Act, from the whole catchment of lake Mývatn to a 200 m zone along the banks of Lake Mývatn and adjacent wetlands, a total of 153 km<sup>2</sup>. There are plans, not yet put into force, to significantly increase this protected area.

### 9.12. THE VESTARI JÖKULSÁ RIVER

The Vestari Jökulsá is a typical glacier-fed river. It is a fourth order river that originates from the glacier, Sátujökull, an outlet glacier from the Hofsjökull Ice Sheet at an altitude of 860 m asl in northern Iceland. The middle section is located at 65°16'N, 19°05'W. It was well studied in the late 1990s under the auspices of a cooperative European project on glacier-fed rivers (Brittain & Milner 2001; Gíslason et al. 2001).

#### 9.12.1. Physiography, Climate and Land Use

The Vestari Jökulsá flows north across the central highland plateau and reaches the lowlands about 40 km from the glacier snout. The mean annual temperature for the upper reaches is -2.1 °C (Icelandic Meteorological Office), and mean monthly temperatures from June to September are above 0 °C. The warmest month is July with a mean temperature of 7.1 °C and January the coldest with a mean of -8.3 °C. Temperatures increase downstream and in the lower reaches the mean annual temperature is 2.8 °C, the mean July temperature is 10.1 °C and the mean January temperature is -2.6 °C. Annual precipitation varies from 380 mm in the lowlands to 727 mm in the upper reaches, with May being the driest month.

The river runs through a barren catchment with little or no vegetation cover in the upper reaches. In the middle reaches vegetation cover is about 4% and in the lower reaches 93%, with an overall vegetation cover of 48% (Gíslason et al. 2001, Photo 9.8). There is no forest in the area. There are small patches of vegetated land in the upper and lower reaches, notably near the spring-fed tributary, Midhlutará, that is used as summer pasture for sheep. The lower parts of the catchment serve as pasture for sheep and cattle. Cultivated land is restricted to the lower reaches and its cover is <1%. Human settlement is also limited to the lower reaches where the population density is about 0.05 individuals/km<sup>2</sup>. There are no forests and only small wetlands are found around Vestari Jökulsá and its tributaries.

#### 9.12.2. Geomorphology, Hydrology and Biogeochemistry

The Vestari Jökulsá originates as three main branches (eastern, middle and western branch) from the northwest outlet glacier, Sátujökull, part of the Hofsjökull Ice Sheet. A hyaloclastite mountain ridge separates the eastern branch from the others. A fissure zone assumed to be connected with a central volcano below the glacier (Björnsson 1988; Sigurdsson 1990) cuts through the area. The river flows with a gradient of 5–10 for most of the way from the glacier to the lowlands, except between the edge of the highland plateau and the lowlands, where its slope increases to around 20. The glacier catchment area of the river is 90 km<sup>2</sup> compared to the 820 km<sup>2</sup> at the lowest gauging station in the lowland valley, 45 km away from the glacier. The annual average discharge (1971–1997) at the lowest sampling site of the river is 21.4 m<sup>3</sup>/s (Gauging station no. 145, National Energy Authority in Iceland, Hydrological Survey).

TDS, deduced from conductivity, indicate that the middle branch is fed by meltwater originating directly or interacting with the assumed volcanic area, as its mineral content is already high (>50 μS/cm) in July, while the other branches have conductivity as low as 10 μS/cm (Gíslason et al. 2000). The eastern branch, close to the



**PHOTO 9.8** The River Vestari-Jökulsá near its confluence with the tributary Hofská, seen from terminal moraines from the end of the last Ice Age (Photo: G.M. Gíslason).

glacier, was dominated by clear meltwater in July 1997, but in September the same year all branches were highly turbid. The conductivity in the eastern branch remained low, while the conductivity in other branches was higher ( $>40 \mu\text{S}/\text{cm}$ ), which indicates that the glacial meltwater was mixed with geothermal water. In mid-winter, the Vestari Jökulsá is mainly spring fed and at the upper gauging station summer discharge decreases from  $30\text{--}40 \text{ m}^3/\text{s}$  to  $<1 \text{ m}^3/\text{s}$  in winter. In the lower reaches the discharge is typically  $15 \text{ m}^3/\text{s}$  in winter and  $35\text{--}50 \text{ m}^3/\text{s}$  in summer. At such discharges, TDS commonly vary between  $65$  and  $80 \text{ mg}/\text{l}$ , which corresponds to  $90\text{--}120 \mu\text{S}/\text{cm}$  (Adalsteinsson et al. 2000), similar to that estimated as the groundwater component late in the summer season.

The conductivity varied from  $8 \mu\text{S}/\text{cm}$  at the glacier snout to  $113 \mu\text{S}/\text{cm}$  in the lower reaches, while pH was  $6.0\text{--}6.7$  near the glacier snout,  $7.2\text{--}7.4$  in the middle reaches and  $7.7\text{--}7.8$  in the lower reaches (Gíslason et al. 2000). Nutrients were low in all reaches, highest in onset of winter and lowest in mid-summer. They were higher in a branch from the glacier with geothermal influence than other glacier outlets (Table 9.3). Total N was varied, but  $\text{NO}_3$  was low,  $0\text{--}1.0 \mu\text{g}/\text{L}$  in upper and middle reaches and  $0\text{--}5.9 \mu\text{g}/\text{L}$  in

lower reaches. N was also present as  $\text{NO}_2$  and  $\text{NH}_4$ , ammonia values being higher

Suspended solids vary considerably with season and between branches. Close to the junction of the branches,  $22.5 \text{ km}$  from the glacier, suspended solids vary between  $100$  and  $1200 \text{ mg}/\text{L}$ . Suspended solids subsequently decrease to  $85 \text{ mg}/\text{L}$  in the lowlands (Gíslason et al. 2001). During summer, chlorophyll a increases from  $0.1 \text{ mg}/\text{m}^2$  at the glacier snout to  $1.6 \text{ mg}/\text{m}^2$   $1.4 \text{ km}$  from the glacier, declining again to  $0.1 \text{ mg}/\text{m}^2$  at  $7.5 \text{ km}$  from the glacier and increasing again downstream to  $0.16 \text{ mg}/\text{m}^2$ . These changes are associated with decreasing proportion of glacial melt water that was  $\sim 50\%$  in the uppermost reaches of the river and only  $20\%$   $42 \text{ km}$  downstream, when tributaries and groundwater have entered the river (Adalsteinsson et al. 2000). Channel stability, expressed by the Pfankuch index, declines downstream from  $55$  to  $21\text{--}35$ , indicating greater channel stability at increasing distance downstream. Maximum water temperatures recorded over the summer increase downstream, from around  $0^\circ\text{C}$  at the glacier snout to approximately  $12\text{--}14^\circ\text{C}$   $4.5 \text{ km}$  downstream. Higher values, up to  $17.3^\circ\text{C}$ , were recorded in some of the tributaries.

**TABLE 9.3** Nutrients ( $\text{PO}_4\text{-P}$ ,  $\text{NO}_3\text{-N}$  and  $\text{SiO}_2\text{-Si}$ ) in the River Vestari-Jökulsá, in upper reaches (close to glacier snout), the middle ranges ( $22 \text{ km}$  from glacier) and lower reaches ( $45 \text{ km}$  from the glacier) (unpublished data)

	$\text{PO}_4\text{-P}$ ( $\mu\text{g}/\text{L}$ )	Total N ( $\mu\text{g}/\text{L}$ )	$\text{SiO}_2\text{-Si}$ ( $\text{mg}/\text{L}$ )
Upper reaches	$0\text{--}2.8$	$7.7\text{--}18.4$	$1.39\text{--}4.5$
Upper reaches with geothermal influence	$0\text{--}22.1$	$7.0\text{--}30.5$	$2.9\text{--}5.5$
Middle reaches	$0\text{--}17.7$	$7.0\text{--}31.0$	$7.1\text{--}11.5$
Lower reaches	$0\text{--}35.6$	$6.4\text{--}40.6$	$11.2\text{--}17.2$

### 9.12.3. Biodiversity

There is considerable seasonal and annual variation in the density of major macroinvertebrate groups in the Vestari Jökulsá. Density and composition change significantly along the downstream gradient, with higher densities and diversities with increasing distance from the glacier margin. Chironomidae are the dominating taxon at all sampling sites (Olafsson et al. 2000). In the upper reaches, nine chironomid species were recorded in window traps: of those, three were *Diamesa*, five Orthocladiinae (*Chaetocladius*, *Cricotopus*, *Eukiefferiella* and *Metriocnemus*) and one Simuliidae (*Simulium vittatum*). In the middle reaches, 6 chironomid species were found and in the lower reaches 12 species. All the species belonged to *Diamesa* and Orthocladiinae. *S. vittatum*, presumably originating from non-glacial streams, was also recorded in the middle and lower reaches (Gíslason et al. 2001). The density of chironomid larvae increased significantly downstream, from 29 to 5877/m<sup>2</sup> (upstream and downstream, respectively). The upstream chironomid assemblages are dominated by the genus *Diamesa*, whereas Orthocladiinae and Tanytarsini dominated lowland reaches (Olafsson et al. 2000; Gíslason et al. 2001).

The only fish species found in the main Vestari Jökulsá is Arctic charr. These are generally small-sized individuals and their size at sexual maturity is <15 cm. Atlantic salmon were caught in small numbers (2–23 annually) from 1974 to 1982 in the tributary Hofsá. This was during a period when salmon were commonly released into rivers to increase the salmon run. At least one of the tributaries, the River Svartá, confluent with the Vestari Jökulsá 45 km from the sea, has always been known for its good salmon run.

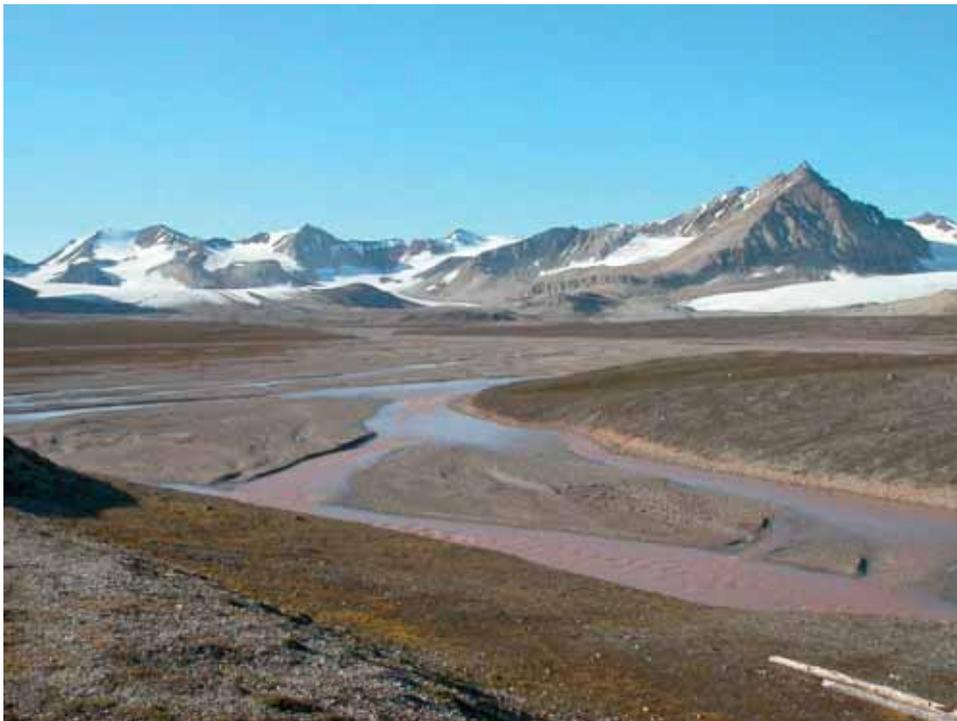
### 9.13. THE BAYELVA RIVER

Bayelva, otherwise known as the Red River because of the high levels of coloured glacial sediment, is located at 79°N, 12°E, in the Kongsfjord on the western part of the island of Spitsbergen. The catchment area is 33 km<sup>2</sup>, of which 55% is glaciated (Brittain & Milner 2001). The highest point of the catchment is 742 m asl. The main sources of Bayelva are two small polythermal glaciers, Austre Brøggerbreen (11.7 km<sup>2</sup>) and Vestre Brøggerbreen (5.3 km<sup>2</sup>) (Photo 9.9).

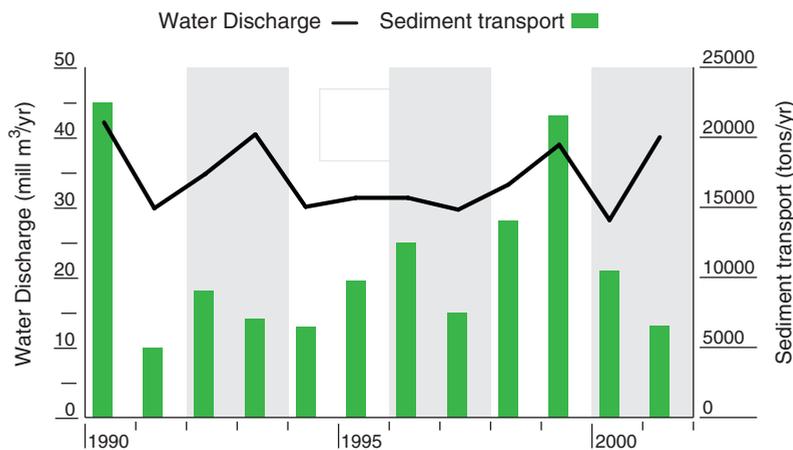
#### 9.13.1. Physiography, Climate and Land Use

The bedrock is sedimentary: limestone, shale and sandstone. The upper parts of the catchment are dominated by glacier, bare rocks and extensive recent moraine material, while tundra vegetation has become established in some areas near the fjord. The landscape is alpine with both cirque glaciers and large valley glaciers, some of which reach the sea. The scientific station of Ny-Ålesund, the world's northernmost permanent settlement, on the Kongsfjord, 2 km to the east of the catchment, has an annual mean air temperature of –6.3 °C and a July mean of 4.9 °C. Precipitation is low with an annual mean of 385 mm recorded in Ny-Ålesund, although calculations adjusted for the increase in precipitation with altitude indicate a mean annual precipitation for the Bayelva catchment of 890 mm (Killingtveit et al. 2003).

There is no permanent habitation within the catchment. There is a small recreational cabin near the gauging station that is located 600 m from the outflow into the fjord. Coal mining was carried out in to the area up until the early 1960s,



**PHOTO 9.9** Bayelva and the source glaciers, Austre and Vestre Brøggerbreen (Photo: J. E. Brittain).



**FIGURE 9.6** Annual sediment transport (suspended load) and mean water discharge in Bayelva.

but is now abandoned. In the Bayelva catchment there are only small vestiges of this activity in the form of tracks, timber and small excavations. Today the catchment is used for research carried out from Ny-Ålesund. A small lake in the catchment, Tvillingvatn, is used as the water supply for Ny-Ålesund. A small airstrip is located on the eastern edge of the catchment.

### 9.13.2. Geomorphology, Hydrology and Biogeochemistry

Most meltwaters leave the glacier via large lateral channels to which fine sediments are supplied by mass wasting of ice-cored moraines at about 100 m asl (Hodson et al. 1998). The channels from these two glaciers converge after about 1 km and the river then flows a further 2 km down to the fjord, alternating between single and braided channels as it breaks through recent terminal moraines. As is typical of glacier-fed rivers, the substrate is unstable (Castella et al. 2001). There are two main tributaries, Tvillingvassbekken and Mørebekken, both of which carry little sediment. Tvillingvassbekken flows out of a small shallow lake Tvillingvatn (area 0.35 km<sup>2</sup>; maximum depth 6.3 m), while the waters of Mørebekken are filtered through extensive terminal moraines. Normally, there is no runoff in Bayelva from early October until the end of May. Snowmelt, and glacial meltwater later, leads to intense flows in June, July and August. Due to rainfall, high floods can occur during late summer and early autumn. In some years, runoff has occurred in late autumn and early winter as a result of the intrusion of Atlantic air into the Arctic Basin.

At the gauging station in Bayelva, the world's northernmost permanent facility, the mean annual discharge is 1.12 m<sup>3</sup>/s (specific discharge 36.2 L/s/km<sup>2</sup>). The highest observed flood was in mid-September 1990 with a daily discharge of 32 m<sup>3</sup>/s. The annual water balance for the whole Bayelva catchment has been estimated for the period 1990–2001 by Killingtveit et al. (2003), based on a wide range of data, both from the Bayelva catchment and other catchments

on Svalbard. The following mean annual estimates were calculated: precipitation 890 mm (summer 277 mm; winter 597 mm), evaporation 37 mm, runoff as a result of negative glacial mass balance 245 mm and runoff 1050 mm. This gives an error term of 31 mm. The Bayelva freezes to the stream bed each winter from September/October to end of May. From mid/late June to late August the river is free of ice. The water temperature is low and normally does not exceed 4 °C. The temperature maximum occurs in early July and freeze up starts some time in September.

The sediment load in the Bayelva is delivered by the polythermal glaciers Austre and Vestre Brøggerbreen as well as eroded material from moraine areas surrounding the glaciers. The total annual suspended load during the period of measurement (1989–2001) shows large year-to-year variation (Photo 9.6). The highest load on record was 23 000 tons in 1990, due to a huge flood in September that year. Exhaustion effects meant that sediment transport did not reach the same level until some years later. The mean specific sediment yield of the glacier and the moraine area has been estimated at 586 tons/km<sup>2</sup>/year (Bogen & Bønsnes 2003). The sediment concentrations are also subject to large seasonal variations. Late in the summer season when the runoff originates from glacial meltwater, the mean suspended sediment concentrations are often about 100–300 mg/L. The huge flood in September 1990 gave a concentration of 4000 mg/L. Rainwater floods in August and September often give rise to high sediment loads.

From 1920 to 1930, Lake Tvillingvatn received groundwater from a sandstone aquifer underlying the lake. Recent water balance studies indicate that there is no longer any groundwater flow of that type (Haldorsen et al. 2002). Previous melting of the permafrost along the glacial front of Brøggerbreen as a result of large amounts of meltwater and a steep hydraulic gradient may have been halted as the glacier retreated and exposed the glacial forelands to renewed permafrost. The river waters are circumneutral. Calcium and magnesium are the major cations, while bicarbonate concentrations are relatively high in relation to other anions. Conductivity is typically 40–80 μS/cm (Lods-Crozet et al.

2001). The major controls on hydrochemistry in the catchment include snowpack solute elution, rapid alteration of minerals via surface reactions and slow, incongruent silicate dissolution (Hodson et al. 2002). The importance of chemical weathering increases downstream. The restricted sub-glacial weathering, because of the largely cold-based thermal regime of the glaciers, means that the proglacial areas are the most important zones of solute acquisition by meltwaters, causing significant enrichment of major ions, silica and dissolved CO<sub>2</sub> within only a short distance from the ice margin (Hodson et al. 2002).

### 9.13.3. Biodiversity

The geographical isolation of the Svalbard archipelago limits the available species pool (Milner et al. 2001; Coulson & Refseth 2004). Water temperatures are low and the substrate is unstable, giving a benthic fauna low in numbers and poor in species, and composed almost exclusively of chironomids (Diamesinae and Orthocladiinae) and oligochaetes (Castella et al. 2001; Lods-Crozet et al. 2001, 2007). Periphyton is the main food source and chlorophyll a concentrations may reach values over 10 mg/m<sup>2</sup> in the shallow waters of the downstream reaches during the period of continuous daylight (Lods-Crozet et al. 2001). Arctic charr occur throughout much of Svalbard (Klementsens et al. 2003; Svenning & Gullestad 2002), but not in the Bayelva river system as there are no accessible lakes to maintain a population during winter.

### 9.13.4. Management and Conservation

While the catchment is not included in any of the designated National Parks, there are strict environmental regulations governing the whole of Svalbard. Owing to its accessibility and infrastructure, the area around Ny-Ålesund is a centre for international Arctic research over a wide range of disciplines ([www.kingsbay.no](http://www.kingsbay.no)).

### Acknowledgements

Randi Pytte Asvall kindly provided information on ice condition in the Altaelva River. We wish to acknowledge the help of Eero Niemelä for providing information on the Tana salmon fishery and Steinar Pedersen for his input to the social history of the Tana River. Tharan Fergus has also provided information on sediment characteristics of the Tana River. We are indebted to Trausti Jonsson, Icelandic Meteorological Office for providing weather data for all Icelandic catchment areas and Björn Traustason for compiling the data on forest cover of Icelandic catchments. The Hydrological Service of the National Energy Authority provided digital maps of catchment areas of the Icelandic rivers. Thanks also to Dr. Árni Einarsson, Mývatn Research Station, for reading and commenting on parts of the manuscript.

### REFERENCES

- Adalsteinsson, H., and Gíslason, G.M. 1998. Áhrif landrínna átta á líf í straumvötnum. (In Icelandic, English summary) (Terrestrial influence on the biota in Icelandic rivers). *Náttúrufræðingurinn* 68: 97–112.
- Adalsteinsson, H., Gíslason, G.M., Gíslason, S.R., and Snorrason, A. 2000. Physical and chemical characteristics of glacial rivers in Iceland, with particular reference to the River W-Jökulsá, North Iceland. *Verhandlungen der Internationale Vereinigung für Theoretische und Angewandte Limnologie* 27: 735–739.
- Albert, V., Jonsson, B., and Bernatchez, L. 2006. Natural hybrids in Atlantic eels (*Anguilla anguilla*, *A. rostrata*): evidence for successful reproduction and fluctuating abundance in space and time. *Molecular Ecology* 15: 1903–1916.
- AMAP. 2004a. AMAP Assessment 2002: Radioactivity in the Arctic. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. xi +100 pp.
- AMAP. 2004b. AMAP Assessment 2002: Persistent Organic Pollutants in the Arctic. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. xvi+310 pp.
- AMAP. 2005a. AMAP Assessment 2002: Heavy Metals in the Arctic. Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. xvi +265 pp.
- AMAP. 2005b. Arctic Climate Impact Assessment (ACIA) – Scientific Report. Arctic Monitoring and Assessment Programme. <http://www.acia.uaf.edu/pages/scientific.html>.
- Andreev, V.A. (ed.). 1995. Arkhangelsk Oblast Red Book. Rare and protected plant and animal species. Arkhangelsk.
- Anon. 1976. Verneplan for vassdrag. *NOU 1976:15* Industridepartementet. 150 pp.
- Anon. 1989. *Scientific-applied reference book on climate of the USSR*. Series 3. Long-term data. Parts 1–6. 1. Arkhangelsk and Vologda oblasts, Komi ASSR. Book 1. Hydrometeoizdat, Leningrad.
- Anon. 1994. Bruk av land og vann i Finnmark i historisk perspektiv. Norges offentlige utredninger. NOU 1994: 21.
- Anon. 2001. *De enkelte nasjonale laksevassdrag og laksefjorder*. Vedlegg til høringsnotat. Norwegian Ministry of the Environment. 111 pp.
- Anon. 2003. *Ecoregional Climate Change and Biodiversity Decline: Kola Ecoregion*. WWF Russia, Moscow. 25 pp.
- Anon. 2004. *Verneforslag og konsekvensutredning for Varangerhalvøya nasjonalpark*. Office of the Finnmark County Governor. 101 pp.
- Anon. 2006. *Ressursregnskap for reindriftsøringen for reindriftsåret 1. april 2004 – 31. mars 2005*. Reindriftsforvaltningen.
- Anufriev, V.V. (Ed.), 2000. *The land of pristine forests: Pechora-Ilychsky nature reserve*. Syktyvkar.
- Anufriev, V.V. 2004. Land mammals. In: *Animate nature of the Nenets autonomous okrug*. Naryan-Mar. pp. 59–68.
- Anufriev, V.V., and Bobretsov, A.V. 1996. *Amphibia and reptiles*. Nauka, St. Petersburg, Fauna of the European North-East of Russia, IV.
- Anufriev, V.V., Bobretsov, A.V., Voylochnikov, A.A., Neyfeld, N.D., Kudryavtseva, E.N., Kupriyanova, I.F., Petrov, A.N., Polezhaev, N.M., Pystin, A.N., Sokolsy, S.M., Soloviev, V.A., Turieva, V.V., and Yushkov, V.F. 1994. *Mammals, Insectivora, Cheiroptera, Lagomorpha, Rodentia*. Nauka, St. Petersburg, Fauna of the European North-East of Russia, II, I.
- Baranovskaya, V.K. 1971. Zooplankton of the middle Pechora River. In: *Biology of the northern rivers in oldlake lowlands*. Syktyvkar. *Proceedings of the Komi branch of the Academy of Science of the USSR* 22, pp. 35–43.
- Baranovskaya, V.K. 1991. Zooplankton of the Pechora River. In: *Biological researches in Pechora-Ilychsky nature reserve*. Syktyvkar. *Proceedings of the Ural Branch of the Russian Academy of Science* 116, pp. 40–45.

- Berg, M. 1964. *Nord-Norske lakseelver*. Johan Grundt Tanum Forlag, Oslo, 300 pp.
- Berg, M. 1977. Pink salmon, *Oncorhynchus gorbuscha* (Walbaum) in Norway. Institute of Freshwater Research. *Drotningholm* 56: 12–17.
- Bergersen, R. 1989. Zoobenthos and food of Atlantic salmon (*Salmo salar* L.) fry in the Alta River, North Norway. *Nordic Journal of Freshwater Research* 65: 99–115.
- Bjerknes, V. 1978. Undersøkelse av fiskebestanden i Iesjohka, Tanavassdraget. *Direktoratet for vilt- og ferskvannsfisk, Fiskerikonsulenten i Finnmark. Rapport 2/78* 29 pp. (In Norwegian).
- Bjerknes, V., and Vaag, A.B. 1980. Migration and capture of pink salmon, *Oncorhynchus gorbuscha* Walbaum in Finnmark, North Norway. *Journal of Fish Biology* 16: 291–297.
- Björnsson, H. 1988. Hydrology of ice caps in volcanic regions. *Societas Scientiarum Islandica*, 45. University of Iceland, Reykjavík, 139 pp.
- Bobretsov, A.V., Neyfeld, N.D., Sokolsky, S.M., Teplov, V.V., and Teplova, V.P. 2004. *Mammals of the Pechoro-Ilychsky Reserve*. Komi Publishing House, Syktyvkar.
- Bogdanova, E.N. 2004. Zooplankton. *Water Ecosystems Bioresources of the Polar Ural*, Ural Branch of the Russian Academy of Science, Ekaterinburg, pp. 57–89.
- Bogen, J., and Bønsnes, T. 2003. Erosion and sediment transport in High Arctic rivers, Svalbard. *Polar Research* 22: 175–189.
- Brittain, J.E., and Milner, A.M. 2001. Ecology of glacier-fed rivers: current status and concepts. *Freshwater Biology* 46: 1571–1578.
- Brown, L.E., Hannah, D.M., and Milner, A.M. 2003. Alpine stream habitat classification: an alternative approach incorporating the role of dynamic water source contributions. *Arctic, Antarctic and Alpine Research* 35: 313–322.
- Bryzgalov, V.A., Ivanov, V.V., and Nechayeva, S.A. 2002. Ecological condition of the Northern Dvina river low streams and mouth and its changes caused by anthropogenic influence. *Arctic and Antarctic Problems*. 73, Hydrometeoizdat, St. Petersburg, pp. 135–152.
- Castella, E., Adalsteinsson, H., Brittain, J.E., Gíslason, G.M., Lehmann, A., Lencioni, V., Lods-Crozet, B., Maiolini, B., Milner, A.M., Olafsson, J. S., Saltveit, S.J., and Snook, D.L. 2001. Macrobenthic invertebrate richness and composition along a latitudinal gradient of European glacier-fed streams. *Freshwater Biology* 46: 1811–1831.
- Chernov, V.K. 1953. Data on algae of the Pechora River and its basin's water reservoirs. *Fishes and Fishery of the Middle and Lower Streams of the Pechora river*, Publishing House of the AS USSR, Moscow-Leningrad, pp. 218–225.
- Chernov, G.A. 1989. *Highlights on the PECHORA Coalfields Discovery*. Komi Publishing House, Syktyvkar.
- Cherny, V.G. (ed.), 1970. USSR hydrogeology. XLII. Komi ASSR and Nenets national okrug of the Arkhangelsk oblast. Nedra, Moscow.
- Coulson, S.J., and Refseth, D. 2004. The terrestrial and freshwater invertebrate fauna of Svalabdr (and Jan Mayen). In Prestrud, P, H. Strøm, and H.V. Goldman (eds). A catalogue of the terrestrial and marine animals of Svalbard. *Norwegian Polar Institute Skrifter* 20, pp. 57–122.
- Dementiev, G.P. and Gladkov, N.A. (eds). 1951/1954. *Birds of the Soviet Union*, Sovetskaya nauka, Moscow, pp. 1–6.
- Dinets, V., and Rotshild, Ye. 1996. *Wild animals*. Encyclopedia of Russian Nature. Moscow, 344 pp.
- Dynesius, M., and Nilsson, C. 1994. Fragmentation and flow regulation of river systems in the northern third of the world. *Science* 266: 753–762.
- Efimov, A.I., and Zaitsev, I.K. (eds.) 1970. *Hydrogeology of the USSR*. XVI. “Nedra”, Moscow.
- Eie, J.A., Brittain, J.E., and Huru, H. 1982. Naturvitenskapelige interesser knyttet til vann og vassdrag på Varangerhalvøya. *Rapport Kontaktutvalget for vassdragsreguleringer, Universitetet i Oslo. Rapport 34*, 64 pp.
- Eie, J.A., Faugli, P.E., Aabel, J. 1996. *Elver og vann. Vern av norske vassdrag*. Norwegian Water Resources and Energy Directorate, Grøndahl og Dreyers Forlag, Oslo, 286 pp.
- Eikeset, K.R., Heitmann, K., Nielsen, J.P. 2001. *I storlaksens rike. Historien om Altaelva og Alta Laksefiskeri Interessentskap*. Alta Laksefiskeri Interessentskap, Alta, Norway, 507 pp.
- Einarsson, M. 1979. Climatic conditions of the Lake Mývatn area. *Oikos* 32: 29–37.
- Einarsson, T. 1994. *Geology of Iceland: Rocks and Landscape*. Mal og Menning, Reykjavík, 309 pp.
- Einarsson, Á., Gardarsson, A., Gíslason, G.M., and Gudbergsson, G. 2006. Populations of ducks and trout of the River Laxá, Iceland, in relation to variation in food resources. *Hydrobiologia* 567: 183–194.
- Eiríksdóttir, E., Gíslason, S.R., Elefsen, S.O., Hardardóttir, J., Hreinsson, E.Ö., Torssander, P., Sveinbjörnsdóttir, Á.E. 2008. Efnasamsetning, rennsli og aurburur í utfalli Mývatns [In Icelandic: Chemistry, discharge and total solids in the Mývatn lake outlet]. Mývatn Research Station. Report No. 7, Sktutustadir. 53 pp.
- Elo, K., Vuorinen, J., and Niemelä, E. 1994. Genetic resources of Atlantic salmon (*Salmo salar* L.) in the Teno and Näätämö Rivers, northernmost Europe. *Hereditas* 120: 19–28.
- Elvebakk, A. 2006. Status for populasjonen av masimjelt (*Oxytropis deflexa* ssp. *norvegica*) i Virdneuoika – September 2006. Rapport to Statkraft, 8 pp.
- Erkinaro, J., Åkland, F., Moen, K., and Niemelä, E. 1999. Return migration of the Atlantic salmon in the Tana River: distribution and exploitation of radiotagged multi-sea-winter salmon. *Boreal Environment Research* 4: 115–124.
- Fefilova, E.B. 2002. Harpacticoida of Timan and Ural water reservoirs. In: Water organisms in natural and transformed ecosystems in the European North-East of Russia. Syktyvkar. *Proceedings of the Ural Branch of the Russian Academy of Science* 170, pp. 51–62.
- Fergus, T., and Rönkä, E. (eds.) 2001. Erosjon og sedimenttransport i Tanaelva. Delrapport 1 fra prosjektet: Bevaring av Tanaelva som en lakseelv i naturtilstand. Norges vassdrags- og energidirektorat, Fylkesmannen i Finnmark, Lappland miljøseniter. *NVE Rapport 4/2001*, 99 pp.
- Filenko, R.A. 1974. *Hydrologic Zoning of the North in the European Part of Russia*. Publishing House of Leningrad State University, Leningrad.
- Filippova, L.G. (ed). 1985. *State water cadastre. Longstanding data on surface waters regimen and resources (1985)*. 1. RSFSR. 9. The Pechora River basin, Hydrometeoizdat, Obninsk.
- Füreder, L. 1999. High alpine streams: cold habitats for insect larvae. In: Margesin, R., Schinner, F. (eds). *Cold Adapted Organisms. Ecology, Physiology, Enzymology and Molecular Biology*, Springer Verlag, Berlin, pp. 181–196.
- Furset, O.J. 1995. *Fangstgroper i Karasjok kommune. Rapport fra forskning-sutgraving 3. juli – 4. august 1995*. Arkeologiseksjonen, Institutt for samfunnsvitenskap, Universitetet i Tromsø. 39 pp.
- Gabler, H.M. 2000. *Feeding ecology and resource partitioning in Atlantic salmon parr (Salmo salar L.) and freshwater sculpins (Cottus gobio L. and C. poecilopus Heckel) in sub-Arctic rivers*. Doctoral thesis, University of Tromsø.
- Gardarsson, A. 1979. Waterfowl populations of Lake Mývatn and recent changes in numbers and food habits. *Oikos* 32: 250–270.
- Geptner, V.G., Nasimovich, A. A., Bannikov, A. G. 1961. *Mammals of the USSR I* Moscow.
- Geptner, V.G., Naumov, N.P., Yurgenson, P.B., Sludsky, A.A., Chirkova, A. F., and Bannikov, A.G. 1967. *Mammals of the USSR. II* Moscow.

- Getsen, M.V. 1971. Algal flora of the water reservoirs in the middle Pechora River valley. In: Biology of northern rivers in the oldlake lowlands. Syktyvkar. *Proceedings of the Komi branch of the AS USSR* 22: 16–26.
- Getsen, M.V. 1973. *The Pechora River Basin Algae and Their Distribution*. Nauka, Leningrad.
- Getsen, M.V., and Barinova, S.P. 1969. Algae of the stony biofouling in the upper streams of the Vychegda river. Abstract of XIII session of the Academic Council, Petrozavodsk: 53–55.
- Gíslason, G.M. 1981. Distribution and habitat preferences of Icelandic Trichoptera. In: Moretti, G.P. (ed.) *Proceedings of the 3rd international Symposium on Trichoptera, Series Entomologica* 20, 99–109.
- Gíslason, G.M. 1994. River management in cold regions: a case study of the River Laxá, North Iceland. In: Calow, P., Petts, G.E. (eds). *Rivers Handbook*, Blackwell Scientific Publications, Oxford, pp. 464–483.
- Gíslason, G.M. 1998. Ramsar á Íslandi – Althjodlegur samningur um votlendi sem hefur althjodlegt gildi, einkum fyrir fuglalíf. (English summary: The Ramsar Sites in Iceland. The Procedure of the Convention on Wetlands of International Importance especially as a Waterfowl Habitat). In: Olafsson, J.S. (ed). *Íslenskt Votlandi*, Univeristy of Iceland Press, Reykjavík, pp. 247–251.
- Gíslason, G.M. 2005. Origin of freshwater fauna of the North-Atlantic islands: present distribution in relation to climate and possible migration routes. *Verhandlungen der internationalen Vereinigung für theoretische und angewandte Limnologie* 29: 198–203.
- Gíslason, G.M., and Johannsson, V. 1991. Effects of food and temperature on the life cycle of *Simulium vittatum* Zett. (Diptera: Simuliidae) in the River Laxá, N-Iceland. *Verhandlungen der Internationale Vereinigung für Theoretische und Angewandte Limnologie* 24: 2912–2916.
- Gíslason, G.M., and Steingrímsson, S. 2004. Seasonal and spatial variation in the diet of brown trout (*Salmo trutta* L.) in the subarctic River Laxá, North-East Iceland. *Aquatic Ecology* 38: 263–270.
- Gíslason, G.M., Hrafnisdóttir, T., and Gararsson, A. 1995. Flight periods of midges (Chironomidae and Simuliidae) in the River Laxá, N-Iceland. In: Cranston, P. (ed). *Chironomids: From Genes to Ecosystems*, CSIRO Publications, Melbourne, pp. 133–154.
- Gíslason, G.M., Olafsson, J.S., and Adalsteinsson, H. 2000. Life in glacial and alpine rivers in Central Iceland in relation to physical and chemical parameters. *Nordic Hydrology* 31: 411–422.
- Gíslason, G.M., Adalsteinsson, H., Hansen, I., Olafsson, J.S., and Svavarsdóttir, K. 2001. Longitudinal changes in macroinvertebrate assemblages along a glacial river system in central Iceland. *Freshwater Biology* 46: 1737–1751.
- Gordeeva, L.I. (ed). 1983. *Modern status and quality of the Onega river waters and its basins' water reservoirs*, Karelia branch of the AS USSR, Petrozavodsk.
- Gudbergsson, G., and Antonsson, T. 1996. *Fiskar í ám og vötnum*. Landvernd, Reykjavík, 191 pp. [In Icelandic: Fish in rivers and lakes].
- Haldorsen, S., Heim, M., Lefauconnier, B., Pettersson, L.E., Røros, M., and Sandsbråten, K. 2002. The water balance of an arctic lake and its dependence on climate change: Tvillingvatnet in Ny-Ålesund, Svalbard. *Norsk Geografisk Tidsskrift* 56: 146–151.
- Hodson, A.J., Gurnell, A.M., Tranter, M., Bogen, J., Hagen, J.O., and Clark, M. 1998. Suspended sediment yield and transfer processes in a small high-Arctic glacier basin, Svalbard. *Hydrological Processes* 12: 73–86.
- Hodson, A.J., Tranter, M., Gurnell, A.M., Clark, M., and Hagen, J.O. 2002. The hydrochemistry of Bayelva, a high Arctic proglacial stream in Svalbard. *Journal of Hydrology* 257: 91–114.
- Hrafnisdóttir, T. 2005. Diptera 2 (Chironomidae). *The Zoology of Iceland* 3: 1–169.
- Huitfeldt-Kaas, H. 1918. *Ferskvandsfiskenes utbredelse og indvandring i Norge, med et tillæg om krebsen*. Centraltrykkeriet, Kristiania, 106 pp.
- Ilyina, L.L., and Grakhov, A.K. 1987. *Rivers of the North*. Hydrometeoizdat, Leningrad.
- Ivanov, A.I., and Shtegman, B.K. 1978. Short key book of the USSR birds (Key books on fauna of the USSA. 115). *Proceedings of Zoological Institute of the AS of USSR*, Leningrad.
- Jensen, A.J., Zubchenko, A., Hvidsten, N.A., Johnsen, B.O., Kashin, E., Kuzmin, O., and Nilsje, T.F. 1997. A comparative study of life histories of Atlantic salmon in two Norwegian and two Russian rivers. *NINA-NIKU Project Report* 7, pp. 1–44.
- Jensen, A.J., Zubchenko, A., Hvidsten, N.A., Johnsen, B.O., Kashin, E., and Nilsje, T.F. 1998. A five year study of Atlantic salmon in two Norwegian and two Russian rivers. *NINA-NIKU Project Report* 8, pp. 1–38.
- Johannesson, H., and Símundsson, K. 1998. *Geological Map of Iceland 1:500 000*. Institute of Natural history and Geodetic Institute of Iceland, Reykjavík.
- Johansen, M. 2005. *Juvenile salmon and aquatic invertebrates in northern Norway*. Doctoral thesis, University of Tromsø. 120 pp.
- Johansen, M., Elliott, J.M., and Klemetsen, A. 2005. A comparative study of juvenile salmon density in 20 streams throughout a very large river system in northern Norway. *Ecology of Freshwater Fish* 14: 96–110.
- Jonasson, P.M. (ed.) 1979a. Ecology of eutrophic, subarctic Lake Mývatn and the River Laxá. *Oikos* 32, pp. 1–306.
- Jonasson, P.M. 1979b. The River Laxá ecosystem, Iceland. *Oikos* 32: 306–308.
- Jonsson, E., Gardarsson, A., and Gíslason, G.M. 1986. A new window trap used in the assessment of the flight periods of Chironomidae and Simuliidae (Diptera). *Freshwater Biology* 16: 711–719.
- Kaliuzhin, S.M. 2003. *The Atlantic Salmon of the White Sea Basin: Problems of Reproduction and Fisheries*. PetroPress, Petrozavodsk, Russia.
- Kemmerikh, A.O. 1961. *Hydrography of the Northern, Sub-Polar and Polar Ural*. Publishing House of the AS USSR, Moscow.
- Khokhlova, L.G. 1994a. Estimation of surface waters condition in the Pechora River basin. *Proceedings of the International Congress*, Moscow 1, pp. 312–320.
- Khokhlova, L. 1994b. Water chemistry of the rivers of the tundra zone. *Extended Abstract International Conferenece Columbus, USA: 144–145*, BPRC Miscellaneous Ser. M-334.
- Khokhlova, L.G. 1997. Modern status of the Mezen river basin water-courses. In: North ecosystem transformation in the intensive wood cuttings zones. Syktyvkar. *Proceedings of the Ural Branch of the Russian Academy of Science*; 154, pp. 100–117.
- Killingtveit, Å., Pettersson, L.E., and Sand, K. 2003. Water balance investigations in Svalbard. *Polar Research* 22: 161–174.
- Kjartansson, G. 1945. Íslenskar fallvatnstegundir. *Naturufríðinurinn* 15113–145, [In Icelandic: Icelandic River Types].
- Kjartansson, G. 1965. Geologiske betingelser for islandske flodtyper. *Geografiske Tidsskrifter* 64: 174–187.
- Klemetsen, A., Amundsen, P.A., Dempson, J.B., Jonsson, B., Jonsson, N., O'Connell, M.F., and Mortensen, E. 2003. Atlantic salmon *Salmo salar* L., brown trout *Salmo trutta* L. and Arctic charr, *Salvelinus alpinus* (L.): a review of aspects of their life histories. *Ecology of Freshwater Fish* 12: 1–59.
- Kline, T. C., Jr., Goering, J.J., and Piorkowki, R.J. 1997. The effect of salmon carcasses on Alaskan freshwaters. In: Milner, A.M. and M.W. Oswood (eds.). *Freshwaters of Alaska. Ecological Studies* 119, Springer, pp. 179–204.
- Kobysheva, N.V., and Narovlyansky, G.Y. 1978. *Climatologic Processing of Meteorological Information*. Hydrometeoizdat, Leningrad.
- Kochanov, S.K. 2001. Fauna and birds population changes in the European North-East of Russia in the 20th Century. *Abstract of the International Conference, Kazan*, pp. 328–329.

- Kokovkin, A.V. 1988. Calculation of summer-autumn mean water characteristics in the rivers of the European North-East. *Syktyvkar*.
- Kokovkin, A.V. 1997. Average long-term annual water yield of the rivers. *Hydrology and Climate Atlas of the Komi Republic*, DiK, Moscow, pp. 102.
- Koksvik, J.I., and Reinertsen, H. 2008. Changes in the macroalgae and bottom fauna in the winter period in the regulated Alta River in Northern Norway. *River Research and Applications* 24: 720–731.
- Kontaktutvalget Kraftutbygging – naturvern 1971. Rapport om vassdrag som bør vernes mot kraftutbygging. Bergen. 203 pp. Passed by Parliament (Verneplan I) in 1973.
- Korde, N.V. 1959. Quantitative plankton of the Vychegda river. *Proceedings of the Komi branch of the all-union Geographical Society*, Syktyvkar, 5, pp. 111–120.
- Kuchina, E.S. 1955. Chemistry of the surface waters. *Productive Forces of the Komi ASSR. II. 2*, Publishing house of the AS USSR, Moscow, pp. 38–153.
- Kulikov, V.S. (ed). 1995. *Natural and Cultural Heritage of the National Park "Vodlozersky"*, Karelia Branch of the AS USSR, Petrozavodsk.
- Kuzmin, S.L. 1999. *Amphibia of the former USSR*. Moscow.
- Kuzmina, Y. 2001. Chironomida (Diptera) of the European North-Eastern Part of Russia. *Bull. of the Institute of Biology. Proceedings of Ural Branch of the Russian Academy of Science* 12, 3–6.
- Landmillingar Íslands. 1993. Ísland. *Grodurmynd* (vegetation map). Landmillingar Íslands, Reykjavík.
- Lárusdóttir, G., Adalsteinsson, H., Olafsson, J.S., and Gíslason, G.M. 2000. River ecosystems in Iceland: catchment characteristics and river communities. *Verhandlungen der Internationale Vereinigung für Theoretische und Angewandte Limnologie* 27: 1607–1610.
- Lashenkova, A.N. 1970. Brief article on flora of the upper Mezen river basin. *Proceedings of the Komi branch of the Geographical Society of USSR* 2, 3 (13), pp. 66–68.
- Leshko, Y.V. 1996. Modern status of the hydrobiological regimen of the Mezen river water basin' water reservoirs. Ecological aspects of the species diversity conservation in the European North-East of Russia. *Syktyvkar. Proceedings of the Ural Branch of the Russian Academy of Science*; 148, pp. 97–106.
- Leshko, Y.V. 1998. *Molluscs* Nauka, St. Petersburg. Fauna of the European North-East of Russia. Y1.
- Leshko, Y.V., and Khokhlova, L.G. 1999. Hydrobiological characteristics of the lower Pechora in the anthropogenic influenced environment. *Proceedings of the II (XXV) International Conference, Petrozavodsk*, pp. 343–345.
- Leshko, Y.V., and Khokhlova, L.G. 2003. Anthropogenic transformation of benthic invertebrate communities in the Izhma river basin. *Proceedings of the XI International Symposium on Bioindicators, Syktyvkar*, pp. 236–246.
- Leshko, Y.V., Martynov, V.G., Baranovskaya, V.K. 1990. Hydrobiology of the Mezen River basin' water reservoirs in anthropogenic influenced environment. *Abstract Symposium on Atlantic salmon, Syktyvkar*: 84.
- Lillehammer, A. 1972. A new species of the genus *Nemoura* (Plecoptera) from Finnmark, North Norway. *Norsk entomologisk tidsskrift* 19: 161–163.
- Lillehammer, A. 1974. Norwegian stoneflies. II. Distribution and relationship to the environment. *Norsk entomologisk Tidsskrift* 21: 195–250.
- Lillehammer, A. 1988. Stoneflies of Fennoscandia and Denmark. *Fauna Entomologica Scandinavica* 21, 165 pp.
- Lillehammer, A., Johannsson, M., and Gíslason, G.M. 1986. Studies on *Capnia vidua* Klapálek (Capniidae, Plecoptera) populations in Iceland. *Fauna norvegica Series B* 33: 93–97.
- Lods-Crozet, B., Lencioni, V., Brittain, J.E., Marziali, L., and Rossaro, B. 2007. Constrasting chironomid assemblages in two high Arctic streams on Svalbard. *Fundamental and Applied Limnology* 170: 211–222.
- Lods-Crozet, B., Lencioni, V., Olafsson, J., Snook, D., Velle, G., Brittain, J. E., Castella, E., and Rossaro, B. 2001. Chironomid (Diptera: Chironomidae) communities in six European glacier-fed streams. *Freshwater Biology* 46: 1791–1809.
- Lukin, E.I. 1954. On Hirudinea fauna in the Komi ASSR. *Proceedings of the Komi branch of the all-union Geographical Society of the USSR* 2, pp. 61–68.
- Magnell, J.P. 1998. Manøvreringens innvirkning på hydrologien. In: Njåse, T.F. (ed.). *Altalaksen. Kultur, kraftutbygging og livsmiljø*. Alta kommune, Norway. pp. 56–63.
- Martynov, V.G., Leshko, Y.V., and Larin, V.B. 1997. Hydrobiology of the salmon rivers of Timan in concentrated forest cuttings environment. In: Northern ecosystems transformation in the area of intensive wood cuttings. *Syktyvkar. Proceedings of the Ural Branch of the Russian Academy of Science*; 154, pp. 127–136.
- Maslenikova, O., and Mangerud, J. 2001. Where was the outlet of the ice-dammed Lake Komi, Northern Russia? *Global and Planetary Change* 31: 337–345.
- McGregor, G., Petts, G.E., Gurnell, A.M., and Milner, A.M. 1995. Sensitivity of alpine stream ecosystems to climatic change and human impacts. *Aquatic Conservation* 5: 233–247.
- Milner, A.M., Brittain, J.E., Castella, E., and Petts, G.E. 2001. Trends of macroinvertebrate community structure in glacier-fed rivers in relation to environmental conditions: a synthesis. *Freshwater Biology* 46: 1833–1847.
- Morozov, V.V. 1987. Data on avifauna of the east of Bolshezemelskaya tundra. *Ornithology* 22: 186–189.
- Morozov V.V. 1989. Birds of the Polar Ural western macroslope. Distribution and birds fauna of the Urals. *Sverdlovsk*, pp. 69–72.
- Morozov, V.V., and Kuliyeu, A.N. 1990. Data on Yügor peninsular and Pay-Hoya ridge flora studies. *Botanical Journal* 75: 1603–1610.
- Niemelä, E. 2004. *Variation in the yearly and seasonal abundance of juvenile Atlantic salmon in a long-term monitoring programme. Methodology, status of stocks and reference points*. Doctoral thesis, University of Oulu, Finland.
- Niemelä, E., Mäkinen, T.S., Moen, K., Hassinen, E., Erkinaro, J., Länsman, M., and Julkunen, M. 2000. Age, sex ratio and timing of the catch of kelts and ascending Atlantic salmon in the subarctic River Tenö. *Journal of Fish Biology* 56: 974–985.
- Niemelä, E., Erkinaro, J., Julkunen, M., Hassinen, E., Länsman, M., and Brørs, S. 2006. Temporal variation in abundance, return rate and life histories of previously spawned Atlantic salmon in a large subarctic river. *Journal of Fish Biology* 68: 1–19.
- Nordbakke, R. 1983. Altaelvas deltaområde. *Lappmeisen* 9: 6–9.
- Norwegian Meteorological Institute. [www.met.no](http://www.met.no).
- Novoselov, A.P. 2000. Modern state of fish communities in the European Earth-North water bodies. Moscow.
- Olafsson, J. 1979a. Physical characteristics of Lake Mývatn and River Laxá. *Oikos* 32: 38–66.
- Olafsson, J. 1979b. The chemistry of Lake Mývatn and River Laxá. *Oikos* 32: 82–112.
- Olafsson, J.S., Gíslason, G.M., and Aalsteinsson, H. 2000. Chironomids of glacial and non-glacial rivers in Iceland: a comparative study. *Verhandlungen der Internationale Vereinigung für Theoretische und Angewandte Limnologie* 27: 720–726.
- Olafsson, J.S., Adalsteinsson, H., Gíslason, G.M., Hansen, I., and Hrafnisdóttir, T. 2002. Spatial heterogeneity in lotic chironomids and simuliids in relation to catchment characteristics in Iceland. *Verhandlungen der*

- Internationale Vereinigung für Theoretische und Angewandte Limnologie* 28: 157–163.
- Olafsson, J.S., Einarsson, Á., Gíslason, G.M., and Kolbeinsson, Y. 2004. *Samhengi botngerar og botndýra í Laxá í S. ingeyjarsýslu*. Líffræðistofnun Háskolans. Report no. 72, 35 pp.
- Olenicheva, A.V. (ed.). 1990–1991. State water cadastre. Annual data on surface waters quality (1989, 1990). 1 (28) RSFSR., 9. The Pechora river basin. 8 (23). Hydrometeoizdat, Archangelsk.
- Pálsson, S., and Vigfusson, G. 1991. *Nidurstödur svifaursmílinga* 1963–1990 [In Icelandic: Data on suspended material]. Orkustofnun, OSV-7405. 29 pp.
- Patova, E.N., and Stenina, A.S. 2004. Algae. In: Ponomarev, V., Munsterman, M., Leummens, H. (eds). *The Pechora River Basin*, IB-KSC-RIZA, Syktyvkar-Lelystad, pp. 47–52.
- Pedersen, S. 1986. Laksen, allmuoen og staten. *Fiskerett og forvaltning i Tanavassdraget før 1888*. Dieut No. 2, 1986. 207 pp.
- Pedersen, S. 1991. Laksen – Tanadalens fremste ressurs. In: Laks, sjøørret og sjørøye i Nord-Norge. Ottar, Tromsø Museum, 2-1991, pp. 58–62.
- Pedersen, S. 2006. Lappekodisillen i nord 1751–1859. – Fra grenseavtale og sikring av samenes rettigheter til grensesperring og samisk ulykke. Doctoral thesis, University of Tromsø, 406 pp.
- Peterson, B.V. 1977. The black flies of Iceland (Diptera: Simuliidae). *Canadian Entomologist* 109: 449–472.
- Peterson, R.C., Gíslason, G.M., and Vought, L.B.M. 1995. Rivers of the Nordic Countries. Chapter 10. pp. 295–341. Cushing, C.E. Cummins, K. W. and Minshall, G.W. editors. *River and Stream Ecosystems. Ecosystems of the World* Vol. 22 Elsevier Press, Amsterdam.
- Pihjala, O., Niemelä, E., and Erkinaro, J. 1998. Introduction and dispersal of the bullhead, *Cottus gobio* L., in a subarctic river in northern Finland. *Fisheries Management and Ecology* 5: 139–146.
- Polezhaev, N.M., Potelov, V.A., Petrov, A.N., Pystin, A.N., Neyfeld, N.D., Sokolsky, S.M., and Tyurnin, B.N. 1998. *Mammals. Cetacea, Carnivora, Pinnipedia, Artiodactyla*. Fauna of the European North-East of Russia, Nauka, St. Petersburg, II, 2.
- Ponomarev, V.I. (ed.) 2001. National park “Yugyd va”. Design. Information, Cartography, Moscow.
- Ponomarev, V., Loskutova, O., Khokhlova, L. and Leummens, H. 2004a. The Pechora river: a natural-functioning river ecosystem, or needs for restoration? 3rd European conference on River restoration. Zagreb, Croatia, 17–21 May 2004, pp. 383–392.
- Ponomarev, V. Munsterman, M. and Leummens, H. (eds). 2004b. *The Pechora River Basin*, IB-KSC-RIZA, Syktyvkar-Lelystad, pp. 183.
- Postovalova, G.G. 1966. On *Elodea canadensis* Michx. Habitats in the Arkhangelsk oblast. *Botanical Journal* 51(3): 408–409.
- Potokina, E.K. 1985. On distribution of some higher water plants species in the European North of the USSR. *Proceedings of Leningrad State University 3. Biology. 4, 24*, pp. 90–103.
- Power, G. 1973. Estimates of age, growth, standing crop and production of salmonids in some north Norwegian rivers and streams. *Institute of Freshwater Research Drottningholm* 53: 78–111.
- Power, G., and Power, M. 1995. Ecotones and fluvial regimes in arctic lotic environments. *Hydrobiologia* 303: 111–124.
- Primmer, C.R., Veselov, A.J., Zubchenko, A., Poututkin, A., Bakhmet, I., and Koskinen, M.T. 2006. Isolation by distance within a river system: genetic population structuring of Atlantic salmon, *Salmo salar*, in tributaries of the Varzuga River in northwest Russia. *Molecular Ecology* 15: 653–666.
- Prowse, T.D. 2000. *River-Ice Ecology*. Environment Canada, Saskatoon, 64 pp.
- Pylnikova, Z.N. (ed.) 1989. Scientific-applied reference book on climate of the USSR. Series 3. Long-term data. Parts 1–6. 1. Arkhangelsk and Vologda oblasts, Komi ASSR. Book 1. Hydrometeoizdat, Leningrad.
- Rebristaya, O.V. 1977. *Flora of the East of Bolshezemelskaya Tundra*. Nauka, Leningrad.
- Rist, S. 1979a. The hydrology of the River Laxá. *Oikos* 32: 271–280.
- Rist, S. 1979b. Water level fluctuations and ice cover of Lake Mývatn. *Oikos* 32: 67–81.
- Rykhter, G.D. (ed.) 1966. North of the European part of USSR. Nauka, Moscow. In Savelieva, E.A. (ed.) 1997. *Archeology of the Komi Republic*. DiK, Moscow.
- Saemundsson, K. 1979. Outline of the geology of Iceland. *Jökull* 29: 7–28.
- Semernoy, V.P. 1990. Bottom biocenoses of the wellhead territory of the Northern Dvina river in the Arkhangelsk pulp-and-paper plant waste waters discharge areas. *Abstract of XIII session of the Academic Council, Syktyvkar*, 34 pp.
- Shmidt, V.M., Sergienko, V.G. 1984. Data on White Sea-Mezen specific floras studies. 1. Systematic composition. *Proceedings of the Leningrad State University 3. Biology 2, 21*, pp. 43–48.
- Shubina, V.N. 1986. *Hydrobiology of the salmon river of the Northern Ural*. Nauka, Leningrad.
- Shubina, V.N. 1997. Invertebrates. Level of knowledge on nature resources of the Komi Republic, Syktyvkar, pp. 78–91.
- Shubina, V. 2004. Aquatic invertebrates. In: Ponomarev, V., Munsterman, M. (eds). *The Pechora River Basin*, IB-KSC-RIZA, Syktyvkar-Lelystad, pp. 61–71.
- Shubina, V.N., and Shubin Y.P. 2002. Benthos of the Pechora river upper streams (Northern Ural) and its significance for fish food. In: Water organisms in natural and transformed ecosystems of the European North-East. Syktyvkar. *Proceedings of the Ural Branch of the Russian Academy of Science*; 170, pp. 34–50.
- Shubina, T.P., and Zheleznova, G.V. 2002. *Cormophyte Mosses of the Plain Part of Middle Taiga in the European North-East*. Ural Branch of the Russian Academy of Science, Ekaterinburg.
- Shubina, V.N., Loskutova, O.A., and Kulida, S.V. 1990. Daily dynamics of bottom invertebrates drift in the Onega River (Arkhangelsk oblast). *Abstract of the Symposium on Atlantic Salmon, Syktyvkar* 87.
- Sidorov, G.P., Shubina, V.N., and Rogovtsova, E.K. 1999. Fauna of invertebrates and fishes in the stony-pebble and sandy grounds in the Mezen river upper streams. *Proceedings of the II (XXV) International Conference, Petrozavodsk.*, pp. 173–175.
- Sigurdsson, F. 1990. Groundwater from glacial areas in Iceland. *Jökull* 29: 7–28.
- Siirala, M. and Huru, H. (eds.), 1990. Flerbruksplan for Tanavassdraget/ Multiuse plan for River Tenö. Norsk-finsk grensevassdragskomisjon/ Norwegian-Finnish Border River Commission, Office of the Finnmark County Governor, Report No. 34, 91 pp.
- Solovkina, L.N. 1975. *Fish Resources of the Komi ASSR*. Komi Book Publishers, Syktyvkar.
- Sørbel, L. and Tolgensbakk, J. 2004. Landformer og løsmateriale på Varangerhalvøya – en beskrivelse til arbeidet med Varangerhalvøya nasjonalpark. Office of the Finnmark County Governor, Report No. 2-2004. 20 pp.
- Spiridonov, Y.A. (ed.) 2001. *Atlas of the Komi Republic*, DiK, Moscow.
- Steffan, A.W. 1971. Chironomid (Diptera) biocenoses in Scandinavian glacier brooks. *Canadian Entomologist* 103: 477–486.
- Steindorsson, S. 1964. *Grodur a Íslandi*. [In Icelandic: Vegetation in Iceland A] AB, Reykjavík. 186 pp.
- Steingrímsson, S., and Gíslason, G.M. 2002. Body size, diet and growth of landlocked brown trout, *Salmo trutta*, in the subarctic river Laxá, North-East Iceland. *Environmental Biology of Fishes* 63: 417–426.
- Stenina, A.S. 1997. Diatoms in the Mezen River water ecosystems as indicators of eutrophic environmental conditions. Transformation of ecosystems of the North in the intensive wood cuttings area. Syktyvkar.

- Proceedings of the Ural Branch of the Russian Academy of Science: 154: 118–126.*
- Stenina, A.S. 2005. First data on diatoms composition in the Pechora river upper streams. (Pechoro-Ilychsky Nature Reserve). *Proceedings of the Pechoro-Ilychsky Nature Reserve*, Syktyvkar, 14, pp. 237–242.
- Stenina, A.S., and Khokhlova, L.G. 2004. Chemical composition peculiarities of waters and plankton complexes of Bacillariophyta in the Pechora river delta. *Proceedings of the 6th International Congress*, Moscow, I, pp. 95–96.
- Stenina, A.S., Patova, E.N., and Noordhuis, R. 2000. Phytoplankton. In: van Eerden, M.R. (ed). *Pechora Delta. Structure and dynamics of the Pechora Delta ecosystems (1995–1999)*, Lelystad, Netherlands, 99–113, 289–308.
- Stockner, J.G., and Macisaac, E.A. 1996. British Columbia Lake Enrichment Programme: two decades of habitat enhancement for sockeye salmon. *Regulated Rivers: Research and Management* 12: 547–561.
- Stolpovsky, P.M. (ed). 1999. *Komi Republik: Encyclopaedia 2*, Komi Publishing House, Syktyvkar.
- Størset, L., Rikardsen, A., Ugedal, O., Dahl-Hansen, G.A., Magnussen, K., Sandbråten, K. and Gaut, A. 2004. EUs rammedirektiv for vann. Karakterisering av vannområder i Nord-Norge. Altavassdraget og Altafjorden. *Sweco Grøner-rapport SG 562711B*. 133 pp.
- Svenning, M., Fagermo, S.E., Barrett, R.T., Borgstrøm, R., Vader, W., Pedersen, T., and Sandring, S. 2005. Goosander predation and its potential impact on Atlantic salmon smolts in the River Tana estuary, northern Norway. *Journal of Fish Biology* 66: 924–937.
- Svenning, M.A., and Gullestad, N. 2002. Adaptations to stochastic environmental variations: the effects of seasonal temperatures on the migratory window of Svalbard Arctic charr. *Environmental Biology of Fishes* 64: 165–174.
- Sviridova T.V., and Zubakina, V.A. (eds.) 2000. Key ornithological territories of the Russia. Vol. 1. Key ornithological territories of the international significance in the European Russia. Union of the Russia birds protection, Moscow. 702 pp.
- Systad, G.H., Äien, I.J. and Nilsen, S.Ä. 2003. *Zoologisk kartlegging innenfor utvalgte områder på Varangerhalvøya, Finnmark*. Office of the Finnmark County Governor, Report No. 11-2003. 35 pp.
- Taskaev, A.I. (ed.) 1997. Level of knowledge of the Komi republic natural resources. Syktyvkar.
- Taskaev, A.I. (ed.) 1998. *Komi Republic Red Book*, Moskow; Syktyvkar.
- Taskaev A.I., Gladkov, V.P., Degteva, S.V., and Alekseeva, R.N. 1996. *Specially protected nature territories system in the Komi Republic* Syktyvkar.
- Tetryuk, B.Y. 2003. Syntaxonomy of water vegetation of the Vychegda river basin. *Abstract of III (XXYI) International Conference Syktyvkar: 88.*
- Tetryuk, B. 2004. Macrophytes. In: Ponomarev, V., Munsterman, M., Leummens, H. (eds). *The Pechora River Basin*, IB-KSC-RIZA, Syktyvkar-Lelystad, pp. 53–59.
- Thorarinsson, T.L., Einarsson, Á., Olafsson, J.S., and Gíslason, J.S. 2004. *Kortlagning Laxár í Suur-íngeyjarsýslu. Könnun ger í ágúst og september 1978*. 1978 [In Icelandic: Mapping of the riverbed of the River Laxá. An assment carried out in August and September 1978]. Líffrlistofnun Háskolans. Report no. 71, 49 pp.
- Tolmochev, A.I. (ed). 1974/1977. *Flora of the North-Eastern Part of USSR*, Nauka, Leningrad, pp. 1–4.
- Traaen, T. S. 2003. Overvåking av Tanavassdraget. *Årsrapport for 2002. NIVA-4758-2003*. 25 pp.
- Traaen, T., Asvall, R.P., Brettum, P., Heggerget, T.G., Huru, H., Jensen, A. J., Johannessen, M., Kaasa, H., Lien, L., Lillehammer, A., Lindstrøm, E. A., Mjelde, M., Rørslett B., and Aagaard, K. 1983. Basisundersøkelser i Alta-Kautokeinovassdraget 1980–1982. Hovedrapport. *NIVA-Rapport No. 0-80002-16. ISBN 82-577-0594-2*. 117 pp.
- Tuxen, S.L. 1938. Plecoptera and Ephemeroptera. *The Zoology of Iceland* 3: 1–4.
- Tyutyunik, A.P. 1983. Zooplankton of the Pechora river upper stream. Water reservoirs of the Pechora and Vychegda rivers. Syktyvkar. *Proceedings of the Komi branch of the AS USSR; 57: 15–20.*
- Ugedal, O., Thorstad, E.B., Nilsje, T.F., Reinertsen, H.R., Koksvik, J.I., Saksgård, L., Hvidsten, N.A., Blom, H.H., Fiske, P., and Jensen, A.J. 2005. Biologiske undersøkelser i Altaelva 2004. *NINA Rapport* 43: 1–97.
- Upplýsingathjonusta landbunadarins. 1994. *Hagtölur landbunadarins* [In Icelandic: Icelandic Agricultural Statistics]. Upplýsingathjonusta landbunadarins, Reykjavík.
- Vähä, J.-P., Erkinaro, J., Niemelä, E., and Primmer, C.R. 2007. Life-history and habitat features influence the within-river genetic structure of Atlantic salmon. *Molecular Ecology* 16: 2638–2654.
- Vekhov, N.V. 1990. Ecological monitoring of the Northern Dvina river low streams ecosystems based on higher hydro- and hydatophytes condition. *Abstract of the XIII session of the Academic Council. Syktyvkar*, 7 pp.
- Vekhov, N.V. 1993. Hydro- and hydatophytes of the cultivated floodplain landscapes of Arkhangelsk outskirts. *Botanical Journal* 78: 97–103.
- Vekhov, N.V., and Kuliev, A.N. 1986. Hydrophilous plants spreading in the Northern Timan, Malozemelskaya tundra and in the west of Bolshezemelskaya tundra. *Botanical Journal* 71(9): 1241–1248.
- Vlasova, T.A. 1988. Main rivers hydrochemistry. Syktyvkar.
- Vorren, Å. 1958. Samisk villreinfangst i eldre tid. *Ottar. Tromsø Museum* 17: 42.
- Walseng, B. and Huru, H. 1997. Ferskvannsinvertebrater i Finnmark, med vekt på sjeldne og truede arter. *NINA Oppdragsmelding* 456. 60 pp.
- Ward, J.V. 1994. Ecology of alpine streams. *Freshwater Biology* 32: 277–294.
- Willoch, G.I. (ed). 1960. *Vardøhus festning 650 år*; Jubileumsskrift, Landstrykkeriet AS, Oslo, 180 pp.
- Yenikeeva, T.V. 1983. Assessment the Pechora river saprobity by phytoplankton. Water reservoirs of the Pechora and Vychegda rivers. Syktyvkar. *Proceedings of the Komi branch of the AS USSR; 57, pp.5–9.*
- Yepishin, N.B., and Yelsukova R.R. 1990. White-fish food composition in the Northern Dvina river mouth area. *Abstract of XIII session of the Academic Council, Syktyvkar: 47.*
- Yermolin, B.V. 1991. Protected nature fund of the Arkhangelsk oblast. *Socio-Ecological Problems of the European North*, Geographical Society of the USSR, Arkhangelsk Branch, Arkhangelsk, pp. 163–174.
- Yestafiev, A.A. 2005. Zonal distribution of the birds in the European North-East of Russia. Mechanisms of the zonal distribution of animals in the European North-East of Russia. Syktyvkar, pp. 32–41.
- Yestafiev, A.A., Voronin, R.N., Mineev, Y.N., Kochanov, S.K., and Beshkarev, A.B. 1995. *Birds. Non-Passerine*. Fauna of the European North-East of Russia, Nauka, St. Petersburg, I, 1. 325 pp.
- Yestafiev, A.A., Mineev, Y.N., Kochanov, S.K., Anufriev, V.V., Demetriades, K.K., and Neyfeld, N.D. 1999. *Birds. Non-passerine*. Fauna of the European North-East of Russia, Nauka, St. Petersburg, I, 2. 290 pp.
- Zhila, I.M. (ed). 1965. *Surface Waters Resources of the USSR: Hydrological study. 3. Northern Lands*, Hydrometeoizdat, Leningrad.
- Zhila, I.M. and Alyushinskaya, N.M. (eds). 1972. *Resources of the Surface Waters in the USSR: 3. Northern Land*, Hydrometeoizdat, Leningrad.
- Ziuganov, V.V., Zotin, A.A., Nezhlin, L.P., Tretiakov, V.A. 1994. *The freshwater pearl mussels and their relationship with salmonid fish*. VNIRO Publishing House, Moscow, 104 pp.
- Ziuganov, V.V., Beletsky, V.V., Neves, R.J., Tretiakov, V.A., Mikhno, I.V., and Kaliuzhin, S.M. 1998. *The Recreational Fishery for Atlantic Salmon and the Ecology of Salmon and Pearl Mussels in the Varzuga River*,

*Northwest Russia*. Virginia Technical Publishers, Blacksburg, Virginia, ISBN 5-85382-126-1.

Zvereva, O.S. 1969. *Biological peculiarities of the main rivers in the Komi Republic*. Nauka, Leningrad.

Zvereva O.S. 1971a. Composition and distribution of higher water plants in the middle Pechora river basin. In: *Biology of the northern rivers in oldlake lowlands*. Syktyvkar. *Proceedings of the Komi branch of the AS USSR 22*, pp. 27–34.

Zvereva, O.S. 1971b. General characteristics of the middle Pechora and its left tributaries benthos in connection with hydrography peculiarities. In: *Biology of the northern rivers in oldlake lowlands*. Syktyvkar. *Proceedings of the Komi branch of the AS USSR 22*: 44–58.

Zvereva, O.S., and Ostroumov, N.A. 1953. Fauna of the water reservoirs. *Productive forces of the Komi ASSR. III, 2*, Komi Branch of the AS USSR, Syktyvkar, pp. 107–141.

## RELEVANT WEBSITES

[www.seNorge.no](http://www.seNorge.no) Snow, weather, water and climate in Norway

[www.hve.no](http://www.hve.no) Hydrology and watercourse management

<http://www.hi.is/HI/Stofn/Myvatn/engframe.htm> Web site on Lake Mývatn and the River Laxá, Iceland

<http://www.polarenvironment.no> Polar Environment Centre, Tromsø, Norway

<http://www.environment.no> State of the Environment Norway

<http://www.bafg.de/servlet/is/2491/?lang=en> Arctic runoff database

<http://www.acia.uaf.edu/> Arctic Climate Impact Assessment

<http://www.amap.no/> Arctic Monitoring and Assessment Programme

<http://www.arctic.noaa.gov/detect/land-river.shtml> A Near-Real Arctic Change Indicator Website

