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Site descriptive modelling SDM-Site

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November 2008

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Preface

The Swedish Nuclear Fuel and Waste Management Company (SKB) is undertaking site characterisation at two different locations, the Forsmark and Laxemar-Simpevarp areas, with the objective of siting a geological repository for spent nuclear fuel. The site investigations started in 2002 and were completed in 2007. The analysis and modelling of data from the site investigations provide a foundation for the development of an integrated, multidisciplinary Site Descriptive Model (SDM) for each of the two sites. A site descriptive model constitutes a description of the site and its regional setting, covering the current state of the geosphere and the biosphere, as well as those natural processes that affect or have affected their long-term development. The site descriptions shall serve the needs of both Repository Engineering and Safety Assessment with respect to repository layout and construction, and its long-term performance. They shall also provide a basis for the Environmental Impact Assessment.

The surface system consists of a number of disciplines that have been worked together within the project group SurfaceNet. The disciplines involved in the description are:

- hydrogeology, surface hydrology and oceanography,
- bedrock- and Quaternary geology and soil-science,
- hydrogeochemistry and surface water chemistry,
- system- and landscape ecology,
- nature- and human geography.

Focus for the description, beside a general description of site conditions, has been to support and answer a few overall questions, such as:

- What types of ecosystems are present and how do they function in terms of transport and accumulation of matter at a local and regional scale?
- How has the site developed in time?
- Can we find evidence for deep groundwater discharge, and describe the processes involved?

Previous versions of these site descriptions have been published for both Forsmark and Laxemar-Simpevarp. The latest version of the overall concluding site description, SDM-Site, is found in the SDM reports (SKB TR-08-05 and SKB TR-09-01). Further, a more comprehensive overall surface system description of Forsmark and Laxemar-Simpevarp, respectively, is found in the two Surface system reports (/Lindborg (ed.) 2008/ Surface System Forsmark, Site descriptive modelling, SDM-Site Forsmark, R-08-11, Svensk Kärnbränslehantering AB and /Söderbäck and Lindborg (ed.) 2009/ Surface System Laxemar-Simpevarp, Site descriptive modelling, SDM-Site Laxemar-Simpevarp, R-09-01, Svensk Kärnbränslehantering AB).

The present report comprises the final description of the limnic ecosystems (lakes and streams) in the Forsmark and Laxemar-Simpevarp areas and is part of the discipline system ecology.

Tobias Lindborg
Project leader, SurfaceNet

Summary

For siting of a geological repository, the Swedish Nuclear Fuel and Waste Management Co has undertaken site characterization at two different locations, Forsmark and Laxemar-Simpevarp. This report is part of the surface system site description, which includes e.g. hydrology, Quaternary deposits, chemistry, ecology, human population and land use. The overall objective of this report is to provide a thorough description of the limnic ecosystems at both Forsmark and Laxemar-Simpevarp. This information may be used in the Safety Assessment and as a basis for the Environmental Impact Assessment. To achieve this, three aims were set up for the report: 1) to characterize and describe the limnic ecosystems today and in the past in the Forsmark and Laxemar-Simpevarp areas and compare these ecosystems with limnic ecosystems in other areas; 2) to evaluate and visualize major pools, fluxes and sinks of elements within the limnic ecosystems; and finally 3) to describe human impact on the limnic ecosystems.

The report includes a thorough description of the lakes and streams in Forsmark and Laxemar-Simpevarp and covers the following areas: catchment area characteristics, hydrology, climate, sediment characteristics, physical characteristics of streams, habitat distribution in lakes, biotic components (biomass as well as production), water chemistry, comparisons with other lakes and streams in the region, and a historical description. Ecosystem models for carbon and mass balances for a number of elements have been calculated to further improve the understanding of the lake ecosystems. Important processes for the safety assessment are described and evaluated in the report. A separate chapter is included to specifically describe how and were these processes are included in the report. The last chapter of the report provides a summary of the knowledge of the limnic systems at the two areas, as well as a comparison between Forsmark and Laxemar-Simpevarp.

The Forsmark regional model area contains more than 20 permanent lakes and pools. All lakes are small and shallow, and are characterized as oligotrophic hardwater lakes. Calcareous soils in the area give rise to high calcium concentrations in the surface water, which in turn leads to high pH and low nutrient concentrations in water as phosphorus often co-precipitates with calcium. The shallow depths and moderate water colour permit photosynthesis in the entire benthic habitat of the lakes, and the bottoms are covered by dense stands of the macroalgae *Chara sp*. Moreover, many of the lakes also have a thick microbial mat (>10 cm), consisting of cyanobacteria and diatoms, in the benthic habitat. Fish in the lakes are dominated by species resistant to low oxygen concentrations, mainly due to poor oxygen conditions during the winter. The streams in Forsmark are all very small, and long stretches of the streams are dry during summer. The downstream parts of some of the streams may function as passages for migrating fish, and extensive spawning migration between the sea and a downstream lake has been observed. Human activities in the area have affected the limnic ecosystem, and large parts of the streams in the Forsmark area consist of man-made ditches. Moreover, one of the lakes has been lowered and one has been divided into two basins.

The ecosystem carbon models for the Forsmark area show that the lakes that contain a microbial mat have larger primary production than respiration, and thus show a positive net ecosystem production (NEP). In lakes that lack a microbial mat, respiration is similar in magnitude as primary production and net ecosystem production is close to zero. Carbon mass balance models for the Forsmark lakes indicate, in accordance with the ecosystem models, that the larger lakes (with a microbial mat) in the area have a positive NEP. However, in contrast to the ecosystem models, the mass balance models indicate that the smaller lakes in the area have negative NEP, regardless of the occurrence of a microbial mat. A low proportion (7–10%) of the carbon incorporated into primary producers in the lake is transported upwards in the food web, and instead most carbon is consumed by bacteria in the form of DOC and POC. The mass balances for a number of elements in Forsmark lakes show that the proportions of different fluxes to and from the lakes are dependent on lake size and position in the catchment, but also on the specific properties of the different elements.

A total of 6 lakes are situated partly or entirely within the regional model area of Laxemar-Simpevarp. The Laxemar-Simpevarp lakes are small and all but one are characterized as brown-water lakes. The lakes have moderate phosphorus concentrations, whereas the concentrations of nitrogen and dissolved organic carbon tend to be high. Because of the brownish water, light penetration is poor and the depth of the photic zone is generally small. In accordance, macrophyte coverage in the lakes is small and biota is dominated by heterotrophic organisms, particularly bacteria. Perch is the predominant fish species in numbers, as well as in weight, in the lakes in the area. Most of the streams in the Laxemar-Simpevarp area are small with mostly calm or slowly flowing water and many of the streams have dry sections in the summer. Most lakes in the Laxemar-Simpevarp area are affected by human activities; the water level in most lakes has been lowered, and one lake, Söråmagasinet, was originally a sea bay but was dammed in order to ensure freshwater reserves to the nuclear power plant. Water is pumped from Laxemarån to Söråmagasinet in order to maintain the available water storage in the lake.

Both the carbon ecosystem model and the mass balance for Lake Frisksjön in Laxemar-Simpevarp indicate a negative NEP, i.e. higher respiration than primary production. The carbon mass balance show that the lake receives large inputs of organic matter and that these inputs are to a large extent mineralized to CO_2 and emitted to the atmosphere. A large part of the carbon influx also contributes to sediment accumulation in the lake. The annual amount of carbon transported to the lake via inflow is of the same magnitude as the internal processes of primary production and consumption, and there is a large probability that carbon entering the lake will be incorporated into the lake food web. A relatively large part of the primary produced carbon (34%) is transported upwards in the food web. Mass balances for a number of elements indicate that, in general, the most important influx of different elements to the lake is via surface water and the most important outflux is via sediment accumulation.

Contents

1 Introduction

1.1 Background

The Swedish Nuclear Fuel and Waste Management Company (SKB) is compiling two Site Descriptive Models (SDM) for the two site investigation areas Forsmark and Laxemar-Simpevarp. The site descriptions must serve the needs of both Repository Engineering and Safety Assessment with respect to repository layout and construction for a geological repository for spent nuclear fuel, and its long-term performance. They must also serve as a basis for the Environmental Impact Assessment.

The site descriptions (symbolized as the upper square in Figure 1-1) will summarize other more detailed reports, called "Main references (level II)" in Figure 1-1. Two of these main references are the reports describing the surface system at each site /Lindborg 2008, Söderbäck and Lindborg 2009/ (the left lower square in the middle section in Figure 1-1), in which terrestrial, limnic and marine ecosystems, surface hydrology and other surface system disciplines are described. The surface system reports are a summary of even more detailed reports, called "Other references (level III)" in Figure 1-1. The present report describes the methodology and input data relating to the site description of the limnic ecosystems in the Forsmark and Laxemar-Simpevarp area (yellow box in the right lower square in Figure 1-1). Two similar reports describe the marine ecosystems /Wijnbladh et al. 2008/ and the terrestrial ecosystems /Löfgren 2008/.

The ecosystem reports (limnic, marine and terrestrial ecosystems) will be published in two editions, where the present report is the first edition of the limnic report. The second edition will include chapters describing the future conditions of the site, as well as the radionuclide models used in the safety assessment for a repository for spent nuclear fuel and their parameterization.

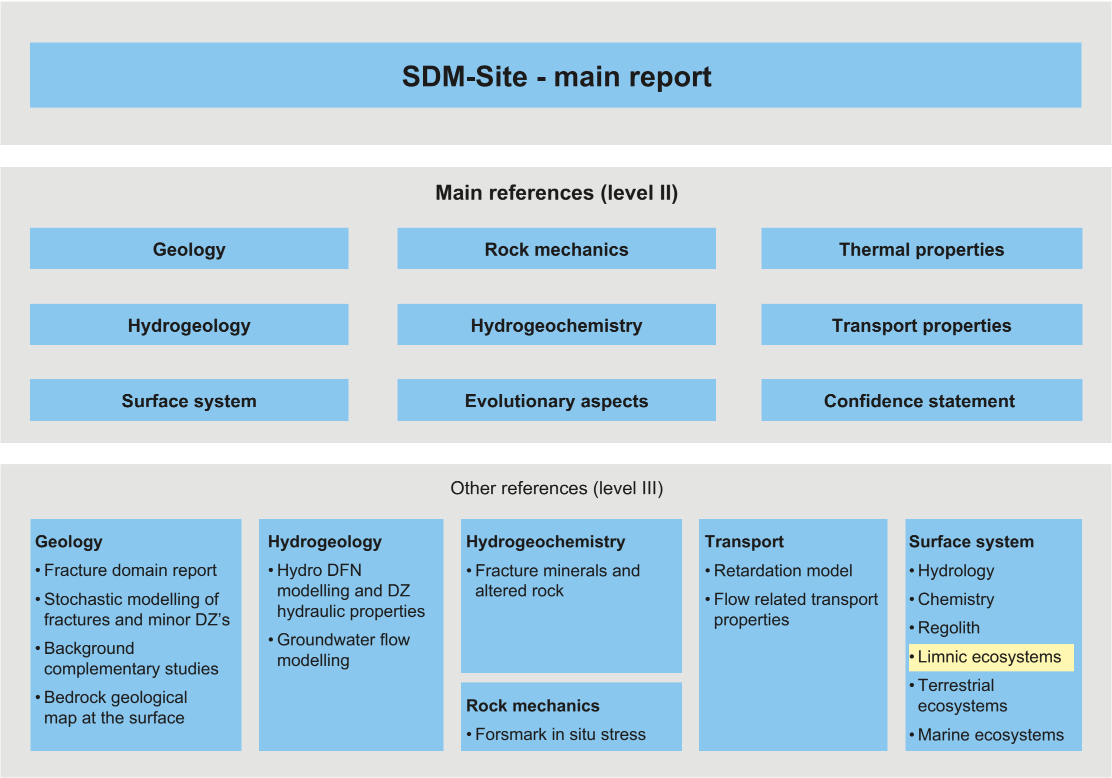

Figure 1-1. *Structure of the reports produced to serve as a basis for the Site Descriptive Models for Forsmark and Laxemar-Simpevarp (note that the level III reports may differ somewhat between the sites).*

1.2 Aims

This report has three primary aims:

1. To characterize and describe the limnic ecosystems today and in the past in the Forsmark and Laxemar-Simpevarp areas, and to compare these systems with limnic system in other areas of Sweden.
2. To evaluate and visualize the major pools, fluxes and sinks of elements in the limnic ecosystems in Forsmark and Laxemar-Simpevarp.
3. To describe the human impact on the limnic ecosystems in Forsmark and Laxemar-Simpevarp.

The report presents summaries of site investigations that are presented in more detail in separate reports, as well as descriptions and estimates not presented elsewhere. The intention is to give the reader a coherent description of the limnic ecosystems at the site. This information is also used to compile descriptions of pools and fluxes of organic matter, water and a number of other elements. These descriptions will promote a thorough understanding of ecosystem patterns and processes at the two sites Forsmark and Laxemar-Simpevarp and furnish the Safety Assessment with quantitative data on the ecosystems. The improved understanding and quantitative descriptions will be used in the Safety Assessment in predicting the fate of a hypothetical unintentional release of radionuclides into the surface ecosystems.

The major outputs of the report can be summarized as:

- A compilation and overview of the studies of different aspects of the limnic systems that have been conducted during the site investigations.
- A general description of the limnic ecosystems at the two sites and factors of importance for the characteristics of the present limnic ecosystems.
- A historical description of the limnic ecosystems both in general terms and for the two sites specifically.
- Ecosystem models that describe pools and fluxes of carbon on a detailed ecosystem level, as well as more generalized carbon mass balance models.
- Ecosystem models that describe pools and fluxes of a wide range of elements.

1.3 Setting

The two sites which this report focuses on, Forsmark and Laxemar-Simpevarp, are located on the Swedish east coast in the catchment of the Baltic Sea (see Figure 1-2 and 1-3).

Sweden in general has a maritime climate, distinguished by cool summers and mild winters. However, further north in Sweden the climate tends to be more continental with a greater difference between summer and winter. The climate in Forsmark therefore tends to be more continental than in Laxemar-Simpevarp. The mean annual air temperature is also somewhat lower in Forsmark.

Both sites are located in the boreonemoral vegetation zone, dominated by pine and spruce.

1.3.1 Geographical definitions and terminology

When the two sites are referred to in a general sense in an SDM-Site context, and without reference to clearly defined outer boundaries, they are called the **Forsmark area** and the **Laxemar-Simpevarp area**. At the start of the site investigations in 2002, regional model areas with clearly defined outer boundaries were defined for each site for the purpose of regional scale modelling (see Figure 1-2 and 1-3). These areas were denominated **the Forsmark regional model area** and **the Simpevarp regional model area**. Furthermore, two smaller areas within the Simpevarp regional model area, the Simpevarp subarea and the Laxemar subarea, were defined, and preliminary site descriptions were produced for both subareas. Since the two subareas are included in the same regional model area, the former Simpevarp regional area is designated the **Laxemar-Simpevarp regional model area** in an SDM-Site context, for clarity and to avoid confusion.

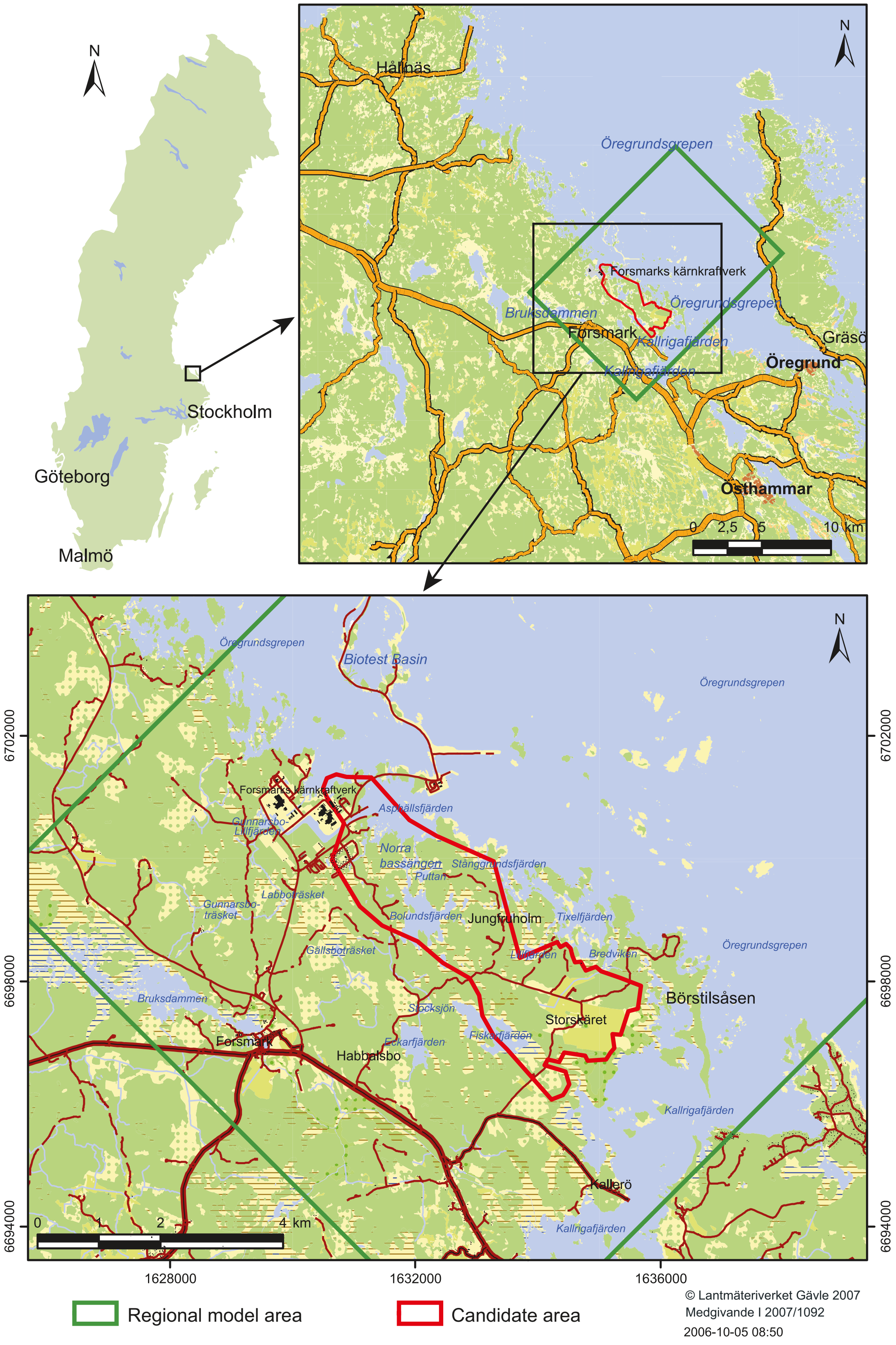

Figure 1-2. *The location of the Forsmark area. The black rectangle shows the boundaries of the enlarged map.*

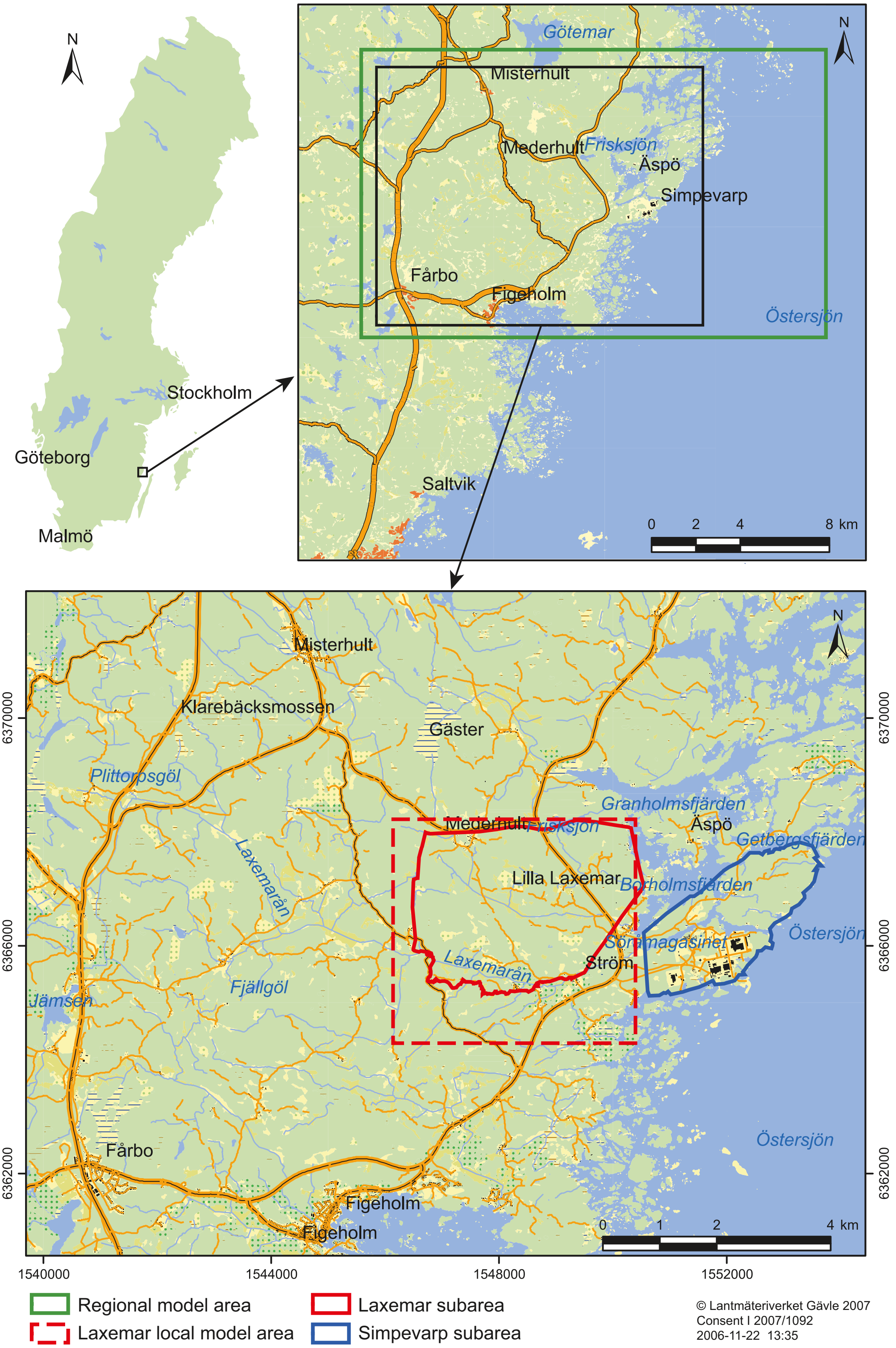

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***Figure 1-3.** The location of the Laxemar-Simpevarp area. The black rectangle shows the boundaries of the enlarged map.*

2 This report

This section provides guidance for the reader and puts the report in a broader context. We present the aims of the report and describe how the sections are related to each other and how they are used in the different steps of the biosphere safety assessment.

2.1 This report in a broader context

The ecosystem is in most cases the link between radionuclides occurring in the biosphere and the exposure of these to humans and biota. In the site descriptions, the landscape is divided into three ecosystems: the limnic, marine and terrestrial ecosystems. The definitions used for these categories are described in section 2.3. This report (second column in Figure 2-1) describes the limnic ecosystems at the two sites Forsmark and Laxemar-Simpevarp by summarizing and making interdisciplinary analyses of data from a large number of reports produced during the site investigations. The limnic ecosystems, divided into lakes and streams, are described by identifying properties that are important for element accumulation and transport.

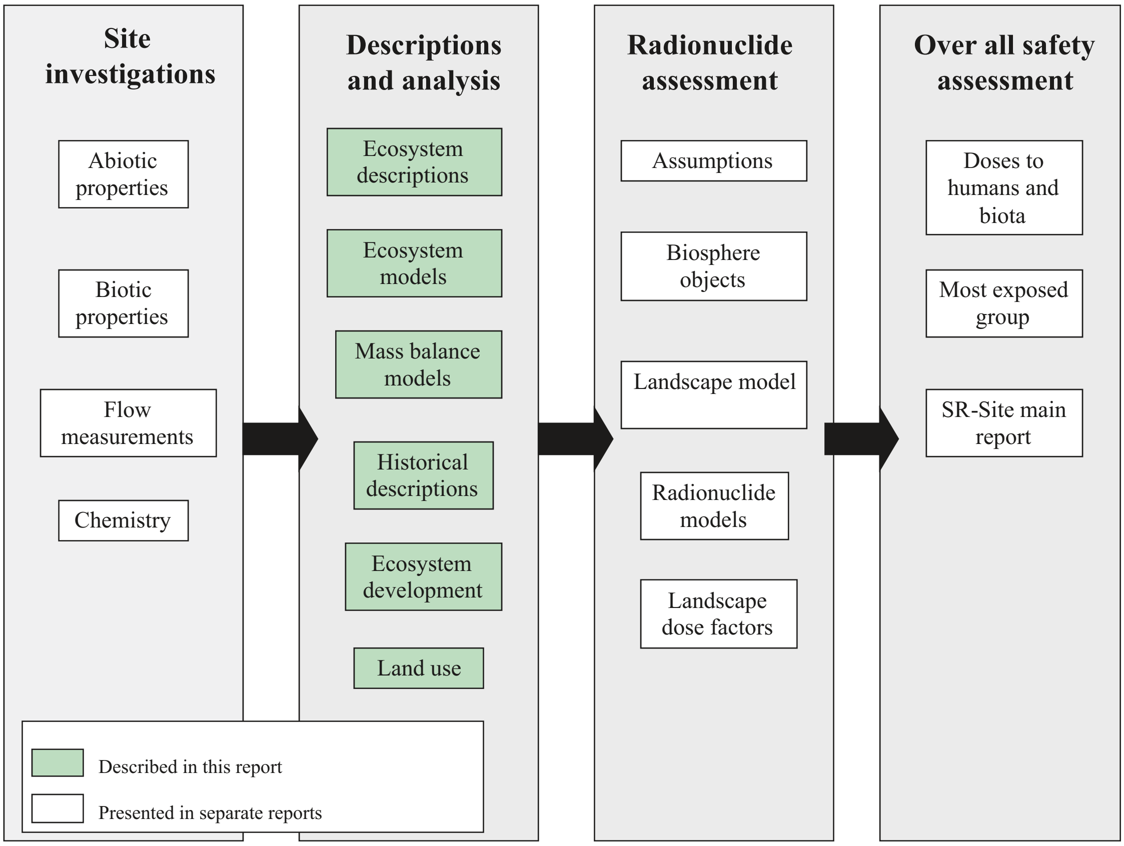

Figure 2-1. A schematic picture of how results from the site investigation are fed into different parts of this report and how the results in this report are in turn fed into biosphere dose modelling and safety assessment.

2.2 Report content – a brief overview

The extent to which elements are transported and accumulated in the biosphere depends on the properties of the element and the context to which it is exposed. The approach used in this report is to examine a number of different aspects concerning pools and fluxes of elements in the landscape of today, but also consider historical aspects that are deemed important for modelling of radionuclide transfer and accumulation in an evolving surface system. Future aspects will also be considered in the next version of the report.

Within the period of time considered in the safety assessment, i.e. a perspective of many thousand years, the landscape of the investigated areas will be altered, largely due to current and predicted shoreline displacement. Due to these processes, marine areas will be transformed into lakes and lakes into wetlands and other terrestrial ecosystems, including agricultural areas. Elements in the limnic ecosystems may accumulate in the geographical area and later be integrated in a terrestrial system. In the same way, elements previously accumulated in the marine ecosystem may be incorporated in the limnic system when new lakes are isolated from the sea.

The first chapters in this report give an overview and synthesis of site data, whereas the subsequent chapters present different aspects of pools and fluxes of elements in limnic ecosystems. Pools and fluxes of elements are investigated and elaborated using site-specific data and the scientific literature in order to devise a model describing element transport and accumulation, which will be applied to radionuclides in the safety assessment. Some of the temporal aspects treated here, such as transitions between ecosystems or landscape development, are not incorporated as such in the transport and accumulation models described here. Below is a brief summary of the content of the different chapters.

In this report, characteristics of the limnic systems in the two investigated areas are described in **Chapter 3,** *Description of lakes and streams in the Forsmark area,* and in **Chapter 4,** *Description of lakes and streams in the Laxemar-Simpevarp area*. Biotic data concerning species composition, biomasses and habitat distributions are presented along with abiotic data on the morphometry, hydrology and chemistry of the systems, as well as the character of the catchments and the thickness and composition of sediments. Climatic conditions are also described, as well as human impact and human use of the systems. Most data have been collected during the site investigations, but when site data are lacking, data from other sources are also used. The chapters conclude with a general description of the lakes and streams in each region in order to put the local conditions in a regional perspective.

Based on the descriptions in Chapter 3 and 4, conceptual models for carbon dynamics in lakes in the two areas are constructed. These models are presented in **Chapter 5,** *The lake ecosystem – conceptual and quantitative carbon models.* Models for streams are described in **Chapter 6,** *The stream ecosystem – conceptual model and model assumptions for carbon*. Two model approaches are presented for lakes: ecosystem carbon budgets and carbon mass balances. The different habitats and functional groups in the ecosystem are defined, the distributions of these groups are described, and their connections are shown in a food web. The same conceptual model is used for lakes in both Forsmark and Laxemar-Simpevarp, and the same stream model is also used for both areas. However, all habitats and functional groups do not occur in both areas which, to some extent, makes the final models site-specific. The assumptions made are in most cases valid for both sites, but some assumptions are site-specific. A summary of the data used in the models is presented. This section also refers back to where in the earlier descriptive chapters these data are presented. The different fluxes comprising the carbon mass balances are presented and estimated values for these are shown. Results of the carbon budgets and mass balances are presented for five selected lakes, four lakes in Forsmark (Bolundsfjärden, Eckarfjärden, Gunnarsbo-Lillfjärden and Labboträsket) and one lake in the Laxemar-Simpevarp area (Frisksjön). Confidence and uncertainties in model assumptions are described and discussed.

Pools and fluxes of a number of elements are presented in **Chapter 7,** *Pools and fluxes of different elements in, out and within lakes.* In this chapter, mass balances for a number of elements are described for 5 lakes in Forsmark and 1 lake in Laxemar-Simpevarp. To calculate ecosystem models for other elements than carbon demands more data than available. Instead, as a complement to the mass balances, pools of elements are described.

Chapter 8, *Long term development of lakes and streams* describes how the limnic systems have evolved at the sites. General predictions for the future development will be presented in version 2 of this report.

The interaction matrix is a tool to describe how important processes for the Safety assessment are considered in this report. **Chapter 9,** *Couplings to the process interaction matrix,* describes which processes are included in the report. In addition, this chapter briefly discusses how the processes are treated and where they are described in the report.

Chapter 10, *Concluding description of the limnic ecosystems in Forsmark and Laxemar-Simpevarp and comparison between the two areas,* presents a concluding synthesis. A description of the limnic ecosystem, (including e.g. major pools, fluxes and human impact) is presented with comparison between the two areas.

2.3 Delimitations and definitions

As mentioned above, the site descriptions of the surface system divide the landscape into three ecosystems: limnic, marine and terrestrial. The principal difference between the terrestrial and aquatic ecosystems is the position of the water table, which has implications for a number of ecosystem characteristics and ecosystem processes, such as life form, plant water availability and decomposition. The interface between the two systems often shows high primary production and accumulation of organic material, for example a reed belt in a lake. Some interface areas show high production but no accumulation, e.g. exposed sea shores with input of marine residues. The interface between aquatic and terrestrial environments is in some cases easy to distinguish, such as a rock outcrop/water interface. However, in other cases the boundary between land and water may not be so clear and easy to identify. In most cases, the interface on a freshwater shore is clearly distinguishable along a transect of a few metres (the littoral of a lake), whereas a sea shore, with larger fluctuations in water level, might be distinguished along a transect of tens of metres. In both Forsmark and Laxemar, zones of high production and accumulation have been identified around lakes and in sheltered bays. In the ecosystem models, these zones are classified as wetlands and treated as part of the terrestrial ecosystem in order to treat all kinds of wetlands in a similar way. The interface zones have to be considered as a transient stage in the succession of sea basins/lakes to land.

Some important terms and concepts used in this report are presented and defined in Table 2-1 below, and in the last sections of this chapter.

2.3.1 Lakes

The definition of what qualifies as a lake differs in the literature, but parameters that are often included are lake size and water retention time. Most of the world's lakes are freshwater systems, although brackish and salt water systems may also be lakes. A pond is defined as a body of water smaller than a lake. The difference between lakes and ponds is, however, subjective and what some define as a lake others may define as a pond. Most lakes are open and have distinct flow into, through, and out of their basins. These throughflows determine the water retention time (the time required to replace all the water in the lake), and the retention time can be used to distinguish between lake and streams, with lakes having longer retention times than streams where water is replaced much more rapidly. The definition of lakes used in this report is "a body of freshwater with a minimum size of 0.5 ha surrounded entirely by land". We do not specify retention time as with our definition of lakes, all the lakes in Forsmark and Laxemar-Simpevarp have relatively long retention times.

Table 2-1. Definitions of important terms and concepts used in the report. Definitions are in accordance with /Chapin et al. 2002/ and /Begon et al. 1987/.

Concept/term	Definition
Abiotic	Not directly caused or induced by living organisms.
Autotroph	Organism that produces organic matter from CO_2 and environmental energy rather than by consuming organic matter produced by other organisms. Here synonymous with primary producers.
Biotic	Caused or induced by living organisms.
Conceptual model	A qualitative description of the components in an ecosystem.
Descriptive model	A quantitative description of the components in a considered ecosystem. Can be static or dynamic (see below).
Dynamic model	A dynamic model describes the behaviour of a distributed parameter system in terms of how one qualitative state can turn into another.
Ecosystem model	Conceptual or mathematical representation of ecosystems. Simplifying complex food webs down to their major components or trophic levels, and quantify these as either numbers of organisms, biomass or the inventory/concentration of some pertinent chemical element.
Flux	Flow of energy or material from one pool to another.
Food web	Group of organisms that are linked together by the transfer of energy and nutrients that originates from the same source.
Functional group	Collections of organisms based on morphological, physiological, behavioural, biochemical, environmental response or trophic criteria.
Gross primary production (GPP)	Carbon input to ecosystems – that is, photosynthesis expressed at ecosystem scale ($g\ C\ m^{-2}\ yr^{-1}$).
Heterotroph	Organism that consumes organic matter produced by other organisms rather than producing organic matter from CO_2 and environmental energy; includes decomposers, consumers and parasites.
Mass balance	A model describing the import and export of elements or matter in a system, which thereby makes it possible to identify unknown mass flows or estimate mass flows that are difficult to measure.
Net ecosystem production (NEP)	The balance between gross primary production and ecosystem respiration.
Net primary production (NPP)	The balance between gross primary production and plant respiration.
Pool	Quantity of energy or material in an ecosystem compartment such as plants or soil.
Respiration	Biochemical process that converts carbohydrates into CO_2 and water, releasing energy that can be used for growth and maintenance. Heterotrophic respiration is animal respiration plus microbial respiration. Ecosystem respiration is heterotrophic plus autotrophic respiration.

The borderline between a lake and the surrounding terrestrial environment may be set differently depending on the aim. In the two site investigation areas, the extents of lakes have been mapped by /Brunberg et al. 2004a and 2004b/, who uses the highest high water level to delimit the lake from terrestrial areas. Using this definition, wetland areas in direct contact with the lake are also included, as well as the “artificial” wetland areas in some lakes where the water level has been lowered due to anthropogenic activities. Hence, in addition to the aquatic plants, wetland plants and even bushes and small trees may occasionally be included in this zone, especially if the area is tufty. In the ecosystem models presented in Chapter 5, we have chosen to treat all areas defined as Littoral I (reed belts and in Frisksjön also wetland plants, trees and bushes) by /Brunberg et al. 2004a and 2004b/ as wetland areas. The main reason for this is to treat all kinds of wetlands within the areas in the same way. The interface zones have to be considered as a transient stage in the succession of lakes becoming land. In the safety assessment of a repository for spent nuclear fuel, fluxes of elements are of interest on a landscape level, and the models for the three ecosystem types (terrestrial, limnic and marine) will be linked together to model the overall fluxes. At this point it is not of particular importance how these areas are defined. The important thing is that these areas are included somewhere. Data from littoral I (reed belts) are presented in Chapter 3 and 4. Neither the reed biomass nor ecosystem processes in the reed belt are explicitly included in the lake ecosystem model, but the resulting transport of elements is indirectly included in the lake budget as import from adjacent terrestrial areas. The biological processes within the reed belt are further described in the account of the terrestrial ecosystems /Löfgren 2008/.

2.3.2 Streams

One definition of streams is "*mass of freshwater moving through the landscape driven by gravity*". This definition also includes water flowing in man-made ditches. As large stretches of the watercourses within the areas at Forsmark and Laxemar-Simpevarp are ditches, we use this definition in this report. For most of the running waters in the two areas the furrow is distinct, which makes the delimitation between the stream and the surrounding terrestrial ecosystem easy. In some parts, the surrounding areas are temporarily flooded during periods of high water flow. This occurs during very short periods and the flooded areas are not considered as part of the limnic ecosystem but are treated as terrestrial areas in /Löfgren 2008/. Areas that are flooded have been defined through field examinations (see sections 3.3.5 and 4.3.4).

A stream often changes character from its source to its outflow into the sea. In large river systems the character of the stream changes along the stretch from the source(s) to the final outlet in the sea. To consider this character change, streams are often divided into stream orders /Strahler 1957/. The stretch from the source is given stream order 1 until it meets another furrow of the same order. From here the stream order is 2 until the furrow meets another with an equal or higher stream order. The stream order system has been used in this report.

2.3.3 Catchments

Terrestrial and aquatic ecosystems are linked by movements of water and materials. There is a continual downstream movement of surface waters in streams and lakes towards the sea. A catchment can be defined as the area draining to a defined point. For example, the catchment of a lake is defined as all area draining to the outlet point of the lake and thus includes all the area draining to the lake as well as the lake itself. The catchment for a lake may contain several lakes in upstream areas, in which case it is common to define sub-catchments for the separate lakes.

3 Description of lakes and streams in the Forsmark area

The Forsmark area includes 8 small catchments, 25 lakes and a number of small streams (Figure 3-1 and 3-2). Site data for description of the limnic systems have been collected during the site investigations. The following text describes these investigations with a focus on describing the limnic ecosystems. The sampling methods used are only briefly described here. For further details the reader is directed to the investigation reports.

3.1 General description of the lakes and streams

The lakes in the Forsmark area are characterized as oligotrophic hardwater lakes. The bedrock in the area is dominated by granite and gneisses, covered by calcareous glacial till and small areas with postglacial clay. The calcareous till gives rise to very high calcium concentrations in the surface water and the superficial groundwater. High concentrations of calcium ions [Ca^{2+}] lead to precipitation of $CaCO_3$, especially in the summer when the pH is high due to high primary production. Nutrients (P, Mn, Fe) often co-precipitate with calcium, leading to oligotrophic conditions; hence the definition oligotrophic hardwater lakes.

The Forsmark lakes are generally small and shallow with small volumes. The water level in the lakes varies over the year, with the highest water levels in March–April following snowmelt and the lowest water levels in July–September. Most of the lakes in the Forsmark area are surrounded by mires and it is not always apparent how to draw the borderline between lake and mire.

The water chemistry in lakes in Forsmark is characterized by high pH, high concentrations of major ions and high electrical conductivity. The phosphorus concentrations are generally low, whereas nitrogen concentrations tend to be high. The water has high concentrations of dissolved organic carbon, which in combination with the moderate water colour in the lakes is unusual.

Due to the shallow water depth and clear water, the biota in the lakes is strongly concentrated in the benthic habitat, which is covered by the macroalgae *Chara* and a thick microbial mat consisting of microphytobenthos and benthic bacteria. The microbial mat is unusually thick, and chlorophyll *a*, which indicates photosynthesising organisms, has been found down to depths of 10–15 cm. In the pelagic habitat, on the other hand, the biomass of microbiota is low. Similar to biomass, primary production is also concentrated in the benthic habitat. The fish populations in the lakes were compared with other Swedish lakes and classified according to Swedish fish index (FIX). The fish populations varied between lakes and there were populations with no deviation from a normal lake but also populations with significant deviation from a normal lake. The lakes which deviated from normal lakes had a high share of biomass from species resistant to low oxygen levels and/or a low biomass share of piscivore percids. Species tolerant to low oxygen conditions, i.e. Crucian carp, dominate in many of the lakes /Borgiel 2004b/.

There are no large streams in the Forsmark regional model area but there are a number of small streams draining the area (Figure 3-2). The mean specific discharge for the largest investigated catchment was 4.88 $L\ s^{-1}\ km^{-2}$, which can be considered low (section 3.3.1). Large parts of the streams are dry for part of the year and all of the automatic discharge gauging stations (4) had zero discharge for relatively long periods in late summers and early autumns. Most of the streams have been excavated (section 3.11).

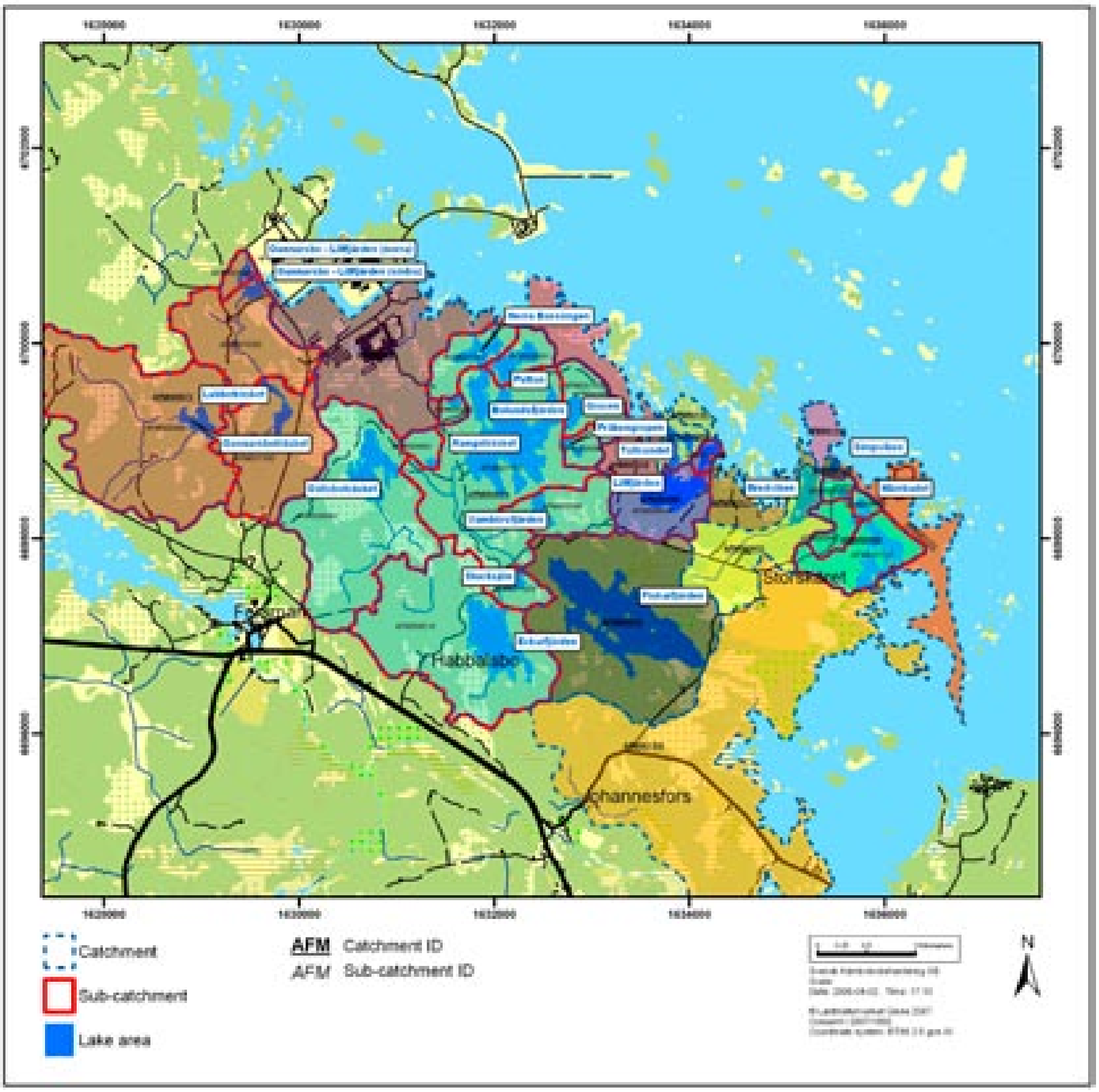

Figure 3-1. Delineated catchments and location of 20 of the 25 lakes in the Forsmark area. Some of the smallest lakes have been omitted from the map for clarity.

As in the lakes, the water chemistry of the streams is characterized by high pH, high alkalinity, and high nitrogen concentrations. The concentration of dissolved organic carbon is very high and shows large temporal variation. The phosphorus concentration varies considerably due to differences in rainfall and water velocity, but is generally low. The coverage of vegetation in the streams varies, but vegetation is often very dense in the uppermost parts of the streams. The most common species of higher vegetation is the common reed.

3.2 Catchment characteristics

The catchment is the land area (including lakes) from which the water is drained to the same stream. The area is delimited by the topography, and all precipitation falling within the catchment less evapotranspiration will eventually reach the sea through the same stream channel.

The catchment clearly determines the characteristics of lakes and streams within it /Wetzel 2001/. The geomorphology of the land determines the ionic composition and slope of the soil, and, in combination with the climate, also the vegetation of the area. The vegetation and soil composition influence the amount of runoff as well as the composition and quantity of organic matter that enters streams and lakes.

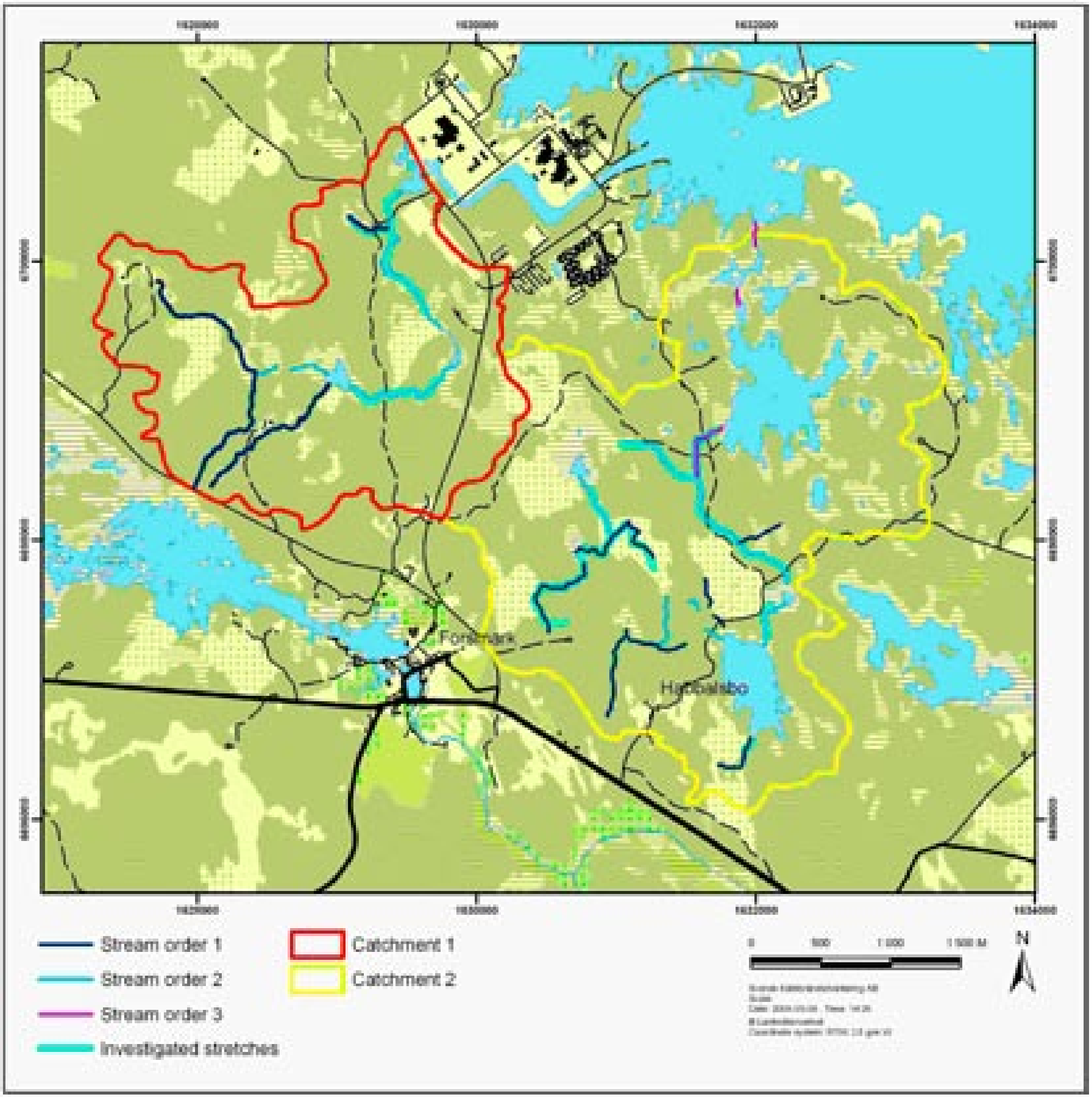

Figure 3-2. *Streams in the Forsmark area. Stream orders and investigated stretches are indicated by different colours.*

Morphological parameters as well as land use, soil composition and vegetation types of the different catchments in the Forsmark area were examined by /Brunberg et al. 2004a/. The maximum elevations above sea level in the different catchments vary between 5 and 27 m, whereas the minimum levels vary between –1 and 5 m (Table 3-1). The number of residents is very low, and only one of the main catchments has a permanent population: 5 people live in catchment 1.

Forest is the most common land use type, comprising on average 70% of the catchments (Table 3-2). The second most common land use type for most catchments is wetland. Agriculture accounts for little land use in all catchments except one, Bredviken, where it represents 28% of the catchment area.

The dominant rock type in the north-eastern part of the Forsmark regional model area is a medium-grained metagranite. Rock domains with strongly deformed and in some cases banded and inhomogeneous rocks occur in the area. The bedrock has a high silica content and, in contrast to the overlaying deposits, a low buffering capacity. The most common soil type is glacial till. Three different kinds of till are represented in the Forsmark area: a sandy till with medium boulder frequency (dominant), a clayey till with low boulder frequency (Storskäret) and a clayey till with high boulder frequency (Börstilåsen) /Hedenström and Sohlenius 2008/.

Table 3-1. Morphological parameters of the catchments in Forsmark. From /Brunberg et al. 2004a/.

ID code	Catchment number	Name	Area (km²)	Maximum level (m.a.s.l.)	Minimum level (m.a.s.l.)	Population (number)
	1	**Forsmark 1**				
AFM000073	1:1-4	Gunnarsbo-Lillfjärden (south)	5.120	27	1	5
AFM001099	01:01	Subarea: Gunnarsbo-Lillfjärden (south)	1.089	12	1	0
AFM000096	01:02	Gunnarsbo-Lillfjärden (north)	0.104	8	1	0
AFM000048	1:3-4	Labboträsket	3.928	27	3	5
AFM001100	01:03	Subarea: Labboträsket	1.193	23	3	0
AFM000095	01:04	Gunnarsboträsket	2.734	27	5	0
	2	**Forsmark 2**				
AFM000074	2:1-10	Norra Bassängen	8.668	20	0	0
AFM001101	02:01	Subarea: Norra bassängen	0.350	8	0	0
AFM000092	02:02	Lake 2:2	0.071	7	1	0
AFM000050	2:3-10	Bolundsfjärden	8.003	20	0	0
AFM001103	02:03	Subarea: Bolundsfjärden	2.244	13	–1	0
AFM000087	2:4-5	Graven	0.531	7	0	0
AFM001104	02:04	Subarea: Graven	0.392	6	0	0
AFM000088	02:05	Fräkengropen	0.139	7	1	0
AFM000089	02:06	Vambörsfjärden	0.484	8	0	0
AFM000093	02:07	Kungsträsket	0.126	9	2	0
AFM000094	02:08	Gällsboträsket	2.141	20	1	0
AFM000090	2:9-10	Stocksjön	2.477	20	2	0
AFM001105	02:09	Subarea: Stocksjön	0.210	12	2	0
AFM000010	02:10	Eckarfjärden	2.267	20	3	0
AFM000091	02:11	Puttan	0.244	9	1	0
	3	**Forsmark 3**				
AFM000086	03:01	Tallsundet	0.215	6	0	0
	4	**Forsmark 4**				
AFM000085	4:1-2	Lake 4:1	0.689	11	0	0
AFM001106	04:01	Subarea: Lake 4:1	0.069	7	0	0
AFM000049	04:02	Lillfjärden	0.621	11	0	0
	5	**Forsmark 5**				
AFM000052	05:01	Bredviken	0.944	10	0	0
	6	**Forsmark 6**				
AFM000084	06:01	Simpviken	0.035	6	0	0
	7	**Forsmark 7**				
AFM000080	7:1-4	Lake 7:1	0.895	8	0	0
AFM001107	07:01	Subarea: Lake 7:1	0.558	8	0	0
AFM000081	7:2-4	Märrbadet	0.337	8	0	0
AFM001108	07:02	Subarea: Märrbadet	0.068	7	0	0
AFM000082	07:03	Lake 7:2	0.192	8	0	0
AFM000083	07:04	Lake 7:3	0.077	5	0	0
	8	**Forsmark 8**				
AFM000051	08:01	Fiskarfjärden	2.926	13	0	0
Mean of the 8 main catchments			2.4	12.6	0.1	0.6
Median of the 8 main catchments			0.9	10.5	0	0
Min of the 8 main catchments			0.04	6	0	0
Max of the 8 main catchments			8.7	27	1	5

Table 3-2. Land use data for the catchments in Forsmark. From /Brunberg et al. 2004a/.

ID code	Catchment number	Name	Water surface (%)	Coniferous and mixed forest (%)	Agricultural land (%)	Remaining open land (%)	Cut forest (%)	Remaining open land without forest contour (%)	Decidious forest (%)	Wetland (%)
AFM000073	**1:1-4**	**Gunnarsbo-Lillfjärden (south)**	**1**	**73**	**1**	**7**	**11**	**8**	**0**	**10**
AFM001099	1:1	Subarea: Gunnarsbo-Lillfjärden (south)	2	62	0	17	8	10	0	12
AFM000096	1:2	Gunnarsbo-Lillfjärden (north)	9	81	0	2	0	8	0	18
AFM000048	1:3-4	Labboträsket	1	75	1	4	11	7	0	10
AFM001100	1:3	Subarea: Labboträsket	1	70	0	1	15	13	0	15
AFM000095	1:4	Gunnarsboträsket	1	78	1	6	10	5	0	7
AFM000074	2:1-10	Norra Bassängen	10	69	0	1	9	10	0	12
AFM001101	**2:1**	**Subarea: Norra bassängen**	**13**	**60**	**0**	**0**	**10**	**18**	**0**	**21**
AFM000092	2:2	Lake 2:2	9	45	0	0	46	0	0	0
AFM000050	2:3-10	Bolundsfjärden	9	70	0	1	9	10	0	11
AFM001103	2:3	Subarea: Bolundsfjärden	20	57	0	0	12	11	0	13
AFM000087	2:4-5	Graven	5	74	0	0	0	21	0	22
AFM001104	2:4	Subarea: Graven	6	71	0	0	0	23	0	24
AFM000088	2:5	Fräkengropen	4	80	0	0	0	16	0	16
AFM000089	2:6	Vambörsfjärden	5	70	0	0	10	15	0	17
AFM000093	2:7	Kungsträsket	3	69	0	0	24	3	0	3
AFM000094	2:8	Gällsboträsket	1	89	0	1	0	10	0	11
AFM000090	2:9-10	Stocksjön	9	65	1	4	16	5	0	6
AFM001105	2:9	Subarea: Stocksjön	3	77	0	1	0	18	0	18
AFM000010	2:10	Eckarfjärden	10	64	1	4	18	4	0	5
AFM000091	2:11	Puttan	17	58	0	0	0	25	0	25
AFM000086	**3:1**	**Tallsundet**	**11**	**58**	**0**	**0**	**0**	**31**	**0**	**35**
AFM000085	**4:1-2**	**Lake 4:1**	**13**	**64**	**0**	**1**	**0**	**23**	**0**	**23**
AFM001106	4:1	Subarea: Lake 4:1	17	45	0	0	0	38	0	38
AFM000049	4:2	Lillfjärden	12	66	0	1	0	21	0	21
AFM000052	**5:1**	**Bredviken**	**7**	**49**	**28**	**11**	**0**	**4**	**0**	**4**
AFM000084	**6:1**	**Simpviken**	**11**	**89**	**0**	**0**	**0**	**0**	**0**	**0**
AFM000080	**7:1-4**	**Lake 7:1**	**13**	**70**	**0**	**2**	**0**	**14**	**1**	**14**
AFM001107	7:1	Subarea: Lake 7:1	18	64	0	3	0	13	2	14
AFM000081	7:2-4	Märrbadet	5	81	0	0	0	15	0	15
AFM001108	7:2	Subarea: Märrbadet	17	47	0	0	0	36	0	36
AFM000082	7:3	Lake 7:2	1	93	0	0	0	6	0	6
AFM000083	7:4	Lake 7:3	2	81	0	0	0	17	0	17
AFM000051	**8:1**	**Fiskarfjärden**	**14**	**68**	**1**	**4**	**0**	**13**	**0**	**16**
Total for the 8 main catchments										
Mean			**10**	**68**	**4**	**3**	**3**	**13**	**0**	**14**
Median			**11**	**69**	**0**	**2**	**0**	**12**	**0**	**13**
Min			1	49	0	0	0	0	0	0
Max			14	89	28	11	11	31	1	35

3.3 Hydrology

The hydrology of the Forsmark area is generally characterized by a shallow groundwater table with many small catchments. No major water courses flow through the catchments, and small brooks connect the lakes with the sea.

3.3.1 Discharge

There are no large streams within the Forsmark regional model area. However, a number of small streams drain the area. Some of these carry water most of the year, while many are dry for long periods (Figure 3-3a and b). Four permanent automatic discharge gauging stations have been installed in the largest streams as a basis for water balance calculations and for calculation of mass transport of different elements (Figure 3-4). Monitoring of water levels, electrical conductivities, temperatures and discharges has been performed at the stations. Measurements have been performed at one station since April 2004 and at the other stations since December 2004 /Johansson and Juston 2007/. This time period is relatively short, so the mean discharge values presented in Table 3-3 should be used with caution.

The mean specific discharge for the largest catchment in Forsmark during the monitored period was 4.88 L s^{-1} km^{-2} (Table 3-3). In comparison, the specific discharge at Vattholma, a station with a considerably larger catchment, situated further inland c. 50 km SW of Forsmark, is approximately 6.5 L s^{-1} km^{-2} /SGU 1983/.

Due to the small catchment areas, the discharge rates at all gauging stations in Forsmark are very low (Figure 3-5). The mean discharge for the largest catchment was 27 L s^{-1} (Table 3-3). In comparison, the mean discharge in the Forsmarksån River (located just outside the Forsmark area) is 2,800 L s^{-1} /Brunberg and Blomqvist 1998/ and the mean discharge in the Dalälven River is 353,000 L s^{-1} at the outlet to the Baltic Sea (average for the time period 1976–2000 according to www.dalalvensvvf.se/omdal.htm**,** accessed 16 April 2008). The highest recorded

Figure 3-3. *Photos showing (left) one of the largest streams in the Forsmark candidate area, taken at the inlet to Bolundsfjärden in May 2007 (later than the highest flow during snowmelt), and (right) a stream section that is dry in the summer, a common sight in the Forsmark area.*

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Figure 3-4. *Location of the four discharge gauging stations and the electrical conductivity monitoring station (PFM002292).*

discharge in the largest catchment in Forsmark (gauging station PFM005764) was 212 L s^{-1} and in the smallest catchment 75.9 L s^{-1} (gauging station PFM002668) (Figure 3-5). All stations had zero discharge for relatively long periods in late summer and early autumn. For a specific station, the variation in specific discharge between selected time periods (hydrological years) was 30–35%, while the variation between stations for a selected time period was 10–17% /Johansson and Juston 2007/.

Table 3-3. Discharge characteristics for the four gauging stations for various time periods (total available time series). From /Johansson and Juston 2007/.

Time interval	PFM005764 Apr 2004– Mar 2007	PFM002667 Dec 2004– Mar 2007	PFM002668 Dec 2004– Mar 2007	PFM002669 Dec 2004– Mar 2007
Mean discharge (L s^{-1})	27.2	15.4	11.55	15.9
Min. discharge (L s^{-1})	0.00	0.00	0.00	0.00
Max. discharge (L s^{-1})	212	131	75.9	183
Specific discharge (L s^{-1} km^{-2})	4.88	5.13	5.07	5.61
Specific discharge (mm yr^{-1})	154	162	160	177
Catchment area (km^2)	5.59	3.01	2.28	2.83

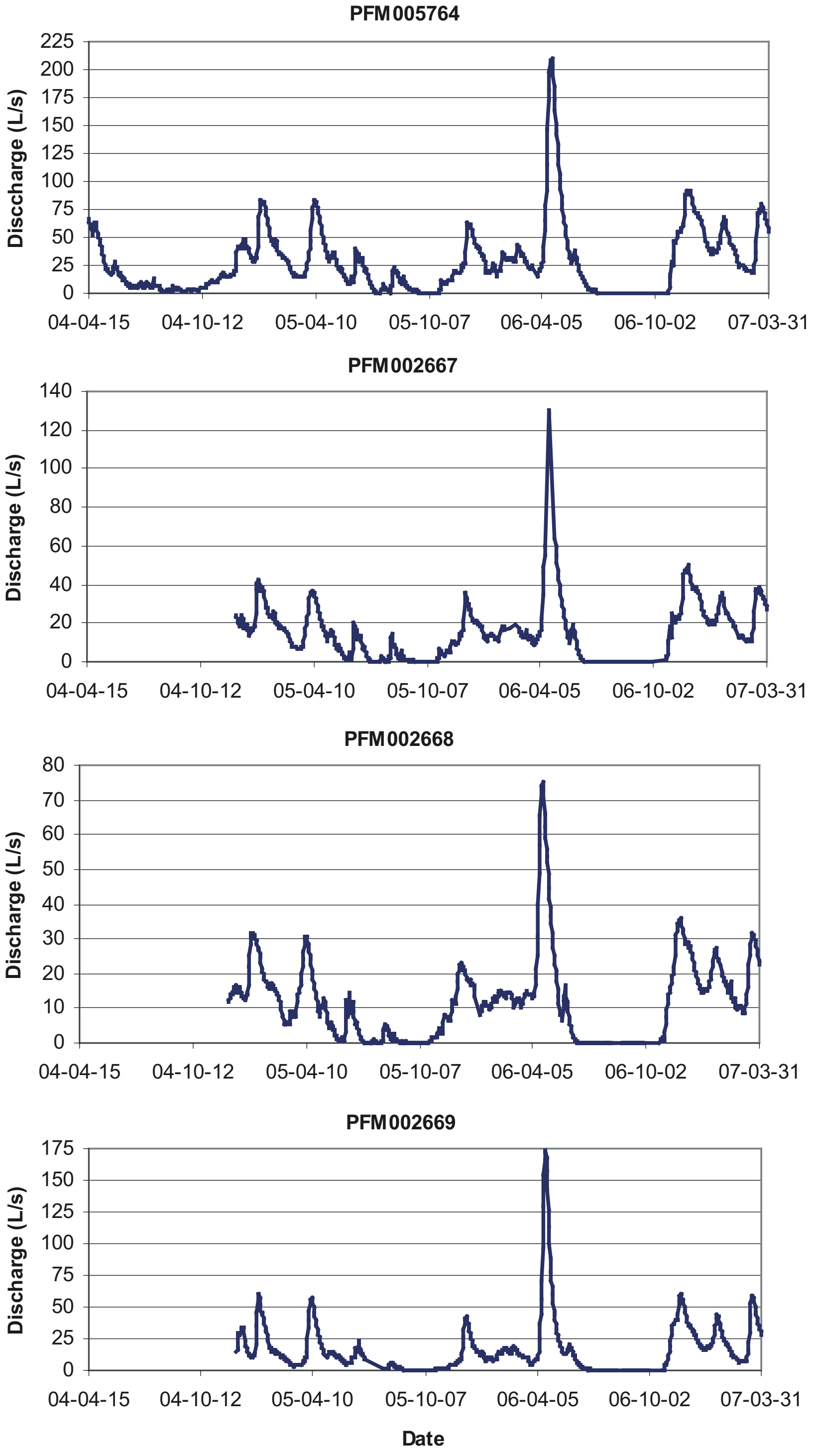

Figure 3-5. *Surface discharge at the four gauging stations in the Forsmark area (daily means). Note the different scale of the discharge axes. Data from /Johansson et al. 2008/*

The surface discharge in the streams is dominated by water of groundwater origin /Johansson et al. 2008/. Overland flow contributes to the discharge mainly during long periods of wet conditions during autumn and winter and in direct connection to snow melt in spring.

3.3.2 Water levels in lakes

The water level has been measured in 6 lakes in the Forsmark area. The measuring period varies from 4 years at maximum to c. 3 years at minimum. The same pattern is seen for all lakes, i.e. maximum water levels in March–April, during snowmelt, followed by a decline to a minimum level during the period July–September. In late October the levels rise again up to a new maximum level in November–December (Figure 3-6). The mean, minimum and maximum water levels in lakes measured during the site investigations are presented in Table 3-4.

3.3.3 Groundwater discharge/recharge

Groundwater levels have been measured in the till below lakes and related to surface water levels measured at the same site in five lakes in the area /Juston et al. 2007/. The gradients were variable and typically small, often within uncertainties of the measurements. All lakes showed changing conditions between upward and downward gradients, indicating that they function as both recharge and discharge areas for groundwater. In some lakes (Eckarfjärden and Bolundsfjärden), there was a higher downward gradient in the late summer and early autumn in 2003 and 2005. Comparison with groundwater measurements in the area surrounding the lakes shows that at least two of the lakes in the area (Bolundsfjärden and Eckarfjärden) seem to act as sources of groundwater recharge to the surrounding (local) areas during some periods and as discharge areas during other periods /Juston et al. 2007, Johansson et al. 2008/. One reason for the observed downward gradient from the lake to the surrounding areas is groundwater abstraction by evapotranspiration. Due to the low permeability of the bottom sediments, the resulting water fluxes can be assumed to be small /Johansson 2008/. The chemistry of the water below the lakes Bolundsfjärden, Fiskarfjärden and Gällsboträsket indicates a very limited flow, since relict marine water is found /Johansson et al. 2008/. The hydrogeological and hydrochemical interpretations indicate that shallow groundwater flow systems involving only Quaternary deposits have discharge areas around the lake and in the near-shore parts of the lake, while deeper systems are drained into the Baltic sea by the highly transmissive shallow bedrock /Johansson et al. 2008/.

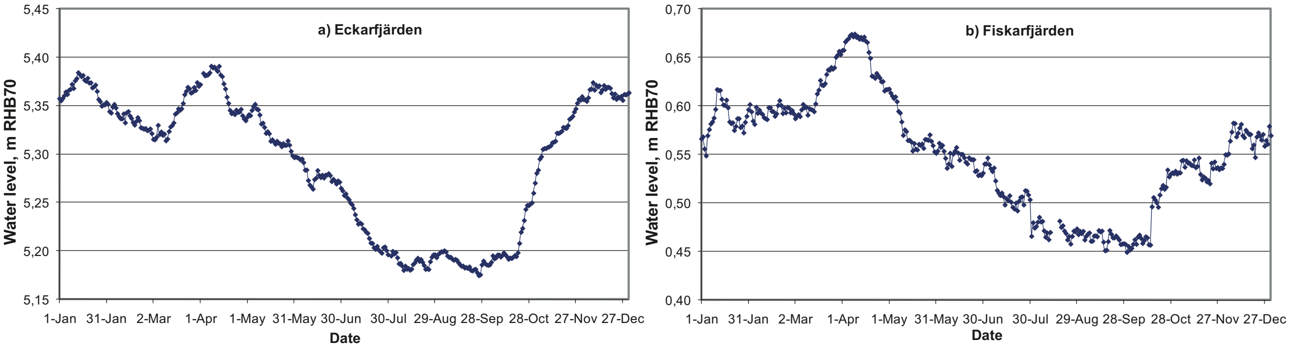

Figure 3-6. *Examples of annual variation in water levels as daily mean values, a) Eckarfjärden and b) Fiskarfjärden (m.a.s.l. RHB 70). From /Johansson and Juston 2007/.*

Table 3-4. Water levels in six lakes in the Forsmark area (m.a.s.l. RHB 70) (data from the database SICADA, March 2008). "N" denotes the number of registrations for each lake (daily measurements).

	Norra Bassängen	Bolundsfjärden	Eckarfjärden	Fiskarfjärden	Gällsboträsket	Lillfjärden
Mean	0.36	0.37	5.28	0.55	1.80	0.09
Min.	0.07	0.11	5.09	0.30	1.51	–0.17
Max.	0.87	0.76	5.54	0.74	2.30	0.71
No. of obs	1,424	1,414	1,251	978	1,066	887

3.3.4 Inflow of marine water to lakes

Several of the lakes in the Forsmark area are very young and some of them still have occasional contact with the Baltic Sea. Two of these lakes are Norra Bassängen and Bolundsfjärden, for which inflow of saline water has been observed occasionally during the site investigation /Johansson et al. 2008/. The measured lake and sea water levels in these two lakes and the Baltic Sea are shown in Figure 3-7.

A station for monitoring of water electrical conductivity is located at the outlet of Bolundsfjärden. It was installed in December 2004, when the measurements also started. The electrical conductivity of the water leaving Bolundsfjärden was for most of the observation period between 70 and 100 mS m^{-1}. However, during events of extremely high sea water levels (Figure 3-8), brackish water flowed into the lake and the electrical conductivity increased up to 900 mS m^{-1} (Figure 3-8). Such events appeared during December 2004–January 2005 and November 2006–January 2007. The two extreme events correspond to the two storms "Gudrun" and "Per".

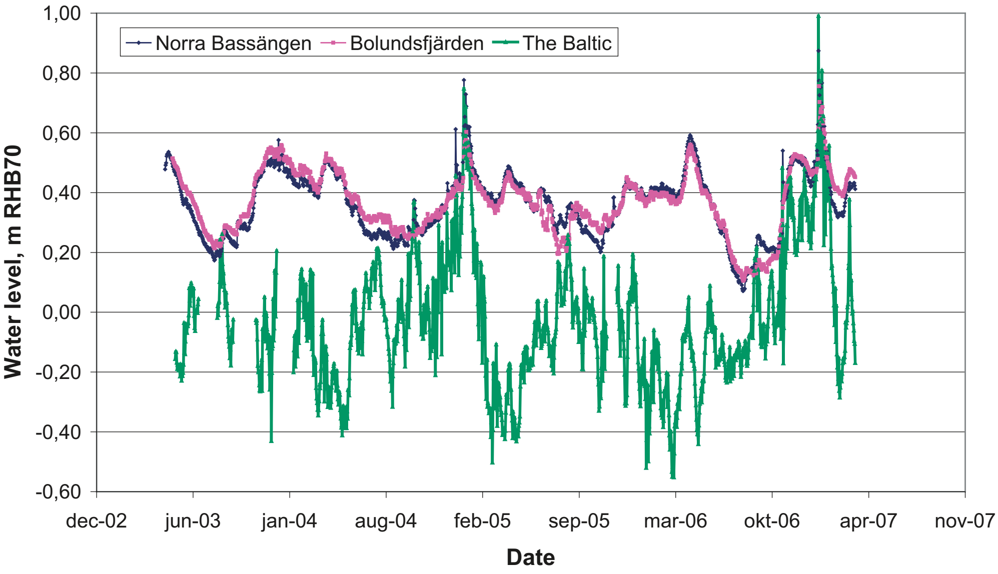

Figure 3-7. Water levels in the Baltic Sea and in the lakes Norra Bassängen and Bolundsfjärden measured during the site investigation in Forsmark. From /Johansson 2008/.

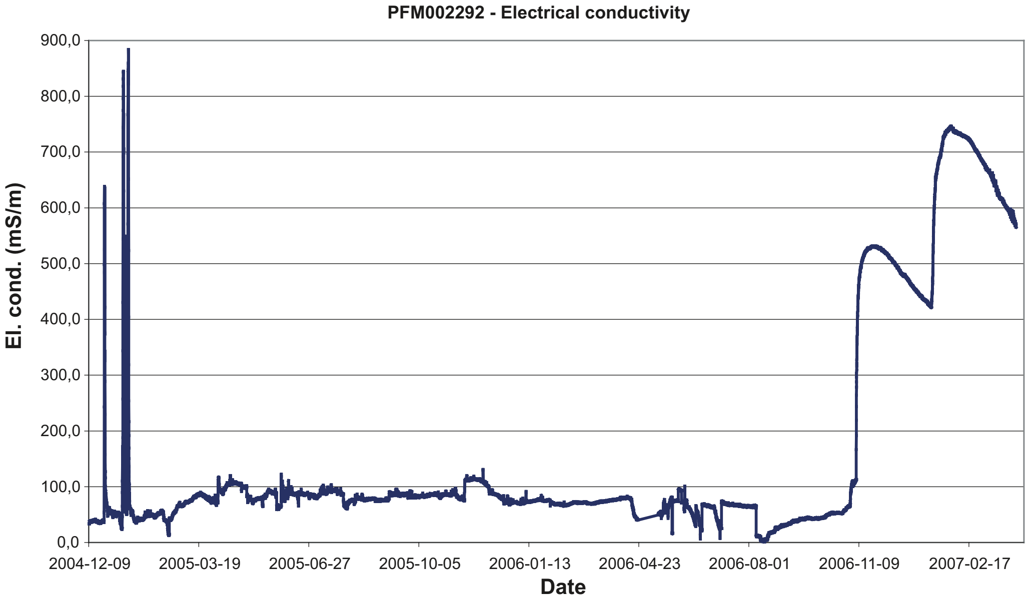

Figure 3-8. *Electrical conductivity at the monitoring station at the outlet of Bolundsfjärden (PFM002292). The two peaks correspond to occasions with salt water intrusion into Bolundsfjärden. From /Johansson and Juston 2007/.*

There is a distinct conductivity profile in Bolundsfjärden following saltwater intrusion (Figure 3-9). Approximately 3 weeks after the seawater intrusions (January 31, 2005) the saline water had settled at the lake bottom. Two months later (March 29, 2005), the conductivity profile was virtually identical. At that time the lake was still covered by ice, preventing wind-driven water mixing. However, in the late summer the profiles indicate well-mixed conditions.

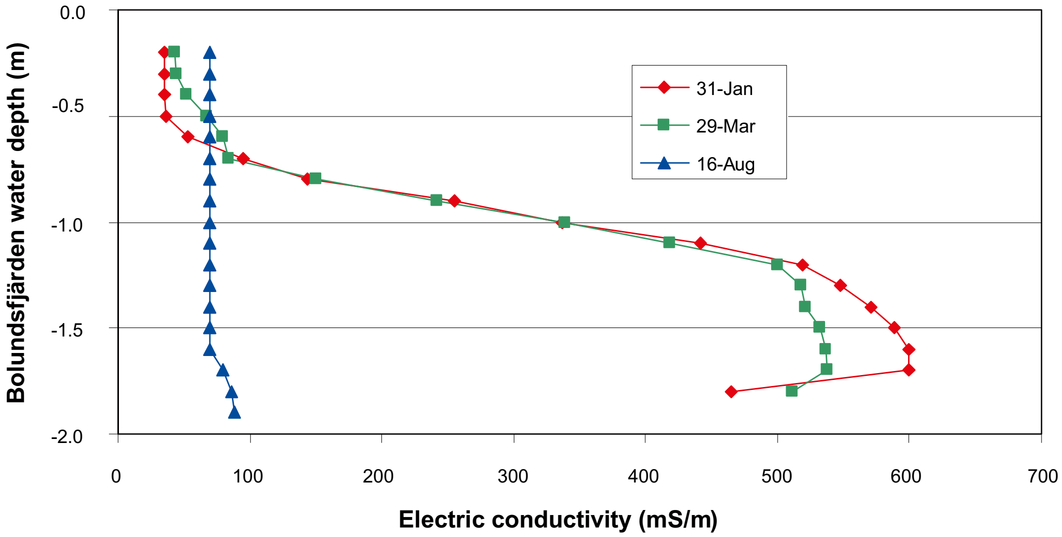

Figure 3-9. *Electrical conductivity profiles in Bolundsfjärden measured during winter, early spring, and summer, 2005. From /Juston et al. 2007/.*

3.3.5 Flooded areas

The Forsmark area is very flat with small elevation gradients. During periods of high water flow, some areas surrounding the streams are flooded (Figure 3-10). The extent of these areas has been investigated in two catchments (Figure 3-11a and b) /Carlsson et al. 2005b/. The sizes of the flooded areas are shown in Table 3-5. The stream in catchment 8 is extremely short (30 m) and the entire length of the stream can be considered to be a periodically flooded area. In catchment 2, 30% of the stream stretch was periodically flooded (Figure 3-11). Altogether, 0.313 km^2 of flooded area was investigated. The flooded areas are classified as (terrestrial) wetland areas and are further described in /Löfgren 2008/.

Table 3-5. The investigated flooded areas of the streams in the Forsmark area (data from /Carlsson et al. 2005b/).

Catchment	Length of investigated stream stretch (m)	Flooded area (km^2)	Flooded area per stream length (km^2/km)	Share of stream stretch with flooded areas[2] (%)
Forsmark 2	4,760	0.134	0.03[1]	c. 30
Forsmark 8	860[3]	0.179	0.21	c. 100
Total	5,620	0.313	0.06	c. 40

[1] investigated stream length including tributaries (N.B. not the total stream length),
[2] rough estimate from GIS map,
[3] including the wetland area with no visible channel.

Figure 3-10. A flooded area in the catchment Forsmark 2 in April 2004. Red arrows indicate the limits of the flooded area. From /Carlsson et al. 2005b/.

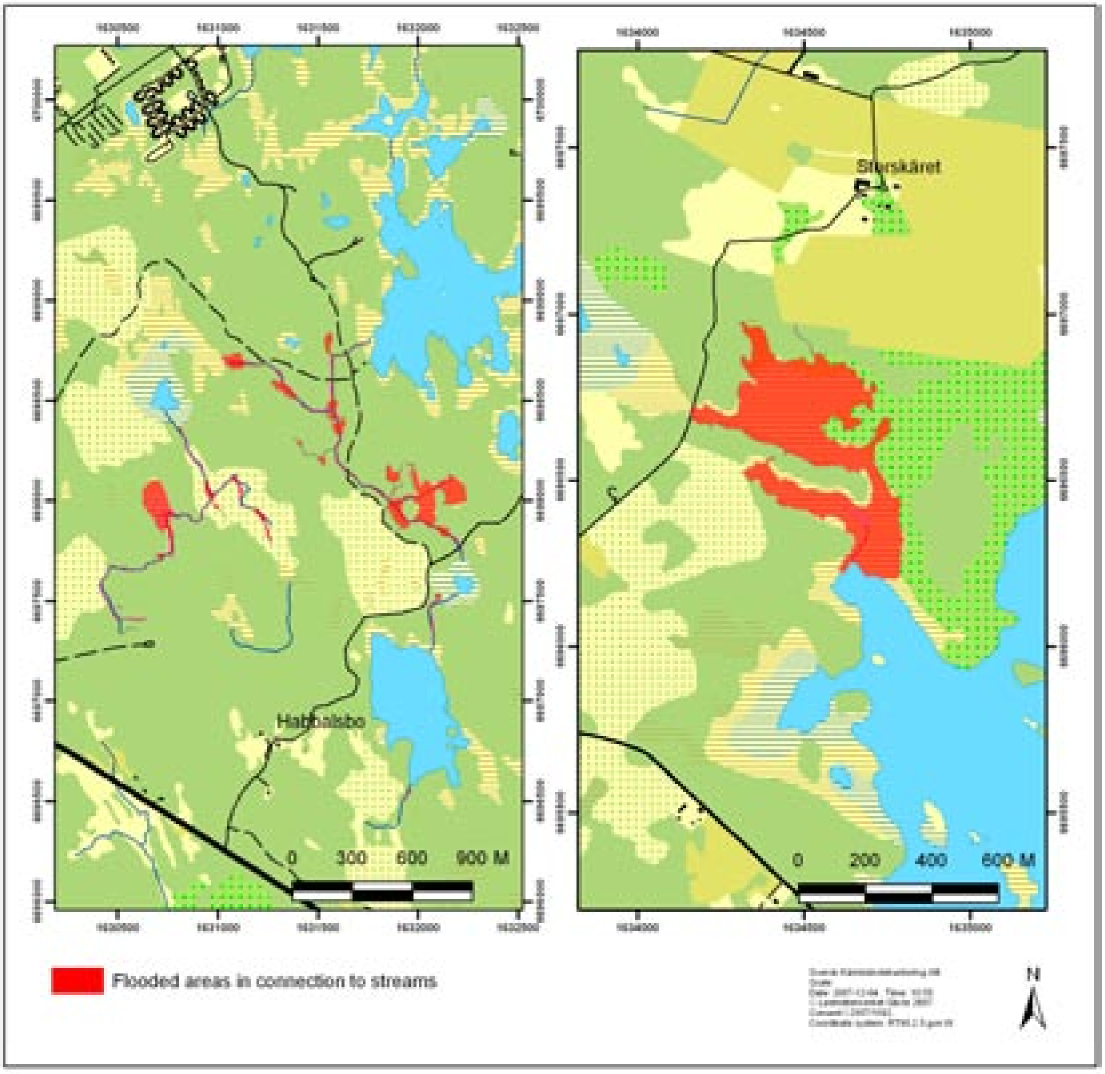

Figure 3-11. *Periodically flooded areas in catchment 2 (left) and 8 (right) in the Forsmark area.*

3.4 Climate

3.4.1 Air temperature

The air temperature at Forsmark has been measured continuously during the site investigations. The investigation period (3 years) is short and the measurements are therefore compared with data from two other climate stations in northern Uppland: Örskär and Film. The first is located on the island of Gräsö north of the Forsmark area, while Film is an inland location.

The winters are slightly milder on the coast than inland. The mean annual temperatures at Örskär and Film were 5.5 and 5.0°C, respectively, for the period 1961–1990 (Figure 3-12). The temperatures in the Forsmark area are somewhere in between the temperatures at these two locations. During 2004–2006, the mean annual temperatures were higher than the long-term means: 7.1, 6.9 and 6.1°C at Örskär, Forsmark and Film, respectively (Figure 3-13).

Figure 3-12. *Long-term (1994–2006) daily mean temperature over the year in Film and Örskär. From /Johansson and Öhman 2008/.*

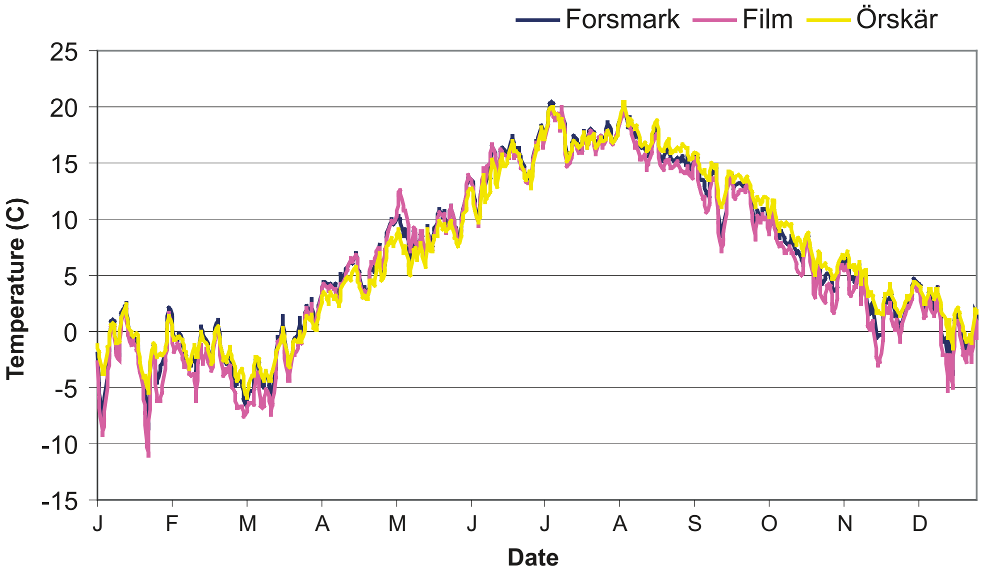

Figure 3-13. *Daily mean temperature over the year in Forsmark, Film and Örskär (mean for the period 2004–2006). From /Johansson and Öhman 2008/.*

3.4.2 Precipitation

The regional mean annual precipitation in the Forsmark area has been estimated to be 559 mm for the period 1961–1990 /Johansson 2008/. Circa 25–30% of the annual precipitation falls in the form of snow. The highest monthly precipitation for the period June 2003–May 2007 was in August, followed by October (Figure 3-14). The lowest precipitation during the same period occurred in April.

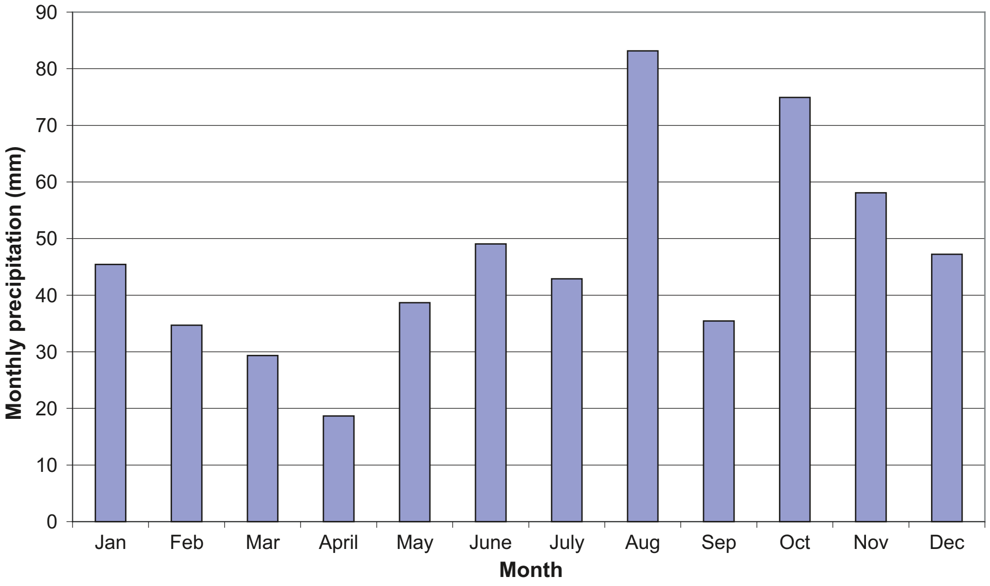

Figure 3-14. *Monthly precipitation in Forsmark, June 2003–May 2007. Mean from the two stations Högmasten and Storskär. From /Johansson 2008/.*

3.4.3 Snow cover

Snow cover has been measured weekly during five seasons, 2002/03–2006/07, at two sites: in forest land and in open land /Aquilonius and Karlsson 2003, Heneryd 2004, 2005, 2006 and 2007/. During this period there was a snow cover an average of 105 days per season on forest land and 80 days on open land (Table 3-6). In general there was a snow cover from the end of November/beginning of December until the end of March/beginning of April. However, during some of the seasons there were periods when the snow cover disappeared. The maximum recorded snow depth was 48 cm on forest land and 25 cm on open land, and the maximum snow water content was 144 and 64 mm, respectively (Table 3-6).

Table 3-6. Summary of snow measurements at Forsmark 2002/03–2006-07, data from /Aquilonius and Karlsson 2003, Heneryd 2004, 2005, 2006 and 2007/.

Year	No. of days with snow cover	Maximum snow depth (cm)	Maximum snow water content (mm)
Open land (AFM000071)			
2002/03	85	20	–
2003/04	75	19	37
2004/05	85	21	53
2005/06	120	25	64
2006/07	40	17	30
Average 2002/03–2006/07	81	25	64
Forest land (AFM000072 and AFM001172)			
2002/03	125	–	–
2003/04	105	31	65
2004/05	110	25	61
2005/06	133	38	101
2006/07	65	24	34
Average 2002/03–2006/07	108	38	101

3.4.4 Ice cover

The ice cover recordings were made at Eckarfjärden, which was considered to be representative for the lakes of the area /Aquilonius and Karlsson 2003, Heneryd 2004, 2005, 2006 and 2007/. Eckarfjärden was usually covered with ice from the middle of November/December until the beginning of April. On average Eckarfjärden was covered with ice 128 days per season. The ice cover data are summarized in Table 3-7.

3.4.5 Global radiation

Global radiation at Forsmark has been measured continuously during the site investigations. The investigation period is short and the measurements are therefore compared with data from another climate station in northern Uppland, Örskär, which is located on the island Gräsö north of the Forsmark area. At Forsmark, the mean global radiation was 949 kWh m^{-2} during 2004–2006. Based on the observations at Örskär, the mean annual global radiation was calculated to 930 kWh m^{-2} for the period 1961–1990 /Johansson et al. 2008/. Global radiation was highest in June, followed by July (Figure 3-15).

Table 3-7. Periods of ice cover on Lake Eckarfjärden at Forsmark 2002/03–2006/07, from /Aquilonius and Karlsson 2003, Heneryd 2004, 2005, 2006 and 2007/.

Year	Date for ice freeze-up	Date for ice break-up	Period of ice cover (days)
2002/03	2002-11-12	2003-04-02	141
2003/04	2003-12-12	2004-04-06	117
2004/05	2004-11-18	2005-04-09	143
2005/06	2005-11-21	2005-12-01	143
	2005-12-12	2006-04-24	
2006/07	2006-12-18	2007-03-26	98
Average 2002/03–2006/07			128

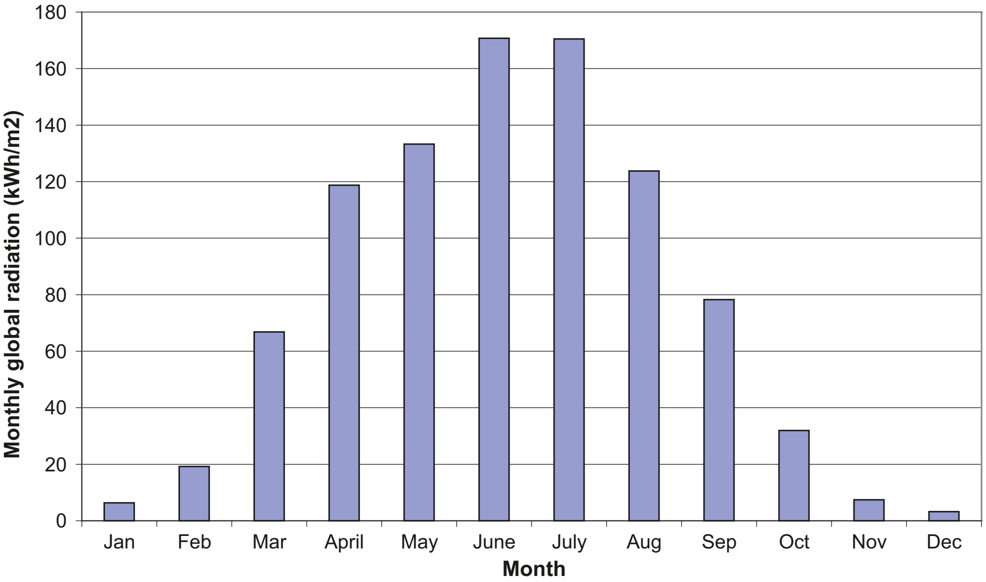

Figure 3-15. Global radiation (monthly mean 2004–2006) at Högmasten in Forsmark (kWh m^{-2}). Data from /Johansson and Öhman 2008/.

3.5 Lake bathymetry

All lake basins in Forsmark are very shallow (maximum depths range between 0.4 and 2.2 m) and – with the exceptions of Bolundsfjärden, Eckarfjärden and Fiskarfjärden – the basins are also very small. The median lake of the area has a mean depth of 0.7 m and a maximum depth of 1.0 m. The retention times of the lakes in Forsmark range from a few days to almost a year. In Table 3-8 some morphometric parameters are presented for the lakes in the Forsmark area. Bathymetric maps for four of the lakes in the Forsmark area is shown in Figure 3-16. These are chosen as examples, and maps for all investigated lakes in the area are presented in /Brunberg et al. 2004a/.

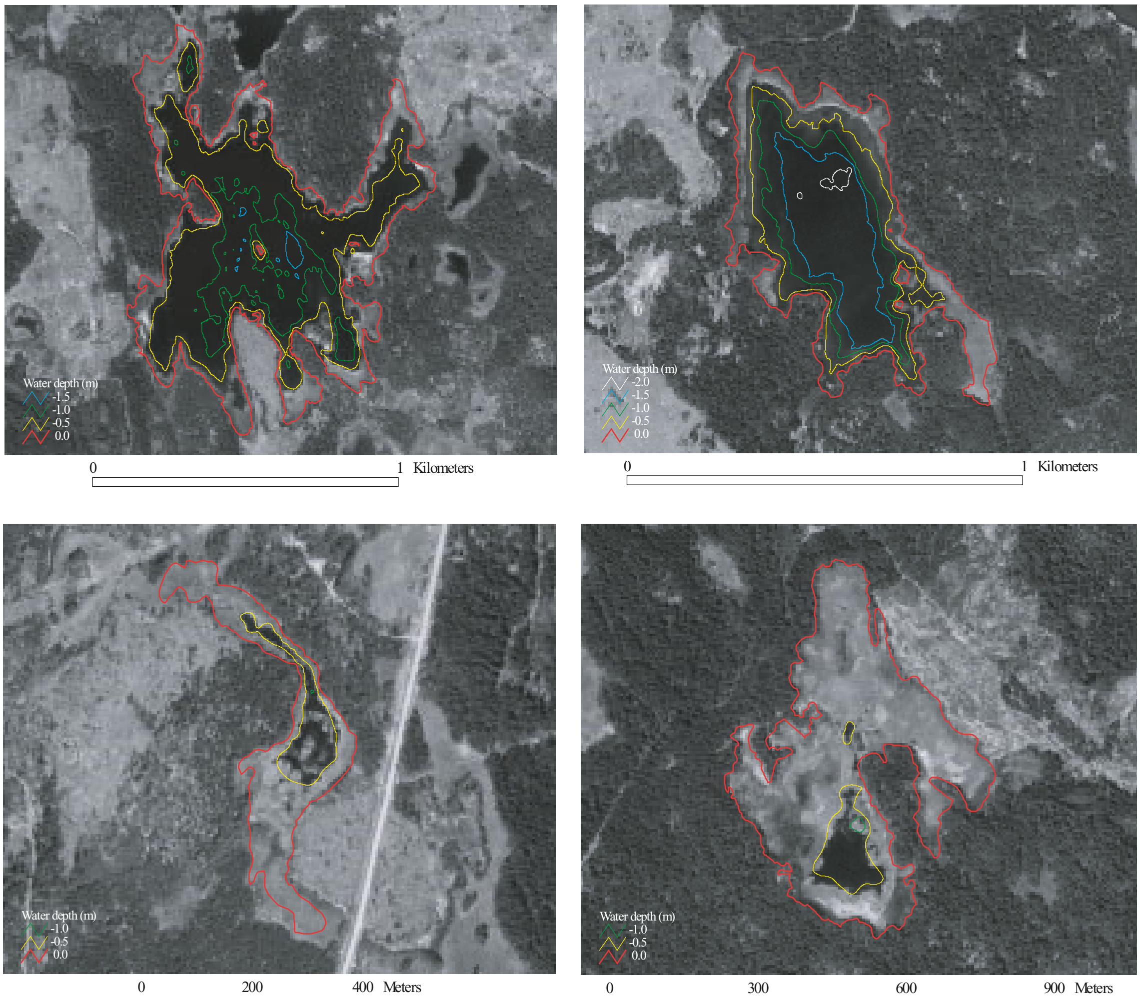

Figure 3-16. *Bathymetric maps for four lakes in the Forsmark area; Bolundsfjärden (upper left), Eckarfjärden (upper right), Labboträsket (lower left) and Gällsboträsket (lower right). From /Brunberg et al. 2004a/.*

Table 3-8. Morphometry parameters for the lakes in the Forsmark area (data from [1]/Brunberg et al. 2004a/, [2]/Brydsten and Strömgren, 2005/ and [3]calculated from SKB's GIS database).

ID Code	Catchment number	Name	Threshold elevation[2] [m.a.s.l. RHB70]	Area[1] [km^2]	Max. depth[1] [m]	Mean depth (Littoral I included)[1] [m]	Mean depth (Littoral I excluded)[3] [m]	Volume (Littoral I included)[1] [Mm3]	Volume (Littoral I excluded)[3] [Mm3]	Shore length[1] [m]	Mean discharge[1] [m3/s]	Retention[1] time [Days]	Fetch[1, A] [m]	Width[1, B] [m]
AFM000073	**1:1-4**	**Gunnarsbo-Lillfj. (south)**	**1.92**	**0.03**	**2.2**	**0.7**	**1.0**	**0.023**	**0.018**	**1,034**	**0.036**	**7**	**198**	**171**
AFM000096	01:02	Gunnarsbo-Lillfj. (north)	1.07	0.02	0.9	0.3	0.5	0.007	0,003	1,041	0.001	110	122	61
AFM000048	1:3-4	Labboträsket	2.65	0.06	1.1	0.3	0.8	0.016	0.002	2,185	0.028	7	62	18
AFM000095	01:04	Gunnarsboträsket	5.68	0.07	1.3	0.5	0.9	0.034	0.017	1,848	0.019	21	204	188
AFM000074	**2:1-11**	**Norra Bassängen**	**0.19**	**0.08**	**0.9**	**0.3**	**0.5**	**0.024**	**0.016**	**2,553**	**0.059**	**5**	**293**	**177**
AFM000092	02:02	Lake 2:2	1.77	0.01	0.6	0.3	0.4	0.003	0.002	518	0.001	66	129	55
AFM000050	2:3-10	Bolundsfjärden	0.28	0.61	1.8	0.6	0.8	0.374	0.324	9,140	0.056	77	1,059	878
AFM000087	2:4-5	Graven	0.44	0.05	0.4	0.1	0.25	0.006	0.002	1,190	0.003	25	153	75
AFM000088	02:05	Fräkengropen	1.34	0.02	0.8	0.2	0.6	0.004	0.002	909	0.001	44	88	44
AFM000089	02:06	Vambörsfjärden	1.02	0.05	1	0.4	0.7	0.021	0.014	1,193	0.003	70	250	132
AFM000093	02:07	Kungsträsket	2.31	0.01	0.5	0.2	0.3	0.002	0.001	466	0.001	20	85	50
AFM000094	02:08	Gällsboträsket	1.47	0.19	1.5	0.2	0.7	0.032	0.006	4,059	0.02	18	138	90
AFM000090	2:9-10	Stocksjön	2.70	0.04	0.8	0.2	0.7	0.008	0.004	890	0.013	9	108	82
AFM000010	02:10	Eckarfjärden	5.15	0.28	2.1	0.9	1.2	0.257	0.226	4,405	0.009	328	755	393
AFM000091	02:11	Puttan	0.48	0.08	1.3	0.4	0.8	0.033	0,021	2,390	0.061	6	255	168
AFM000086	**03:01**	**Tallsundet**	**–0.23**	**0.08**	**0.8**	**0.2**	**0.6**	**0.018**	**0.006**	**2,624**	**0.002**	**141**	**154**	**78**
AFM000085	4:1-2	Lake 4:1	–0.34	0.04	1.5	0.4	0.8	0.013	0.006	1,520	0.005	32	188	66
AFM000049	04:02	Lillfjärden	–0.35	0.16	0.9	0.3	0.6	0.047	0.025	2,947	0.004	125	367	279
AFM000052	**05:01**	**Bredviken**	**–0.26**	**0.1**	**1.7**	**0.7**	**1.1**	**0.072**	**0.057**	**2,049**	**0.004**	**191**	**518**	**67**
AFM000084	**06:01**	**Simpviken**	**–0.32**	**0.01**	**1.8**	**0.5**	**0.8**	**0.005**	**0.002**	**517**	**0**	**232**	**61**	**36**
AFM000080	**7:1-4**	**Lake 7:1**	**–0.47**	**0.16**	**1.1**	**0.3**	**0.5**	**0.053**	**0.037**	**4,818**	**0.006**	**97**	**489**	**192**
AFM000081	07:02	Märrbadet	–0.29	0.02	1	0.4	0.8	0.009	0.003	768	0.002	42	117	71
AFM000082	07:03	Lake 7:3	0.17	0.01	0.7	0.3	0.5	0.002	0.001	421	0.001	14	66	35
AFM000083	07:04	Lake 7:4	0.36	0.01	0.8	0.2	0.6	0.002	0.001	434	0.001	49	47	29
AFM000051	**08:01**	**Fiskarfjärden**	**0.28**	**0.75**	**1.9**	**0.4**	**0.5**	**0.274**	**0.190**	**7,584**	**0.02**	**155**	**1,370**	**555**
Mean			**1.08**	**0.12**	**1.2**	**0.4**	**0.7**	**0.053**	**0.039**	**2,300**	**0.014**	**76**	**291**	**160**
Median			**0.44**	**0.05**	**1.0**	**0.3**	**0.7**	**0.018**	**0.006**	**1,520**	**0.004**	**44**	**154**	**78**
Min			–0.47	0.01	0.4	0.1	0.3	0.002	0.001	421	0.000	5	47	18
Max			5.68	0.75	2.2	0.9	1.2	0.374	0.324	9,140	0.061	328	1,370	878

[A] Fetch maximum length (m), the longest straight line over the water.

[B] Width maximum width (m), the longest straight line perpendicular to the length line.

3.6 Lake sediments

The sediments of the majority of the lakes and small ponds in the area have been investigated in different studies /Bergström 2001, Borgiel 2004a, Hedenström and Risberg 2003, Hedenström 2003, 2004, Strömgren and Brunberg 2006, Nordén 2007/. These studies include stratigraphy, carbon content and chemical composition of the sediment, as well as depth of the redox zone and sediment accumulation rate.

3.6.1 Stratigraphy

A lake in the Forsmark area is a temporary stage of a basin in the transition between a marine environment into a terrestrial area (further described in Chapter 8). Accumulation of sediment starts already during the marine phase, so the deeper sediments present in a lake are often older than the lake itself. The distribution of sediments in lakes is relatively uniform and a general stratigraphy for the Forsmark area has been presented (Table 3-9, from /Hedenström 2004/). Gyttja is deposited during the lake stage, whereas clay gyttja and clay are deposited in the Baltic and during the lagoon stage.

Below is a description of the different layers, including the upper biological layer of microphytobenthos.

1. Microphytobenthos: a layer containing benthic algae and bacteria, often seen as a distinct green upper part in sediment cores from the lakes.

2 and 3. Gyttja: organic rich sediment layer deposited during the lake stage of the basin. Limnologists often divide this sediment layer into “gyttja” and “dy” according to the origin of the organic matter (produced by the surrounding terrestrial environment or produced within the lake basin). In Forsmark, a typical feature is calcareous gyttja, formed as a result of the high lime content in the surrounding deposits.

4. Clay gyttja: organic rich sediment layer deposited during the marine phase of the basin. This layer contains more clay than the gyttja layer and also has a lower content of water and organic matter.

5. Sand and gravel: coarse-grained minerogenic deposits with high hydraulic conductivity.

6 and 7. Clay: dense and often thin layer with low content of water and organic carbon. Deposited during the melting of the glacial ice.

8. Till: coarse-grained inorganic layer, located on top of bedrock.

In this report we have chosen to concentrate on the upper layers of the sediment: gyttja and clay gyttja, which contain most of the organic matter. In some sections, such as Chapter 7, the clay layer is also considered.

Table 3-9. Generalized stratigraphy of the sediment in the Forsmark area and the environment in the water column at the formation of the units /from Hedenström 2004/.

Layer	Environment during sedimentation	Lithology
1	Freshwater lake	Microphytobenthos
2	Freshwater lake	Calcareous gyttja
3	Freshwater lake and coastal lagoons	Algal gyttja
4	Postglacial Baltic basin	Clay gyttja
5	Shallow coast	Sand and gravel
6	Postglacial Baltic basin	Postglacial clay
7	Late glacial Baltic basin	Glacial clay
8		Till

A compilation of sediment characteristics in the lakes in the Forsmark area is shown in Table 3-10. Stratigraphical data for all lakes presented in the table are based on data from /Hedenström 2004/. The stratum thicknesses shown are the average thickness for each sediment layer in each lake. This data do not include the upper part of the gyttja layer or the microphytobenthos layer since these are not captured with the sampling technique used in that study. The depth of the missing layer should not be more than 0.5 m (Hedenström, personal communication). The stratum thickness varies between lakes mirroring different lake ages and also different sedimentation conditions during the marine lagoon stadium of the lakes (see Chapter 8). The spatial distribution of different Quaternary deposits (at 0.5 m sediment depth) in two of the lakes in the Forsmark area (Bolundsfjärden and Eckarfjärden) is shown in Figure 3-17.

3.6.2 Redox zone

The upper part of the sediment layer in the Forsmark lakes is very loose and the boundary between the water phase and the sediment is often hard to distinguish; it consists of a continuous transition towards more compacted sediment with gradually less water content. As in most lake sediments the carbon content decreases downwards in the sediment profile. A somewhat different characteristic is that the very upper part of the sediment in most Forsmark lakes contains an active layer of microphytobenthos, i.e. benthic algae and bacteria. The thickness of this layer varies within the same lake, between lakes and over the year (see section 3.9 for more details). The zone where the redox potential changes from positive (aerobic conditions) to negative (anaerobic environment) is often present within this layer of microphytobenthos. This zone can sometimes be seen in cores as a thin red layer which consists of purple sulphur bacteria. These bacteria migrate vertically and follow the border between aerobic and anaerobic environments. This zone is of importance both chemically and biologically. Due to the change in redox potential some elements change chemical state leading to a change in mobility (e.g. iron and manganese). The reducing conditions in the deeper part of the sediment restrict the habitat for biota, resulting in a bioactive upper sediment layer. In the very shallow lakes of Forsmark, the lake sediments may also easily be disturbed by wind, leading to a mixing of the upper sediment.

3.6.3 Carbon content and accumulation rate

The carbon content has been estimated for the three layers (gyttja, clay gyttja and clay) in three lakes: Eckarfjärden /Hedenström and Risberg 2003/, Fiskarfjärden and Puttan /Hedenström 2004/ (Table 3-10). In addition, carbon content was analyzed in sediments from Eckarfjärden and Stocksjön by /Hannu and Karlsson 2006/ and /Strömgren and Brunberg 2006/. The water content has been estimated for the gyttja layer in Eckarfjärden, Bolundsfjärden and Puttan /Nordén 2007/. In that study no separation of gyttja and clay gyttja was performed. An examination of the values from one of the cores (PFM007372) shows that the water content is almost constant down to the clay layer and we therefore assume that no clay gyttja was present in this sediment core. The same is true also for the other lakes, which means that no site-specific data on water content from the clay gyttja layer in lakes are available. Data for this sediment type are, however, available from two marine bays in the area Kallrigafjärden and Tixelfjärden /Sternbeck et al. 2006/, and an average value from these two bays is presented in Table 3-10. A comparison with data on water content in clay gyttja from Lake Frisksjön in the Laxemar-Simpevarp area shows good agreement (14% dry weight in Frisksjön, 15% in Tixelfjärden and 16% in Kallrigafjärden). Water content data from the clay layer is available from Eckarfjärden /Nordén 2007/.

The amount of carbon per area (g C m^{-2}) has been calculated using the site-specific water and carbon contents and an assumption of a density for mineral particles of 2,650 kg m^{-3}. As site specific data for (most) parameters are available only for Eckarfjärden, the value is only shown for this lake in the table. The total carbon content in the lake sediment was calculated using the lake area (excluding reed belts).

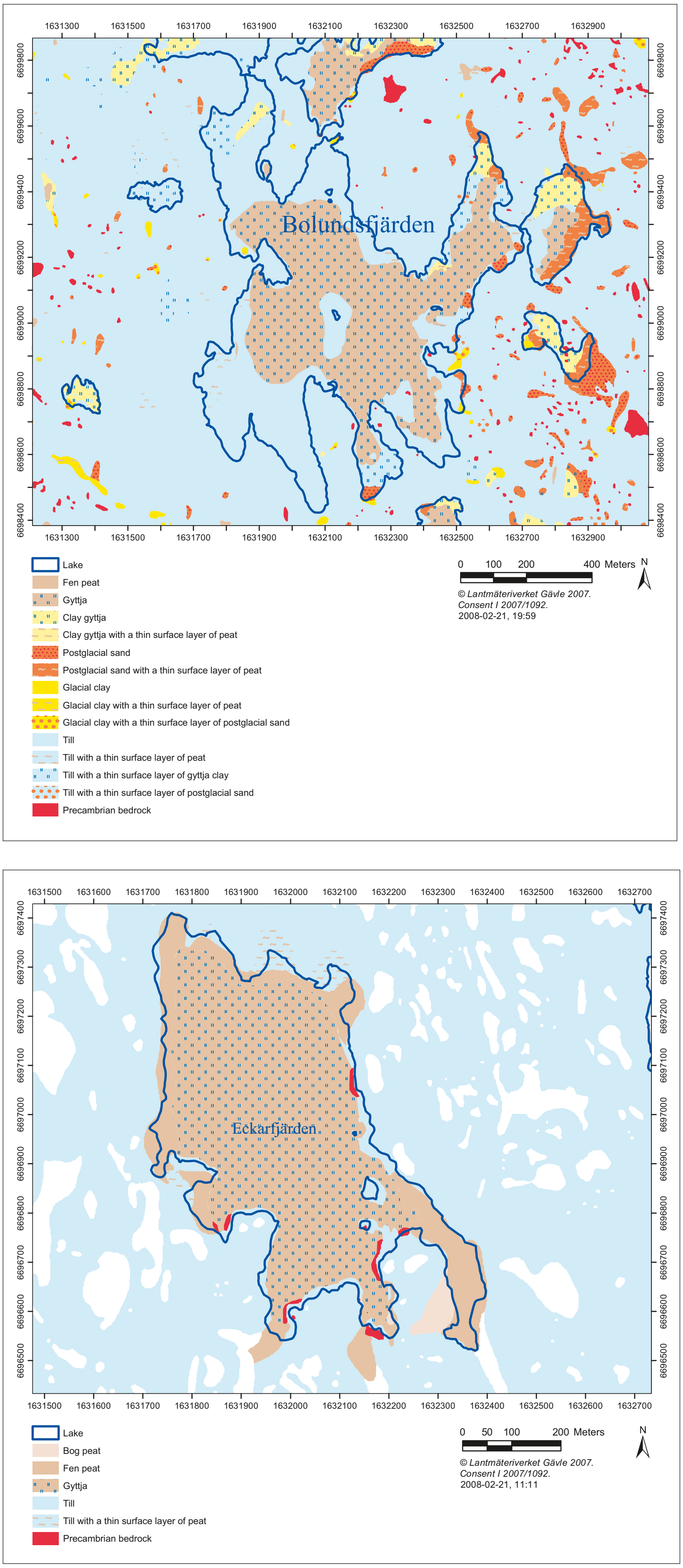

Figure 3-17. *Spatial distribution of Quaternary deposits at 0.5 m sediment depth in the lakes Bolundsfjärden (above) and Eckarfjärden (below).*

Table 3-10. Characteristics of lake sediments in the Forsmark area. Only data measured in the area are presented with one exception. Data from /Hedenström and Risberg 2003, Hedenström 2004, Nordén 2007/.

	Stratum thickness (m)	Carbon content (g C/g dw)	Water content (–)	Carbon content (g C/m³)	Total carbon content (g C)	Acc. rate (m/y)	Acc. rate (g C/m² y)	Acc. rate (g C/y)
Eckarfjärden	1.75			3.8E+04	4.6E+10			
Gyttja	0.96	0.27	0.93	1.9E+04	3.5E+09	0.001	19.4	3.7E+06
Clay gyttja	0.11	0.08	0.845[1)]	1.2E+04	2.5E+08			
Clay	0.68	0.01	0.53	6.6E+03	8.5E+08			
Fiskarfjärden	3.52							
Gyttja	1.00	0.17						
Clay gyttja	0.61	0.05						
Clay	1.91	0.01						
Stocksjön	0.49							
Gyttja	0.4							
Clay gyttja	0.03							
Clay	0.06							
Gällsboträsket	1.41							
Gyttja	0.34							
Clay gyttja	0.37							
Clay	0.7							
Bolundsfjärden	0.6							
Gyttja	0.48		0.90					
Clay gyttja	0.07							
Clay	0.05							
Puttan	0.82							
Gyttja	0.8	0.20	0.89					
Clay gyttja	0.02	0.09						
Clay	0							
Norra Bassängen	0.16							
Gyttja	0.15							
Clay gyttja	0.01							
Clay	0							

[1)] mean value from the marine bays Kallrigafjärden and Tixelfjärden /Sternbeck et al. 2006/.

In Forsmark, long-term accumulation of matter has been estimated in sediments from Eckarfjärden /Hedenström and Risberg 2003/. The estimated average accumulation rate during the last 1,200 years was 1 mm year^{-1}. The accumulation rate of carbon within the lake sediment has been estimated using this accumulation rate, combined with the average carbon content of the gyttja layer in Eckarfjärden (27% of dry weight) /Hedenström and Risberg 2003/, the average water content of that sediment layer (93%) /Nordén 2007/, and assuming that the density of minerals is 2,650 kg m^{-3} and that the amount of organic matter can be calculated by multiplying the carbon content by 1.7 /Hedenström et al. 2008/. As mentioned before, the gyttja was deposited during the lake stage, whereas the clay gyttja and clay were deposited in the Baltic and during the lagoon stage. Therefore, the estimate of the carbon accumulation rate of the lake stage has only been based on accumulation of the gyttja layer. The resulting accumulation rate of 19 g C m^{-2} year^{-1} is of the same order of magnitude as carbon accumulation rates estimated in one of the sea bays outside the Forsmark area (14 g C m^{-2} year^{-1} in Kallrigafjärden) /Sternbeck et al. 2006/, but is lower than the accumulation rates estimated in Lake Frisksjön in the Laxemar-Simpevarp area (74 g C m^{-2} year^{-1}) /Sternbeck et al. 2006/.

3.6.4 Chemical composition

Chemical characterization of sediments from Forsmark lakes has been performed by /Hannu and Karlsson 2006/ and /Strömgren and Brunberg 2006/. In the first study, one sediment sequence from Eckarfjärden was been analyzed for 64 elements, while the other report contains data for 54 elements in a sediment sequence from the smaller lake Stocksjön. Data from these two studies are presented in Appendix 9. In addition, data on contents of carbon, nitrogen, sulphur and $CaCO_3$ in some Forsmark lakes are presented in /Hedenström 2004/.

The relative amounts of different elements differ between sediment layers (Figure 3-18). However, the ten most common elements are present in virtually the same amounts in all layers. Carbon is the most common element in the gyttja layer (4,700 tonnes, 63% of investigated elements), followed by silicon (1,100 tonnes) and calcium (850 tonnes). The carbon content decreases downwards in the sediments: the share is 24% of investigated elements in the clay gyttja layer and only 2% of investigated elements in the clay layer. The most common element in the clay gyttja and clay layers is silicon, which constitutes 43 and 48% of the weight of investigated elements in those layers, respectively. Aluminium is an important component, as is iron. In the gyttja layer, on the other hand, aluminium and iron contribute less to the total weight of the elements (Figure 3-18).

Compared with the gyttja layer in Frisksjön in the Laxemar area (section 4.6) the sediments in the Forsmark lakes have a higher carbon content and lower content of silicon and aluminium. The share of calcium is much higher in the Forsmark gyttja, 11% compared with less than 2% in Frisksjön. The sediment from Frisksjön more closely resembles the clay gyttja layer of the Forsmark lakes. Both are dominated by silicon followed by carbon, aluminium and iron. The carbon content is somewhat higher in Frisksjön while the aluminium content is somewhat lower. The chemical composition of sediments as well as other parts of the limnic ecosystems in the Forsmark area is further discussed in Chapter 7.

Large amounts of gas have been found in the sediments of lakes and shallow coastal bays during the site investigations /Borgiel 2004a/. No estimations have been made of the quantities, but the chemical composition of this gas was examined in one gas sample from Puttan /Karlsson and Nilsson 2007/. The sample contained 56% (by volume) of methane. The origin of this gas is most probably from the decomposition of organic matter within the sediments.

3.7 Habitat distribution in the lakes

Lakes may be divided into five different habitats: Littoral I, II, and III, Pelagic and Profundal /Brunberg et al. 2004a and 2004b/. The areal distribution of each habitat has been investigated by /Brunberg et al. 2004a/. The habitats are defined in /Brunberg et al. 2004a/ as follows:

Littoral I, with emergent and free-floating macrophytes, is developed in shallow wind-sheltered areas with soft substrate. The upper limit of this zone, which distinguishes it from the surrounding terrestrial area, was set by the high water level. Wetland areas in direct contact with the lake are also included, as are “artificial” wetland areas in some lakes where the water level has been lowered due to anthropogenic activities. Hence, in addition to aquatic plants, wetland plants and even bushes and small trees may occasionally be included in this zone.

Littoral II has a hard substrate and develops in wind-exposed areas. The photosynthetic organisms in this area consist of species that are able to attach to the hard substrate, e.g. periphytic algae.

Littoral III is found in the deeper areas of the lake where there is enough light to sustain photosynthetic primary production by submerged vegetation.

The profundal habitat is the benthic habitat where light penetration is less than needed to sustain a permanent vegetation of primary producers. The profundal organisms are dependent on carbon supplies imported from other habitats of the lake or from allochthonous sources.

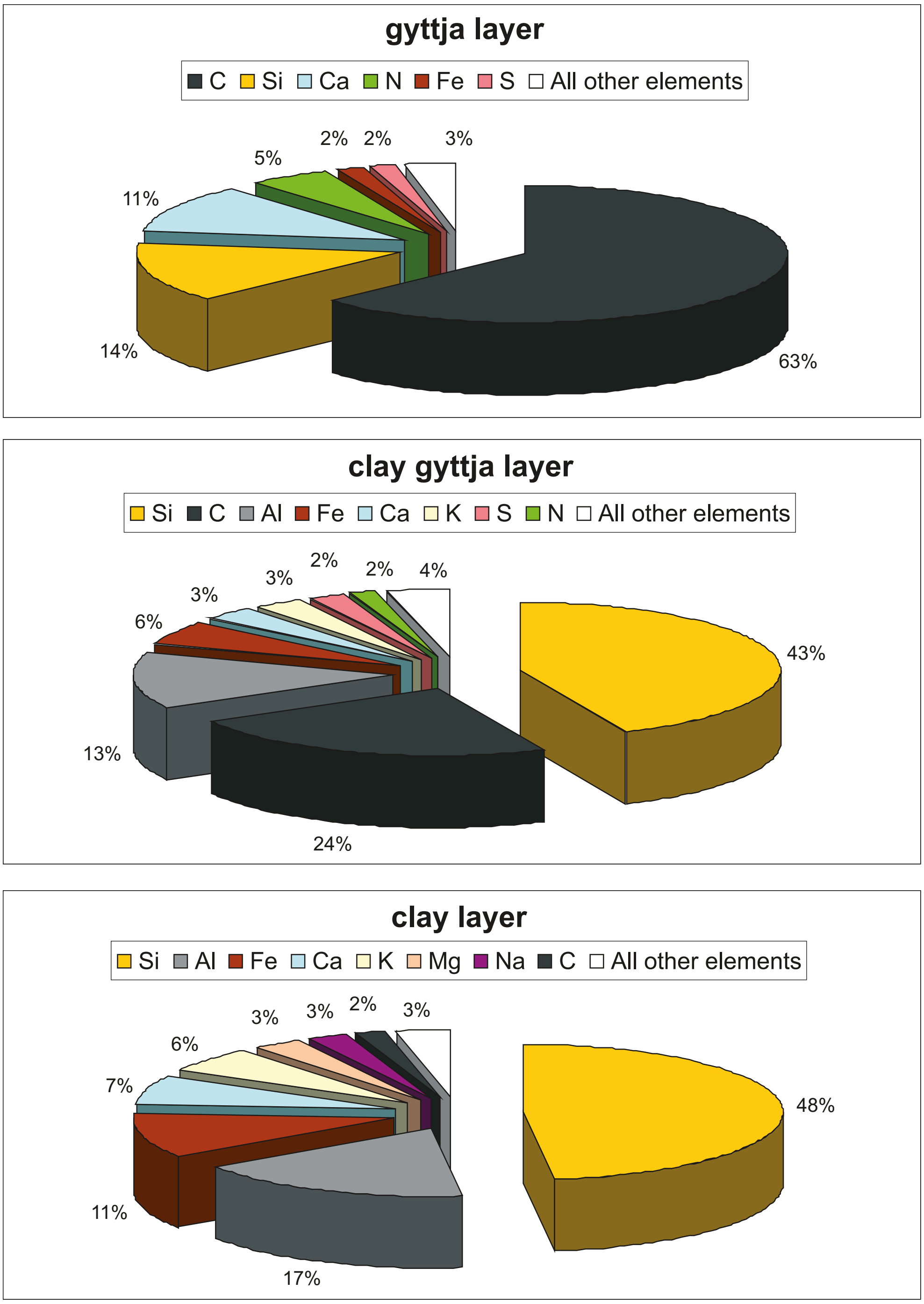

Figure 3-18. *Relative amounts of different elements (%) in the three upper sediment layers of Eckarfjärden. Note that hydrogen and oxygen are not analyzed and that the figure shows percentage of dry weight of analyzed elements.*

The pelagic habitat includes the open water and a pelagic food web with planktonic organisms. Depending on the light availability, the plankton is dominated either by photosynthetic production (by autotrophic phytoplankton) or, if the water is strongly coloured or turbid, by heterotrophic carbon processing (e.g. by heterotrophic bacterioplankton and mixotrophic phytoplankton). The pelagic habitat covers the same area as the sum of Littoral II, Littoral III and the profundal habitat.

Since the lakes in the Forsmark area are small and shallow, only three habitats were found, Littoral I, Littoral III, and the pelagic habitat /Brunberg et al. 2004a/. Littoral I with emergent macrophytes was the dominant habitat in the lakes, on average comprising 69% of the lake area (range 34–96%). In general, Littoral I constitutes a larger share of total lake area in the smaller lakes than in the larger ones. The distribution of different habitats in the lakes is presented in Table 3-11. The habitat distributions in two of the larger lakes, Bolundsfjärden and Eckarfjärden, and in the small Labboträsket are illustrated in Figures 3-19a, b and c.

The borderline between a lake and the surrounding terrestrial environment may be set differently depending on the aim. /Brunberg et al. 2004a and 2004b/ used the highest high water level to delimit the lake (Littoral I) from terrestrial areas. Using this definition, wetland areas in direct contact with the lake are also included, as well as the "artificial" wetland areas in some lakes

Table 3-11. Distribution of habitats and total lake area for the lakes in Forsmark. The pelagic habitat covers the same area as Littoral III.

Catchment	Lake	Littoral I m^2	% of total lake area	Littoral III m^2	% of total lake area	Total lake area m^2
Forsmark 1	Gunnarsbo-Lillfjärden S basin	15,177	46	17,930	54	33,107
	Gunnarsbo-Lillfjärden N basin	17,998	78	5,150	22	23,148
	Labboträsket	57,843	96	2,199	4	60,042
	Gunnarsboträsket	49,649	74	17,804	26	67,453
Forsmark 2	2:1 N. Bassängen	44,395	58	31,675	42	76,070
	Lake no 16	4,954	50	4,975	50	9,929
	2:3 Bolundsfjärden	206,719	34	404,593	66	611,312
	2:4 Graven	42,185	84	7,902	16	50,087
	2:5 Fräkengropen	16,913	87	2,510	13	19,423
	2:6 Vambörsfjärden	29,781	60	19,796	40	49,577
	2:7 Kungsträsket	4,755	62	2,978	39	7,733
	2:8 Gällsboträsket	178,344	95	8,704	5	187,048
	2:9 Stocksjön	31,012	85	5,468	15	36,480
	2:10 Eckarfjärden	95,318	34	188,532	66	283, 850
	2:11 Puttan	56,230	68	26,511	32	82,741
Forsmark 3	Tallsundet	68,944	87	10,470	13	79,414
Forsmark 4	Lake no 8	27,455	78	7,603	22	35,058
	Lillfjärden	118,167	73	43,102	27	161,269
Forsmark 5	Bredviken	44,369	45	53,295	55	97,664
Forsmark 6	Simpviken	7,045	77	2,074	23	9,119
Forsmark 7	Lake no 1	89,723	55	73,329	45	163,052
	Märrbadet	19,359	82	4,252	18	23,611
	Lake no 4	5,030	79	1,362	21	6,393
	Lake no 5	8,475	91	837	9	9,312
Forsmark 8	Fiskarfjärden	373,541	50	380,762	50	754,303
Average		**64,535**	**69**	**52,953**	**31**	**117,488**
Standard deviation		**82,792**	**19**	**109,423**	**19**	**184,033**
Median		**42,185**	**74**	**8,704**	**26**	**50,087**
Min.		**4,755**	**34**	**837**	**4**	**6,393**
Max.		**373,541**	**96**	**404,593**	**66**	**754,303**

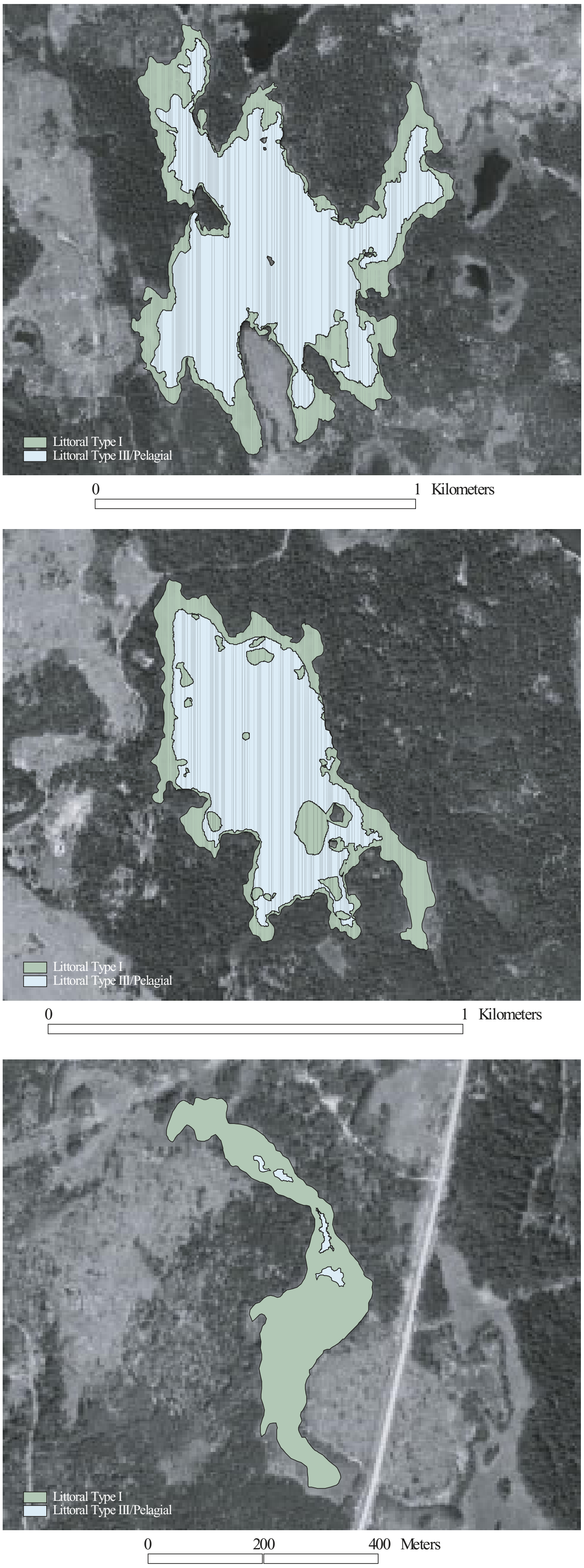

Figure 3-19. *Distribution of major habitats in a) Bolundsfjärden, b) Eckarfjärden and c) Labboträsket /from Brunberg et al. 2004a/.*

where the water level has been lowered due to anthropogenic activities. Hence, in addition to the aquatic plants, wetland plants and even bushes and small trees may occasionally be included in this zone, especially if the area is tufty. In the lake models presented in Chapter 5 and 7, we have chosen to treat all areas defined as Littoral I (reed belts and in Frisksjön also wetland plants, trees and bushes) by /Brunberg et al. 2004a and 2004b/ as wetland areas. Thus, lake areas used in Chapter 5 and 7 are smaller than presented by Table 3-11.

3.8 Physical characteristics of streams

The streams in the catchments Forsmark 1, 2 and 8 were investigated in 2004 and 2005 /Carlsson et al. 2005b, Brydsten and Strömgren 2005/. Bottom substrate, morphometry (x, y and z coordinates), water velocity, bottom vegetation, shading from terrestrial vegetation and technical encroachments were recorded. Bottom substrate, morphometry and shading from terrestrial vegetation are described below. Water velocity is described in section 3.3.1 and vegetation is described in section 3.10.

In the investigations of bottom substrate and shading from terrestrial vegetation, the observer walked along the streams and made observations each 10 m. The same stretches were investigated in the early summer (June) and during the drier late summer (August). For the morphometry investigation, the deepest part in the watercourse was determined every 20 metres. If the gradient was large, shorter distances were used. Every 100 m along the watercourses the cross-sections were measured: one measurement was made at the deepest part of the section, at two points on each shoreline, and at two points in the middle.

The total length of the stream stretches in the two catchments estimated from maps is c. 15 kilometres. Stream order 1 is the most abundant stream order covering 7.8 km (52% of the total stream length). Stream order 2 is the next most common stream order (6.1 km and 42% of the total stream length) and stream order 3 is the least common stream order (0.8 km and 5% of the total stream length (Figure 3-2). The stream orders were investigated approximately in proportion to their abundance in the two catchments; 62% of the total investigated length was of stream order 1, 32% of stream order 2 and 6% of stream order 3. Altogether, c. 7 kilometres of the streams were investigated in the field.

3.8.1 Bottom substrate

Fine organic matter dominates as the bottom substrate in stretches with stream order 1, whereas clay is more common and dominates in stretches with stream order 2 and 3 (Table 3-12).

Table 3-12. Distribution of different bottom substrates (%) in the investigated stream stretches in the Forsmark area (data from /Carlsson et al. 2005b/).

Catchment	1			2				1 and 2			
Stream order	**1**	**2**	**total**	**1**	**2**	**3**	**total**	**1**	**2**	**3**	**total**
Fine organic detritus	84	40	47	82	13	–	38	82	25	0	41
Coarse organic detritus	16	3	5	10	3	–	5	10	3	0	5
Clay	–	46	39	5	75	86	50	4	62	86	46
Sand	–	1	1	–	3	5	2	0	2	5	2
Gravel	–	–	–	–	1	–	0.4	0	0	0	0
Cobble	–	10	8	3	5	9	5	3	7	9	6
Boulder	–	–	–	–	0.4	–	0.2	0	0	0	0

3.8.2 Morphometry

Catchment 1

The morphometry of the stream is clearly defined all the way from the start of the investigated stretch upstream Labboträsket down to the lake, except for a section at the outlet from Gunnarsboträsket and a section approximately 500 m from the outlet where the water overflows the banks of the streams. The gradient is very low at first, but about 300 m downstream of Labboträsket the upper part of the stream has a well-defined geometry. At some locations the bank is several metres high. Further downstream the stream flows into a swampy area where a distinct channel is hardly distinguishable. The slope is mostly very gentle except for the last 200 m where it is steeper. The total gradient in this catchment is about 4.5 m height in 2.5 km length.

Catchment 2

In the section from Eckarfjärden to Stocksjön the morphometry of the stream is clearly defined. The gradient is low in the beginning and increases after c. 250 m downstream Eckarfjärden. The gradient is about 2 m in c. 300 m. The stream is clearly defined also in the section between Stocksjön and Bolundsfjärden. In some parts, however, the water overflows the banks and the channel is difficult to distinguish. The stream has its largest gradient in the beginning. The gradient is about 2.5 m in c. 1.6 km. Between Bolundsfjärden and Norra Bassängen the water flows through a wide area with reed vegetation and stony bottom and without any clear channel. The gradient is negligible. The part of the stream between Norra Bassängen and the outlet to the sea does not have a clearly defined channel. The gradient is about 0.5 m over a distance of a few metres.

Upstream of Gällsboträsket the stream has a clearly defined channel along the entire stretch. The gradient varies: it is steep in the beginning, than flat and c. 200 m upstream of Gällsboträsket the gradient is steep again. In the easterly channel, the stream was investigated from Gällsboträsket and approximately 150 m upstream until the stream dried up. This channel is not as clearly defined as the westerly channel, appearing more like a ditch with stationary water.

The total gradient in the measured stretches upstream of Gällsboträsket is about 5 m in c. 450 m. The channel of the stream between Gällsboträsket and the junction with the stream from Eckarfjärden is clearly defined down to approximately 30 m from the junction, where the stream discharges its waters into a marsh. The gradient is about 1 m in c. 800 m.

Catchment 8

The outflow from Fiskarfjärden is mostly diffuse with large areas flooded and it is not until the last 50 m from the outlet that the channel is clearly defined. The gradient is about 0.8 m in c. 800 m.

3.8.3 Shading

With the exception of some areas with cut forest, the investigation by /Carlsson et al. 2005b/ showed that the streams in catchment 1 and 2 were most often densely shaded (see Figure 3-20). In catchment 8 the section closest to Fiskarfjärden was moderately shaded (5–50%) by the surrounding terrestrial vegetation whereas downstream, close to the sea, the channel was not shaded at all, since the surrounding wetland lacked trees and bushes. Due to the small sizes of the streams they ought to be shaded to a high degree unless the forest was recently cut.

Figure 3-20. *Many streams in the Forsmark area are, like this small stream, densely shaded.*

3.9 Hydrochemical characteristics of lakes, streams and shallow groundwater

Six lakes and 8 stream stations belonging to 4 catchments were monitored during the site investigations predominantly on a monthly basis (Figure 3-21). In addition, groundwater in 46 soil tubes and wells were sampled up to four times per year. The description of water chemistry in lakes and streams includes data from March 2002 to March 2005 and the description of groundwater chemistry includes data from July 2002 to February 2005 /Tröjbom and Söderbäck 2006b/. The surface water chemistry was compared with regional and national data from the national survey of lakes and watercourses /cf. Wilander et al. 2003/ (data available for downloading from http://info1.ma.slu.se/db.html). The groundwater chemistry was compared with a database from the Geological Survey of Sweden, containing data from private wells /SGU 2005/. The data were also compared with Swedish Environmental Quality Criteria (EQC) /Naturvårdsverket 1999b/ (groundwater), /Naturvårdsverket 2000/ (lakes and streams). Some of the comparison of the chemical composition in the lakes and streams with regional and national reference data is presented in box plots (Figure 3-22).

Concentrations of major elements and major ions, pH, temperature, oxygen concentrations and water colour, in lakes, streams and groundwater are presented below and in Appendices 7 and 8. Water chemistry for minor elements is presented in Appendices 6 and 7 and in /Tröjbom and Söderbäck 2006b/.

From GSD-Fastighetskartan © Lantmäteriverket
Gävle 2001, Consent M2001/5268
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Figure 3-21. *Monitored lakes (red) and stream sites (yellow) in the Forsmark area. The SKB ID code for each sampling site is given in brackets. The water divides between the different catchments are also shown.*

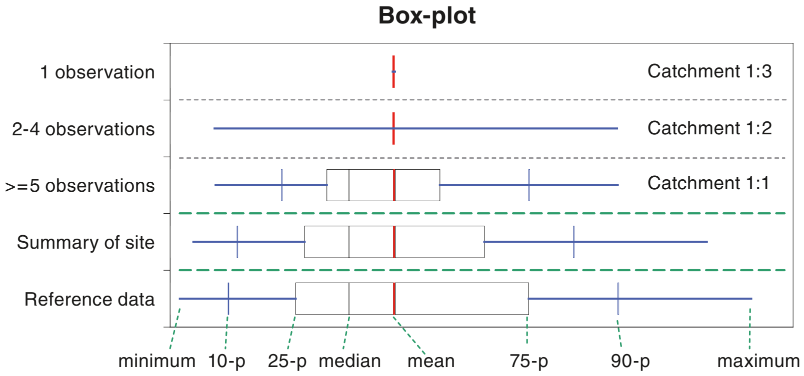


Figure 3-22. *The structure of box plots, showing statistical distributions of parameter values for individual sampling sites or soil tubes, and for different categories (summary of site). The corresponding distributions for local, regional and national reference data are included under "Reference data". 10-p denotes the 10th percentile etcetera. When applicable, the colour scale of the Swedish Environmental Quality Criteria is included in the box plots. The meaning of the different colours differs depending on the parameter and usually ranges from low (blue) to high (red). The scale often refers to statistical distributions and is not necessarily coupled to "good" or "bad" conditions.*

3.9.1 Water chemistry in lakes

The lakes in Forsmark are characterized by high pH, high concentrations of major ions and high electrical conductivity. Phosphorus concentrations are generally low while nitrogen concentrations tend to be high /Tröjbom and Söderbäck 2006b/. The water has a high content of dissolved organic carbon, which is unusual in combination with the moderate water colour in the lakes /Brunberg et al. 2002/. Due to the shallowness of the lakes, the concentration of dissolved oxygen can reach very low levels during winter, and in some lakes anoxia occurs. Generally, the chemical conditions in freshwaters in the Forsmark area are relatively unaffected by anthropogenic influence.

Acidity and alkalinity

The pH values are high, with a median pH of 7.9 in the Forsmark lakes (Table 3-13). The pH values are occasionally very high and pH-values of more than 9 have been measured in Bolundsfjärden, Norra Bassängen and Fiskarfjärden. These high pH occasions generally occur in late summer or early autumn and coincide with high primary production. Alkalinity is also very high in the Forsmark lakes compared with the majority of Swedish lakes. Accordingly, the buffering capacity against acidification is high.

Major elements

Phosphorus is often considered to be a limiting factor for the growth of microbiota in lakes /Vollenweider 1976, Elser et al. 1995, Vadeboncoeur et al. 2003/. This may be the case in the Forsmark lakes, as phosphorus concentrations are low according to EQC (Table 3-13, Figure 3-23). The concentration of total phosphorus is at the same level as in the majority of Swedish lakes but is, with exception of Fiskarfjärden, lower than what is typical for lakes in the region /Sonesten 2005/. Fiskarfjärden show higher concentrations of all phosphorus fractions than the rest of the lakes in Forsmark. Moreover, a gradient with increasing phosphorus concentrations downstream is evident among the lakes in the Norra Bassängen catchment. This is what can be expected considering the greater influence of the catchment downstream in a system.

Besides phosphorus, primary producers in lakes can also be limited by ***nitrogen*** /Blomqvist et al. 1993, Jansson et al. 1996, Camacho et al. 2003/. In the Forsmark lakes, nitrogen seem to be in good supply as the concentrations are high or very high according to EQC (Table 3-13, Figure 3-24). However, in the summer, inorganic nitrogen concentrations decrease and there are indications that the benthic primary production in the microbial mat is stimulated by nitrogen influxes, indicating nitrogen limitation /Andersson and Brunberg 2006b/. The concentrations of total nitrogen are approximately at the same level as in the lakes in the region, except for in Fiskarfjärden and Eckarfjärden, where concentrations are higher. Most of the nitrogen in the lakes is associated with organic substances. However, occasionally during episodes of decomposition, the inorganic fractions (NH_4, NO_3, and NO_2) increase in importance. This is indicated by a relatively narrow distribution but with a few observations with very high inorganic nitrogen concentrations (Figure 3-24).

Concentrations of total organic ***carbon*** (TOC) are very high according to EQC (Figure 3-25). Although the TOC concentrations are lower than in many lakes in the region, they are on average in the 75th–90th percentiles compared with national lakes. The dissolved organic carbon (DOC) concentrations are very high, especially in combination with the moderate watercolour of the lakes (water colour see below) /Brunberg et al. 2002/. This suggests that much of the DOC could be of autochtonous origin, i.e. produced by primary producers within the lakes in contrast to coloured DOC, which often consists of humic compounds originating from the catchment. Both DOC and TOC concentrations vary over the year within the lakes. Particulate organic carbon (POC) concentrations are generally highest in Fiskarfjärden (Figure 3-25). Dissolved inorganic carbon (DIC) concentrations (Figure 3-25) are very high compared with Swedish lakes as a whole.

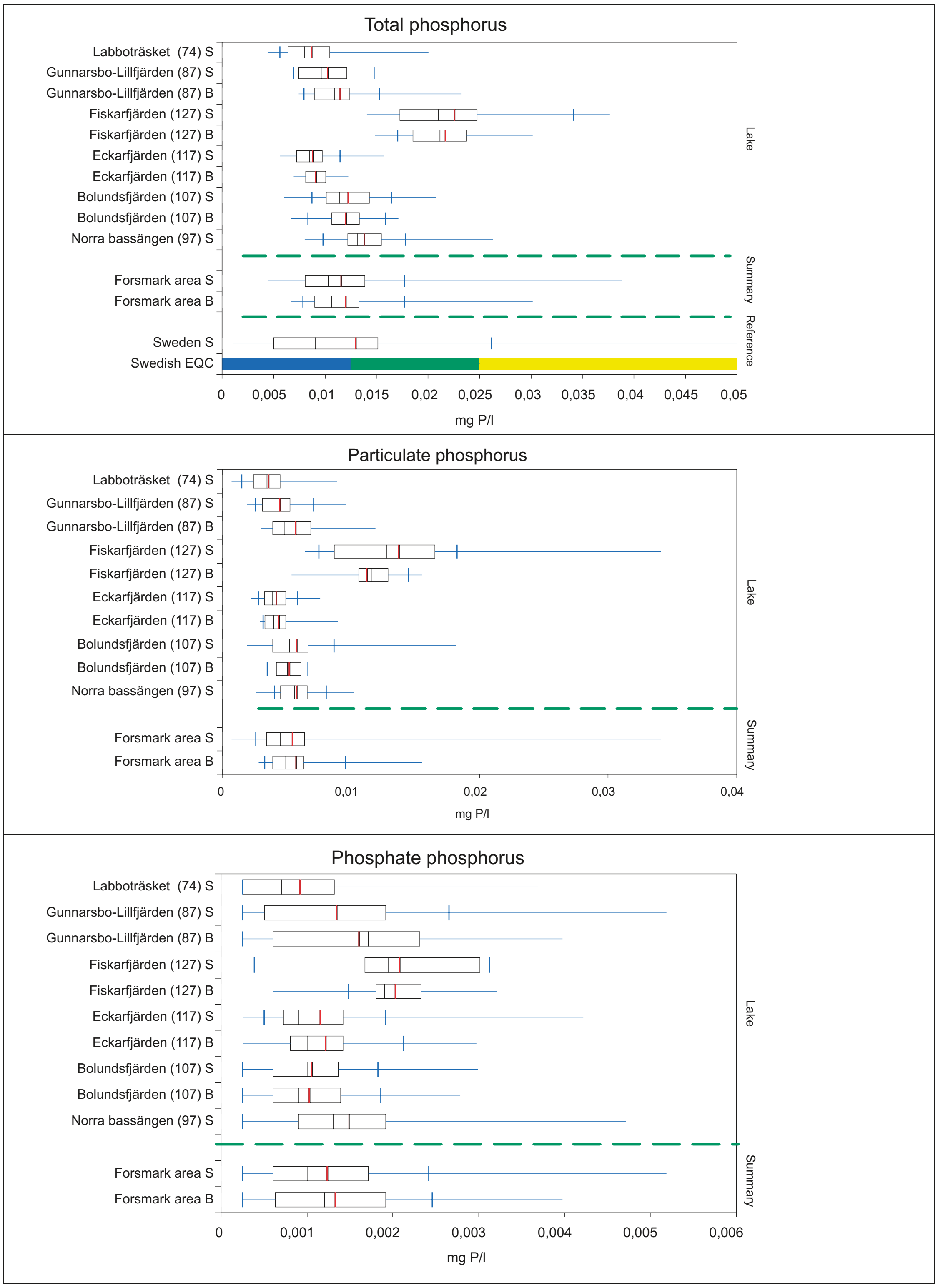


Figure 3-23. *Concentrations of total, phosphate and particulate phosphorus species in surface (S) and bottom (B) water in lakes in the Forsmark area. For an explanation of the box plots, see Figure 3-22. Numbers within brackets represent the last digits in the ID code used in the database SICADA. Data from Appendix 1 in /Tröjbom and Söderbäck 2006b/.*

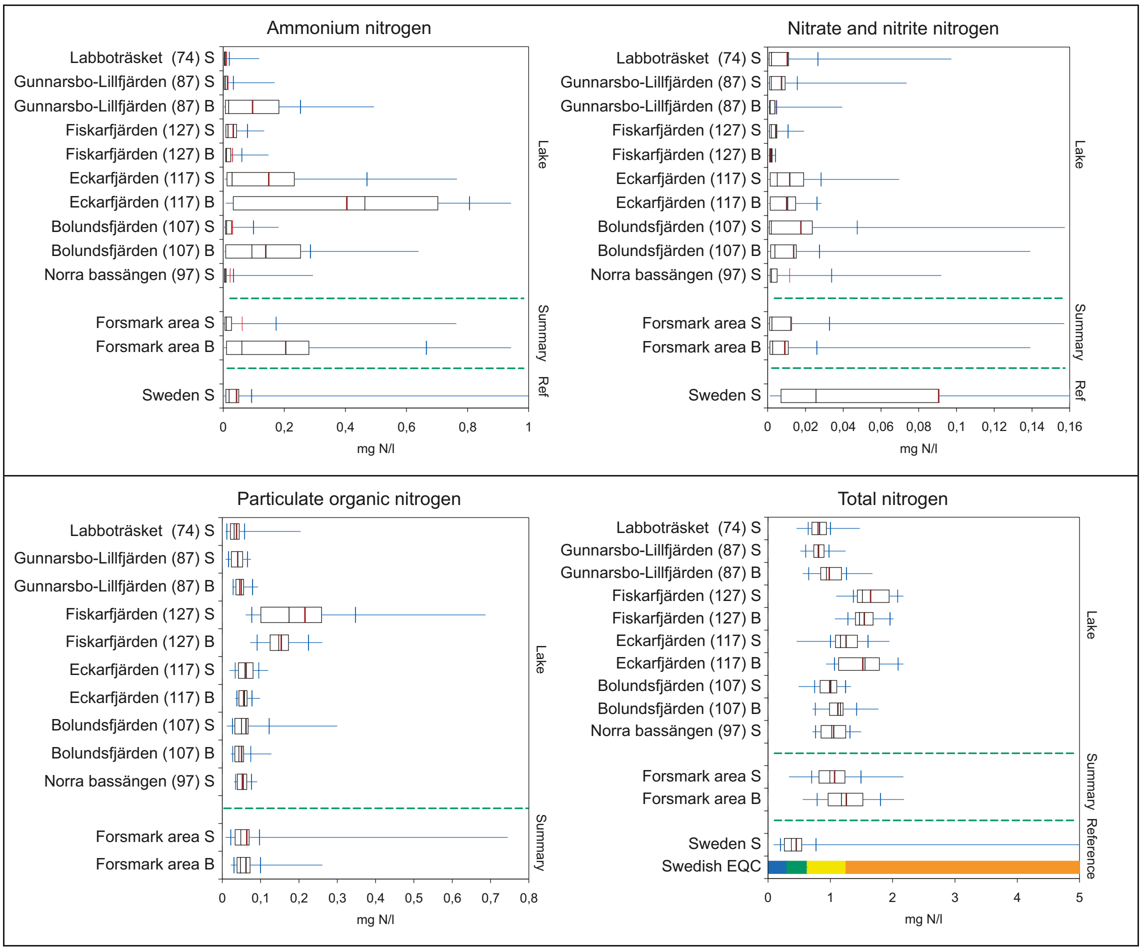


Figure 3-24. *Concentrations of total, nitrate and nitrite, ammonium and particulate nitrogen species in surface (S) and bottom (B) water in lakes in the Forsmark area. For an explanation of the box plots, see Figure 3-22. Numbers within brackets represent the last digits in the ID code used in the database SICADA. Data from Appendix 1 in /Tröjbom and Söderbäck 2006b/.*

The ***sulphate*** concentrations in the Forsmark lakes are, as in many other lakes in the region, higher than in the majority of Swedish lakes. The exception is Eckarfjärden, which shows comparably low sulphate concentrations /Sonesten 2005/. The high sulphate concentrations can in most lakes be attributed to leaching from the catchments, as the atmospheric deposition in the region is similar to many other parts of the country.

Silicon originates from weathering, and the concentrations are comparable to those in other Swedish lakes. Only Lillfjärden deviates with higher concentrations. Silicon is characterized by its utilization by diatoms, hence a marked seasonality can be seen in the concentrations, with lower summer concentrations and higher winter concentrations. In Eckarfjärden where phytoplankton and microphytobenthos have been investigated, phytoplankton diatom biomass is low but diatoms are present in high biomass in the benthic microbial mat.

Dissolved ions and conductivity

The total amount of dissolved ions, measured as the electrical ***conductivity***, is markedly higher in the Forsmark lakes and the lakes in the region compared with the majority of Swedish lakes. The elevated amounts of dissolved ions are caused by the calcareous till in the catchments and by the recent emergence of the catchments from the sea. There is an increase in conductivity from the upper parts to the lower parts of the Norra Bassängen catchment.

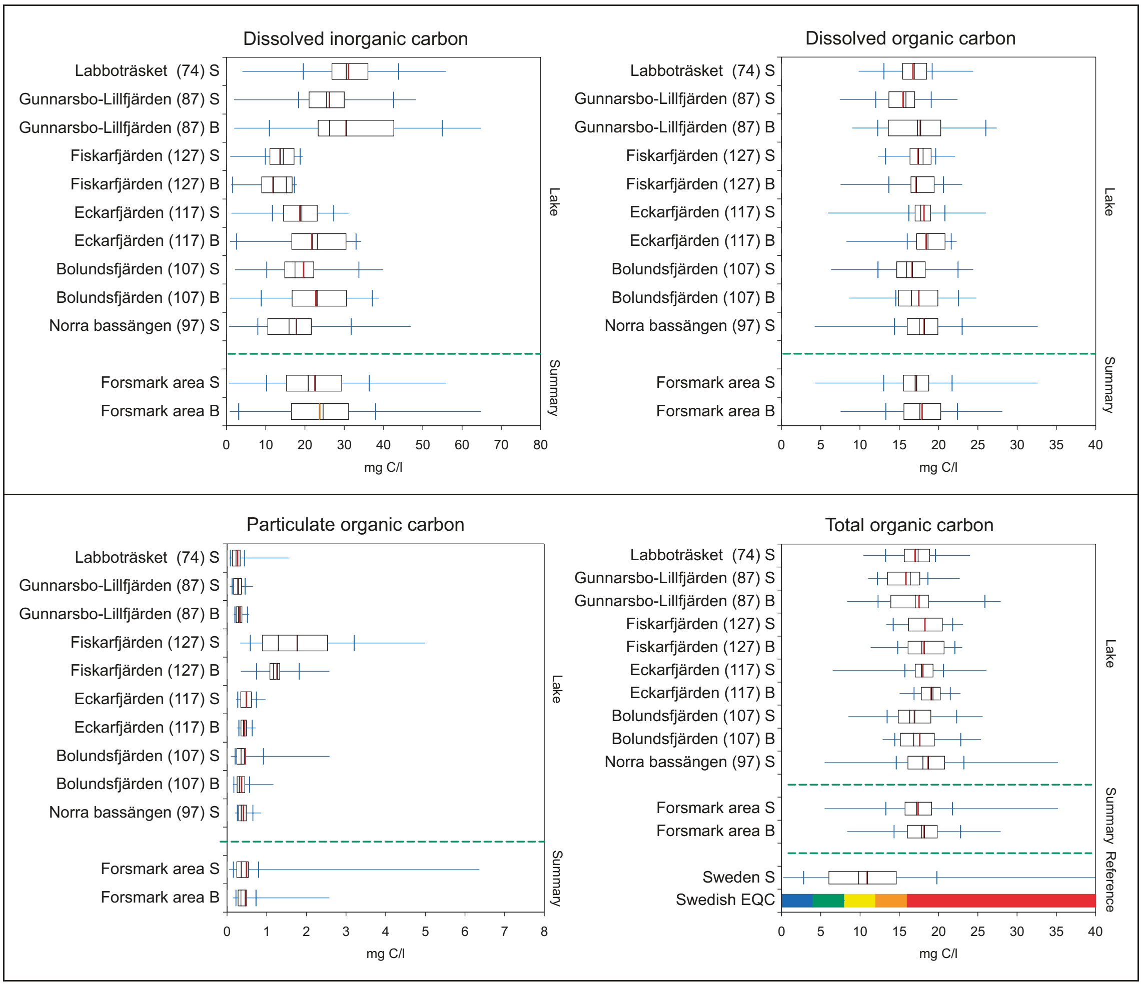


Figure 3-25. Concentrations of total, dissolved and particulate organic carbon species, as well as contents of dissolved inorganic carbon, in surface (S) and bottom (B) water in lakes in the Forsmark area. For an explanation of the box plots, see Figure 3-22. Numbers within brackets represent the last digits in the ID code used in the database SICADA. Data from Appendix 1 in /Tröjbom and Söderbäck 2006b/.

The lakes in the Forsmark area all show high levels of ***cations***. The levels of calcium, magnesium and potassium in particular are higher than in the majority of Swedish lakes, as well as in most other lakes in the region. Sodium concentrations are also comparatively high in Bolundsfjärden, Norra Bassängen and Fiskarfjärden, whereas the other lakes show sodium levels more common to the majority of Swedish lakes. There is a high seasonal variation in ***calcium*** levels in all lakes. This is due to precipitation of calcium carbonate into a solid state during periods of high primary production and high pH. In connection with degradation and lower pH, the process is reversed and calcium carbonate concentrations rise again. The levels of ***magnesium, sodium and potassium*** are highest in Bolundsfjärden and Norra Bassängen. These lakes also have the highest variation in the concentrations of the ions, which is probably caused by intrusion of brackish water from the Baltic Sea (further discussed in section 3.3). There is also some evidence for brackish water intrusion into Fiskarfjärden.

In accordance with the high concentrations of cations, the amounts of ***anions*** in the Forsmark lakes are also high. The concentrations of ***chloride*** are generally higher than in most other regional and Swedish lakes. The highest levels of chloride are recorded in Bolundsfjärden and Norra Bassängen, followed by Fiskarfjärden. This corresponds well with the expected occasional intrusion of brackish water to these lakes. Other common anions are carbonates, sulphate, fluoride, bromide and iodide.

Table 3-13. Mean water chemistry (March 2002–March 2005) for major elements in surface water (0.5 m depth) in the investigated lakes in the Forsmark area. Percentiles, mean, minimum and maximum values have been calculated from all measurements in all the monitored lakes. pH and conductivity have been measured in the field, while the other parameters are from laboratory analyses.

Element	Count	Min.	25-p	Median	75-p	Max.	Mean	SD
pH	245	6.31	7.30	7.92	8.52	9.52	7.94	0.73
Conductivity (mS m^{-1})	246	17	30	35	42	450	45	40
Tot-P (mg L^{-1})	250	0.0044	0.0084	0.010	0.014	0.039	0.012	0.005
POP (mg L^{-1})	253	0.0010	0.0036	0.0047	0.0065	0.036	0.0057	0.004
PO4-P (mg L^{-1})	255	<0.001	<0.001	0.0010	0.0018	0.0052	0.0013	0.0009
Tot-N (mg L^{-1})	250	0.33	0.82	0.99	1.2	3.7	1.1	0.4
NH_4-N (mg L^{-1})	255	<0.01	<0.01	<0.01	0.033	1.4	0.069	0.2
NO_2+NO_3-N (mg L^{-1})	255	<0.01	<0.01	<0.01	0.010	0.26	0.011	0.03
PON (mg L^{-1})	249	0.0078	0.035	0.050	0.069	0.74	0.065	0.07
TOC (mg L^{-1})	254	5.5	16	17	19	35	17	4
DOC (mg L^{-1})	255	4.2	15	17	19	33	17	4
POC (mg L^{-1})	248	0.046	0.25	0.37	0.53	6.3	0.50	0.6
SO_4-S (mg L^{-1})	247	0.43	2.7	4.9	6.5	25	5.2	3
Si (mg/l)	247	<0.03	0.76	2.3	4.2	11	2.8	2
Fe (mg L^{-1})	70	0.0069	0.036	0.056	0.11	0.67	0.094	0.1
Mn (mg L^{-1})	70	<0.003	0.0041	0.0088	0.027	0.64	0.034	0.08
Cations								
Ca (mg L^{-1})	247	13	37	46	61	130	49	20
Mg (mg L^{-1})	247	0.70	3.3	4.7	6.2	26	5.4	3
Na (mg L^{-1})	247	1.4	7.0	12	28	210	23	30
K (mg L^{-1})	247	0.73	2.0	2.5	3.3	9.6	2.8	1
Anions								
Cl (mg/l)	246	0.90	7.6	15	43	430	38	60
HCO_3 (mg L^{-1})	244	46	120	140	190	370	160	50
F (mg L^{-1})	223	<0.2	<0.2	0.24	0.29	3.1	0.27	0.3
Br (mg L^{-1})	245	<0.2	<0.2	<0.2	<0.2	12	<0.2	0.8
I (mg L^{-1})	200	<0.001	0.0050	0.0060	0.0090	0.026	0.0073	0.004

Iron and ***manganese*** are micronutrients that can be limiting nutrients for primary production at some occasions /Hyenstrand et al. 2001/. The iron level in the Forsmark lakes is generally lower than in many other lakes in the region and also compared with Swedish lakes as a whole. On the contrary, iron concentrations in the streams are at the same level or higher than in most regional streams (section 3.8.2), indicating that there is an uptake of iron in the lakes. Thus, iron could potentially limit primary production in the Forsmark lakes. A study in Lake Eckarfjärden with nutrient additions to mesocosms suggests that there is no iron limitation of either phytoplankton or bacterioplankton (Andersson and Brunberg unpublished). However, iron limitation may occur in the benthic habitat. The manganese concentrations are slightly lower than in the lakes in the region, but agree well with the concentration distribution in Swedish lakes. There are a few exceptions with very high concentrations of manganese in Labboträsket, Lillfjärden and Fiskarfjärden.

Dissolved oxygen

The concentration of dissolved oxygen is dependent on mixing of the water column, temperature, inflow of oxygen-rich water, inflow of oxygen-depleted groundwater, and on the balance between primary production and decomposition of organic matter. In connection with primary production, dissolved oxygen is released to the water and the concentrations increase. In connection with decomposition, oxygen is consumed and concentrations decrease. The concentrations of dissolved oxygen are highest in the spring and autumn circulation (Figure 3-26).

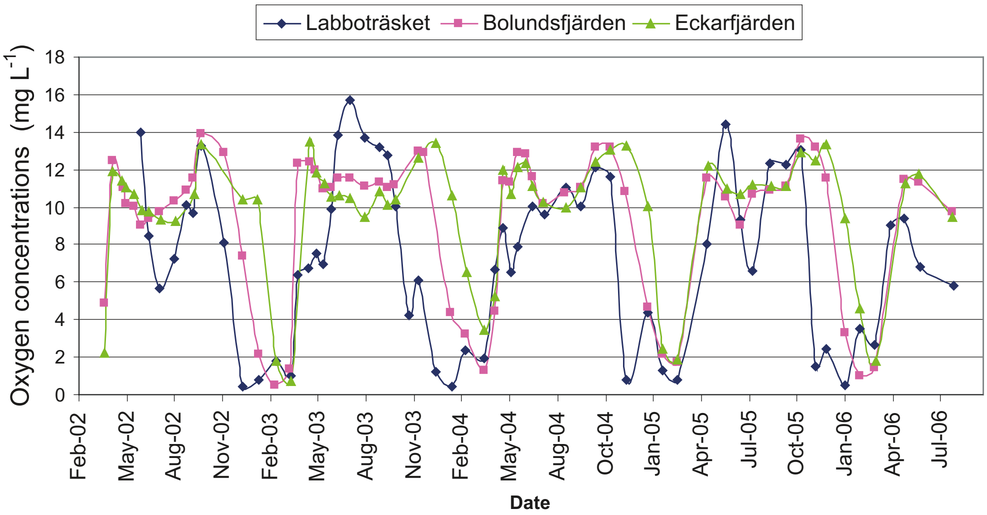


Figure 3-26. *Concentrations of dissolved oxygen in surface waters of three Forsmark lakes during the period April 2002–August 2006.*

In the summer, oxygen concentrations show strong diurnal variation and generally lower values than in the spring and autumn. This is probably due to the lower solubility of oxygen at elevated temperatures. Other possible reasons for the decreased oxygen concentrations in the summer can be increased decomposition and also a higher proportion of groundwater inflow compared with stream inflow during summer. Groundwater generally contains low amounts of dissolved oxygen. However, studies in Eckarfjärden have shown over-saturation of oxygen concentrations during large parts of the open water season, indicating that the lower concentrations are mainly caused by temperature-dependent solubility /Brunberg et al. 2002/. In winter, there is only limited primary production, but decomposition of organic matter consumes oxygen and anoxic conditions prevail in some of the lakes. Because of the shallow water depth, the whole water body is well mixed for most of the year. Only when the lake is covered with ice does stratification occur, resulting in an oxygen deficit in the bottom waters (Figure 3-27).

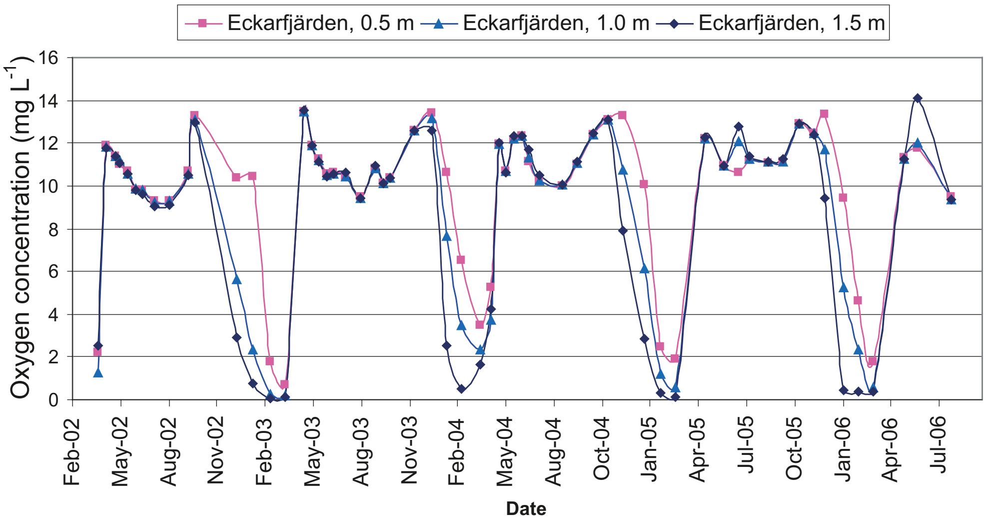


Figure 3-27. *Concentrations of dissolved oxygen at different water depths in Eckarfjärden.*

Temperature

Water temperature has been measured in several of the Forsmark lakes. Data for four lakes are presented in Figure 3-28 (data from the database SICADA, October 2006). The water temperatures varied between a few tenths of a degree above zero in the winter up to above 20°C in the summer. The same pattern is seen for all four lakes.

Water colour

The water colour of the Forsmark lakes is moderate. The annual mean water colour measured as absorbance at 420 nm is 0.149 (n=15) for Eckarfjärden /Brunberg et al. 2002/. Unfortunately, no reliable data on water colour are available from the site investigations but there are no reasons to suggest any substantial differences between the lakes in the area.

3.9.2 Water chemistry in streams

The water chemistry of the streams in Forsmark is similar to the water chemistry in lakes with high pH, alkalinity, carbon and nitrogen concentrations, but relatively low phosphorus concentrations.

Acidity and alkalinity

The pH values in the streams are, like those in the lakes, generally high and are seldom below 7 (Table 3-14). Even though the pH is high in the streams, it is not as high as in the lakes; nor does it deviate as much from other Swedish watercourses as the pH in lakes does. This is due to the fact that really high pH values generally are caused by extensive primary production, which is most often found in lakes. The measurements of alkalinity in the Forsmark streams are all considerably higher than the 90th percentile of alkalinity in streams in the national survey.

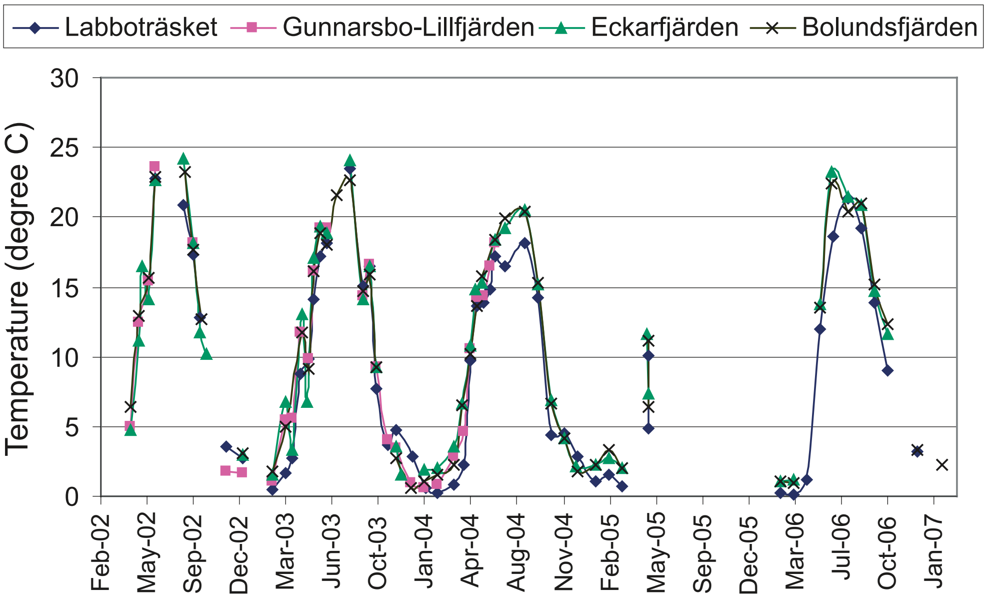


Figure 3-28. Water temperature in the surface waters of four Forsmark lakes. (Data from the database SICADA, October 2006).

Major elements

The variation in ***phosphorus*** concentrations is high, which is expected since levels in watercourses may vary considerably due to differences in rainfall and water velocity. The total phosphorus concentrations in the streams in the Forsmark area, as in the majority of Swedish streams and rivers, are in most cases low or moderately low according to EQC (Figure 3-29, Table 3-14). However, the levels in the inlet to Eckarfjärden and Bredviken, as well as in the outlet from Fiskarfjärden, are somewhat higher, corresponding to high or very high levels (but on the same levels as many streams and rivers in the county). The levels of phosphate and particulate phosphorus species are also elevated at these locations.

The total ***nitrogen*** levels in streams are high or very high according to EQC, but with the exception of the inlet to Bredviken, the levels are significantly lower than for many other streams in the county (Figure 3-30, Table 3-14). In contrast to the other locations where ammonium is the dominant nitrogen species, the dominant species in the inlet to Bredviken are nitrate and nitrite. The origin of the nitrate is probably the agricultural activities in the catchment. The ammonium nitrogen levels in the Forsmark streams are generally in the same range as the concentrations in streams from the national survey, while the particulate organic nitrogen level in the outlets to the Baltic Sea in the area seems to be higher. There are no obvious explanations for this tendency.

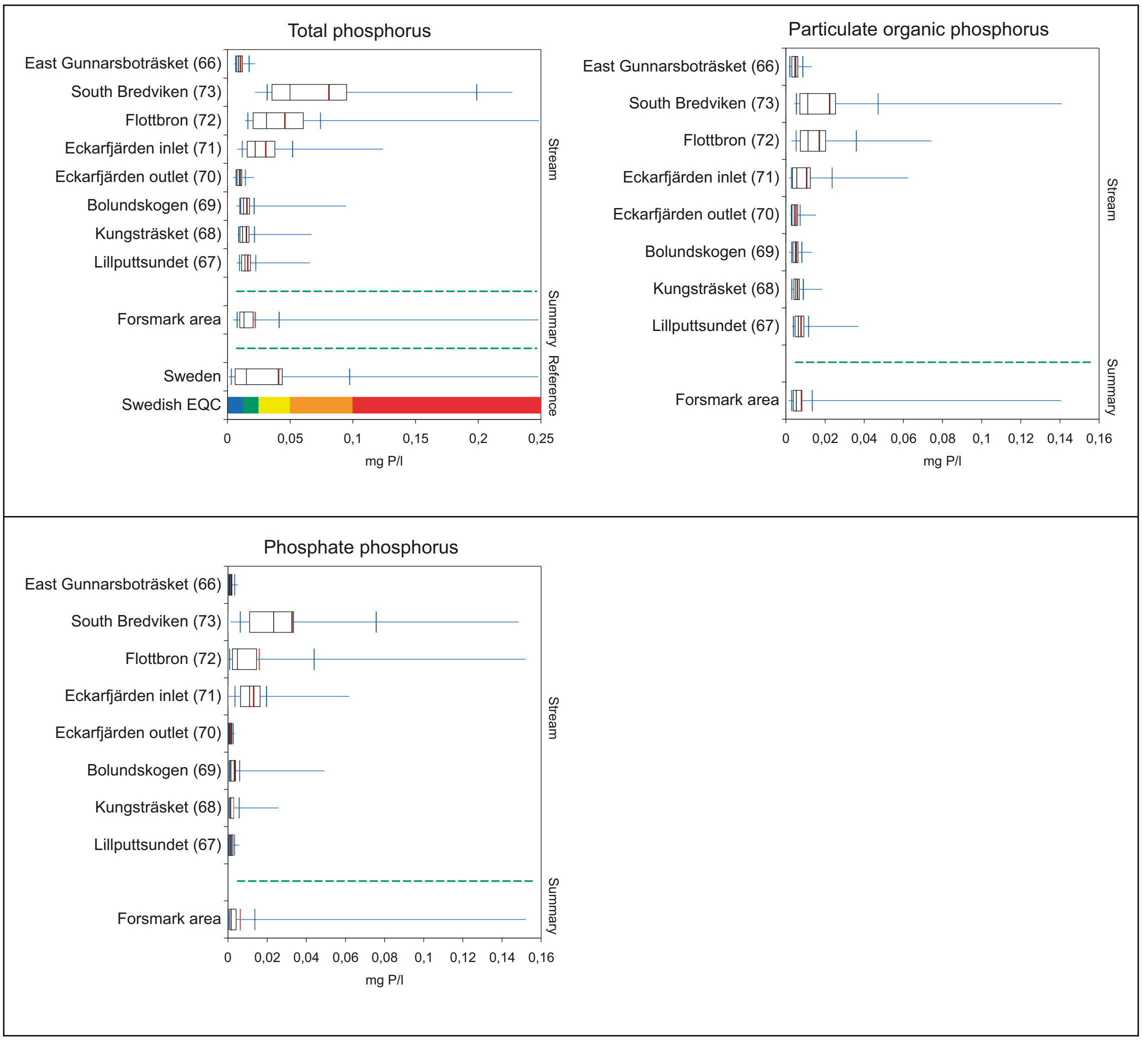


Figure 3-29. *Concentrations of total, phosphate and particulate phosphorus species in streams in the Forsmark area. Numbers within brackets represent the last digits in the ID code used in the database SICADA. Data from Appendix 1 in /Tröjbom and Söderbäck 2006b/.*

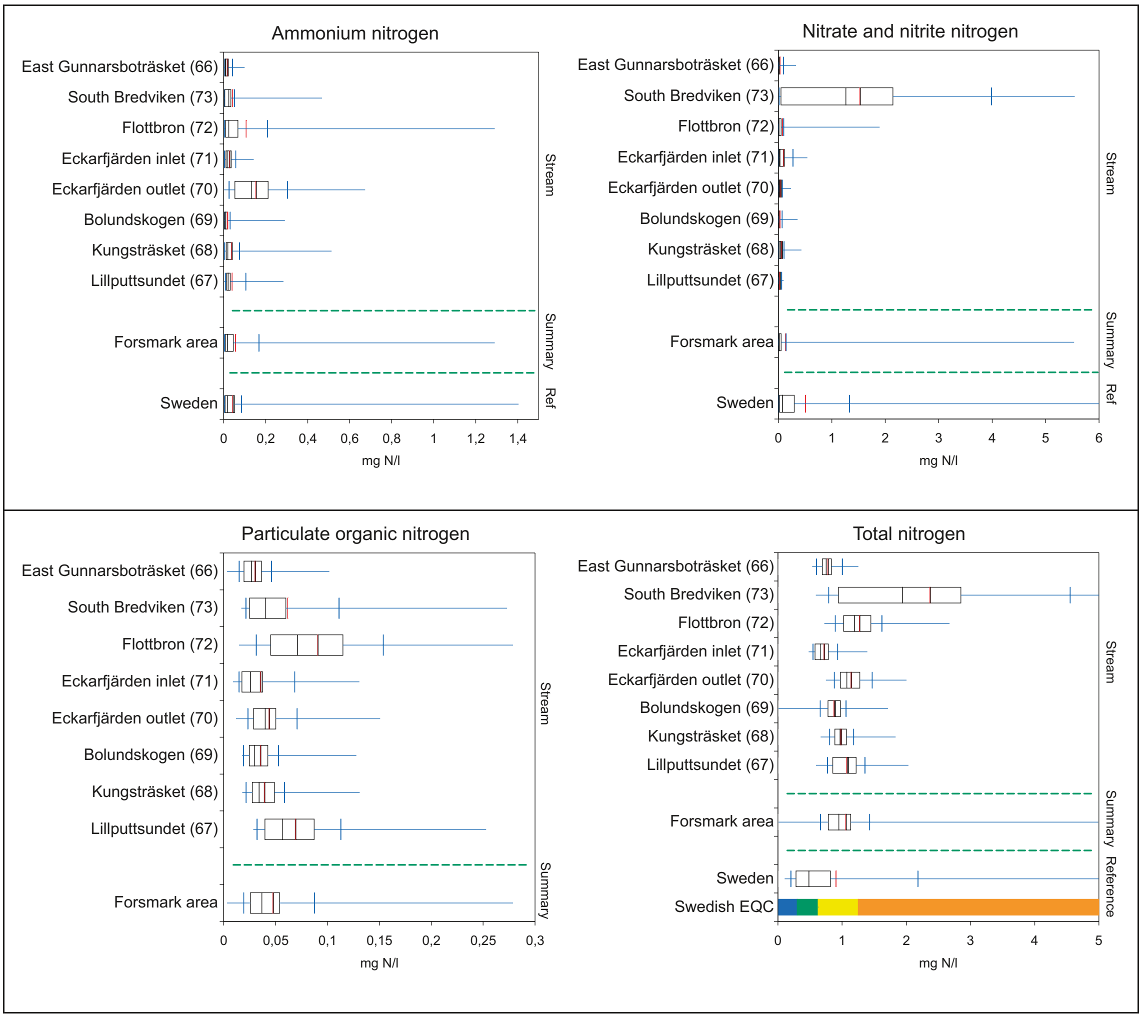


Figure 3-30. *Concentrations of total, nitrate and nitrite, ammonium and particulate nitrogen species in streams in the Forsmark area. Numbers within brackets represent the last digits in the ID code used in the database SICADA. Data from Appendix 1 in /Tröjbom and Söderbäck 2006b/.*

Like the carbon levels in the lakes, the level of total organic ***carbon*** in the Forsmark streams is high or very high according to EQC (Figure 3-31, Table 3-14). There are two exceptions: the inlet to Eckarfjärden, which has a significantly lower TOC content than in lake water or in water from the outlet, and the inlet to Bredviken, which exhibits the lowest TOC levels of all the investigated streams and lakes in the Forsmark area. Dissolved organic carbon constitutes most of the total organic carbon pool in streams. The content of dissolved organic carbon is, like in the lakes, very high and exhibits considerable in-site variation. The temporal variation in concentrations of DOC and TOC follows the same pattern. The levels of particulate carbon (POC) in streams are similar to those in most of the Forsmark lakes, but the streams generally show higher temporal variation of POC than lakes. The DIC content is very high and exhibits considerable in-site variation. There seems to be a certain loss of DIC in Eckarfjärden as the concentrations in the inlet are significantly higher than in the lake and in the outlet.

The ***sulphate*** levels in the Forsmark streams are within the normal range of Swedish water-courses in the national survey. However, the level is considerably lower than in other streams in the county.

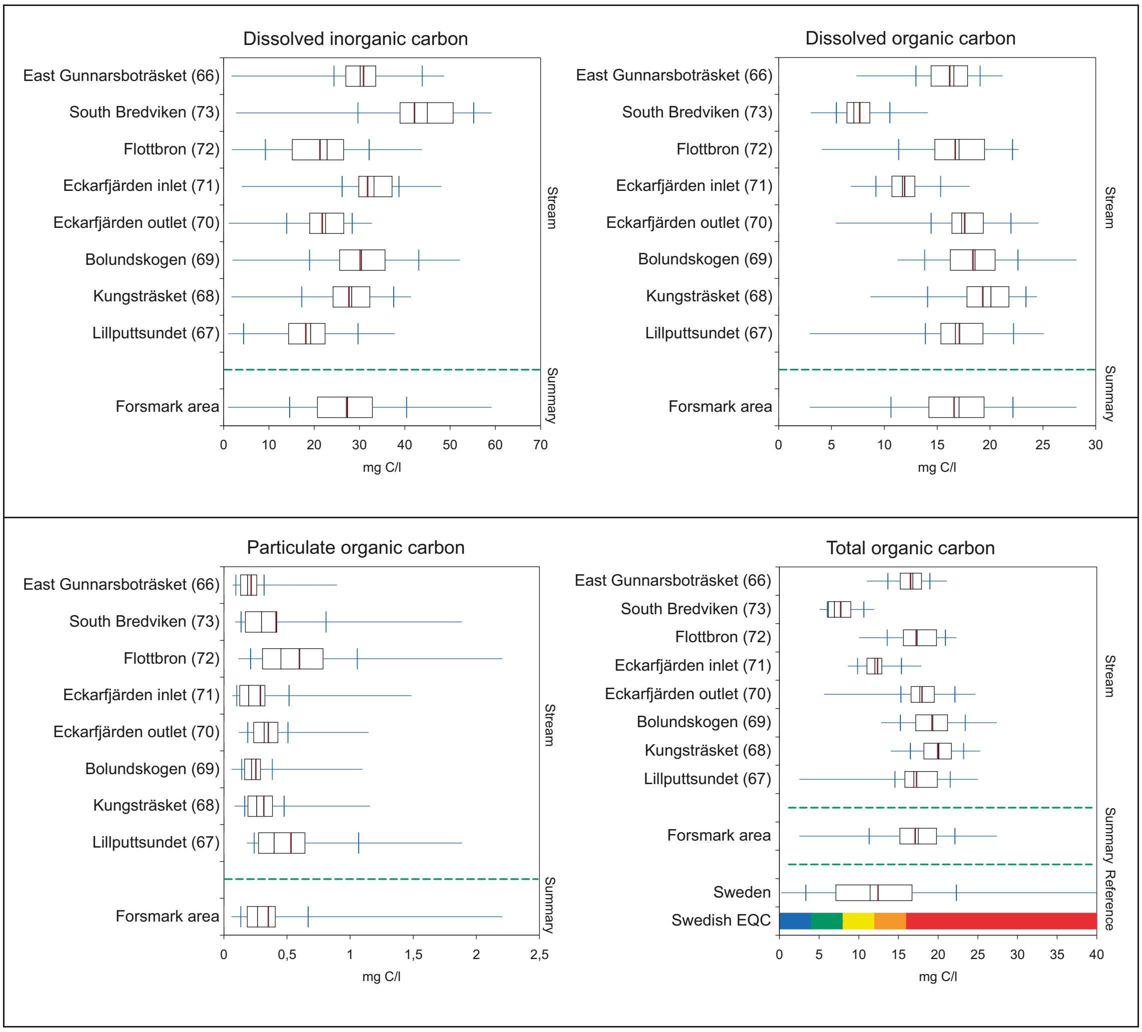


Figure 3-31. Concentrations of total, dissolved and particulate organic carbon species, as well as contents of dissolved inorganic carbon, in streams in the Forsmark area. Numbers within brackets represent the last digits in the ID code used in the database SICADA. Data from Appendix 1 in /Tröjbom and Söderbäck 2006b/.

The ***silicate*** levels in the Forsmark streams are generally within the range of most Swedish streams and rivers. An exception is the outlet from Bolundsfjärden to Norra Bassängen, which has lower values. This may be an effect of brackish water intrusions from the Baltic Sea (further discussed in section 3.3.4).

Dissolved ions

The total amount of dissolved ions is considerably higher in the streams in Forsmark than in most watercourses in Sweden. In contrast to the lakes in the area, the streams have a somewhat lower ***conductivity*** than the majority of streams in the county.

Generally, the highest levels and greatest variation of ***cations*** in the Norra Bassängen catchment are found in the lower part. These higher levels are an effect of the fact that these areas were recently submerged below the sea and therefore contain high concentrations of marine ions. The large variations are an effect of brackish water intrusion from the Baltic Sea. A major exception from this pattern is the ***calcium*** levels in the streams, as the water from the Bolundsskogen sub-catchment contains very high amounts of calcium. The ***sodium*** level is higher in the outlet from Fiskarfjärden than in the other streams (except the outlet from Bolundsfjärden) indicating that brackish water may enter the lake at high water levels in the Baltic Sea. The highest levels of ***magnesium*** and ***potassium*** are found in the inlet to Bredviken. The reason for this is not clear, but the agricultural activities within the catchment may be one explanation.

The levels of ***chloride*** and ***fluoride*** in the Forsmark streams are higher than the median Swedish watercourse in the national survey. Compared with watercourses in the county as a whole, the fluoride levels are within the normal range. The ***bromide*** levels and their variation are roughly the same as for chloride, with the highest levels and the greatest variation at the outlets from Bolundsfjärden and Fiskarfjärden and intermediate levels at Bolundsskogen and Kungsträsket. The ***iodine*** level is somewhat higher in the outlet from Fiskarfjärden and in the lower parts of the Norra Bassängen catchment.

Both the ***iron*** and ***manganese*** levels in the Forsmark streams are on the same level or slightly higher than those in other streams in the county. Compared with the Laxemar-Simpevarp streams, on the other hand, concentrations are low.

Table 3-14. Mean water chemistry (March 2002–March 2005) for major elements in the investigated streams in the Forsmark area. Percentiles, mean, minimum and maximum values have been calculated from all measurements in all the monitored streams. pH and conductivity have been measured in the field, while the other parameters are from laboratory analyses.

Element	Count	Min.	25-p	Median	75-p	Max.	Mean	SD
pH	309	6.40	7.06	7.27	7.47	8.66	7.31	0.37
Conductivity (mS m^{-1})	309	9.4	31	37	42	100	39	10
Tot-P (mg L^{-1})	320	0.0043	0.0098	0.014	0.021	0.25	0.024	0.03
POP (mg L^{-1})	312	0.0012	0.0039	0.0053	0.0082	0.14	0.0086	0.01
PO4-P (mg L^{-1})	323	<0.001	<0.001	0.0017	0.0048	0.15	0.0070	0.02
Tot-N (mg L^{-1})	320	0.48	0.78	0.95	1.2	8.0	1.1	0.7
NH_4-N (mg L^{-1})	323	<0.0005	0.0069	0.016	0.041	1.3	0.053	0.1
NO_2+NO_3-N (mg L^{-1})	323	0.00030	0.0044	0.014	0.047	5.5	0.15	0.6
PON (mg L^{-1}))	311	0.0030	0.025	0.037	0.056	0.28	0.049	0.04
TOC (mg L^{-1})	320	2.5	14	17	20	27	17	4
DOC (mg L^{-1})	319	2.9	13	17	19	28	16	5
POC (mg L^{-1})	311	0.058	0.18	0.26	0.41	2.2	0.36	0.3
SO_4-S (mg L^{-1})	317	0.55	2.9	4.7	7.1	31	6.3	5
Si (mg L^{-1})	317	0.080	1.9	3.5	4.5	8.7	3.3	2
Fe (mg L^{-1})	89	0.024	0.068	0.11	0.22	1.5	0.18	0.2
Mn (mg L^{-1})	89	<0.003	0.0080	0.014	0.039	0.65	0.034	0.07
Cations								
Ca (mg L^{-1}))	317	10	45	55	66	150	59	20
Mg (mg L^{-1})	317	0.70	3.2	4.5	6.4	17	5.5	3
Na (mg L^{-1})	317	1.9	5.6	12	22	100	17	20
K (mg L^{-1})	317	<0.4	1.9	2.3	3.1	12	2.9	2
Anions								
Cl (mg L^{-1})	313	1.5	4.7	15	36	210	26	30
HCO_3 (mg L^{-1})	315	30	140	170	200	540	180	70
F (mg L^{-1})	270	<0.2	<0.2	0.24	0.31	1.1	0.25	0.1
Br (mg L^{-1})	316	<0.2	<0.2	<0.2	<0.2	0.87	<0.2	0.1
I (mg L^{-1})	229	<0.001	0.0040	0.0050	0.0080	0.023	0.0061	0.004

Dissolved oxygen

Oxygen concentrations in streams vary over the year (Figure 3-32). The oxygen concentration in streams is affected by inflowing water, inflowing groundwater and by decomposition and production in parts of the streams with slowly flowing or standing water. The investigated streams are shallow and the water flow is generally low, especially during the summer and/or winter. The net water amounts entering the streams in the summer are limited due to high evapotranspiration. The situation is the same in the winter due to the fact that most of the surface water is kept in a frozen state, preventing inflow to the streams. This suggests that the influence of groundwater is comparatively greater during these episodes of low water flow. Groundwater generally contains very low amounts of dissolved oxygen. This means that during periods with a high proportion of groundwater in the water entering a stream, the dissolved oxygen content will be low, at least in the area close to the groundwater discharge.

The oxygen concentrations at the four measuring stations show relatively strong co-variation during most of the measurement period, but a discrepancy can be seen between the autumn of 2003 and the spring of 2004. During this period the oxygen concentrations in the outlet from Eckarfjärden (PFM000070) show high values, while minimum values are recorded in the other three locations. We have no explanation for this pattern.

Temperature

Water temperature has been measured continuously (every 10 minutes) at the four permanent automatic discharge stations in the largest streams in the Forsmark area since March/December 2004. The water temperature varied between a few tenths of a degree below zero in the winter up to well above 20°C on hot summer days with low discharge (Figure 3-33) /Johansson and Juston 2007/.

Water colour

No reliable data on water colour are available from the site investigations in the streams, but there is nothing to suggest any substantial differences between the lakes in the area. Thus, the stream can be assumed to possess moderate water colour.

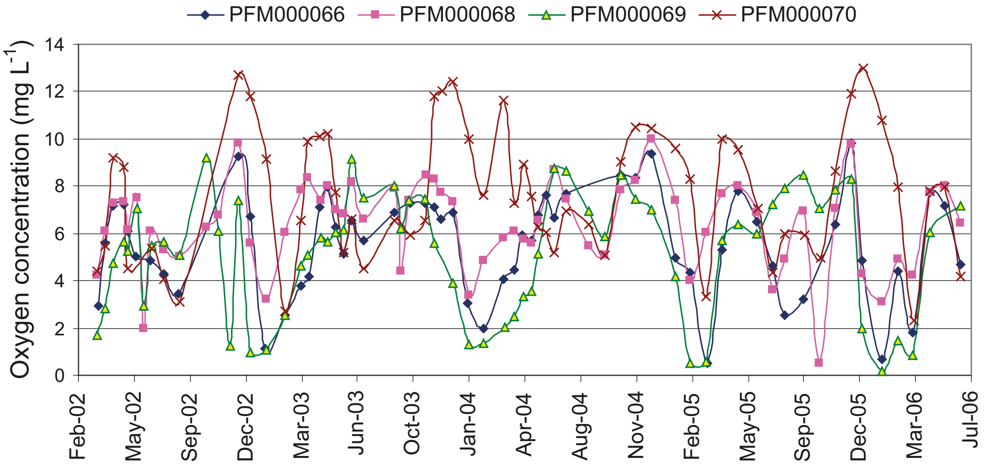


Figure 3-32. *Concentrations of dissolved oxygen in some of the streams in the Forsmark area in the period from March 2002 to June 2006. For location of the measuring stations, see Figure 3-21.*

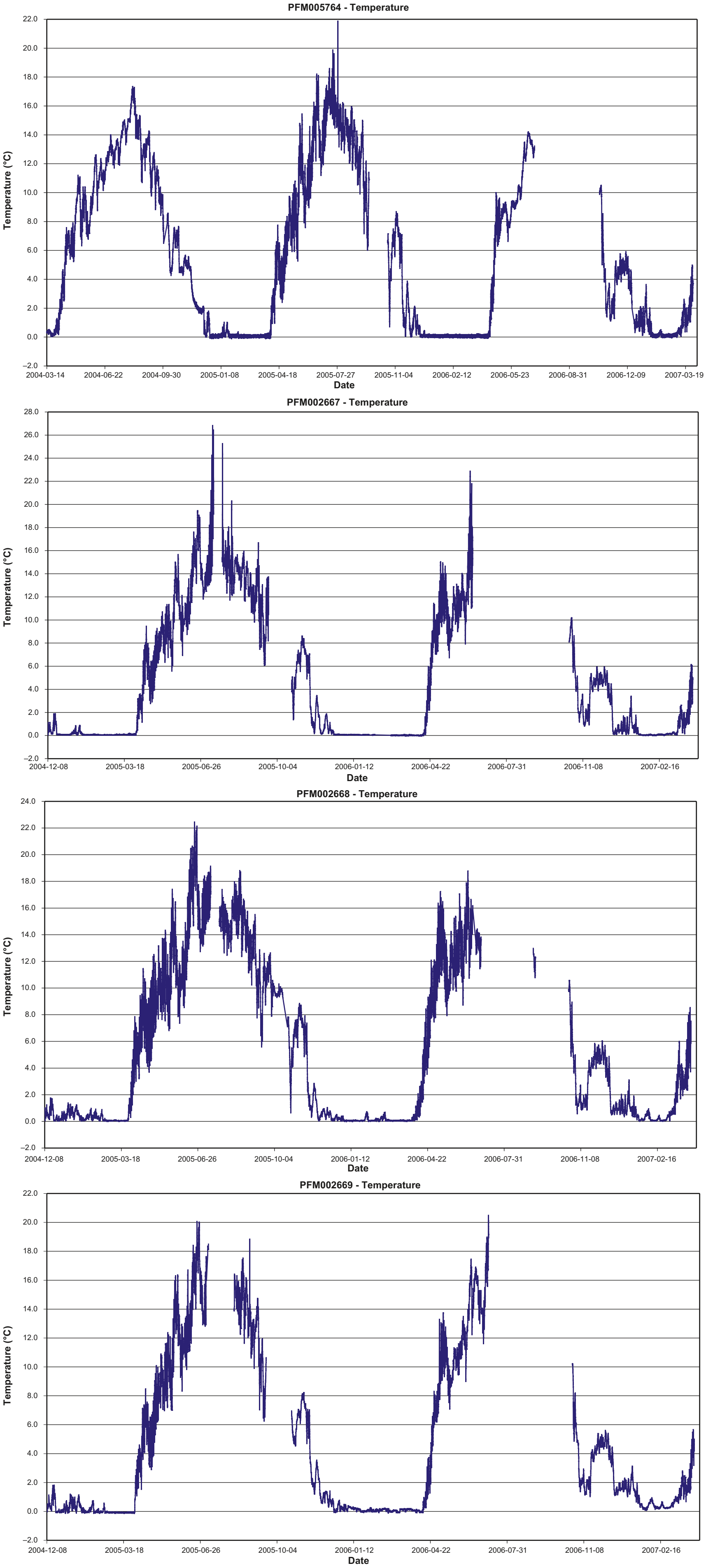


Figure 3-33. *Water temperature measured in the Forsmark streams during the period from December 2004 to March 2007. From /Johansson and Juston 2007/. For the location of the measuring stations, see Figure 3-21.*

3.9.3 Chemistry in groundwater

The shallow groundwater in the Forsmark area is characterized by high pH-values and a high content of major constituents, especially calcium and bicarbonate. "Lower" situated localities, in presumed discharge areas, are strongly influenced by marine relicts, resulting in a high content of e.g. chloride, bromide, sodium and manganese. Higher situated localities, presumably in recharge areas, show clear influences of the calcite-rich overburden, resulting in very high levels of calcium, bicarbonate and strontium. Several parameters show large discrepancies compared with national reference data. Calcium, bicarbonate and manganese median concentrations correspond to the 90th percentile of national reference data for Swedish wells, indicating very high values.

Acidity and alkalinity

The pH values are neutral or slightly basic (Table 3-15). All measurements of alkalinity are classified as very high according to EQC. The pH is generally lower in shallow groundwater compared with stream, lake and sea water. A typical pH value in shallow groundwater in Forsmark is 7.2.

Major elements (C, N, P)

Total organic ***carbon*** (TOC) concentrations are almost entirely composed of dissolved organic carbon (DOC) (Figure 3-34, Table 3-15). The concentrations of TOC and DOC are lowest in the lowest situated soil tubes located in lakes or at sea, and highest concentrations are found in high situated soil tubes.

Total ***nitrogen*** concentrations (tot-N) are highest in low situated soil tubes, while higher situated soil tubes usually show lower concentrations (Figure 3-35, Table 3-15). In soil tubes at lower levels, most of the total nitrogen usually occurs as ammonium. In contrast, in most soil tubes at higher locations, nitrogen occurs as particulate organic nitrogen.

The concentration of total ***phosphorus*** (tot-P) differs from nitrogen in displaying higher variability and the fact that the differences between high and low situated soil tubes are less accentuated (Figure 3-35, Table 3-15). Most of the phosphorus occurs as particulate species, and in general only a small fraction of the total phosphorus consists of phosphate.

Major constituents

Major constituents of the groundwater are generally calcium, chloride, magnesium, silica, sodium, sulphate and carbonic acid. The shallow groundwater in the Forsmark area can be divided into two main water types with respect to content of major constituents: the Ca-HCO_3 type that is found in higher situated soil tubes (presumably recharge areas) and the Na-CHO_3 or Na-Cl types that are found in most lower situated soil tubes (presumably discharge areas). The major constituents of sea water – e.g. chloride, sodium, magnesium and sulphate – occur in elevated levels in many of the soil tubes due to the influence of relict marine water.

Calcium concentrations are considerably elevated in the Forsmark area compared with both regional and national wells. Especially high calcium concentrations are found in soil tubes located below lakes or at sea. There are relatively small differences between calcium concentrations in low and high situated soil tubes. Calcium concentrations are generally higher in shallow groundwater compared with stream, lake and sea water.

Magnesium concentrations are slightly elevated compared with regional and national wells. The magnesium concentrations in shallow groundwater are generally higher than in stream and lake water but of the same magnitude or lower than in sea water.

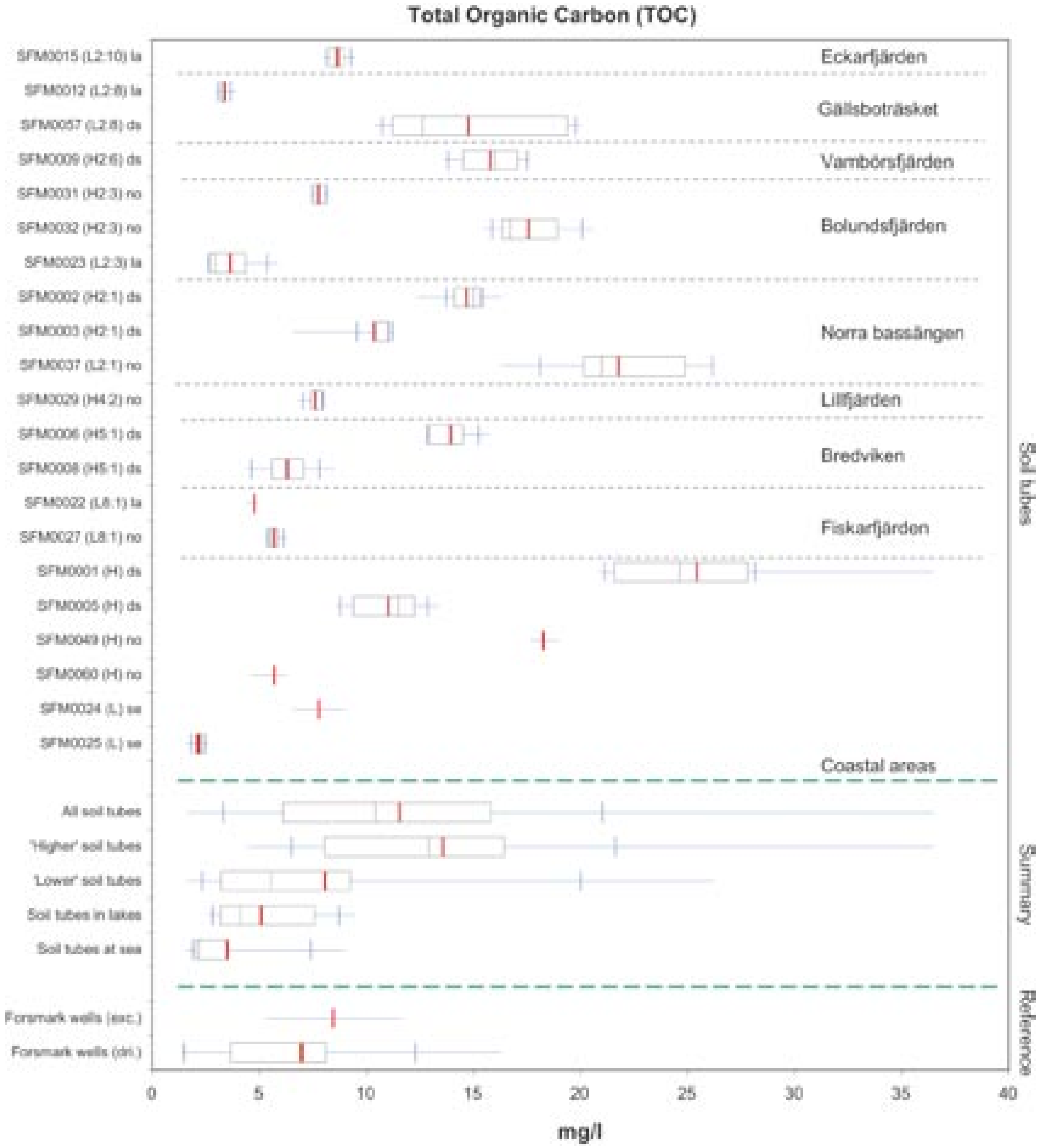


Figure 3-34. *Total organic carbon in shallow groundwater in the Forsmark area. The annotation within brackets denotes the position of the sampled soil tubes ('higher' (H) or 'lower' (L) location according to /Tröjbom and Söderbäck 2006b/, the sub-catchment number, and finally the supplementary information as to whether the soil tube is located at a drill site (ds), in till below lake sediments (la) or sea sediments (se). The rest of the soil tubes are marked 'no'.*

Sodium concentrations in higher situated soil tubes are on the same level as concentrations in most Swedish wells. Sodium concentrations in lower situated soil tubes show considerably elevated concentrations, however. The lowest concentrations are found at topographical heights, indicating that marine relict is the major factor behind the sodium pattern. The sodium concentrations are generally higher in shallow groundwater than in stream and lake water but on the same magnitude as in sea water.

The concentrations of ***silica*** range from 1–10 mg L^{-1} with a typical concentration of 5 mg L^{-1}. This is about half the concentration measured in soil tubes in the Laxemar-Simpevarp area.

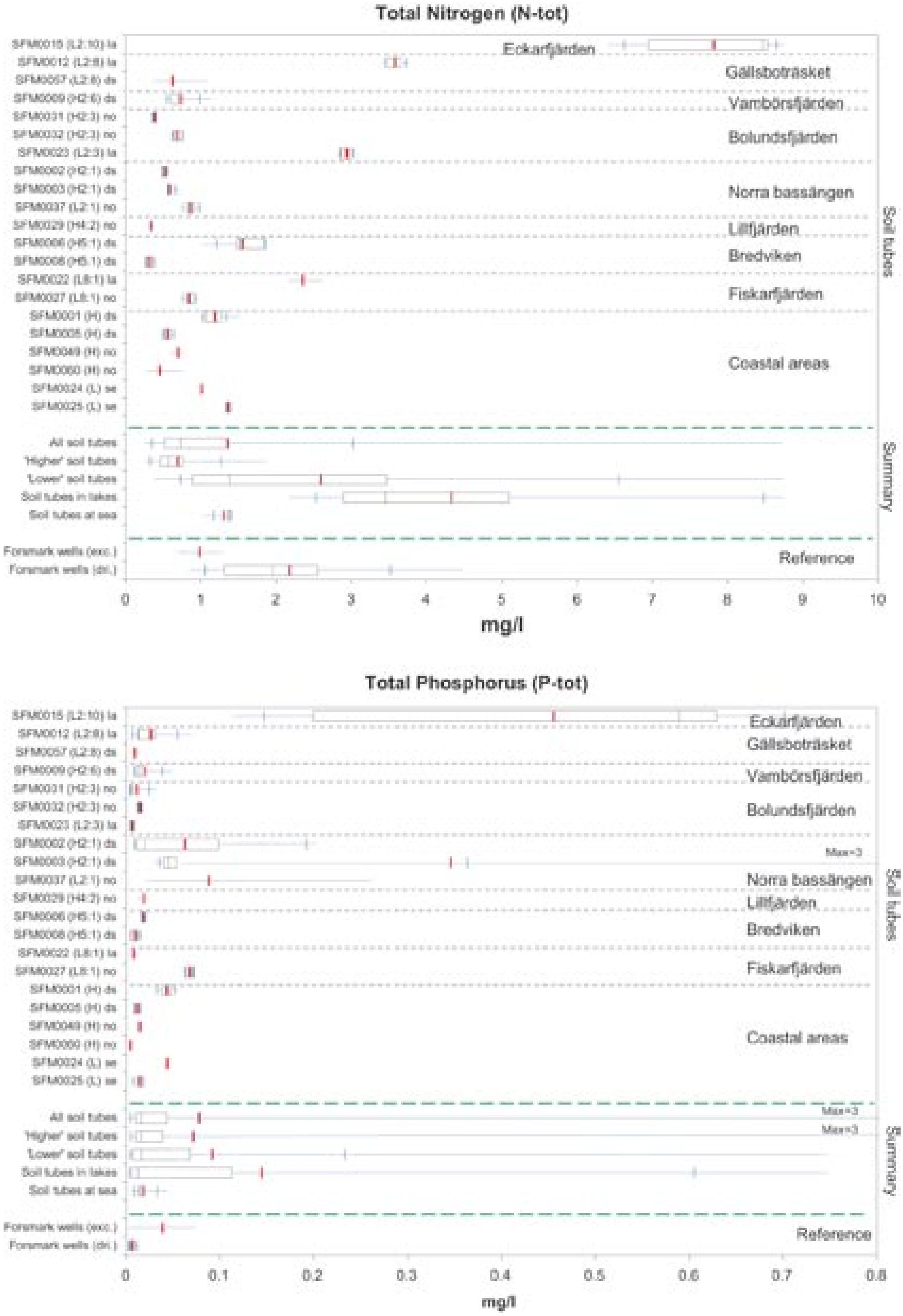


Figure 3-35. *Concentration of a) total nitrogen and b) total phosphorus in shallow groundwater in the Forsmark area. The annotation within brackets denotes the position of the sampled soil tubes ('higher' (H) or 'lower' (L) location according to /Tröjbom and Söderbäck 2006b/, the sub-catchment number, and finally the supplementary information as to whether the soil tube is located at a drill site (ds), in till below lake sediments (la) or sea sediments (se). The rest of the soil tubes are marked 'no'.*

Table 3-15. Mean water chemistry (July 2002–February 2005) for major elements in the shallow groundwater in the Forsmark area. Percentiles, mean, minimum and maximum values have been calculated from all measurements in all the locations (soil tubes). Parameters have been measured by laboratory analyses.

Element	Count	Min.	25-p	Median	75-p	Max.	Mean	SD
pH	178	6.38	7.08	7.22	7.39	8.04	7.25	0.27
Conductivity (mS m^{-1})	171	36	68	86	200	1,200	210	300
Tot-P (mg L^{-1})	108	0.0029	0.0096	0.015	0.043	3.0	0.076	0.3
POP (mg L^{-1})	10	0.0048	0.019	0.031	0.052	7.7	0.90	2
PO4-P (mg L^{-1})	128	<0.0005	0.0019	0.0050	0.012	0.20	0.012	0.02
Tot-N (mg L^{-1})	111	0.26	0.51	0.72	1.3	8.7	1.3	2
NH_4-N (mg L^{-1})	128	<0.0005	0.032	0.092	0.47	8.6	0.86	2
NO_2+NO_3-N (mg L^{-1})	126	<0.0002	0.00033	0.0016	0.011	0.85	0.048	0.1
PON (mg L^{-1})	10	0.0042	0.0083	0.032	0.037	0.055	0.026	0.02
TOC (mg L^{-1})	128	1.6	6.1	10	16	36	11	7
DOC (mg L^{-1})	127	2.1	6.6	11	16	37	12	7
POC (mg L^{-1})	10	0.15	0.42	0.55	0.82	0.97	0.57	0.3
DIC (mg L^{-1})	124	8.1	49	62	72	140	62	30
SO_4-S (mg L^{-1})	199	0.25	8.4	16	43	120	30	30
Si (mg L^{-1})	199	1.0	5.0	6.3	7.8	14	6.4	2
Fe ((mg L^{-1})	135	<0.02	0.16	1.3	2.3	510	6.3	40
Mn (mg L^{-1})	139	0.0027	0.11	0.17	0.24	1.4	0.23	0.2
Cations								
Ca (mg L^{-1})	197	29	91	110	140	680	150	100
Mg (mg L^{-1})	199	4.2	8.5	13	35	180	32	40
Na (mg L^{-1})	197	2.2	17	37	260	1,600	240	400
K (mg L^{-1})	197	1.7	5.0	7.8	18	70	14	10
Anions								
Cl (mg L^{-1})	196	4.2	18	56	340	3,800	460	900
HCO_3 (mg L^{-1})	199	72	320	360	420	770	370	100
F (mg L^{-1})	195	<0.2	0.34	0.55	0.66	2.3	0.53	0.3
Br (mg L^{-1})	199	<0.2	<0.2	0.23	1.3	20	2.0	4
I (mg L^{-1})	157	<0.001	0.0050	0.0070	0.021	0.11	0.016	0.02

Chloride concentrations differ between low and high situated soil tubes. Concentrations in high situated soil tubes are only slightly elevated compared with Swedish wells, while concentrations in low situated soil tubes are considerably elevated. Chloride concentrations in lower situated soil tubes are generally higher compared with stream and lake water. Soil tubes at higher levels show concentrations at lower or the same levels as in stream and lake water.

Sulphate concentrations are elevated 3–6 times compared with concentrations in most Swedish wells. The lowest sulphate concentrations are found at topographical heights. The sulphate concentrations are generally higher in shallow groundwater than in stream and lake water, but lower or of the same magnitude as in sea water.

Bicarbonate concentrations are elevated ten times compared with concentrations in most Swedish wells. Bicarbonate concentrations are generally higher in shallow groundwater than in stream, lake and sea water. Except for very high concentrations in the soil tube in Eckarfjärden and very low concentrations in the soil tube in Bolundsfjärden, the bicarbonate concentrations are rather uniformly distributed in the area.

Redox potential

No calculations based on redox pairs have been performed to evaluate the redox potential. However, a simplified classification based on iron, manganese and sulphate is presented /Tröjbom and Söderbäck 2006b/. The redox potential in most soil tubes is low according to EQC and there are only two exceptions with a high redox potential. In soil tubes with a low redox potential, concentrations of hydrogen sulphide are usually elevated and the fraction of Fe^{2+} of total iron is usually substantial. In soil tubes with a high redox potential, on the other hand, the fraction of Fe^{2+} is lower than 50% of total iron.

Iron and ***manganese*** concentrations in Forsmark wells are higher compared with Swedish wells, indicating elevated levels in shallow groundwater in the area. The iron and manganese concentrations are generally higher in shallow groundwater compared with stream, lake and sea water.

3.10 Biota

3.10.1 Biota in lakes

In Forsmark, the biomass in lakes is strongly concentrated to the benthic habitat where the macroalgae C*hara sp.* is very abundant and where there is a thick microbial mat consisting of heterotrophic bacteria and microphytobenthos. The biomass of pelagic microbiota (phytoplankton, bacterioplankton) is low and also zooplankton biomass is low. The fish biomass varies between investigated lakes and is close to the regional average in some lakes, but only half of the regional average in others.

The biomass of biota in the lakes has been thoroughly investigated and primary production measurements have been performed for some organisms. Annual averages of both biomass and primary production have been calculated from monthly means. All species found in the site investigations are listed in Appendix 4.

Biomass of primary producers

The ***phytoplankton*** biomass in the Forsmark lakes is low. The annual mean biomass in Eckarfjärden, estimated by microscopic counts, was 41 mg C m^{-3} (n=3 years based on a total of 36 samples, SD = 17 mg C m^{-3}, min. annual mean 22 mg C m^{-3}, max. annual mean 57 mg C m^{-3}) with a seasonal variation showing maximum values in summer and minimum in winter (Figure 3-36) /Blomqvist et al. 2002, Andersson et al. 2003/. The highest recorded biomass was 184 mg C m^{-3} and occurred in June 2000. The phytoplankton biomasses are in agreement with literature values: according to /Wetzel 2001/ the phytoplankton biomass in oligotrophic lakes ranges between 20–100 mg C m^{-3}. Phytoplankton in Eckarfjärden is dominated by mixotrophic species (mainly chrysophytes), that is, species that are able to consume bacteria as an energy source in addition to photosynthesis. This is often an indication of nutrient or light limitation. Light conditions in Eckarfjärden are good, but the dominance of mixotrophic species corresponds well to the relatively low inorganic phosphorus concentrations measured in the lake. The measured phytoplankton biomass in Bolundsfjärden was of the same order of magnitude as the phytoplankton biomass in Eckarfjärden (n=6 samples) /Franzén 2002/. However, the species composition differed and the community was instead dominated by truly autotrophic cyanobacteria. Chl *a* concentrations, which is another estimate of the phytoplankton biomass, were low to moderate in 6 studied lakes (Table 3-16) /Tröjbom and Söderbäck 2006b, Naturvårdsverket 2000/. The only lake that deviates some from the rest is Fiskarfjärden, showing somewhat higher chl *a* concentrations. Fiskarfjärden is the lake with the highest nutrient concentrations in the area.

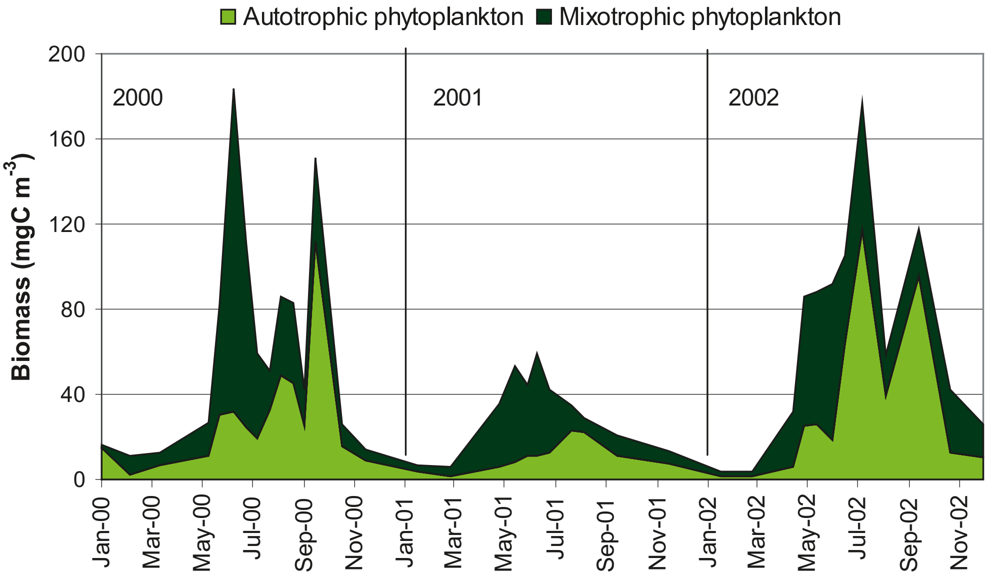


Figure 3-36. *Phytoplankton biomass (mg C m^{-3}) in Eckarfjärden during 2000 to 2002. A large part of the phytoplankton community is made up of mixotrophic species. Data from /Blomqvist et al. 2002, Andersson et al. 2003/.*

The biomass of the ***microphytobenthos*** in the Forsmark lakes is extremely high. An unusually thick microbial mat is found in the benthic habitat of Eckarfjärden with chlorophyll down to a depth of 10–15 cm (Figure 3-37) /Andersson et al. 2003/. The mean annual biomass of the microphytobenthos measured in the top 5 cm of the microbial mat was 3.8 g C m^{-2} (n=3 years based on 39 samples, standard deviation 1.7, min. annual mean=2.8 g C m^{-2}, max. annual mean=5.8 g C m^{-2}). There is a seasonal fluctuation with a summer maximum, but the seasonality is less pronounced than for phytoplankton (Figure 3-38). The highest recorded biomass of the microphytobenthos in the top 5 cm of the microbial mat was as high as 13 g m^{-2}. The microbial mat is dominated by non-nitrogen fixing cyanobacteria and purple sulphur bacteria. Some pennate diatoms and a few green algae are also present. Some species of cyanobacteria are known o produce toxins that may inhibit other organisms. Toxins was not found in analysis of microphytobenthos in Eckarfjärden (E. Andersson, unpublished) indicating that the microbial mat is composed of non-toxic species. The purple sulphur bacteria thrives at the boundary between oxic and anoxic conditions, and in the winter a distinct purple layer could often be seen at varying depth in the microbial mat. The biomass of the microphytobenthos in Bolundsfjärden (n=5) was in the same magnitude as in Eckarfjärden.

Table 3-16. Chl *a* concentrations (*µg L^{-1}*) in lakes in the Forsmark area (surface samples). Fiskarfjärden are represented twice, reflecting two different sampling sites within the lake (data from /Tröjbom and Söderbäck 2006b/).

Lake	Count	Min	Max	Median	Mean	SD
Labboträsket	43	<0.5	5.6	1.0	1.2	1.13
Gunnarsbo-Lillfjärden	41	<0.5	6.6	1.3	1.6	1.46
Eckarfjärden	48	<0.5	3.7	1.7	1.8	0.98
Bolundsfjärden	48	<0.5	6.6	1.5	1.9	1.63
Norra bassängen	36	<0.5	6.1	1.2	1.4	1.19
Fiskarfjärden NW	14	1.1	16	5.1	7.0	5.13
Fiskarfjärden SE	19	<0.5	18	1.8	3.3	4.62

***Figure 3-37.** Sediment sample from Eckarfjärden showing the microbial mat in the top 10 cm.*

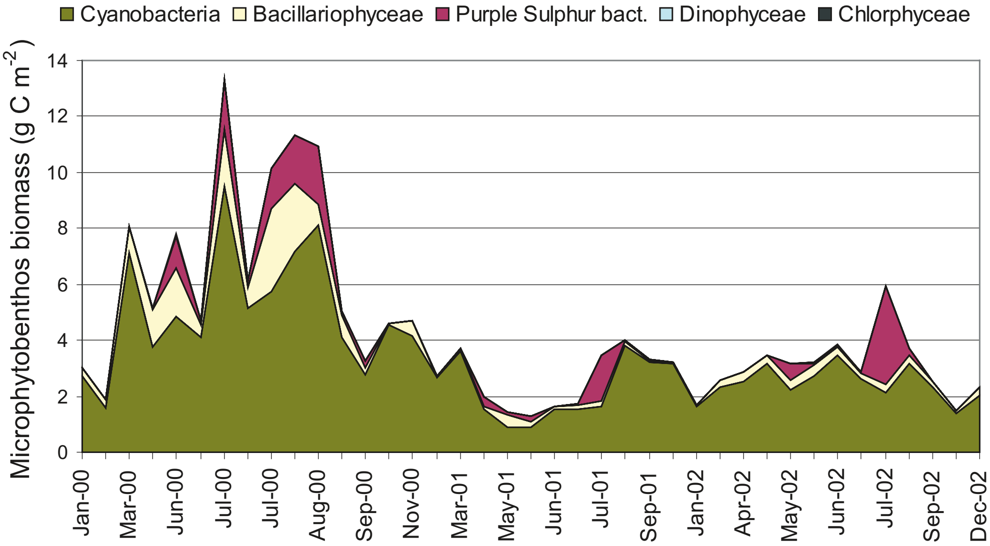


***Figure 3-38.** Biomass of the microphytobenthos in the top 5 cm of the microbial mat in Eckarfjärden during the period January 2000 to December 2002. Note that the biomasses of Dinophyceae and Chlorophyceae are too small in comparison with the cyanobacteria to be visible in the graph. Data from /Blomqvist et al. 2002, Andersson et al. 2003/.*

The thickness of the microbial mat has been investigated in 5 lakes in the winter and in 8 lakes in the summer (Table 3-17). Overall, the microbial mat in the Forsmark area is remarkably thick compared with that in other lakes. The microphytobenthos reaches several centimetres and sometimes even decimetres in thickness, whereas in most lakes the microbial mat is usually only a few millimetres thick /e.g. Hargrave 1969, Wiltshire 2000/. In the winter investigations, a microbial mat was found in all 5 investigated lakes: Eckarfjärden, Bolundsfjärden, Fiskarfjärden, Gunnarsbo-Lillfjärden and Labboträsket (Table 3-17). In the latter, however, only one centimetre of algal mat was found in one of 16 samples. In the summer study, a substantial microbial mat was also observed in Stocksjön, Vambörsfjärden and Fräkengropen, whereas one other lake in the area (Lillfjärden) was found to have a very thin algal layer (Andersson and Brunberg unpublished). No microbial mat was found in Labboträsket in 7 replicates in the summer investigation, and this, along with the fact that only one out of 16 samples in the winter contained a microbial mat, shows that the microbial mat in Labboträsket is practically absent.

Occasions with pieces of microbial mat being detached from the benthic habitat in the spring have been reported in Eckarfjärden and could potentially exist in the other lakes as well (Figure 3-39) /Andersson 2005/. The reason for this has not been investigated, but it can be speculated that strong winds in the spring and bad conditions of the microbial mat immediately after ice break-up are responsible.

Four species of ***emergent macrophytes*** were noted in a quantitative investigation of macrophytes in Eckarfjärden /Andersson et al. 2003/: common reed (*Phragmites australis*), bulrush (*Typha sp.*), common club-rush (*Schoenoplectus lacustris*), and water horsetail (*Equisetum fluviatile*). The by far most common species were *P. australis* and *Typha sp.* (Table 3-18). The average biomass of emergent macrophytes within Littoral I was 458 g dry weight m^{-2} which corresponds to a biomass of 181 g C m^{-2} assuming a conversion factor of 0.395 g C g dw^{-1} (from /Kautsky 1995/). Although the reed stands are dense, the biomass is rather low compared with the reed biomass in Frisksjön in the Laxemar-Simpevarp area (287 g C m^{-2}) and only 1/3 of the biomass in a lake in northern Germany (687 g C m^{-2}) /Gessner et al. 1996/. Still, the biomass is within the same order of magnitude as in the studies above, and the number of reed straws (49 m^{-2}) is similar to what is reported from a lake in the Netherlands (53 m^{-2}) /Meulemanns 1988/. The biomass can therefore be considered to be within reported values in literature.

Table 3-17. Thickness of the microbial mat (cm) in lakes in the Forsmark area in the winter (w) /Borgiel 2004a/ and summer (s) (Andersson and Brunberg, unpublished).

Lake	Number of samples	Depth interval	Mean	Median	Min	Max	SD
Eckarfjärden (w)	17		1.9	2.5	0	5	2.0
Bolundsfjärden (w)	17		3.0	3.8	0	7	2.8
Fiskarfjärden (w)	17		1.7	0.5	0	7	2.3
Gunnarsbo-Lillfjärden (w)	16		4.6	5.0	1	8	2.4
Labboträsket (w)	16		0.1	0.0	0	1	0.3
Eckarfjärden (s)	15	0.1–2.0	6	6	1	12	2.7
Bolundsfjärden (s)	9	0.5–1.5	1	1	0	2	0.8
Labboträsket (s)	7	0.05–1.0	0	0	0	0	0.0
Lillfjärden (s)	3	0.2–0.3	0	0	0	0.01	0.0
Stocksjön (s)	6	0.15–0.5	20	20	8	30	11.4
Vambörsfjärden (s)	9	0.1–0.85	6	6	3	14	0.5
Fräkengropen (s)	7	0.1–0.27	4	4	4	5	3.3
Fiskarfjärden (s)	10	0.25–2.0	8	8	0	11	3.2

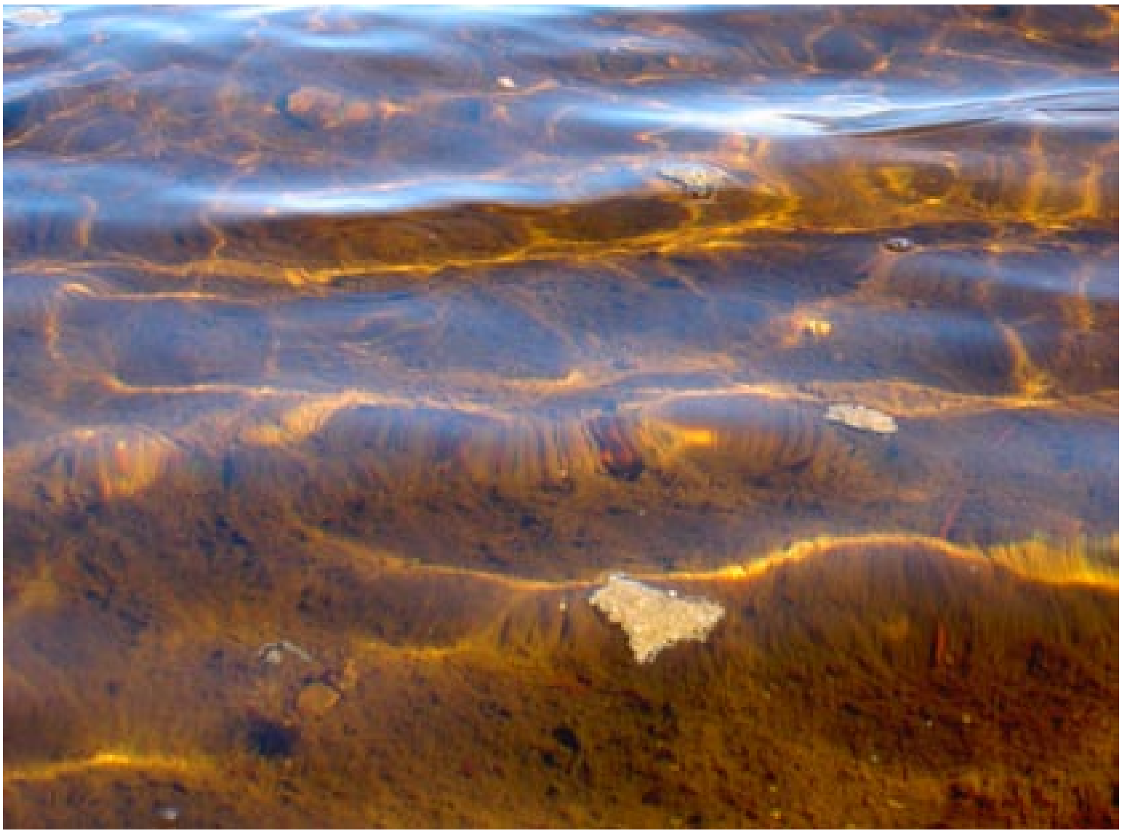


***Figure 3-39.** Occasionally in the spring, parts of the microbial mat detach from the benthic habitat and floats to the surface.*

Table 3-18. Biomass (mean ± SD) of emergent macrophytes in areas containing that macrophyte species, and coverage (m²) of lake area in Eckarfjärden /Andersson et al. 2003/. Note that *Typha sp.* and *Schoenoplectus lacustris* are growing within the stand of *Phragmites* and therefore the total area of macrophytes is smaller than the sum of areas of separate macrophyte species.

Species	Biomass g dw m^{-2}	Coverage in Eckarfjärden (m²)	Carbon biomas g C m^{-2}
Phragmites australis	296 (316)	82,287	74
Typha sp.	184 (246)	3,511	13
Schoenoplectus lacustris	54 (11)	88,424	117
Equisetum fluviatile	34 (27)	7,267	21
Total macrophytes		**91,935**	**181**

The biomass of ***submerged vegetation*** investigated in Fiskarfjärden /Huononen 2005/ and Bolundsfjärden /Huononen 2005, Karlsson and Andersson 2006/ is generally high, and dense mats of the macroalgae *Chara spp.* are found in the benthic habitat (Figure 3-40, Table 3-19). The biomass of submerged vegetation exhibits great spatial variation within the lakes. In Bolundsfjärden, the biomass ranged between 0 and 475 g C m^{-2} and the median biomass was 22 g C m^{-2} (83 g dw m^{-2}, n=60) /Karlsson and Andersson 2006/. There was a clear seasonal distribution in Bolundsfjärden with the highest biomass at midsummer and lower at the beginning and end of the growing season (Table 3-19). The median biomass of submerged vegetation (22 g C m^{-2}) from Bolundsfjärden is within the range of *Chara* biomass reported in the literature (42–500 g dw m^{-2}, which using the same conversion factor as in this study corresponds to 11–134 g C m^{-2}) /Kufel and Kufel 2002/.

Figure 3-40. *Dense stands of the macroalgae Chara spp. are often found in the benthic habitat of the lakes in Forsmark.*

Three species of submerged vegetation were identified in Bolundsfjärden and Fiskarfjärden: *Chara baltica*, *C. tomentosa* and *C. intermedia*. The latter was found in Fiskarfjärden and is classified as "Near threatened" according to www.artdata.slu.se/rodlista, accessed 2008-04-17. The abundance and biomass of other submerged macrophytes was low, and only two species were noted in the quantitative investigations: *Potamogeton pectinatus* and *Najas marina* /Huononen 2005, Karlsson and Andersson 2006/. In addition, the species *Potamogeton filiformus* and *P. natans* were noted although not quantified in Eckarfjärden /Brunberg et al. 2004a/.

Table 3-19. Biomass of the submerged vegetation (mainly *Chara spp.*) in Bolundsfjärden and Fiskarfjärden.

	Median value (g dw m^{-2})	Minimum value (g dw m^{-2})	Maximum value (g dw m^{-2})	Number of samples
Bolundsfjärden /Karlsson and Andersson 2006/				
June–September 2006	83	0	1,774	60
June 2006	81	0	1,060	20
July 2006	209	0	1,239	20
September 2006	51	0	1,774	20
Bolundsfjärden /Huononen 2005/				
September 2004	99	0	2,005	10
Fiskarfjärden /Huononen 2005/				
September 2004	43	0	934	10

Primary production

The net primary production (NPP) of ***phytoplankton*** in Eckarfjärden was measured by ^{14}C incorporation during a two-year period (2001–2002, n=18) (Figure 3-41) /Blomqvist et al. 2002, Andersson et al. 2003/. The mean annual NPP was 24 g C m^{-2} y^{-1} (n=2 years, min. 23.2 g C m^{-2} y^{-1}, max. 25.5 C m^{-2} y^{-1}) and thereby relatively low compared with the median NPP (100 g C m^{-2} y^{-1}) in 35 clear-water lakes reviewed by /Nürnberg and Shaw 1999/. However, the range of NPP in clear-water lakes is large and the NPP in Eckarfjärden is well within the reported range (1–1,403 g C m^{-2} y^{-1}) /Nürnberg and Shaw 1999/. There was a clear summer maximum and winter minimum in the production (Figure 3-41). The maximum phytoplankton production observed in the summer was 24 mg C m^{-2} h^{-1}.

The annual ***microphytobenthos*** production in Eckarfjärden was twice the phytoplankton production on an areal basis, 56 g C m^{-2} y^{-1} (Figure 3-41) (based on 16 samplings during 2001 and 2002, n=2 years, min. 34 g C m^{-2} y^{-1}, max. 77 g C m^{-2} y^{-1}) /Blomqvist et al. 2002, Andersson et al. 2003, Andersson and Brunberg 2006a/. There was a clear summer maximum and winter minimum in production. The maximum recorded production was 144 mg C m^{-2} h^{-1} (July 2001). The production at a depth of 1.5 m was assumed to be the average microphytobenthos production in the entire lake area. Values of primary production from literature are not always easily compared since they are estimated by different methods and therefore presented in different units. Moreover, few studies cover entire years but more often present productions for separate dates. However, a few whole-year studies of microphytobenthos production in lakes in the literature suggest that primary production in Eckarfjärden is within reported values although in the higher range /Hargrave 1969, Gruendling 1971, Björk-Ramberg 1981, Björk-Ramberg and Ånell 1985, Heat 1988/. This is expected considering the very high abundance of microphytobenthos in the Forsmark lakes compared with other lakes (see above).

The production of ***emergent macrophytes*** in Eckarfjärden, estimated as the maximum standing stock in Littoral I in August, was on average 458 g dw m^{-2} y^{-1} (which is equivalent to 181 g C m^{-2} y^{-1}) /Andersson et al. 2003/. This biomass and thereby the production is rather low compared with the reed biomass in Lake Frisksjön in Laxemar-Simpevarp area and compared with a lake in northern Germany (687 g C m^{-2})

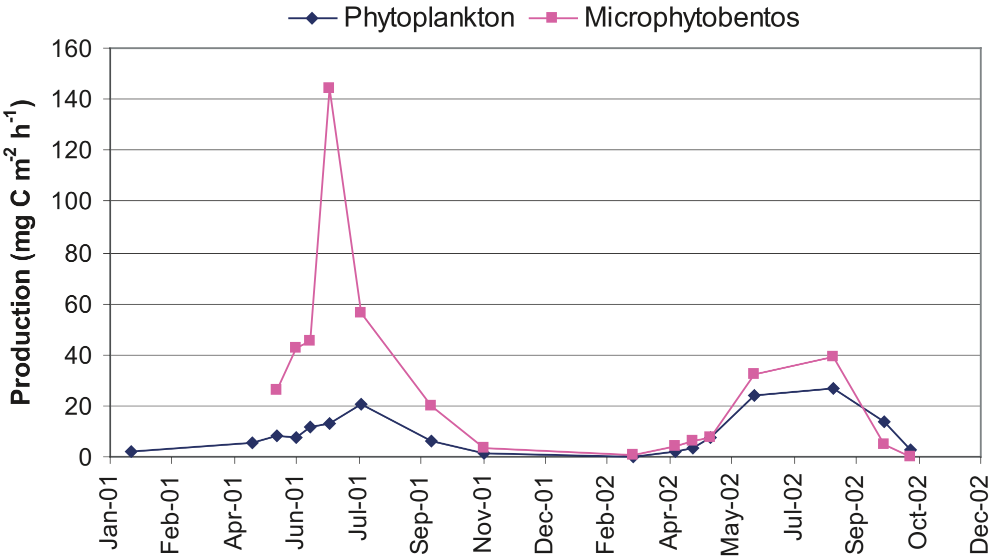


Figure 3-41. *Primary production of phytoplankton and microphytobenthos in Eckarfjärden during the period 2001–2002. Data from /Blomqvist et al. 2002, Andersson et al. 2003/.*

The net primary production of the ***macroalgae Chara sp.*** in Bolundsfjärden varied seasonally, with highest production in July (118 mg C m^{-2} h^{-1}), intermediate production in June (34 mg C m^{-2} h^{-1}) and low production in September (11 mg C m^{-2} h^{-1}) /Karlsson and Andersson 2006/. The estimated yearly net primary production of macroalgae in Bolundsfjärden was high, approximately 87 g C m^{-2} y^{-1} (n=1 year based on 5 replicates at 3 occasions net primary production during day: 108 g C m^{-2} y^{-1}, night respiration: 21 g C m^{-2} y^{-1}). Annual net primary production of submerged vegetation was calculated assuming a direct linear response between net primary production and light, and by subtracting night respiration which was calculated by assuming the same respiration at night as measured in dark bottles during the day. The respiration varied from 3 mg C m^{-2} h^{-1} (in September) to 35 mg C m^{-2} h^{-1} (in July). As the annual production is based on measurements from only three occasions, the value is somewhat uncertain. However, the estimate should provide a realistic picture of the magnitude of production of submerged vegetation, and the primary production is within reported values from the literature. The production is similar to that reported for a lake in Northern Poland /Pereyra-Ramos 1981/ but small compared with reported *Chara* production in Oakland, USA /Hough and Putt 1988/.

Biomass of consumers

Heterotrophic bacteria make up a substantial part of the microbial mat in the lakes /Blomqvist et al. 2002, Andersson et al. 2003, Andersson and Brunberg 2006a/. The annual mean biomass of ***benthic bacteria*** in Eckarfjärden was 3.7 g C m^{-2} (n=3 years and 36 samplings, SD = 0.58, min. annual mean 3.0 g C m^{-2}, max. annual mean 4.2 g C m^{-2}), which was almost the same as that of the microphytobenthos (mean 3.8 g C m^{-2}, SD = 0.026). The seasonal fluctuation of benthic bacteria was high and the biomass varied between 1,021 and 8,212 mg C m^{-2} (Figure 3-41). The number of sediment bacteria can vary within a wide span, but typically ranges between 10^8 and 10^{10} cells per ml sediment /Schallenberg 1989/. The benthic bacterial number in Eckarfjärden is 10^9 cells per ml sediment and thus within the reported range.

The annual mean biomass of ***bacterioplankton*** in Eckarfjärden was 54 mg C m^{-3} (n= 3 years and 27 samples) and much lower than biomass of benthic bacteria (about 2% of the benthic bacterial biomass on an areal basis in a water column with the mean depth 1.2 m). As for benthic bacteria, the seasonal fluctuation of the bacterioplankton biomass was high, between 11 and 164 µg C L^{-1}. The estimated bacterioplankton biomass 0.05 g C m^{-3} is within reported values from the literature, although the bacterial number (1.1×10^6 cells ml^{-1}) is somewhat low compared with the median cell number (3.3×10^6 cells ml^{-1}) for 91 clear-water lakes /Nürnberg and Shaw 1999, Wetzel 2001/.

The annual mean meta-***zooplankton*** biomass in Eckarfjärden was low, 0.057 g C m^{-3} (based on 8 sampling occasions in 2002) (data from /Blomqvist et al. 2002, Andersson et al. 2003/). In addition there were on average 0.007 g C m^{-3} ciliates (annual average, n=2 year and 26 samples, min. 0.003 g C m^{-3}, max. 0.012 g C m^{-3}) and 0.0016 g C m^{-3} heterotrophic flagellates (annual average, n=3 year and 38 samples, min. 0.009 g C m^{-3}, max. 0.029 g C m^{-3}). /Gyllström et al. 2005/ showed that the zooplankton biomass in 81 shallow European lakes was correlated to phosphorus concentrations, and the observed zooplankton biomass together with the phosphorus concentration in Eckarfjärden fit well into their correlation graph. Thus, although the zooplankton biomass (0.07 g C m^{-3}) was at the lower end of the 81 shallow European lakes (0.0047–5.151 g dw m^{-3}, equivalent to 0.02–2.3 g C m^{-3} /Gyllström et al. 2005/), it is a realistic estimate due to the low phosphorus concentrations in the Forsmark lakes. The metazooplankton community was dominated by copepods in winter and rotifers (mainly *Polyarthra*) in summer. The metazooplankton biomass in Eckarfjärden showed an opposite seasonal trend compared with most other Swedish lakes, with a summer minimum and winter maximum (Figure 3-42). One explanation for this seemingly inverse seasonal trend could be that the copepods are mainly benthic, but are forced to move to higher strata in the winter when oxygen concentrations near the bottom are low. Another possible explanation is a high grazing pressure by fish in the summer.

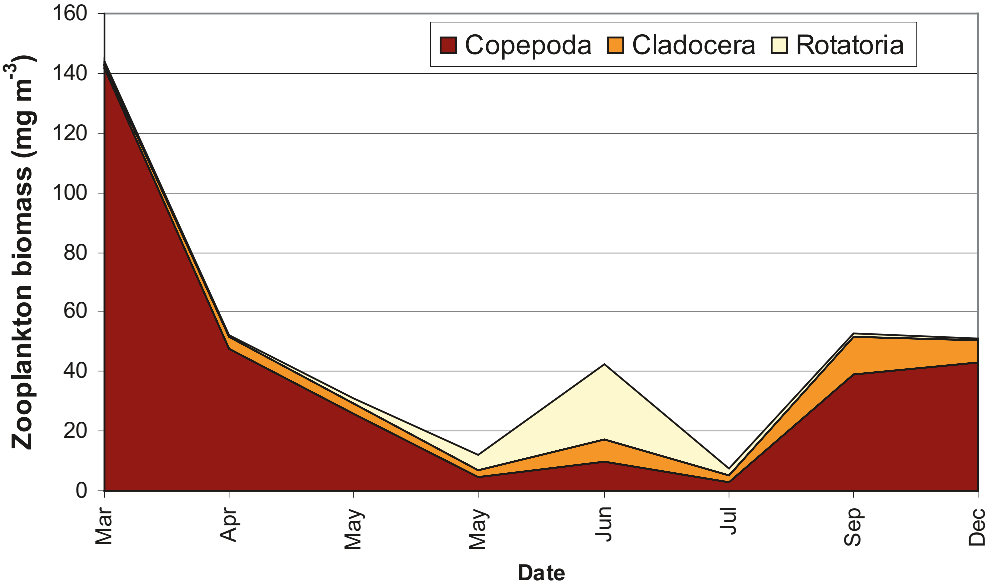


***Figure 3-42.** Metazooplankton biomass in Eckarfjärden during the period March 2002 to December 2002.*

The biomass of ***benthic fauna*** in Eckarfjärden, Bolundsfjärden, and Fiskarfjärden is generally relatively low /Andersson et al. 2003, Huononen 2005/. Different sampling techniques gave different results in terms of biomass and dominant species (Table 3-20). The estimated biomass of benthic fauna in Eckarfjärden, based on sampling with an Ekman grabber, was 0.47 g dw m^{-2}, which is in the same order of magnitude as the corresponding estimates for biomass in Bolundsfjärden and Fiskarfjärden (0.57 g dw m^{-2} in both lakes). The estimated biomass of benthic fauna in Bolundsfjärden based on sampling with a frame (2.03 g dw m^{-2}) was considerably higher than the biomass sampled with an Ekman grabber /Huononen 2005/. In Fiskarfjärden as well, the biomass was higher when sampled with a frame, but the difference was less pronounced. In general, carnivores (e.g. *Tanypodinae*) constituted a major part of benthic fauna, but omnivores, detrivores and herbivores also made significant contributions to the biomass. Benthic fauna have been shown to correlate with macrophyte coverage /van den Berg et al. 1997/, so the different sampling techniques could explain the different biomass estimates from the same lake as the frame was used in areas with dense macrophytes. The benthic fauna biomass in Bolundsfjärden and Fiskarfjärden was low (2.0 and 0.74 g dw m^{-2}, respectively in frame samples) compared with the benthic fauna biomass in *Chara* habitats in Krankesjön in southern Sweden (almost 15 g dw m^{-2}) /Hargeby et al. 1994/. However, the biomass was

Table 3-20. Biomass (g dw m^{-2}) of benthic fauna in Eckarfjärden, Bolundsfjärden and Fiskarfjärden sampled using different methods /[1]Andersson et al. 2003, [2]Huononen 2005/. The value in parenthesis represents the biomass including one large *Anodonta*. The biomass of one large *Anodonta* was excluded when calculating the mean value. Mussels are quite common in the lake, but have a scattered distribution. Considering the small number of bottom fauna samples in the study, including the biomass of one single *Anodonta* will lead to an unrealistically high mean biomass value

Biomass	Eckarfjärden[1] Ekman grabber	Bolundsfjärden[2] Ekman grabber	Bolundsfjärden[2] Frame	Fiskarfjärden[2] Ekman grabber	Fiskarfjärden[2] Frame
Filter feeders	0.11	0.06 (25.5)	0.14	0.01	0.18
Herbivores	0.23	0.02	0.39	0.00	0.12
Carnivores	0.05	0.16	0.94	0.46	0.28
Omnivores	–	0.22	0.23	0.03	0.03
Detrivores	0.08	0.12	0.33	0.06	0.14
Sum	0.47	0.57	2.03	0.57	0.74

higher than in vegetation-free habitats and of the same size as the benthic fauna biomass in the *Potamogeton* habitats in the study by /Hargeby et al. 1994/. Thus, considering the small sample size in our data we may have underestimated of the biomass of benthic fauna, but there may also be a true difference between lakes. Nevertheless, the estimate can be considered to be of a realistic magnitude.

In total, 8 ***fish*** species were caught in a fish survey conducted in 2003 in 4 of the Forsmark lakes /Borgiel 2004b/. Most species were found in Bolundsfjärden (8), followed by Fiskarfjärden (6), Eckarfjärden (5) and Gunnarsbo-Lillfjärden (3). The catch per unit effort (CPUE = kg fish per net) was similar in Eckarfjärden, Bolundsfjärden and Gunnarsbo-Lillfjärden, whereas Fiskarfjärden had almost twice the CPUE (Table 3-21). In all lakes, roach (*Rutilus rutilus,* sw. *mört*) and perch (*Perca fluviatilis*, sw. *abborre*) dominated in terms of number of individuals. In terms of biomass, however, tench (*Tinca tinca*, sw. *sutare*) dominated in Eckarfjärden and Bolundsfjärden, and Crucian carp (*Carassius carassius*, sw. *ruda*) dominated in Fiskarfjärden. In a study in 2007, Crucian carp was the only fish found in Labboträsk (Nordén, unpublished). Crucian carp is tolerant of low oxygen conditions, and the oxygen concentrations in Labboträsket are very low in the winter, which could explain why only one species is found there. The fish biomass in Labboträsket was also low; one gillnet gave a catch of 7 small Crucian carps (mean weight 11.5 g ww, median = 13.4 g ww, min. = 0.4, max. = 2.2, SD = 0.4). Length and weight distribution diagrams for different species in the different lakes are presented in Appendix 5.

The results of the gillnet fishing in Forsmark /Borgiel 2004b/ were compared with other data according to the Swedish fish index (FIX) /Naturvårdsverket 2000/ which gave the following classification of the lakes: Eckarfjärden is classified as a "normal lake", whereas Gunnarsbo-Lillfjärden and Bolundsfjärden deviate slightly, mainly due to their large proportion of fish

Table 3-21. Catch per unit effort (kg ww), weight per hectare (kg ww ha^{-1}) and total fish biomass (kg ww) in Eckarfjärden, Bolundsfjärden, Fiskarfjärden and Gunnarsbo-Lillfjärden.

Functional group	Species	Eckarfjärden	Bolundsfjärden	Fiskarfjärden	Gunnarsbo-Lillfjärden
		CPUE	CPUE	CPUE	CPUE
Z-fish		**0.10**	**0.003**	**0.037**	**0.007**
	Crucian Carp			0.005	
	Perch	0.014	0.0003	0.018	0.007
	Roach	0.081	0.0025	0.014	
	Rudd		0.0004		
B-fish		**2.47**	**2.09**	**4.12**	**2.39**
	Crucian carp		0.234	2.640	2.048
	Perch	0.282	0.353	0.138	0.327
	Roach	0.712	0.470	0.457	0.010
	Rudd		0.003		
	Ruffe	0.005	0.019	0.005	
	Tench	1.470	1.005	0.879	
	White bream		0.002		
P-fish		**1.08**	**0.36**	**0.475**	**0.80**
	Perch	0.625	0.320	0.434	0.802
	Pike	0.451	0.044	0.041	
Total CPUE		**3.65**	**2.45**	**6.63**	**3.195**
Total biomass per hectare (kg ww ha^{-1})		**120.1**	**80.9**	**152.8**	**105.4**
Total biomass in the lake (kg ww)		**2,264**	**3,273**	**5,919**	**189**

species resistant to low oxygen conditions. Fiskarfjärden deviates significantly from a "normal lake" because of the large share of the species resistant to low oxygen levels and low proportion of percids.

Fish were classified into the functional groups zooplanktivore fish (Z-fish), benthivore fish (B-fish) and piscivore fish (P-fish), based on the weight of individual fish according to /Holmgren and Appelberg 2000/. In the case of Crucian carp (*Carassius carassius*), no information about feeding preferences for individuals smaller than 64 g is available. Here we have assumed that individuals smaller than 8 g feed on zooplankton, whereas larger individuals mainly feed on benthic fauna. All lakes were dominated by fish feeding on benthic fauna (B-fish).

The fish survey was conducted using benthic multi-mesh gillnets according to standardized methods /Fiskeriverket 2001, Naturvårdsverket 2000, Naturvårdsverket 1999a/. The species, length and weight of all fish were determined. To calculate the total fish biomass in the Forsmark lakes, a conversion factor of 33 kg fish ha^{-1} $CPUE^{-1}$ was used (i.e. 1 kg fish in the net represents 33 kg fish ha^{-1} in the lake) (as proposed by Per Nyberg at Fiskeriverket Örebro, personal communication). The fish biomass was also investigated in two earlier investigations in Eckarfjärden (1991) /Nyberg 1999/ and Bolundsfjärden (2001) /Franzén 2002/. The fish survey performed in Eckarfjärden 1991 gave almost identical CPUE (3.87) as the study in 2003 (3.65). The species composition, however, had changed between the years. In 1991, the biomass of pike and roach was half of that in 2003, whereas the perch biomass was almost twice the biomass in 2003. The fish survey in Bolundsfjärden 2001 deviated from the survey 2003 and showed more than twice the CPUE (4.8 compared to 2.2). However, in the fish survey in 2001 only 4 gillnets were used compared with 16 in 2004, and any comparison should therefore be interpreted with caution.

3.10.2 Biota in streams

Abundance of primary producers

Chlorophyll *a* (chl *a*), which can be used as an indirect measure of the ***phytoplankton*** biomass, was measured in 8 different streams in the Forsmark area (n=108) /Tröjbom and Söderbäck 2006b/. The chl *a* concentrations is generally low with a median for all streams of 0.67 µg chl *a* L^{-1}. This is about half of the median chl *a* concentration found in the lakes in the area. The low chl *a* concentration is expected, as the phytoplankton biomass is generally low in small streams /Wetzel 2001/. The plankton in the water from the upstream lakes will settle to the bottom in the calm water of the small streams. No identification of species was done, but it seems reasonable that the phytoplankton composition in streams is similar to what is found in the upstream lakes.

Streams in catchments nos. 1, 2, and 8 were investigated for vegetation in 2004 /Carlsson et al. 2005b/. In total, 56 species of ***macrophytes*** were noted in the streams. The common reed was the most abundant species in all catchments, but otherwise species composition differed between catchments. The coverage of the stream section by macrophytes was classified in five classes:

1. Vegetation lacking
2. Single plants (covering < 5% of the area)
3. Moderate growth (covering 5–50% of the area)
4. Substantial growth (covering 50–75% of the area)
5. Intense growth (covering > 75% of the area)

The aquatic vegetation was very dense in stretches of the lowest stream order (i.e. in upstream parts), but was less dense in downstream parts. In stream order 3 (only found in catchment 2), more than half of the stretches lacked vegetation (Table 3-22).

Table 3-22. Total abundance of vegetation (%) growing in each section of the investigated stream stretches in the Forsmark area.

Catchment	1			2				1 and 2			
Stream order	**1**	**2**	**total**	**1**	**2**	**3**	**total**	**1**	**2**	**3**	**total**
Vegetation lacking	–	2	2	6	11	66	16	5	8	67	13
Single plants (<5% cov.)	–	12	11	1	7	23	7	1	8	23	8
Moderate growth (5–50% cov.)	–	23	20	4	22	7	16	3	22	7	17
Substantial growth (50–75% cov.)	6	30	26	11	36	2	26	10	34	2	26
Intense growth (75–100% cov.)	94	33	41	78	24	–	34	81	27	0	36

The coverage of vegetation differed between catchments, and the dominant species and coverage of the stream sections for the three catchments are described below:

In catchment no 1, dominating species besides Common reed (*Phragmites australis*) were spiked water-milfoil (*Myriophyllum spicatum*) and water horsetail (*Equisetum fluviatile*). The vegetation was denser in the upstream compared to the downstream parts in August and September (Figure 3-43).

In catchment no. 2, the vegetation was dominated by common reed (*Phragmites australis*), water moss (*Fontinalis sp.*), unbranched bur-reed (*Sparganium sp.*), tufted loosestrife (*Lysimachia thyrsiflora*) and corn mint (*Mentha arvensis*). The abundance of vegetation varied along the stream. A large part of the channel close to the inlet to Bolundsfjärden lacked vegetation, whereas the areas upstream of Gällsboträsket were dominated by intense growth (75–100%) (Figure 3-44).

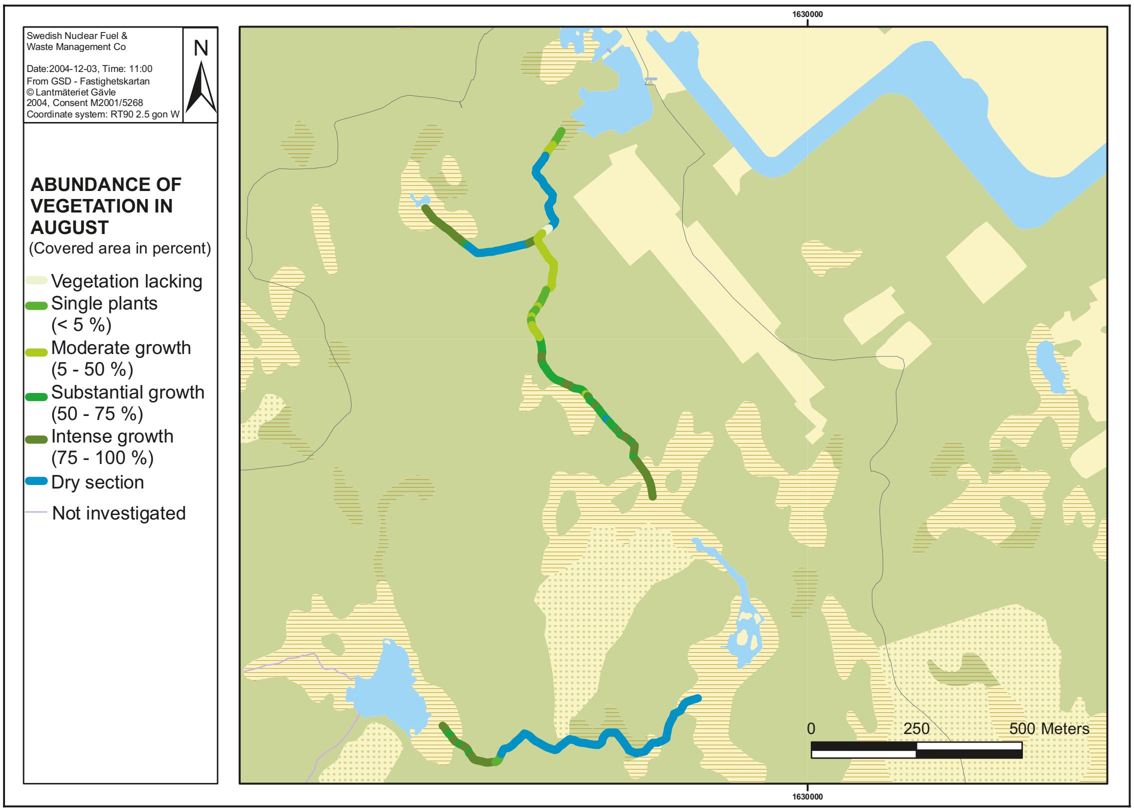


Figure 3-43. *Vegetation abundance in the stream of catchment Forsmark 1 in late summer.*

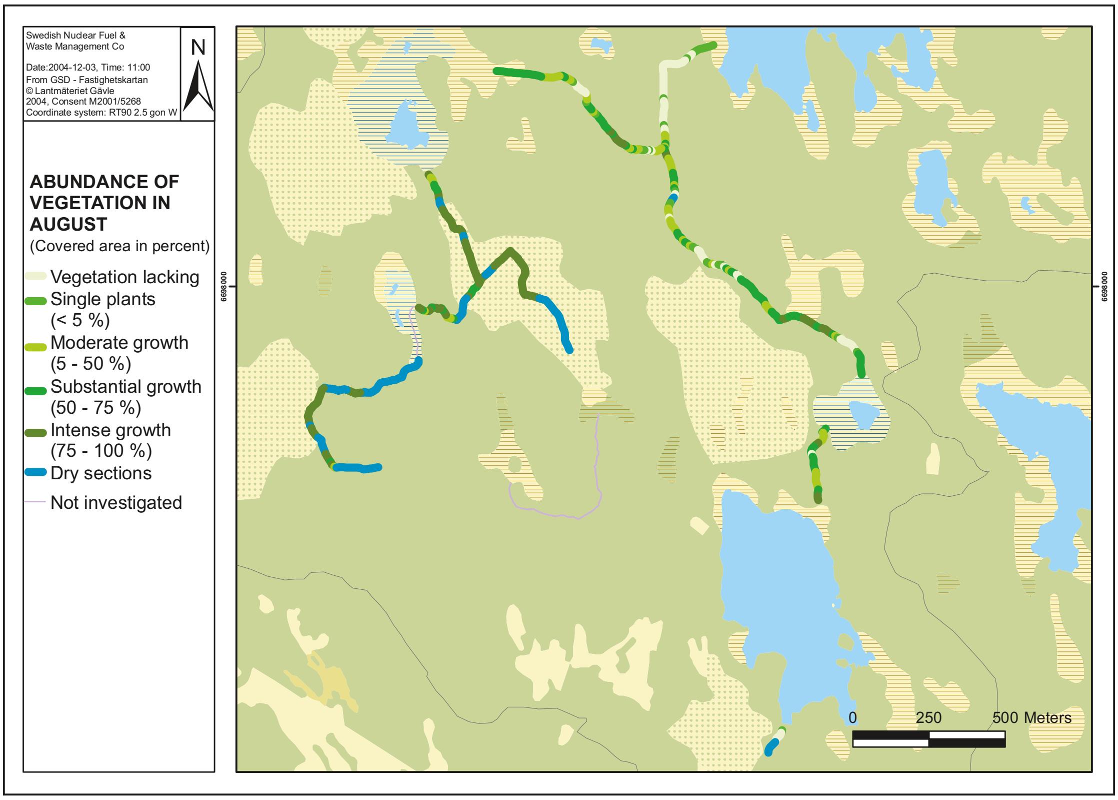


Figure 3-44. *Vegetation abundance in the stream of catchment Forsmark 2 in late summer.*

In catchment no. 8, the vegetation was dominated by common reed (*Phragmites australis*) and yellow iris (*Iris pseudacorus*). The yellow iris is a characteristic plant for eutrophic conditions. In contrast to catchment no. 1, the vegetation was denser in the downstream part (5–50%) than in the upstream part (single plants <5%) (Figure 3-45).

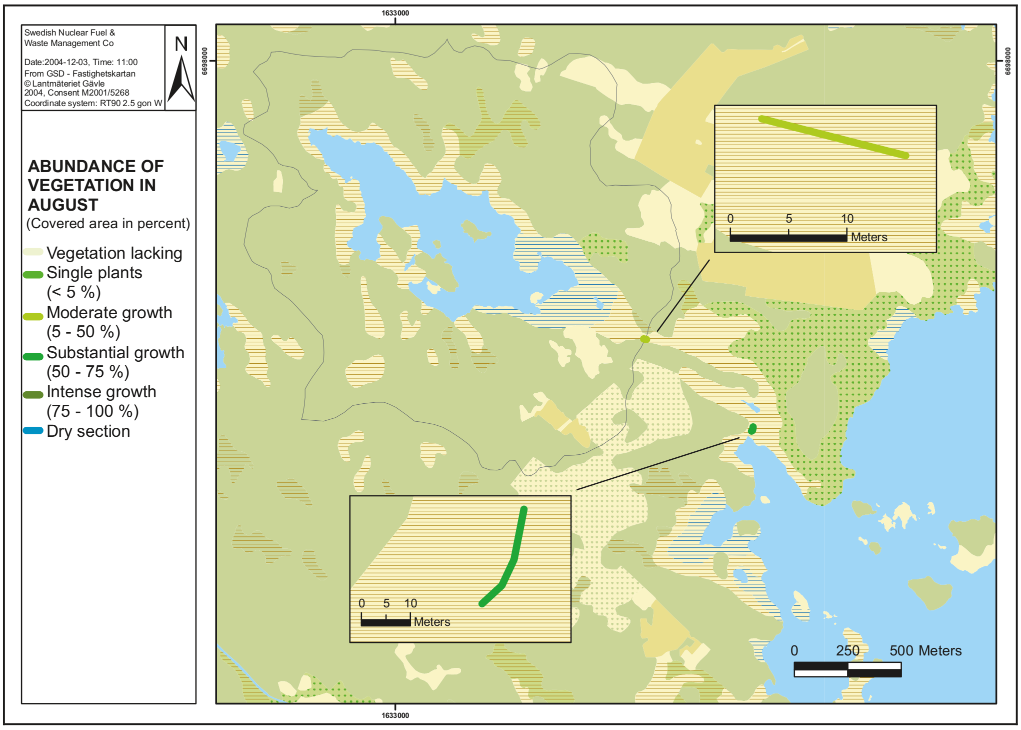


Figure 3-45. *Vegetation abundance in the channel downstream of catchment Forsmark 8 in late summer.*

Biomass of consumers

The small and sometimes dry streams of the Forsmark area cannot sustain a stationary ***fish*** population. Instead, the streams may function as feeding areas and/or channels for migration of fish during the times of the year when there is enough water. Fish migration was quantified during the period from the 4th of April to 12th of May 2004 in the outlet stream from Norra bassängen and in one of the inlet streams to Bolundsfjärden (main inlet) /Loreth 2005/. Fish were caught with a fyke-net that catches all fish moving upward in the stream. There was a large migration of sexually mature fish from the Baltic Sea to Norra Bassängen in the spring. Altogether 18,567 fish were caught migrating from the coast (Asphällsfjärden) to Norra Bassängen. 4 species were caught: ruffe (*Gymnocephalus cernua*), roach (*Rutilus rutilus*), perch (*Perca fluviatilis*) and pike (*Esox lucius*). In number of individuals, ruffe clearly dominated the migration (12,394), followed by roach (4,704), perch (1,257) and pike (212). A small number of fish (129) were caught in the inlet to Bolundsfjärden and many of these were sexually immature. Thus, there was no significant spawning migration to areas upstream of Bolundsfjärden, indicating that spawning of migratory fish takes place predominantly in Norra Bassängen and Bolundsfjärden.

The outlet from Fiskarfjärden is a short stretch, more like a reed wetland than a stream. A small bridge crosses the stretch and under this a small pond of water is created when the area dries out. Observations of fish in this pond indicate that there are fish in the stream stretch and that migration may occur during wetter periods, i.e. when the small pond is in contact with the sea and Fiskarfjärden.

The biomasses of ***bacteria***, ***zooplankton*** and ***benthic fauna*** in the streams in Forsmark were not investigated. The bacterial biomass in streams can be high, especially in small streams that receive high inputs of allochthonous carbon sources /Wetzel 2001/. The zooplankton biomass in small streams is generally lower than in rivers, which in turn tend to have a lower zooplankton biomass than lakes /Wetzel 2001/. Moreover, the zooplankton biomass tends to be positively correlated to the phytoplankton chl *a* biomass. Thus, the low chl *a* concentrations in the streams in the area indicate that the zooplankton biomass was also low. Macroinvertebrates larger than 0.5 mm, particularly insects, can be important components of streams /Wetzel 2001/. However, benthic fauna may differ considerably between different streams depending on stream size, substrate, temperature, oxygen etc, and it is therefore difficult to estimate the biomass from literature studies. The fact that many of the streams are dry for long periods of the year indicates that the biomass of benthic fauna should be low.

Primary production

No estimations of primary production have been performed in the Forsmark streams.

3.10.3 Edible biota in lakes and streams

It is of importance for the safety assessment to estimate the production of edible biota. Today, the use of lake biota in lakes is assumed to be negligible as fishing is assumed to take place predominantly in the coastal marine areas. Nevertheless, the production of food that can be sustainably produced by the limnic ecosystem has been estimated to provide input data for the models of the safety assessment, since the future usage of the lakes as food source may be higher than today.

Food production was categorized as food normally consumed and edible products /SKB 2006a/. Food normally consumed for a lake includes fish, while edible products are everything that has some potential to be consumed by humans. Edible products could be worms, larvae, molluscs as well as fish etc above a certain practical size. In SR-Can this size was set at 1 mm (i.e. macrofauna).

Production was estimated for species or taxa where biomass was quantified in the site investigations in SR-Can. Production for most species was estimated by means of production per biomass ratios (P/B) from the literature. Some estimates (for e.g. fish) were based on calculations of the mass balance from metabolic demands and consumption using literature values /Kautsky 1995, Lindborg 2005/. Production was estimated as the weight of organic carbon (m^{-2} $year^{-1}$). This partly compensates for the energetic quality of food as structural components such as bones, shells etc which normally are not eaten also contain a low fraction of organic carbon.

The results in SR-Can was that the production of normally eaten products (here fish) was 4 g C m^{-2} $year^{-1}$ /SKB 2006c/. This estimate was used as the food production in the SR-Can safety assessment.

However, when this value was compared with the estimates of yields of fish as food from lakes, these were about 0.03 to 0.17 g C m^{-2} $year^{-1}$ (calculated from /Degerman et al. 1998/). This value was considerable lower than in SR-Can and cannot be attributed to the fact that SR-Can considers all fish while the estimated yields consider only fish normally fished for food. The fish production figures were reviewed and production was estimated using P/B ratios instead.

The P/B ratios are dependent on fish size (weight and length), and an allometric relationship has been established from studies of 79 freshwater species in Canada /Randall and Minns 2000/ Several of the fish species are similar to the Scandinavian species, and as this paper and other papers show, the P/B ratio is well correlated to size for most animals /Banse and Mosher 1980, Downing and Plante 1993, Randall and Minns 2000/.

The maximum lengths of the fish species caught in the surveying gillnets were taken from the site study at Forsmark /Borgiel 2004b/. These ranges were compared with the data from /Randall and Minns 2000/ and for each species a mean P/B was estimated for this range (Table 3-23). This P/B ratio was multiplied by the estimated biomass per m^2 /Lindborg 2005/ to obtain the area-specific fish production for each tabulated species in each of the studied lakes: Eckarfjärden, Fiskarfjärden, Bolundsfjärden and Gunnarsbo-Lillfjärden. The total sum of fish production for each lake was used to obtain an average fish production estimate for the area, which is 0.5 g C m^{-2} $year^{-1}$. This estimate is one order of magnitude lower than the estimate in SR-Can and considerably higher than the maximum generic estimates by /Degerman et al. 1998/. Some of the differences can be explained by the fact that our data also includes fish that are not popular food species, which is evident from Table 3-23. Moreover, the sustainable yield from a lake must be less than the production, to compensate for natural mortality. Thus the production of edible fish is lower than 0.5 g C m^{-2} $year^{-1}$.

Additionally a future potential food item in this area could be crayfish. There are no crayfish in the lakes studied today at the sites, but future lakes could contain them. The generic yield of a good crayfish lake is about 50 kg ha^{-1} /Fiskeriverket 2003/, which corresponds to a production of 0.4 g C m^{-2} $year^{-1}$. Thus, a maximum total food production from a lake is less than 0.9 g C m^{-2} $year^{-1}$.

If the range is extended to other theoretical food items, molluscs and insect larvae could be eaten. There is no evidence that insect larvae from aquatic habitats are eaten on a regular basis, while molluscs are at least utilized in marine environments. Freshwater mussels of the family Unionidae (e.g. *Anodonta anatina*, duck mussel, sw. *allmän dammmussla*) are abundant in the lakes, although there are no biomass estimates for the lakes in Forsmark. Comparing with production in the River Thames, a theoretical upper estimate of production is 132 g fw ha^{-1} y^{-1} /Negus 1966/. The abundance of mussels in the Thames is about 100 times higher compared with semiquantitative estimates from Lake Mälaren in Sweden /Lundberg and Proschwitz 2007/. Thus, probably a very high estimate of the production of large molluscs is 0.3 g C m^{-2} $year^{-1}$. There are no records of humans eating unionids on a regular basis, and general discussion of the edibility of unionids seems to rate them as distasteful /Bourquin 2008 www/.

Thus the maximum production of food from lakes similar to the present and future lakes in the Forsmark area is composed of fish and crayfish and is estimated to less than 0.9 g C m^{-2} $year^{-1}$.

Table 3-23. Biomass, B (g C m^{-2} $year^{-1}$), and production, P (g C m^{-2} $year^{-1}$), of different fish species in Forsmark area, based on average P/B ratios (1/y) of size range from /Randall and Minns 2000/. Biomass and size estimates from /Lindborg 2005/ and /Borgiel 2004b/, respectively.

Species	Size length	P/B	Eckarfjärden		Fiskarfjärden		Bolundsfjärden		Gunnarsbo-Lillfjärden		Mean
	(mm)		B	P	B	P	B	P	B	P	P
Roach *Rutilus rutilus*	200–300	1.0	0.23	0.23	0.14	0.13	0.14	0.13	0.00	0.00	0.12
Tench *Tinca tinca*	500–600	0.3	0.42	0.14	0.25	0.08	0.29	0.09	0.00	0.00	0.08
Perch *Perca fluviatilis*	300–400	0.5	0.26	0.14	0.17	0.09	0.19	0.10	0.33	0.17	0.12
Pike *Esox lucius*	700–1,300	0.2	0.13	0.03	0.01	0.00	0.01	0.00	0.00	0.00	0.01
Ruffe *Gymnocephalus cernuus*	100–200	1.5	0.001	0.002	0.00	0.00	0.01	0.01	0.00	0.00	0.01
Crucian carp *Carassius carassius*	250–500	0.5	–	–	0.76	0.41	0.07	0.04	0.59	0.32	0.19
Total			1.04	0.53	1.33	0.72	0.70	0.38	0.92	0.49	0.53

3.10.4 Chemical characteristics of biota

The chemical composition of biota in the Forsmark lakes has been investigated /Hannu and Karlsson 2006/. In total, 23 samples from limnic environments were analyzed (Table 3-24). In addition to the content of macronutrients (carbon, nitrogen and phosphorus), the concentrations of 61 other elements in biota were also determined.

Since all the lakes in the area are oligotrophic hardwater lakes with similar characteristics, and as the number of analyzed samples is restricted, data is presented here per functional group, irrespectively of from which lake the samples were collected. The concentrations of carbon, nitrogen, phosphorus, iodine and uranium are presented in Table 3-25. The compiled data for all analyzed elements are presented in Appendix 10, while primary data are provided in /Hannu and Karlsson 2006/. For many of the trace elements (and sometimes also for other elements), the results of the analyses were below the detection limit. In these cases, a value equal to half of the detection limit was used in the calculation of mean concentrations. The number of samples varied from one to at most 15.

The carbon content expressed as g C g dw^{-1} was relatively constant in different functional groups and varied only by a factor of two. The carbon content was lowest in macroalgae (*Chara sp.*) and highest in fish.

Nitrogen and phosphorus concentrations were also lowest in macroalgae and highest in fish. High concentrations of phosphorus were also noted in benthic fauna (mussels). Differences in concentrations between functional groups were greater for nitrogen than for carbon, and these differences were even more pronounced for phosphorus. The concentrations of phosphorus varied somewhat between fish of different functional groups. However, it should be borne in mind that there were only two samples for planktivorous fishes. The reported concentrations of nitrogen and phosphorus in the macroalgae *Chara sp.* agrees well with values reported by /Pereyra-Ramos 1981/.

Table 3-24. Description of biological samples analyzed for elemental composition /Hannu and Karlsson 2006/. "repl." denotes number of replicate samples.

	Sampling site/ ID code	Number and description of samples	Sample state before analysis
Fish	Bolundsfjärden AFM000050	Benthivorous fish: ruffe 1 repl.[1] tench 3 repl. Piscivorous fish: pike 1 repl.	Frozen
	Eckarfjärden AFM000010	Planktivorous fish: small roach 1 repl.[2] Benthivorous fish: tench 3 repl. Piscivorous fish: pike 2 repl.	
	Fiskarfjärden AFM000051	Planktivorous fish: small roach 1 repl.[3] Benthivorous fish: tench 3 repl. Piscivorous fish: pike 1 repl.[4]	
Macroalgae	Bolundsfjärden AFM000050	3 repl. (*Chara tomentosa*)	Dried
	Fiskarfjärden AFM000051	1 repl. (*Chara tomentosa*)	
Microalgae	Eckarfjärden PFM002502	Algal mat 1 repl.	Freeze-dried
Benthic fauna (mussel)	Bolundsfjärden AFM000050	3 repl. (*Anodonta sp.*)[5]	Frozen

[1] 6 individuals

[2] 18 individuals

[3] 16 individuals

[4] 5 individuals

[5] 2 individuals, muscle only.

Two elements which are not main constituents of biota are included in Table 3-24: iodine and uranium. For both of these elements, the concentrations show an opposite distribution to C/N/P, with the highest concentrations in producers, somewhat lower concentrations in benthic biota and the lowest concentrations in fish. The concentration of uranium is very high in microalgae. However, this group is represented by only two samples with high variation, and the figure should therefore be used with caution. However, both these values are much higher than those recorded for any of the other groups. As uranium is toxic to biota, one possible explanation for the lower concentrations in higher biota such as fish could be an active avoidance of this element, either through blocking of uptake and/or through effective excretion. It should be noted that all but one iodine concentration reported for fish were below the reported detection limit. Two of the concentrations of uranium in fish were below the detection limit (see footnotes in Table 3-25). A comparison between these data and corresponding data for the Laxemar-Simpevarp area is made in section 4.10.4.

Table 3-25. Concentrations of a number of selected elements in biological samples from the Forsmark lakes. Samples from different lakes have been pooled in order to present the results for functional groups. Data from /Hannu and Karlsson 2006/ and /Strömgren and Brunberg 2006/.

Element	Sample type	N	Mean	Median	Min.	Max.	SD
Total carbon (g/kg dw)	Microbial mat	1	380	380			
	Macroalgae	4	268	250	240	330	41.9
	Total producers	*5*	*290*	*250*	*240*	*380*	*62.0*
	Benthic fauna	3	340	340	340	340	0
	Planktivorous fish	4	440	440	440	440	0
	Benthivorous fish	12	445	450	430	460	12.4
	Piscivorous fish	6	432	430	420	450	9.83
	Total consumers	*25*	*428*	*440*	*340*	*460*	*35.1*
Total nitrogen (g/kg dw)	Microbial mat	1	37.3	37.3			
	Macroalgae	4	6.83	6.75	6.20	7.60	0.591
	Total producers	*5*	*12.9*	*6.90*	*6.20*	*37.3*	*13.6*
	Benthic fauna	3	73.7	73.0	71.0	77.0	3.06
	Planktivorous fish	4	158	140	140	213	36.3
	Benthivorous fish	12	116	133	64.1	148	30.3
	Piscivorous fish	6	142	144	130	150	6.73
	Total consumers	*25*	*124*	*140*	*64.1*	*213*	*34.9*
Total phosphorus (g/kg dw)	Microbial mat	2	0.847	0.847	0.546	1.15	0.847
	Macroalgae	4	0.525	0.496	0.479	0.629	0.525
	Total producers	*6*	*0.632*	*0.523*	*0.479*	*1.15*	*0.632*
	Benthic fauna	3	28.4	27.5	19.6	38.2	28.4
	Planktivorous fish	2	10.3	10.3	10.0	10.6	10.3
	Benthivorous fish	10	10.8	10.6	9.39	12.3	10.8
	Piscivorous fish	4	13.3	13.6	12.0	14.1	13.3
	Total consumers	*19*	*14.1*	*11.9*	*9.39*	*38.2*	*14.1*
Iodine (mg/kg dw)	Microbial mat	1	6.04	6.04			
	Macroalgae	4	7.29	6.15	5.58	11.3	2.69
	Total producers	*5*	*7.04*	*6.04*	*5.58*	*11.3*	*2.40*
	Benthic fauna	3	4.4	4.7	3.8	4.7	0.49
	Planktivorous fish	2	0.275[1]	0.275[1]	0.250[1]	0.300[1]	0.035[1]
	Benthivorous fish	10	0.205	0.200	0.200	0.250	0.016
	Piscivorous fish	4	0.40[3]	0.20[3]	0.20[3]	1.0	0.40[3]
	Total consumers	*19*	*0.92*	*0.20*	*0.20*	*4.7*	*1.6*
Uranium (mg/kg dw)	Microbial mat	2	37	37	2.9	70	48
	Macroalgae	4	0.75	0.69	0.62	0.98	0.16
	Total producers	*6*	*13*	*0.84*	*0.62*	*70*	*28*
	Benthic fauna	3	0.27	0.26	0.21	0.33	0.058
	Planktivorous fish	2	0.0017[4]	0.0017[4]	0.00030[4]	0.0030[4]	0.0019[4]
	Benthivorous fish	10	0.0012[5]	0.00055[5]	0.00010[5]	0.0051[5]	0.0015[5]
	Piscivorous fish	4	0.00040	0.00040	0.00010	0.00070	0.00024
	Total consumers	*19*	*0.043*	*0.00060*	*0.00010*	*0.33*	*0.10*

[1] Both values below detection limit, varying between <0.5 and <0.6 mg/kg dw.
[2] All 10 values below detection limit, varying between <0.4 and <0.5 mg/kg dw.
[3] 3 of 4 values below detection limit (<0.4 mg/kg dw).
[4] Value below detection limit (analytical result: <0.0006 mg/kg dw).
[5] One value below detection limit (<0.0006 mg/kg dw).

3.11 Land use and human impact

The streams in the Forsmark area are greatly affected by human activities, whereas most lakes are relatively unaffected by human impact, although there are examples of lowering of the lake levels. Human settlement can affect limnic systems by e.g. water use and pollution. However, the population in the Forsmark area is small today.

3.11.1 Human impact on lakes

The largest human impact on lakes in the area has been to Gunnarsbo-Lillfjärden. According to /Brunberg and Blomqvist 1998/, the lake was isolated from the sea in 1970–72 (before the construction of the nuclear power plants at Forsmark). During the construction of the nuclear power plant, parts of the lake were filled in with construction material and a small road was constructed through the original lake basin, separating the lake into a north and a south basin. Water draining the catchment enters the northern basin, and drainage from the northern to the southern basin is channelled through a pipe, but diffuse drainage may also occur through the construction material. The main damage to the lake seems to be that the lake has been isolated from its natural outlet, and the water from the southern basin drains through pipes under the adjacent road. The altitude difference between the outlet pipe and the sea probably makes it difficult for aquatic organisms to migrate between the Baltic Sea and the lake basins /Brunberg et al. 2004a/.

The water level in Eckarfjärden has been lowered by dredging of the outlet stream, thereby lowering the lake threshold /Brunberg and Blomqvist 1998/.

Due to the special characteristics of the lakes (shallow water depth and thick loose sediments), they are not used for bathing. Some fishing may occur, but considering the closeness to the coastal areas, our opinion is that this activity has a very limited impact (if any) on the lake ecosystem. In section 3.10.3 the amount of biota in lakes that can theoretically be used as food is described. This figure is certainly larger than actual food outtake from the lakes today. Theoretically lake organisms could also be harvested as food supply to cultivated animals but this does not occur today and is an unlikely scenario also for the future.

3.11.2 Human impact on streams

Most of the stream stretches in catchments 1 and 2 are affected by human activities (Table 3-26). Most of the streams consist of man-made ditches, and the original channels have most probably been straightened. The streams in catchment 1 are less affected than those in catchment 2. Beside the pipes in Gunnarsbo-Lillfjärden, there are three more pipes under small roads in catchment 1 and another 5 pipes in catchment 2.

A stretch of c. 130 m along the stream in catchment 2 is lined with wooden poles on both sides (see photo in Figure 3-46). We can only speculate about the reason, but one possible explanation is that it is some kind of structure previously used for fishing in the area. Another possible explanation is that the structure was built to brace the stream banks. Today the streams in the area are too small to be of any importance for fishing.

Table 3-26. Technical encroachments in the investigated stream stretches in the Forsmark area (%).

Catchment	1			2				1 and 2			
Stream order	1	2	total	1	2	3	total	1	2	3	total
Natural, no excavation	–	21	18	10	–	–	4	9	9	0	9
Moderate excavation	–	25	21	2	12	–	7	2	17	0	11
Substantial excavation	100	54	60	88	88	100	89	90	73	100	80

Figure 3-46. *Wooden poles along the stream in catchment Forsmark 2.*

3.12 Streams and lakes in the region

This section describes the lakes and streams in the region in order to put the local conditions in the Forsmark area into a regional perspective (northern Uppland). The Forsmark area belongs to catchment 54/55 "Between Tämnarån and Forsmarksån". Data from two streams and a number of lakes in the three catchments 54/55, 55, and 56 are discussed in this section (Figure 3-47).

3.12.1 Lakes

According to the SMHI system, the catchment situated west and north of the Forsmarksån catchment is called catchment 54/55 "Between Tämnarån and Forsmarksån" (Figure 3-47). The Forsmark area is part of this catchment and the lakes within catchment 54/55 are very similar to the lakes within the Forsmark area, i.e. most of them are oligotrophic hardwater lakes. Most of the lakes within the Forsmarksån catchment (55), on the other hand, are classified as brown-water lakes. Data for the lakes from these two catchments have been compiled in /Brunberg and Blomqvist 2000/ and are presented below. Data for the lakes within the catchment of Olandsån are described in /Brunberg and Blomqvist 1998/ and a summary of the information is presented below.

Lowering of water levels has been carried out for lakes in Uppland County, mainly during the 18th century when iron mills used the streams to supply hydropower to the mills, a practice that continued for more than 200 years. The main reason for lowering of lake levels in the county has been to gain new agricultural land. Compared to the rest of the county, lowering of lake water levels has been less extensive in the Forsmark area. The average lowering of the lake water levels caused by drainage in Sweden is 0.75 m, while the corresponding value for the lakes in the Forsmark area is 0.28 /Brunberg and Blomqvist 2000/.

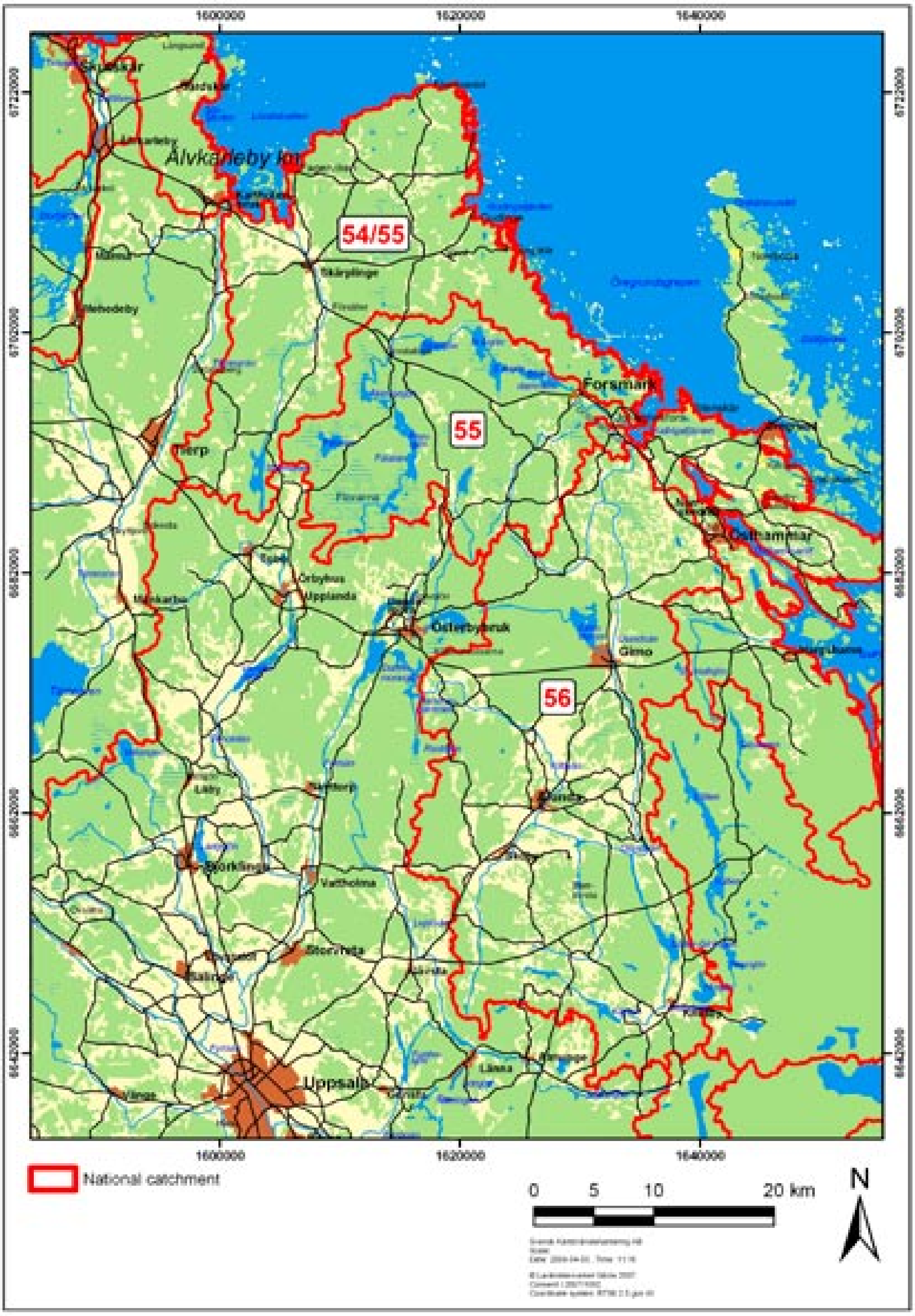


Figure 3-47. National catchments in northern Upland according to the SMHI numbering system. The Forsmark area described in this report is part of catchment 54/55 "between Tämnarån and Stream Forsmarksån".

Catchment 54/55 between Tämnarån and Forsmarksån – oligotrophic hardwater lakes

The lakes in catchment 54/55 are, like the lakes in the Forsmark area, characterized as oligotrophic hardwater lakes. A map showing the position of the lakes mentioned in the text is shown in Figure 3-48. The lakes are nutrient-poor and are very calcium-rich. The bedrock in the area is composed of granite and gneiss but covered with calcium-rich till and postglacial clays. The soils are easily weathered and contribute large amounts of dissolved salts to the surface waters. Phosphorus co-precipitates with calcium, leading to the nutrient-poor conditions in the oligotrophic hardwater lakes.

The lakes within this catchment are smaller, shallower and have smaller water volumes than the lakes in Uppsala County in general (Table 3-27). Their water retention time is also shorter. The Forsmark lakes belong to the catchment 54/55 and have similar area as the other lakes in the catchment but are somewhat shallower leading to smaller water volumes than in the rest of the catchment. Also the water renewal times are generally shorter in the Forsmark area than in the rest of the catchment (Table 3-27).

The catchments of oligotrophic hardwater lakes in catchment 54/55 are generally very small. The vegetation in the catchments is dominated by forest and wetlands and there is less intensive land use compared with the average situation in the county. This can be seen when comparing the percentage of the catchments consisting of wetlands and farmland, for example on average 4% are used as farmland in catchment 54/55 compared with 10% in the county (Table 3-28). Visible inlets as well as outlets are often more or less absent, unless drainage projects have been carried out in the catchment. Thus, much of the water transported through the catchments is more or less filtered through the surrounding wetlands before entering the lakes. Like the brown-water lakes in catchment 55, most of the oligotrophic hardwater lakes are surrounded by mires and common reed is often a dominant plant species along the shores.

The oligotrophic hardwater lakes in catchment 54/55 are well buffered and moderately nutrient-rich. The oligotrophic lakes are characterized by high conductivity and high concentrations of dissolved calcium and magnesium in the water. The amount of phosphorus transported to the lakes is limited, due to precipitation of calcium-rich particulate matter occurs due to both chemically and biologically induced processes. Nitrogen tends to be present in relatively high concentrations in the water, although concentrations of inorganic nitrogen in summer are low due to biotic uptake. The lakes have high concentrations of dissolved organic carbon, which is unusual in combination with their relatively moderate water colour /Brunberg and Blomqvist 2003/.The oligotrophic hardwater lakes within the catchment often experience oxygen deficit during the winter period (Table 3-29). When the water chemistry of the lakes is compared with that of the other lakes in the county, alkalinity, water colour and oxygen conditions are found to be quite similar, while lakes in catchment 54/55 are slightly less nutrient-rich compared with the average for the lakes in the county (Table 3-29).

Besides the lakes in the site investigation, another 5 lakes situated within the catchment 54/55 have been subject to standardized survey gillnet fishing /Brunberg and Blomqvist 2000/. Fish were caught in all lakes, and a total of 6 species were encountered: roach, Crucian carp, tench, perch, ruffe and pike (Table 3-30). The number of encountered species is thereby similar to the average for the lakes in the county (5.8). However, the catch per unit effort was lower in the oligotrophic hardwater lakes than in the average lake in the county. The lakes can be divided into two groups: one with low fish biodiversity and dominance by Crucian carp, and another group with a higher fish biodiversity. The lakes of the first class are smaller and shallower than the other lakes and the dominance of Crucian carp indicates severe oxygen deficiency in the water in the winter /Brunberg and Blomqvist 2000/. It seems that Crucian carp is more abundant in the oligotrophic hardwater lakes than in other lakes in the county.

Figure 3-48. *Lakes in the catchment 54/55 "Between Tämnarån and Forsmarksån".*

Table 3-27. Morphological parameters for lakes in three different catchments in northern Uppland, for lakes in the Forsmark area, and totally for all lakes in Uppland County. Data from [1]/Brunberg and Blomqvist 1998/ and [2](SKB site investigations, further described in section 3.5). The lake in the Forsmark area belong to the catchment 54/55 but the presentation below of lakes in this catchment only includes data from 9 lakes derived from /Brunberg and Blomqvist 1998/ since by including the Forsmark data would give a strong bias to this smaller area.

Lake	Area (km^2)	Average depth (m)	Max depth (m)	Volume (Mm3)	Theoretical water retention time, days
Lakes in the catchment between Tämnarån and Forsmarksån (54/55) [1] (oligotrophic hardwater lakes)					
Average	**0.14**	**1.0**	**1.8**	**0.155**	**194**
Median	0.07	0.9	1.7	0.066	229
N obs	11	9	9	9	9
Max	0.61	1.9	3.2	0.427	383
Min	0.03	0.5	0.9	0.022	1.2
Lakes in the catchment of Forsmarksån[1] (55) (brown-water lakes)					
Average	**1.30**	**1.5**	**2.6**	**2.14**	**69**
Median	1.14	1.5	2.7	0.999	31
N obs	14	11	12	11	11
Max	4.09	2.8	4	7.77	249
Min	0.09	0.5	1.2	0.17	2
Lakes in the catchment of Olandsån[1] (56)					
Average	**0.96**	**1.3**	**2.9**	**1.736**	**114**
Median	0.39	1.3	2.4	0.975	87
N obs	15	10	10.0	10	10
Max	3.02	1.5	5.9	6.1	273
Min	0.06	0.9	1.8	0.15	35
Lakes in the Forsmark area[2]					
Average	**0.12**	**0.4**	**1.2**	**0.053**	**76**
Median	0.05	0.3	1.0	0.018	44
N obs	25	25	25	25	25
Max	0.75	0.9	2.2	0.374	328
Min	0.01	0.1	0.4	0.002	5
Lakes in Uppland County[1]					
Average	**1.04**	**1.98**	**3.8**	**2.35**	**263**
Median	0.25	1.5	2.6	0.38	91
N obs	141	119	122	119	117
Max	36.7	22	52	47.8	6,954
Min	0.01	0.4	0.9	0.01	1

Table 3-28. Characteristics of the catchments of oligotrophic hardwater lakes in the catchment 54/55. From /Brunberg and Blomqvist 2000/.

Catchment	Area (km^2)	Forest %	Wetland %	Farmland	Lakes %	Other land use %
Lake catchments in the catchment 54/55 (oligotrophic hardwater lakes)						
Mean	59	69	20	4	6	0
Median	15	69	20	2	6	0
Max	285	87	46	20	17	1
Min	0.22	50	5	0	0	0
N observations	29	29	29	29	29	29
Lake catchments in Uppsala County						
Mean	54	72	11	10	6	1
Median	9.9	74	8	5	5	0
Max	707	95	55	74	24	69
Min	0.22	14	0	0	0	0
N observations	142	142	142	142	142	142

Table 3-29. Water chemistry classification for lakes in the catchments 54/55, 55 and 56, and for lakes in the Forsmark area and in Uppland County. Data from /Brunberg and Blomqvist 2000/.

	Total P µg L^{-1} 1=≤12.5 2=12.5–25 3=25–50 4=50–100 5=>100	**Alkalinity meq L^{-1}** 1=>0.20 2=0.10–0.20 3=0.05–0.10 4=0.02–0.05 5=≤0.02	**Water colour mg Pt L^{-1}** 1=≤10 2=10–25 3=25–60 4=60–100 5=>100	**Oxygen conditions** 1=small risk of low O2 2=risk of <5 mg O2/ 3=risk of <1 mg O2/ 4=risk of anoxic conditions
The lakes in the catchment of Forsmarksån[1] (brown-water lakes)				
Average	2.2	1.0	4.3	1.9
Median	2.0	1	4	2
Min.	2	1	4	1
Max.	3	1	5	4
No. of observations	12	13	14	13
Lakes in the catchment between Tämnaren and Forsmarksån (54/55) (including oligotrophic hardwater lakes)				
Average	2.1	1.0	3.5	3.1
Median	2	1	3.5	4
Min.	1	1	2	1
Max	3	1	5	4
No. of observations	8	10	10	7
Lakes in the catchment of Olandsån (56)				
Average				3.0
Median				4
Min.				9
Max.				4
No. of observations				1
Lakes in Uppland County				
Average	3.5	1.3	4.0	2.6
Median	3	1	4	2
Min.	2	1	1	1
Max.	5	5	5	4
No. of observations	105	121	131	107

Table 3-30. Data from standardized survey involving gillnet fishing in oligotrophic hardwater lakes of the catchment between Tämnarån and Forsmarksån. From [1]/Brunberg and Blomqvist 2000/, [2]/Borgiel 2004b/ and [3](Nordén, unpublished). Cr=Crucian carp, Pe=perch, Pi=pike, Ro=roach, Ru=ruffe, Rd=Rudd, Te=tench, Wh=white bream.

	Fish species	CPUE No. of individuals	CPUE kg ww	Lake area ha	Mean depth m
Catchment 54/55					
Storfjärden (Hållen)[1]	Cr, Pe, Pi, Ro,	18	2.2	11	0.6
Dalarna[1]	Cr, Pe, Ro, Ru	35	7.8	7	0.5
Käringsjön[1]	Cr	26	0.32	4	0.6
Västersjön (Stora Hållsjön)[1]	Cr, Pe,Pi, Ro, Ru	76	3.4	19	.19
Strönningsvik[1]	Cr, Pe, Ro,	24	3.9	8	1.0
Eckarfjärden[2]	Pe, Pi, Ro, Ru, Te	63	3.7	28	0.9
Bolundsfjärden[2]	Cr, Pe, Pi, Ro, Ru, Rd, Te, Wh	29	2.5	61	0.6
Fiskarfjärden[2]	Cr, Pe, Pi, Ro, Ru, Te,	48	4.6	75	0.4
Gunnarsbo-Lillfjärden[2]	Cr, Pe, Ro	40	3.2	3	0.7
Labboträsk[3]	Cr	7	0.08	6	0.3
Average		**37**	**3.17**	**22**	**0.6**
Median		32	3.30	9.5	0.6
Max		76	7.8	75	1.0
Min		7	0.08	3	0.2
N observations		10	10	10	10
Average Uppland County					
Lake size 0–10 ha		**44**	**2.62**		
Lake size 11–50 ha		**78**	**3.59**		
Lake size 51–150 ha		**130**	**4.36**		
Lake size > 150 ha		**88**	**3.63**		
Average Forsmark area (N=4)					
Mean for Bolundsfjärden, Eckarfjärden, Fiskarfjärden and Gunnarsbo-Lillfjärden		45	3.48		

Lakes in catchment 55 Forsmarksån – brown-water lakes

The lakes in catchment 55 are characterized as brown-water lakes, referring to their dark water colour. Brown-water lakes are characteristic of the boreal zone. The colour of the water stems from large amounts of dissolved organic matter in the form of humus, originating from the surrounding land in the catchment. Data from all lakes larger than 3 hectares is included in the following text. A map showing the locations of the lakes mentioned in the text is presented in Figure 3-49.

The catchments of the lakes vary considerably in size, but the median size of the catchments is larger than that of lake catchments in Uppsala County in general. The vegetation is dominated by forest. Wetlands contribute to a large part of the catchments (median 26%). The proportion of farmland is lower than in other parts of Uppsala County. The riparian zone of the lakes consists to a large extent of peatland, often in the form of mires, which are frequently flooded at high water flows. Common reed is often the dominant plant species along the shores.

The median surface area of the brown-water lakes in the Forsmarksån catchment (Table 3-27) is four times greater than that of the lakes in Uppsala County in general, and much greater than that of oligotrophic hardwater lakes in catchment 54/55. The mean depth is lower than the mean depth of lakes in the county, but larger than that of the Forsmark lakes. Hence, the brown-water lakes also have larger water volumes than the oligotrophic hardwater lakes. Because of their

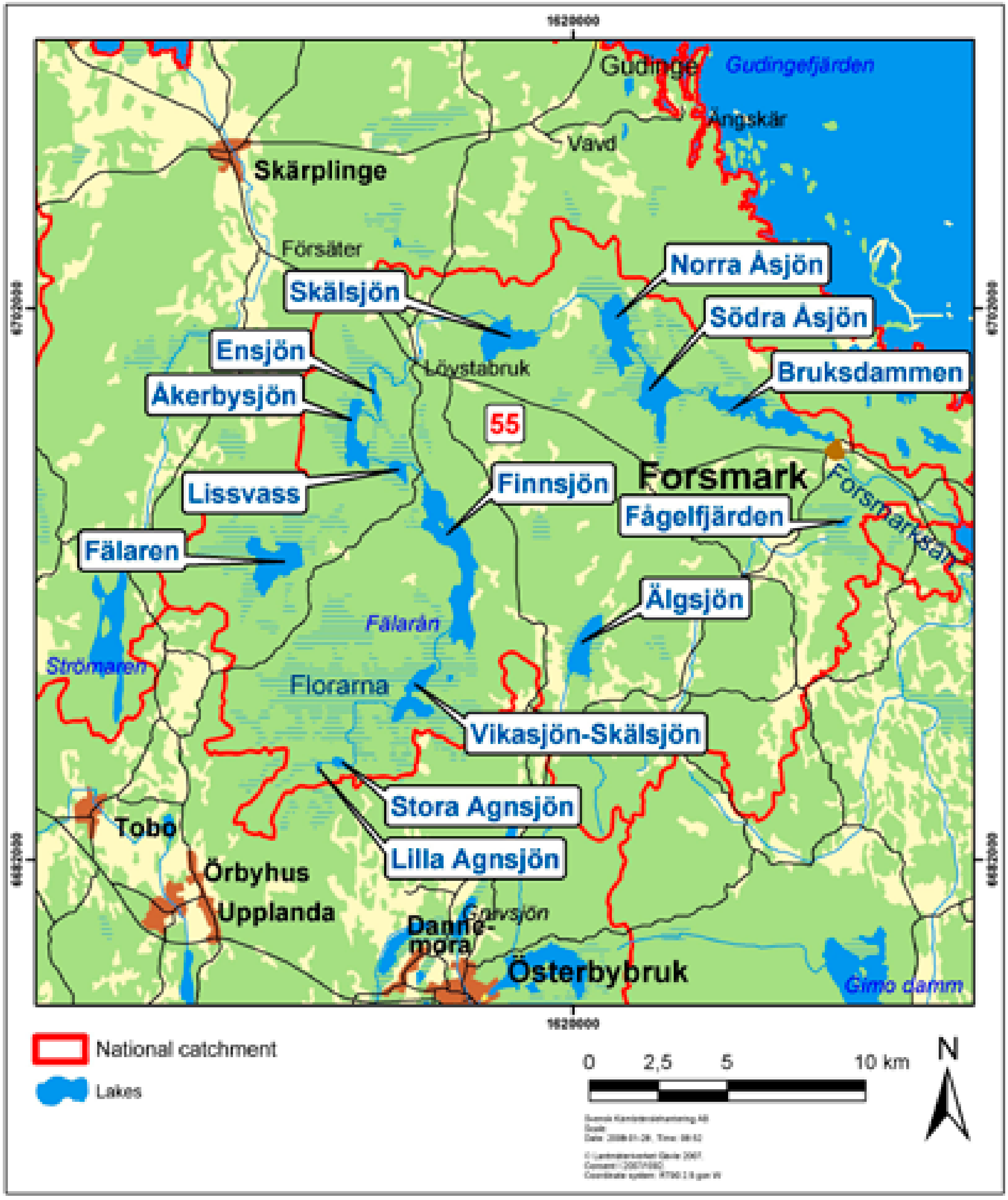


Figure 3-49. Lakes in catchment 55, Forsmarksån.

large catchments, the retention time of the brown-water lakes is shorter than that of both oligotrophic hardwater lakes and other lakes in the county. The short water retention time reflects the fact that the main stream passes through most of the lakes. Moreover, results from a few sediment investigations in lakes situated in the Forsmarksån catchment show that the lake sediments have a brown colour and are organogenic, with high C/N and C/P ratios. This indicates a large contribution by allochtonous material /Brunberg and Blomqvist 2000/.

The water chemistry in the brown-water lakes shows small differences between the different parts of the catchment. The water in the system has a relatively strong water colour and dominance of Ca^{2+} and HCO_3^- ions, which is typical for the brown-water lakes in lowland areas of Uppsala County in general /Brunberg and Blomqvist 2000/. Due to the large amounts of humic substances, brown-water lakes are typically high in total organic compounds (TOC), most of which are present as dissolved organic compounds (DOC). The phosphorus concentrations of the lakes in the catchment of Forsmarksån are usually moderately high (12.5–25 µg P L^{-1}).

It is likely that a large part of the phosphorus is associated with dissolved organic compounds and thereby less available to the primary producers. The alkalinity is high and the oxygen situation during winter is normally good in most of the lakes (Table 3-29).

According to a few studies of phytoplankton in lakes in the catchment of Forsmarksån, the biomasses were very low. Investigations of benthic fauna in Skälsjön, Lissvass, Ensjön and Åkerbysjön reported low biomasses. Chironomid larvae strongly dominated the species composition /Brunberg and Blomqvist 2000/. Twelve lakes in Table 3-31 have been subject to standardized gillnet fishing and fish were caught in all these lakes. A total of 9 species were encountered: pike, roach, perch, ruffe, bream, white bream, rudd, tench and Crucian carp. The average number of species per lake was 7.1. The results show a relatively diverse fish community, and the number of species caught was higher than the average for the county (5.8 species). On the other hand, the fish biomass and abundance was much lower than the county mean.

Lakes in catchment 56, Olandsån

The lakes in the catchment of Olandsån are larger and deeper than the oligotrophic hardwater lakes in the Forsmark area and therefore also have a much larger water volumes (Table 3-27). The catchments are also large, so the lakes have shorter water retention times than the lakes in catchment 54/55 and lakes in Uppland County in general. They are more similar to the brown-water lakes in the catchment of Forsmarksån. A map showing the position of the lakes mentioned in the text is presented in Figure 3-50.

Table 3-31. Data from standardized survey involving gillnet fishing in lakes in the catchment of Forsmarksån (catchment 55). Pi=pike, Ro=roach, Pe=perch, Ru=ruffe, Br=bream, Wh=white bream, Rd=rudd, Te=tench, Cr=Crucian carp. From /Brunberg and Blomqvist 2000/.

	Fish species	CPUE No. of individuals	CPUE kg ww	Lake area ha
Catchment 55				
Bruksdammen	Pi,Ro,Pe,Ru,Br,Wh,Rd,Te,Cr	24	2.0	206
Södra Åsjön	Pi,Ro,Pe,Ru,Br,Wh,Rd,Te	34	1.8	198
Älgsjön	Pi,Ro,Pe,Rd,Te	49	2.2	117
Norra Åsjön	Pi,Ro,Pe,Ru,Br,Wh,Rd	51	1.3	177
Skälsjön	Pi,Ro,Pe,Ru,Br,Wh,Rd,Te,Cr	88	4.1	183
Ensjön	Ro,Pe,Ru,Br,Wh,Rd	38	1.2	34
Åkerbysjön	Ro,Pe,Ru,Br,Wh,Rd,Te	42	1.8	111
Lissvass	Pi,Ro,Pe,Ru,Br,Wh,Rd,Te	64	3.7	35
Finnsjön	Pi,Ro,Pe,Ru,Br,Wh,Rd,Te	57	1.6	409
Fälaren	Ro,Pe,Ru,Br,Wh,Rd,Te	18	1.2	205
Vikasjön-Skälsjön	Ro,Pe,Ru,Br,Wh,Rd	44	0.42	104
Stora Agnsjön	Ro,Pe,Ru,Br,Rd	32	1.7	24
Average		**45**	**1.92**	**150**
Median		43	1.75	147
Max		88	4.1	409
Min		18	0.42	24
N observations		12	12	12
Average Uppland County				
Lake size 0–10 ha		44	2.62	
Lake size 11–50 ha		78	3.59	
Lake size 51–150 ha		130	4.36	
Lake size > 150 ha		88	3.63	
Average Forsmark area				
Mean for Bolundsfjärden, Eckarfjärden, Fiskarfjärden and Gunnarsbo-Lillfjärden		45	3.48	

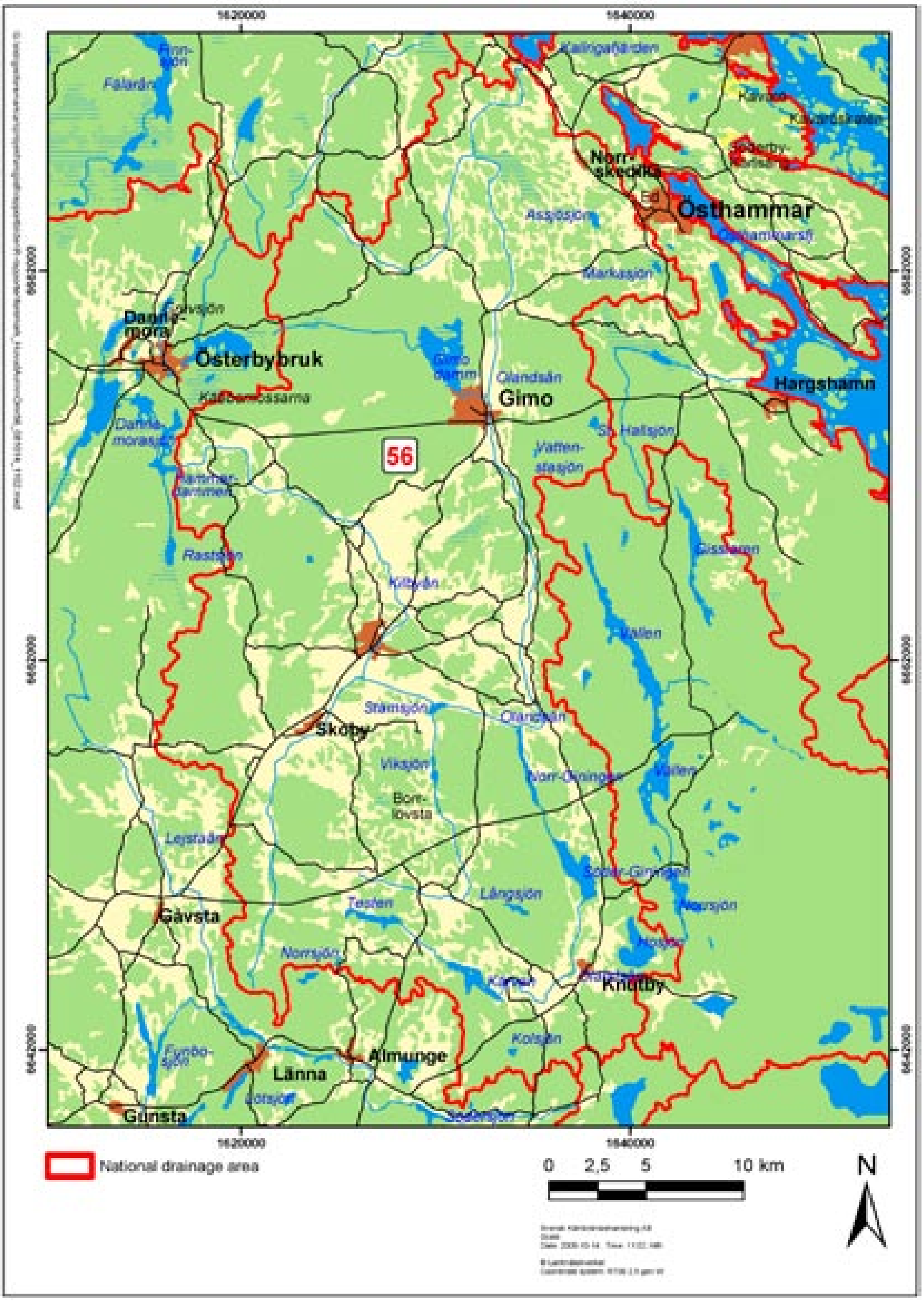


Figure 3-50. *Lakes in the catchment of Olandsån.*

The lakes show variable oxygen conditions: good oxygen conditions prevail in 2 lakes, while there is a risk of oxygen depletion beneath the ice during the winter period in 5 of the investigated lakes in the catchment (Table 3-29). Net fishing was performed in 10 lakes during 1991 (1992 for Vattenstasjön) (Table 3-32). In one of the lakes no fish were caught (Kolsjön), and one of the other not-investigated lakes (Markasjön) most probably has no fish according to /Brunberg and Blomqvist 2000/. Several of the other lakes have a diverse fish fauna. For lakes with fish, the average number of species per lake was 5.6, which is close to the average for the county (5.6). However, there was a large variation between lakes and number of species ranged from 1 to 9.

3.12.2 Streams

There are two large streams in the Forsmark region: Forsmarksån and Olandsån. Each of them drains a large area and they discharge into the bay Kallrigafjärden (Figure 3-47) These two watercourses are much larger than the small streams in the site investigation area described earlier in this chapter, which might be characterized as ditches rather than streams. Data for the two large streams have been collected from /Brunberg and Blomqvist 1998/. Their catchments are named catchment 55 (Forsmarksån) and 56 (Olandsån) according to the SMHI numbering system.

Table 3-32. Fish data for some of the lakes in the catchment Olandsån. From /Brunberg and Blomqvist 1998/. Br=bream, Bu=burbot, Cr=Crucian carp, Ide=ide, Pe=perch, Pi=pike, Ro=roach, Ru=ruffe, Rd=rudd, Te=tench, Wh=white bream. The average represents the 10 lakes where fishing was not performed.

Lake	Fish species	CPUE No. of individuals	CPUE kg ww	Lake area ha
Markasjön*		*	*	18
Assjösjön	Cr, Pe, Pi, Ro, Te,	58	6.33	25
Stora hallsjön	Pe, Pi, Ro,	90.5	3.55	28
Gimo damm	Br, Cr, Pe, Ro, Rd, Ru, Te	66	3.44	297
Vattenstasjön	Cr	0.4	0.41	8
Stamsjön	Br, Ide, Pe, Ro, Rd, Te, Wh	17.7	1.8	45
Långsjön	Br, Pe, Pi, Ro, Rd, Ru, Te, Wh	43.8	2.6	31
Söder-giningen	Br, Cr, Pe, Ro, Rd, Ru, Te, Wh,	160	9.03	303
Hosjön	Pi			
Kärven	Br, Bu, Cr, Pe, Pi, Ro, Rd, Ru, Te,	62	3.9	186
Kolsjön	–	–	–	15
Testen	Br, Cr, Pe, Ro, Ru, Rd, Te	121.7	6.25	107
Average		**62**	**3.7**	**105**
Median		60	3.5	38
N obs		10	10	10
Max		160	9.0	303
Min		0	0	8
Average Uppland County				
Lake size 0–10 ha		44	2.62	
Lake size 11–50 ha		78	3.59	
Lake size 51–150 ha		130	4.36	
Lake size > 150 ha		88	3.63	
Average Forsmark area (N=4)				
Mean for Bolundsfjärden, Eckarfjärden, Fiskarfjärden and Gunnarsbo-Lillfjärden		45	3.48	

* most probably has no fish.

Forsmarksån

The main catchment of Forsmarksån is 375 km^2 and it is, like the small catchments of the Forsmark area, dominated by forest (69%) and wetland (17%). Fields and meadowland make up 9% and lakes make up 5% of the catchment. The difference in altitude is 55 m, and the average slope is 0.7 m km^{-1}. The catchment is further divided into 16 sub-catchments. Land use within each sub-catchment is shown in Table 3-33. The sources are situated within the wetland area Florarna, which is a nature reserve. Almost all lakes in the catchment are affected by regulation dams that were created during the 17th and 18th centuries for hydropower generation, mainly for iron production. Two of the lakes (Stora and Lilla Agnsjön) originally drained into the Fyrisån catchment, but were diverted to the catchment of Forsmarksån during this period. Many of the dams are not in use today and some have been restored. There are about 20 dams (or remnant of dams) within the water system today.

The large area of the Forsmarksån catchment makes the water flow relatively large in the summer. Forsmarksån is c. 40 km long and has an average water flow of 2.8 m^3 s^{-1}. This is about 100 times higher discharge than in the streams of the Forsmark area, where annual mean discharge varies between 0.01 and 0.03 m^3 s^{-1} (section 3.3.1). The normal high-water flow in Forsmarksån is 15 m^3 s^{-1}, the highest high-water flow is 35 m^3 s^{-1}, the normal low-water flow is 0.3 m^3 s^{-1}, and the lowest low-water flow is 0 m^3 s^{-1}.

The water in Forsmarksån is moderately nutrient-rich, strongly coloured and has a very high buffering capacity. The lower parts of Forsmarksån (including some tributaries) are reproduction areas for freshwater fish from the Baltic Sea (e.g. bream (*Vimba vimba*)). Migrating sea trout are also found in the lower parts of the stream. During a fish inventory in 1990, 10 fish species were caught: bullhead, roach, perch, white bream, burbot, pike, sea trout, rudd and European brook lamprey /Brunberg and Blomqvist 1998/.

The ionic composition and water colour at two stations in Forsmarksån (Vikasjön 668814 161417 in the upper part of the catchment and at Johannisfors 669500 163246 1.5 km from the outlet to the Baltic Sea) are shown in Table 3-34 /Brunberg and Blomqvist 2000/. The county administrative board has two other water sampling locations in Forsmarksån: Forsmarks bruk (coordinates 669500, 163249) and Lövstabruk (670158, 161442) /Brunberg and Blomqvist 1998/. As in the Forsmark streams, calcium levels are very high.

Table 3-33. Land use in the sub-catchments of Forsmarksån, from /Brunberg and Blomqvist 1998/.

Sub-catchment	Area (km^2)	Forest (%)	Wetland (%)	Farmland (%)	Lakes (%)	Other land use (%)	Difference in altitude (m)
Totally for Forsmarksån 55	375	69	17	9	5		55
1	24.2	77	10	13	0		25
2	65.7	74	6	20	0		50
3	17.0	62	22	4	12		15
4	38.0	77	12	6	5		30
5	31.6	78	5	14	3		35
6	17.0	59	21	9	11		15
7	24.2	75	11	7	7		45
8	29.3	83	7	10	0		30
9	8.63	66	31	0	3		25
10	12.1	69	21	2	8		25
11	2.58	51	34	1	14		10
12	37.9	65	19	4	11	1	20
13	21.0	59	31	0	10		20
14a+b	39.3	47	49	1	3		20
15	1.20	51	30	0	19		10
16	4.80	73	25	0	2		20

Table 3-34. Ionic composition (equiv. %, average values) and water colour (mg Pt L^{-1}) at two stations in Forsmarksån: Vikasjön, in the upper part of the catchment, and Johannisfors, 1.5 km from the outlet to the Baltic Sea. Average values from regular monitoring programmes /Wilander et al. 2003/, compared with the "standard composition" of fresh water lakes according to /Rodhe 1949/. From /Brunberg and Blomqvist 2000/.

	Ca	Mg	Na	K	HCO3	SO4	Cl	Water colour
Lake Vikasjön, 28 m.a.s.l.	73	10	14	2	76	8	15	180
Johannisfors, 3 m.a.s.l.	79	8	11	2	74	15	11	75
Standard composition /Rodhe 1949/	63.5	17.4	15.7	3.4	73.9	16.0	10.1	–

Olandsån

The catchment of Olandsån is 886 km^2 and contains 67% forest, 4% wetland, 27% fields and meadowland and 2% lakes. The catchment of Olandsån is, like the catchment of Forsmarksån and the small catchments in the Forsmark area, strongly dominated by forest (almost 70%). Hence, although the catchment of Olandsån has somewhat more fields and meadows than the other catchments, there are no larger differences in land use between the catchments. The difference in altitude in catchment Olandsån is 70 m. The catchment is further divided into 26 sub-catchments. Land uses within each sub-catchment are shown in Table 3-35.

Table 3-35. Land use in the sub-catchments of Olandsån, from /Brunberg and Blomqvist 1998/.

Sub-catchment	Area (km^2)	Forest (%)	Wetland (%)	Farmland (%)	Lakes (%)	Other land use (%)	Difference in altitude (m)
Total for Olandsån	886	67	4	27	2		70
1	155	63	3	33		1	40
2	51.4	77	1	22			45
3	35.0	56	7	36		1	20
4	8.65	67	8	24	1		25
5	9.35	66	2	30	2		20
6	19.6	84	5	11			35
7	4.14	83	11		6		20
8	17.7	66	12	1	21		25
9	58.3	92	7	1			40
10	1.85	89	7	1	3		15
11	18.0	71	8	17	4		30
12	92.5	56	1	43			60
13	11.1	74	11	11	3	1	30
14	53.3	63	3	34			40
15	4.99	83	10	1	6		25
16	118	64	2	33		1	45
17	23.6	68	4	28			25
18	35.9	77	4	19			60
19	25.3	72	8	20			30
20	28.0	65	5	20	10		30
21	13.8	60	12	16	12		30
22	40.4	60	5	34		1	40
23	29.9	66	6	23	5		30
24	3.72	88	9		3		15
25	4.21	80	8	11	1		20
26	21.3	61	4	31	4		20

Today, there are 14 dams and three municipal wastewater treatment works in the catchment. The dams are mainly concentrated at Gimo bruk in the northern part of the catchment. Part of the catchment formerly drained into Fyrisån, but is now linked to Olandsån. Almost all lakes within the catchment have been subject to drainage activities, which has turned some former lakes into wetlands. All larger stream channels, and 95% of the smaller streams, have been excavated and turned into channels and ditches. However, the main channel is unique as it provides a free passage for migrating fish all the way up to the upper parts of the stream.

The main channel of Olandsån is c. 35 km long, whereas the eastern channel is c. 30 km and the western channel c. 25 km. The average water flow is 6 $m^3 s^{-1}$, the normal high-water flow is 35 m^3/s, highest high-water flow is 80 m^3/s, the normal low-water flow is 0.7 m^3/s and the lowest low-water flow is 0.1 m^3/s. The average flow is almost twice that in Forsmarksån, and accordingly the flow in Olandsån is much higher than that in the Forsmark streams.

The water in Olandsån is nutrient-rich, strongly coloured and has a very high buffering capacity. Fish data from the stream are not available, but fish data are available from many of the lakes in the water systems /Brunberg and Blomqvist 1998/.

The county administrative board has six water sampling locations in Olandsån: Ledsundet (coordinates 668303, 163357), Gimo damm (667566, 163131), Ekeby (666493, 163478), Ålsunda (665920, 163249) and Giningen (665415, 163555).

3.13 Confidence and uncertainties in site data

The amount of data from the limnic ecosystems in the Forsmark area is large, especially for the lakes in the area. This provides good conditions for a relevant and correct characterization of the limnic ecosystems of Forsmark today. An evaluation of the robustness and uncertainties associated with the different kinds of data from the limnic system in the Forsmark area follows below.

Catchment characteristics

The size and land use of the catchments have been investigated mainly with GIS and aerial photos. The delimitation of some of the subareas has been adjusted as a result of the evaluation of the runoff data. The evaluation revealed inexplicable differences between subareas sharing the same border, which triggered a new field investigation of the area of interest. This is an example of how several investigations within the same area can be compared with each other to find mismatches. In our opinion the updated catchment delimitation is of good quality and acceptable to use for area descriptions and for further use in e.g. calculation of mass balances. The delimitation of land use and soil characteristics within the catchments is more uncertain since no validation has been performed of that data.

Hydrological measurements

Hydrological measurements have been performed in several ways. The water flow in streams has been measured since April 2004, whereas data for lake water levels is available from May 2003 (the number of measuring stations increased during the site investigation). As the site investigations were carried out during a relatively short time period, the time series are not of impressive length but the spatial density is quite good. Monitoring data from larger streams in the region are available from a much longer time period, but these results are valid for considerably larger streams than the small brooks and ditches within the Forsmark area. Accordingly, these data cannot be used directly. Instead, for long-term calculations, the data series from the streams in the Forsmark area can be compared with data series from SMHI from the larger stream Olandsån. Irrespective of whether the streams are large or small, the same patterns with high and low flows should be about the same in the whole region. This permits the calculation of long-term flow series.

The extent of periodically flooded areas around streams in the Forsmark area has been investigated in two of the catchments. The areas were delimited in the field using a D-GPS, which gives very good spatial precision. The two investigated catchments are very different from each other in terms of stream length and flooded area per stream length, making it difficult to draw any general conclusions. A comparison of the results from field investigations with the extent of wet areas on the vegetation map created from aerial photos showed that the vegetation map was not always correct. If this information is of critical importance it may therefore be appropriate to delimit the borders in field.

Climate parameters

Climate parameters have been measured locally since May 2003. Measurements have been performed at two stations within the area, which show very similar data. This strengthens the assumption that climate data varies insignificantly within the small site investigation area, whereas a gradient is seen for some parameters (i.e. precipitation) when comparing inland with coastal areas. As with the hydrological data, the time series are short but can be compared with longer time series from the region.

Lake bathymetry

The lake bathymetry has been measured with good precision. The shorelines have been delimited in the field using a D-GPS and a distance between measuring points of approximately 4 m. The water depths were measured by means of echo sounding in larger lakes (i.e. Eckarfjärden and Bolundsfjärden) from a boat and in smaller lakes (i.e. Labboträsket) from ice. The distance between the measuring points differs /Brydsten et al. 2004/. However, this must be considered as acceptable spatial precision.

Physical characters of the streams

The physical characters of the streams in the Forsmark area have been investigated in the field in stretches of 10 m each and this must be considered as very good spatial precision. Bottom substrate, water velocity, bottom vegetation, shading from terrestrial vegetation and technical encroachments were investigated, so that a large amount of data are available to describe the stream character. The entire investigation was performed by the same person, so differences within the data as a consequence of different judgments of the somewhat subjective parameters can be excluded. However, this also means that the correctness of the investigation results cannot be validated since no stretches have been investigated independently by two persons. A comparison of the bottom substrate data from this investigation with the map of Quaternary deposits reveals large discrepancies, but the latter investigation reflects the composition at a soil depth of 0.5 m and no special effort has been made to investigate the stream channel. The data collected in the stream investigation are therefore most probably more correct in these cases.

Sediment

The amount of sediment data from lakes in the Forsmark area is substantial, although most of the data stems from one lake: Eckarfjärden. This lake has been well characterized with regard to stratigraphical information (n=13, see section 3.6), sediment water (n=12 for gyttja layer and 6 for clay layer) and carbon content (n=8) as well as long-term sediment accumulation rate (based on 3 radiocarbon dates). The only parameter missing from this lake is water content from the gyttja clay–clay gyttja layer. As it is assumed that this sediment type settled in the marine phase, this information has been estimated using data for this sediment type in the shallow sea bays Kallrigafjärden and Tixelfjärden in the Forsmark area. The water content found there resembles the water content of this sediment layer in Frisksjön in the Laxemar-Simpevarp area, which also supports the use of this data. Data from Eckarfjärden have been compared with data from three other lakes in the region /Hedenström and Risberg 2003/. The comparison provides information on the variation in different sediment parameters in this special lake type and is further discussed in section 5.2.3 and 5.6.

For other lakes in the Forsmark area, some sediment data are available for comparison. Water content in the gyttja layer is also available from Bolundsfjärden (n=15) and Puttan (n=21), representing one larger and one smaller lake in the area. Data on the carbon content of gyttja, gyttja clay–clay gyttja and clay layers are also available from Fiskarfjärden (n=6, 10 and 6, respectively) and Puttan (n=17 and 2, respectively (no clay data)). Stratigraphical data for a number of lakes in the Forsmark area are available in /Hedenström 2004/. The number of observation points in each lake varies with lake size. Overall, the sediment description is detailed and gives good estimates of order of magnitudes.

Lake habitats

The lake habitats have been delimited in the field using D-GPS equipment and must be considered to be of good quality. The problem with the habitat delimitation is rather the delimitation between limnic and terrestrial ecosystems. The shoreline used in the lake investigation is the highest water level, which has the consequence that wetlands in direct contact with the lake are also included in the lake, as discussed earlier (see section 2.3.1). As the water level is not constant, the impact of these wetland areas on the rest of the lake varies over time and we have no information about the exchange of substances between the wetlands and the lakes. There can be expected to be a flow of substances from the wetland to the lake. In this report, all wetlands bordering on the lakes have been considered to be terrestrial areas (wetlands). The inflow of carbon from these areas is addressed in the chapter dealing with carbon mass balance calculations (Chapter 5).

Chemistry data

The amount of water chemistry data from limnic environments in the Forsmark area is unusually large, in space as well as in time, even though the data set is certainly not unique. The amount of data differs between different parameters, for example isotopes of certain elements have been measured only once every four months, compared with most other elements, which have been measured every month.

The sampling and measurements have been performed by qualified personal, and the analyses have been performed by accredited laboratories, which should guarantee high data quality. The data series for some of the sampling points are longer than for others: 5 years instead of 2. In the sampling points with data from 5 years there are no obvious differences in water chemistry between the 2 years monitored for all sampling stations and the additional 3 years. The 2 monitored years in the area can therefore be regarded as representative for a longer time period.

Chemistry data for sediments are less extensive. Analyses of carbon and water contents have been performed on sediments from more than one lake, and these data can therefore be considered to provide a robust estimate of the order of magnitude of these substances in lake sediments in the Forsmark area. A characterization of 64 elements has been performed once in Eckarfjärden /Hannu and Karlsson 2006/ and once in Stocksjön /Strömgren and Brunberg 2006/. This represents one of the larger and one of the smaller lakes. The data are from different sediment depths, thus representing different time periods. However, there is only one sediment core from each lake, so the characterization provides no estimates of variations within the lake. Overall, these measurements give robust estimates of the amounts of elements in lake sediments in the Forsmark area.

Chemical characteristics of limnic biota in Forsmark have been investigated once in samples from three lakes: Bolundsfjärden, Eckarfjärden and Fiskarfjärden. The number of organism groups is restricted (fish, mussel, macroalgae and benthic microalgae) and the number of replicates differs, which means that the reliability of the data also differs between functional groups. Overall, the chemical distribution between biota can be viewed as robust with regard to the order of magnitudes of different elements in different functional groups, although the absolute figures may be more uncertain.

Biota in lakes

Biomass

The amount of data on biota in Forsmark lakes is extensive. For many functional groups, biomass data from several years are available. One weak point in the biota data is that most of the information is on biomass, and little effort has been spent on the quantification of biological processes. The exception is primary production, which has been investigated for phytoplankton, microphytobenthos and submerged vegetation, while data on respiration and consumption from the area are lacking. However, an unrealistic effort is required to measure the respiration and consumption of biota in Forsmark area, and it is unclear whether site-specific studies would provide a greater understanding of the sites than the literature data on respiration and consumption for functional groups we have used in this report (Chapter 5).

In many cases, biomass data are from one lake only, and in most cases this is Eckarfjärden. Some data have been collected from Bolundsfjärden and Fiskarfjärden. Data from the smaller lakes are scarce, which may be seen as a weak point. However, investigations of the thickness of the microbial mat, chlorophyll *a* concentrations in the water (a measure of phytoplankton biomass) and gillnet fishing permit comparison between smaller and larger lakes, and there is no reason to suggest any significant differences in terms of biota. The biomass estimates for the different functional groups are within values reported in the literature, which is an indication of robustness in the results.

The biomasses of the functional groups phytoplankton, microphytobenthos, benthic bacteria and bacterioplankton have been measured repeatedly in Eckarfjärden over a period of three years (n=38, 39, 36, 29 and 38, respectively), which must be considered good temporal coverage. Accordingly, calculated annual means can be seen as robust estimates. Zooplankton was divided into three subgroups, which were measured for different time periods: small heterotrophic flagellates (3 y), ciliates (2 y) and larger metazooplankton (1 y). Altogether, the zooplankton biomass can be considered a reliable estimate, although longer time series would be necessary to evaluate variation between years. The biomass of the macroalgae *Chara* has been measured on three occasions during one year, which makes it possible to estimate the within-year variation, but investigations provide no information on the between-year variation. The large number of replicates on each sampling occasion (n=20) indicates that the high variation and skewed distribution in biomass reflect a real within-lake variation.

The benthic fauna biomass was investigated in more than one lake, so variations between lakes in the area can be estimated. However, the benthic fauna was only investigated once in each lake and thus we have no information about between-year variation. In the studies of benthic fauna, two different sampling techniques (frames versus Ekman grabber) were used, making it difficult to compare the results. We have chosen to view the different techniques as different ways to sample two different microhabitats (areas covered with submerged vegetation versus vegetation-free bottoms). The number of samples is small, which is also indicated by a large variation. Moreover, small meiofauna is not included in the biomass of benthic fauna, and it is therefore likely that the biomass of benthic fauna is somewhat underestimated.

The fish biomass was investigated in several lakes, so variations between lakes in the area can be estimated. The study of fish biomass was performed using a standardized technique and the results must be considered robust and possible to compare with the results of other investigations. The biomass of fish was only investigated once in each lake, which provides no information about between-year variations. The most important uncertainty associated with this data is the conversion factor used to estimate the fish biomass from the CPUE (catch per unit effort) value gained during the standardized gillnet fishing. The conversion factor we used was recommended by a Swedish fish expert, but no conversion factors have been published in the scientific literature. The classification of fish species into different functional groups according to their size may also be somewhat uncertain. The conversion from zooplanktivore to piscivore may not be total and may differ between lakes depending on food resources and competition

The biomass of emergent macrophytes has been investigated once in the late summer in Eckarfjärden. The results provide an estimate of the maximum amount of biomass, but offer no information on variations within or between years or variations between lakes.

Primary production

Primary production by phytoplankton and microalgae has been measured with a relatively good temporal coverage over two years (n=18 and 16, respectively). The primary production of submerged vegetation (mainly *Chara sp.*) was measured on three occasions during one year. The calculated annual mean productions of phytoplankton, microphytobenthos and submerged vegetation provide rather rough estimates. Production of phytoplankton can be assumed to be directly proportional to light /Wetzel and Likens 1991/. This is not true of the phytoplankton at the water surface, but for the whole water column. The same direct proportionality between light and productions was assumed for microphytobenthos and submerged vegetation. However, the microphytobenthos and submerged vegetation are fixed at certain depths in the water column and may thus be more dependent on light limitation or light saturation, which would affect this proportionality. Moreover, we have extrapolated the production for all primary producers from measurements on a few dates to an entire year. Extrapolating production from light to a few days gives relatively accurate production values, whereas extrapolation for longer periods is more uncertain /Wetzel and Likens 1991/. Thus it is clear that our estimates of annual primary production are associated with uncertainty. However, they are probably good estimates of the order of magnitude of the production of phytoplankton, microphytobenthos and submerged vegetation.

Dark respiration of primary producers is difficult to assess and may have resulted in some uncertainties in the estimation of annual production. Dark respiration by phytoplankton is not accounted for in the model, but net primary production has been measured during daytime. However, dark respiration by phytoplankton is low compared to light respiration /e.g. Stelmakh 2003/. Moreover, primary production by phytoplankton is relatively small compared to production by macrophytes and benthic primary producers, and dark respiration by phytoplankton is probably of minor importance. Dark respiration at night by the macroalgae *Chara sp.* was calculated from measured dark respiration during the daytime. However, dark respiration is not necessarily the same as plant respiration during the daytime. Nevertheless, we consider the estimate to be realistic, and even if dark respiration is somewhat altered, the magnitude should be correct. Net primary production by the microphytobenthos was measured by ^{14}C incorporation and respiration was not assessed. This may result in an underestimate as dark respiration during the nighttime is not included. Dark respiration may not be the same as light respiration and dark respiration by phytoplankton may be lower than the light respiration /Stelmakh 2003/. The same is probably true for the microphytobenthos. Thus, although primary production by the microphytobenthos may be overestimated, the error should not be greater than 20% (dark respiration by *Chara sp.*).

Biota in streams

The information on biota in the Forsmark streams consists of data on vegetation and on fish migration. No measurements of primary production or respiration have been performed. This may be seen as a weak point, but as the streams are mainly man-made ditches and long stretches are dry during part of the vegetation period this should not be an important information gap.

Vegetation in streams has been investigated in 10 m sections (in total c. 7 km stream length). The spatial distribution of data must therefore be regarded as very good, although parts of the streams were not investigated. The investigation was performed by one person, so differences within the data as a consequence of different judgements of the somewhat subjective parameters can be excluded. This also means that results cannot be validated since no stretches have been investigated independently by two persons.

Migration of spawning fish in the Forsmark streams was investigated during the course of one year. All fish migrating from the sea to Norra Bassängen in the spring of 2004 were caught and recorded, providing a good estimate of the magnitude of the migration. The study gives no information about variations between years.

Land use and human impacts

Land use and human impacts on limnic environments have been investigated in the two characterization studies of lakes and streams in the Forsmark area. In the lake characterization, no extra effort was made to find such information and only conditions known to the authors were recorded. Some human impact may therefore have been overlooked, but considering the relative young age of the area this is less likely. The presence of barriers to migratory fish and human impacts in streams are well documented for the stretches that have been investigated, while information for other stretches is lacking.

Conclusions

In general, an impressive amount of data has been gathered from the area during the site investigations. The data quality is most often judged as high, whereas the spatial and/or temporal density in the available data varies.

4 Description of lakes and streams in the Laxemar-Simpevarp area

The Laxemar-Simpevarp regional model area contains 26 catchments, 5 lakes and a number of streams. Data for description of the limnic systems have been collected from site-specific investigations in streams and lakes. The following text describes these investigations with a focus on describing the limnic ecosystems. The sampling methods used are only briefly described. For further details the reader is directed to the investigation reports.

4.1 General description of the lakes and streams

One lake, Frisksjön, is situated completely within the Laxemar local model area and another 4 lakes are situated within the Laxemar-Simpevarp regional model (Figure 4-1). In addition, a couple of lakes are situated partly within the area, and there are also some small but permanent pools. In this report, the lakes in the regional model area are described with a focus on Frisksjön.

The bedrock in the Laxemar-Simpevarp area, as well as in most parts of south-eastern Sweden, is dominated by igneous rocks, and most of the bedrock in the area has a granite mineral composition. The lakes often have very thick sediment layers, and e.g. in Frisksjön the gyttja layer reaches a depth of 10 m.

The lakes are small with relatively shallow depths. They are characterized as mesotrophic brown-water lakes, i.e. with moderate nutrient concentrations and with brown water colour. The water colour is caused by a high input of organic matter from the surrounding catchment, and the concentration of organic carbon is very high in comparison with the majority of Swedish lakes. Because of the brownish water, light penetration is poor and the depth of the photic zone is generally small. In accordance, macrophyte coverage is small in the lakes and biota is dominated by heterotrophic organisms, particularly bacteria. Perch is the dominant fish species in numbers as well as in weight in the lakes in the area.

The lakes in the area are small but generally deeper than the lakes in the Forsmark area. The retention time of the lakes varies between 218 days and as much as 829 days.

Most lakes in the area are affected by human activities. The names of some wetlands and minor fields in the area indicate that a number of former lakes have disappeared during the past centuries due to human activities, probably with the aim of gaining farmland. There are also indications that the water level in several of the remaining lakes has been lowered by man.

The streams in the Laxemar-Simpevarp area are presented in Figure 4-2. Most of the streams are small with mostly calm or slowly flowing water. Many streams are dry in the summer but a few, such as Laxemarån, have a permanent water flow. The streams are characterized as mesotrophic brown-water systems. Similar to the situation in lakes, stream water is strongly coloured due to high amounts of humic substances, leading to very high concentrations of dissolved organic carbon. The streams are also relatively rich in nitrogen and phosphorus. Five fish species have been noted in Laxemarån: ide (*Leuciscus idus)*, roach (*Rutilus rutilus)*, burbot (*Lota lota)*, pike (*Esox lucius)* and ruffe (*Gymnocephalus cernua*), and there are indications that the stream is an important spawning ground for both ide and roach. The streams are to a large extent influenced by human activities, which have altered the channel by various technical encroachments.

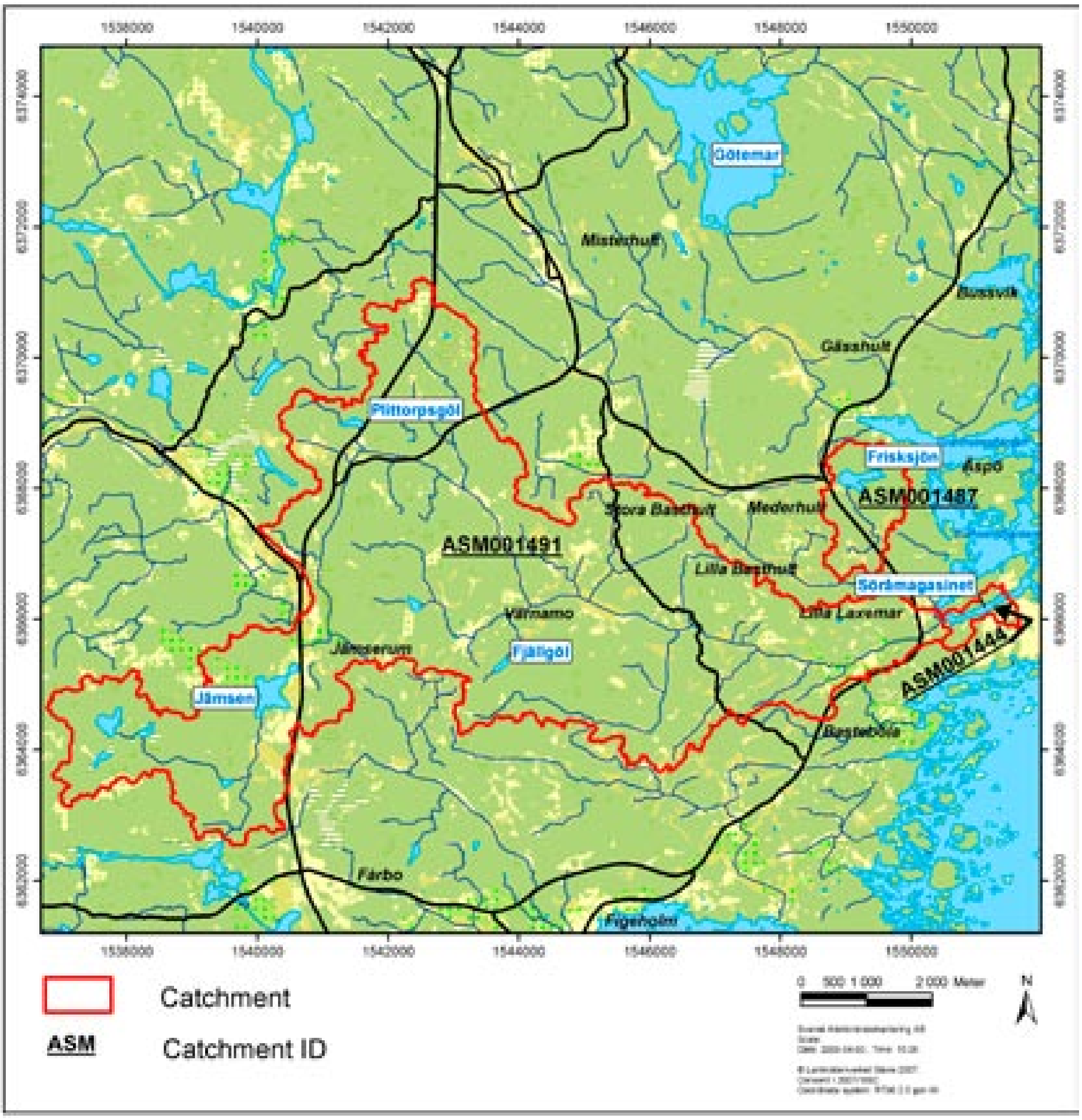


Figure 4-1. Lakes in the Simpevarp regional model area.

4.2 Catchment characteristics

The catchment is the land area (including lakes) from which the water is drained to the same stream. The area is delimited by the topography and all precipitation falling within the catchment will eventually reach the sea through the same stream channel. The Laxemar-Simpevarp regional area contains 26 catchments of different sizes. Most catchments have a small area (median 0.6 km^2) although some catchments are large resulting in a relatively large mean catchment area (4.1 km^2). The catchments contain five lakes.

The catchment clearly regulates the characteristics of lakes and rivers within it /Wetzel 2001/. The geomorphology of the land determines the ionic composition and slope of the soil, and, in combination with the climate, also the vegetation of the area. The vegetation and soil composition influence the amount of runoff as well as the composition and quantity of organic matter that enters streams and lakes.

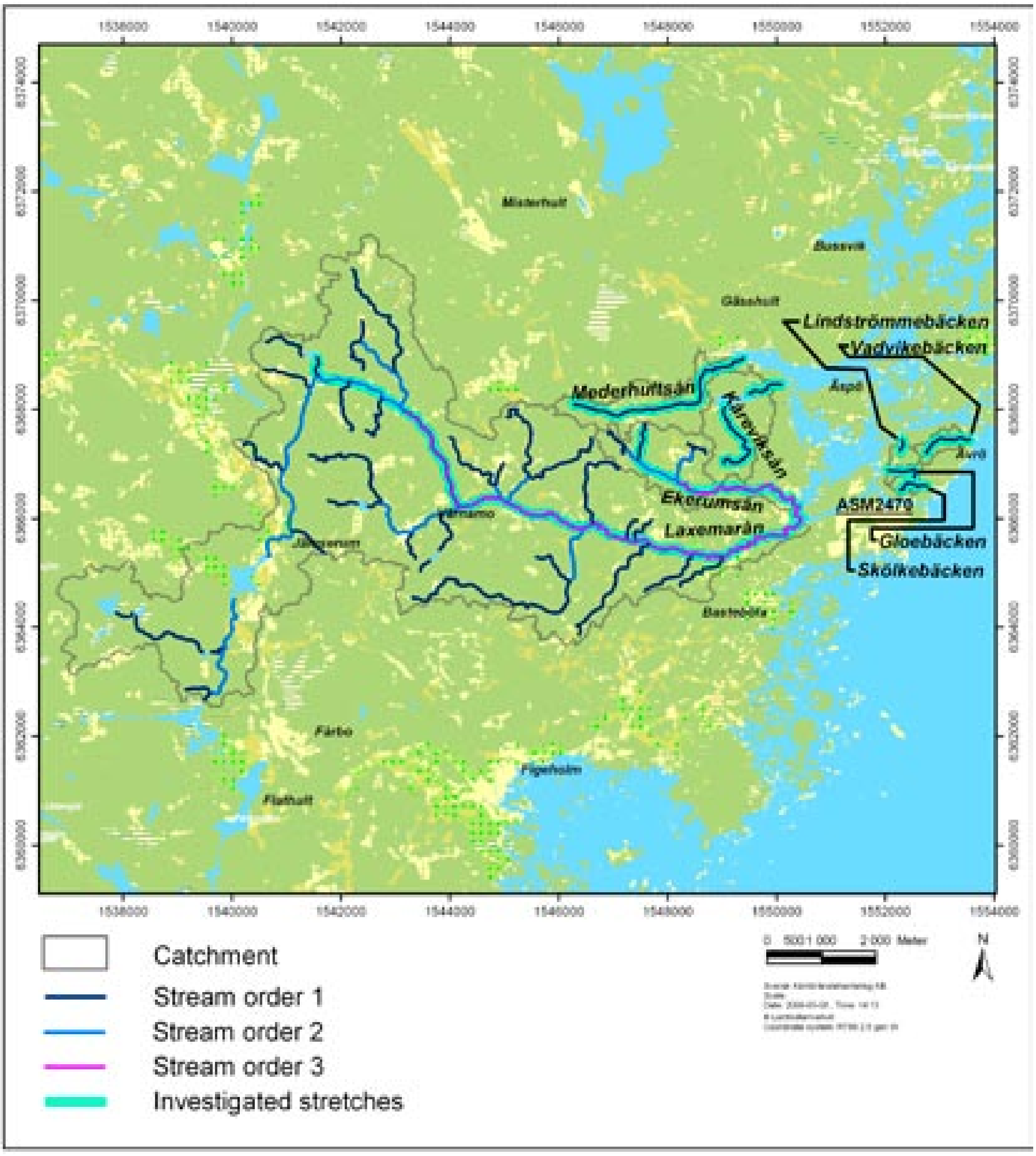


Figure 4-2. *Streams in the Laxemar-Simpevarp area. The stretches which have been investigated are marked. Stream orders are also presented.*

Morphological parameters as well as land use, soil composition and vegetation types of the different catchments in the Laxemar-Simpevarp area were examined in /Brunberg et al. 2004b/. The maximum elevation above sea level varies from 10 to 63 m, whereas the minimum level varies from 0 to 30 m. Most of the catchments are dominated by forest, which covers 90% of the total catchments. The lakes are relatively few and only 1% of the catchments are made up of water. Land use for the 5 lake catchments is shown in Table 4-1. Like the other catchments in the area, forest dominates completely, covering between 74 and 95% of the lake catchments.

The bedrock in the Laxemar-Simpevarp area, as well as in most parts of south-eastern Sweden, is dominated by igneous rocks, and most bedrock in the area has a granite mineral composition.

Table 4-1. Land use data for the catchments of five lakes in parts of the Laxemar-Simpevarp area (data from /Brunberg et al. 2004b/).

	Size (km^2)	% forest	% open land	% water
Average	2.1	88	3	9
Median	0.7	91	0	7
Min.	0.3	74	0	3
Max.	7	95	7	20

4.3 Hydrology

Surface waters in the Laxemar-Simpevarp area are mainly located in low-lying areas. In most of these areas, the till is overlain by relatively low-permeable postglacial sediments. This means that surface waters interact to a large extent with overland flow and near-surface groundwater flow, which yields temporally variable surface water flows and dry streams in the summer. All streams are relatively small and many of the streams are affected by human activities such as excavation (Figure 4-3). In many parts of the area, the locations of topographical water divides have been changed by ditching or blasting, causing the water to take another pathway than that dictated by the topography.

Figure 4-3. *Photos showing Laxemarån (upper left), one of the largest streams in the area, and Ekerumsån (lower left) and the outlet from Frisksjön (right), two of the smaller streams in the area.*

4.3.1 Discharge

Nine permanent automatic discharge gauging stations have been installed in the streams in the Laxemar-Simpevarp area as a basis for water balance calculations and for calculation of mass transport of different elements (Figure 4-4). Water levels, electrical conductivities, temperatures and discharges have been monitored at the stations. The available time series from the different stations differ due to the fact that the start of the measurements varied from March 2003 to February 2005 /Sjögren et al. 2007/. For all stations, the time period is relatively short and therefore the mean discharge values presented in Table 4-2 should be used with caution.

The mean specific discharge during the monitored period ranged between 3.5 and 7.3 L s^{-1} km^{-2} at the different monitoring stations (Table 4-2). In comparison, the specific discharge in Forsmark varied between 4.9 and 5.6, which means that the specific discharge is of a similar magnitude but the variation is somewhat greater in Laxemar-Simpevarp. Overall, discharge rates were generally low in the Laxemar-Simpevarp area. The results for each station are presented in Table 4-2. The mean discharge of all stations was 60 L s^{-1}, but the maximum discharge in the largest catchment in the Laxemar-Simpevarp area is quite high, 4,260 L s^{-1} (Laxemarån). The lowest recorded discharge rate is zero due to that several of the streams are dry in the summer. In comparison, the mean discharge downstream of Forshulteån 35 km southwest of Simpevarp was 609 L s^{-1} (SMHI station 1619, time period 1955–August 2007, data from the database SICADA) and the mean discharge in the Dalälven River is 353,000 L s^{-1} at the outlet to the Baltic Sea (average for the time period 1976–2000 according to www.dalalvensvvf.se/omdal.htm, accessed 2008-04-16).

Figure 4-4. Location of the nine discharge gauging stations in the Laxemar-Simpevarp area.

Table 4-2. Discharge characteristics for the nine gauging stations for various time periods (total available time series) in the Laxemar-Simpevarp area. From /Werner et al. 2008/.

	PSM 000341	PSM 000343	PSM 000345	PSM 000347	PSM 000348*	PSM 000353	PSM 000364	PSM 000365	PSM 000368	Mean all stations
Time interval	Mar 2003–Dec 2007	Mar 2003–Dec 2007	Mar 2003–Dec 2007	Nov 2004–Dec 2007	Jul 2004–Dec 2007	Sep 2004–Dec 2007	Nov 2004–Dec 2007	Feb 2005–Dec 2007	Jul 2004–Dec 2007	
Mean discharge ($L\cdot s^{-1}$)	1.5	0.5	0.7	4.6	6.6	59.4	293.4	13.2	164.0	60.4
Min. discharge ($L\cdot s^{-1}$)	0.0005	0	0	0	0.08	4	10	0	20	
Max. discharge ($L\cdot s^{-1}$)	44	19	27	140	98	988	4,261	449	4,260	
Specific discharge ($L\cdot s^{-1}km^{-2}$)	5.2	4.5	4.4	5.0	3.5	4.2	7.3	5.5	6.1	5.1
Specific discharge ($mm\cdot yr^{-1}$)	164	142	139	158	111	134	231	175	192	161
Catchment area (km^2)	0.29	0.11	0.16	0.91	1.88	14	40	2.38	27	9.6

* N.B. The measurements in the outlet of Frisksjön (PSM000348) are associated with great uncertainties, and the results from this station are probably erroneous /cf. Werner et al. 2008/.

4.3.2 Water levels in lakes

The water level in the four lakes Frisksjön, Söråmagasinet, Jämsen and Plittorpsgöl are shown in Figure 4-5. The same pattern is seen for all lakes, i.e. maximum water levels occur in spring, during snowmelt, followed by a decrease until a minimum level is reached in late summer and early autumn. Then the levels rise again up to a new maximum level in the spring. The mean, minimum and maximum water levels in lakes measured during the site investigations are presented in Table 4-3.

Table 4-3. Water levels (m.a.s.l.) in Jämsen, Plittorpsgöl, Frisksjön and Söråmagasinet.

	Jämsen	Plittorpsgöl	Frisksjön	Söråmagasinet
mean	25.6	25.0	1.6	1.8
median	25.5	25.0	1.5	1.8
min.	25.4	24.8	1.3	1.5
max.	26.0	25.4	2.2	2.1
n	1,256	1,256	1,256	1,228

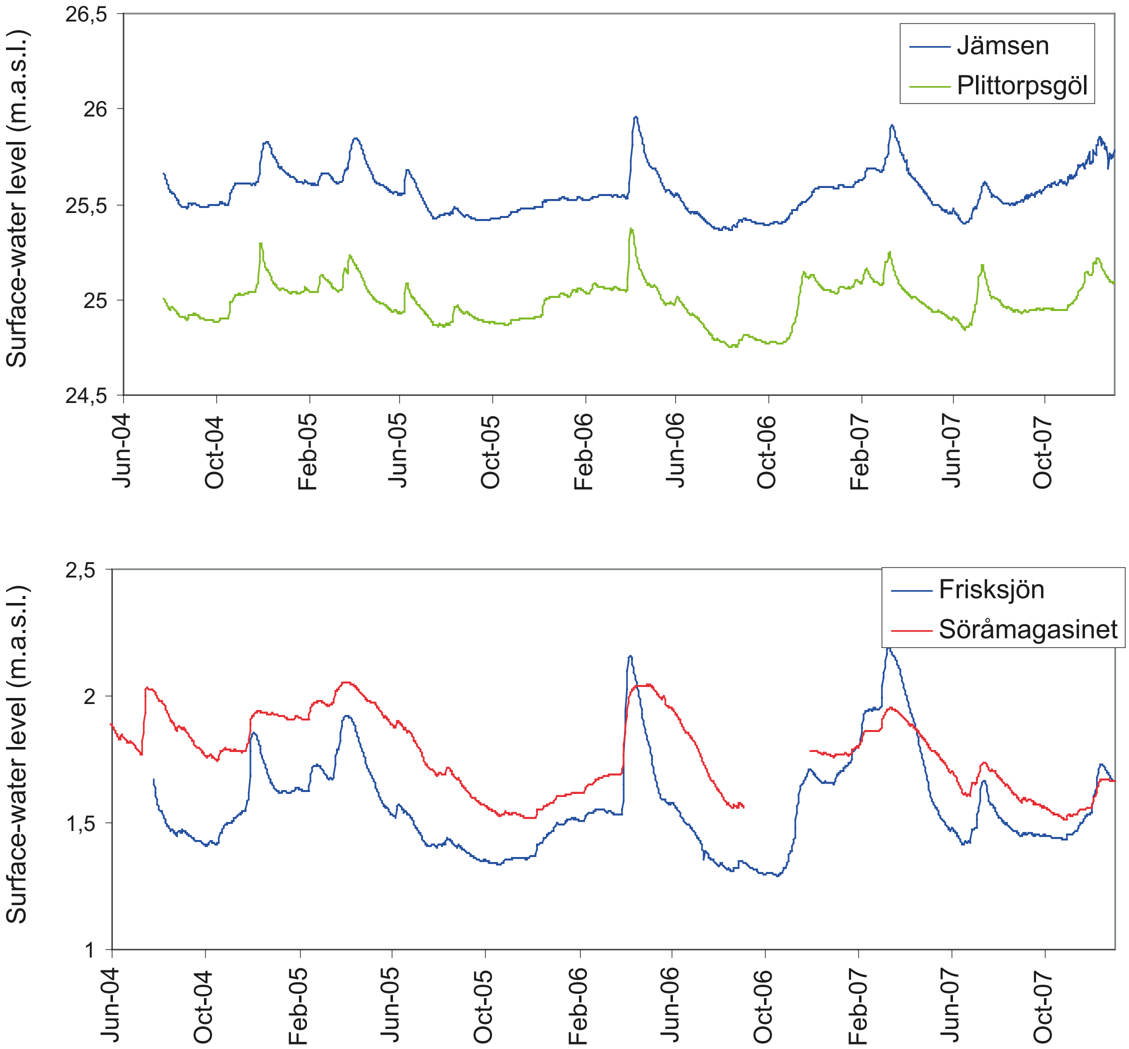


Figure 4-5. *Water levels in lakes Jämsen, Plittorpsgöl, Frisksjön and Söråmagasinet from June 2004 to December 2007.*

4.3.3 Groundwater discharge/recharge

The lakes in the Laxemar-Simpevarp area can function both as recharge and discharge areas for groundwater. Comparison of the groundwater table measured in till at the shoreline of Lake Jämsen (groundwater monitoring well SSM000035) and the lake water level indicates a temporally variable head gradient between the lake and the till (Figure 4-6a). The data indicate an upward head gradient for most of the year, shifting to a downward head gradient during dry periods in the summer. In Frisksjön, on the other hand, the data indicate a small downward gradient from the lake to the till for the entire year (Figure 4-6b).

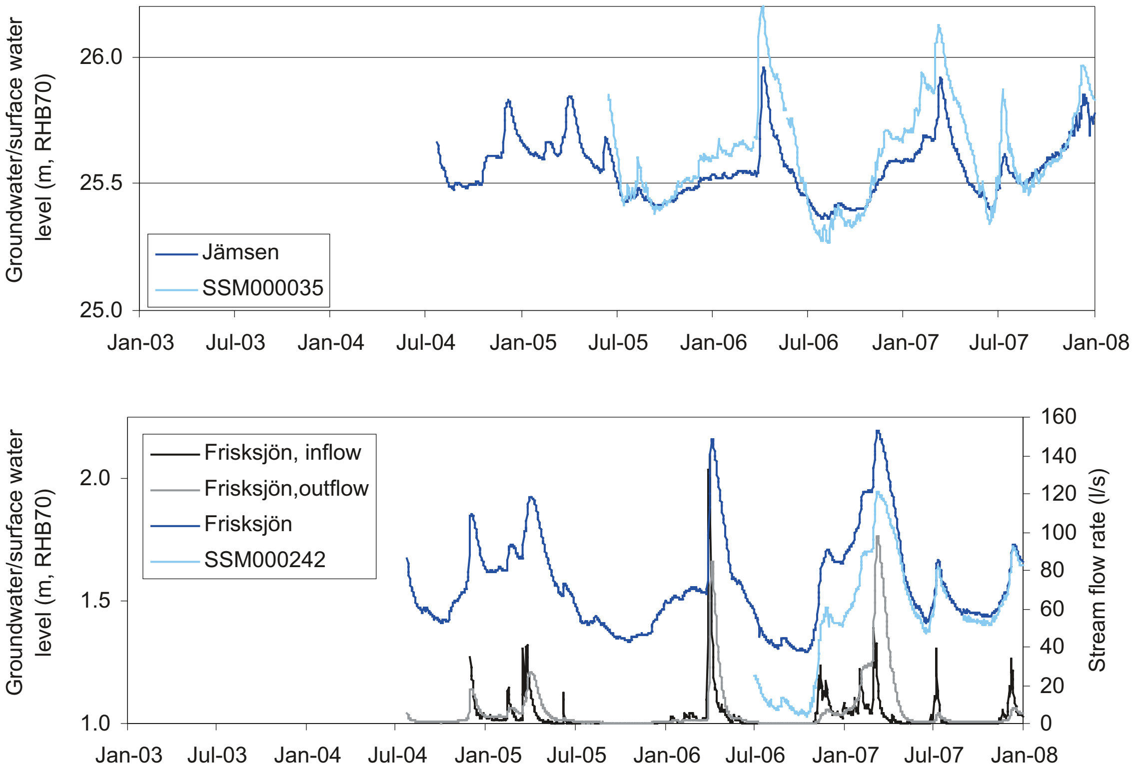


Figure 4-6. *Groundwater level and lake water level in a) Jämsen and b) Frisksjön.*

4.3.4 Flooded areas

Some parts of the Laxemar-Simpevarp area have small altitude gradients. During times of high water flows in the streams, surrounding areas are flooded. The extent of these areas has been investigated in four catchments (Figure 4-7) /Strömgren et al. 2006/. The sizes of the flooded areas were not determined, but the length of the stream stretches can be estimated from the investigation data (Figure 4-7, Table 4-4). The flooded areas are classified as wetlands belonging to terrestrial areas and are further described in /Löfgren 2008/.

Table 4-4. The investigated flooded areas of the streams in the Laxemar-Simpevarp area (data from /Strömgren et al. 2006/).

Catchment	Length of investigated stream stretch (m)	Share of stream stretch with flooded areas (%)
Mederhultsån 6	3,950	c. 2
Kåreviksån 7	2,530	c. 13
Ekerumsån 9	3,920	c. 4
Laxemarån 10[1]	25,700	c. 12
Total	36,100	c.10

[1] investigated stream length including tributaries, not the whole length of the stream.

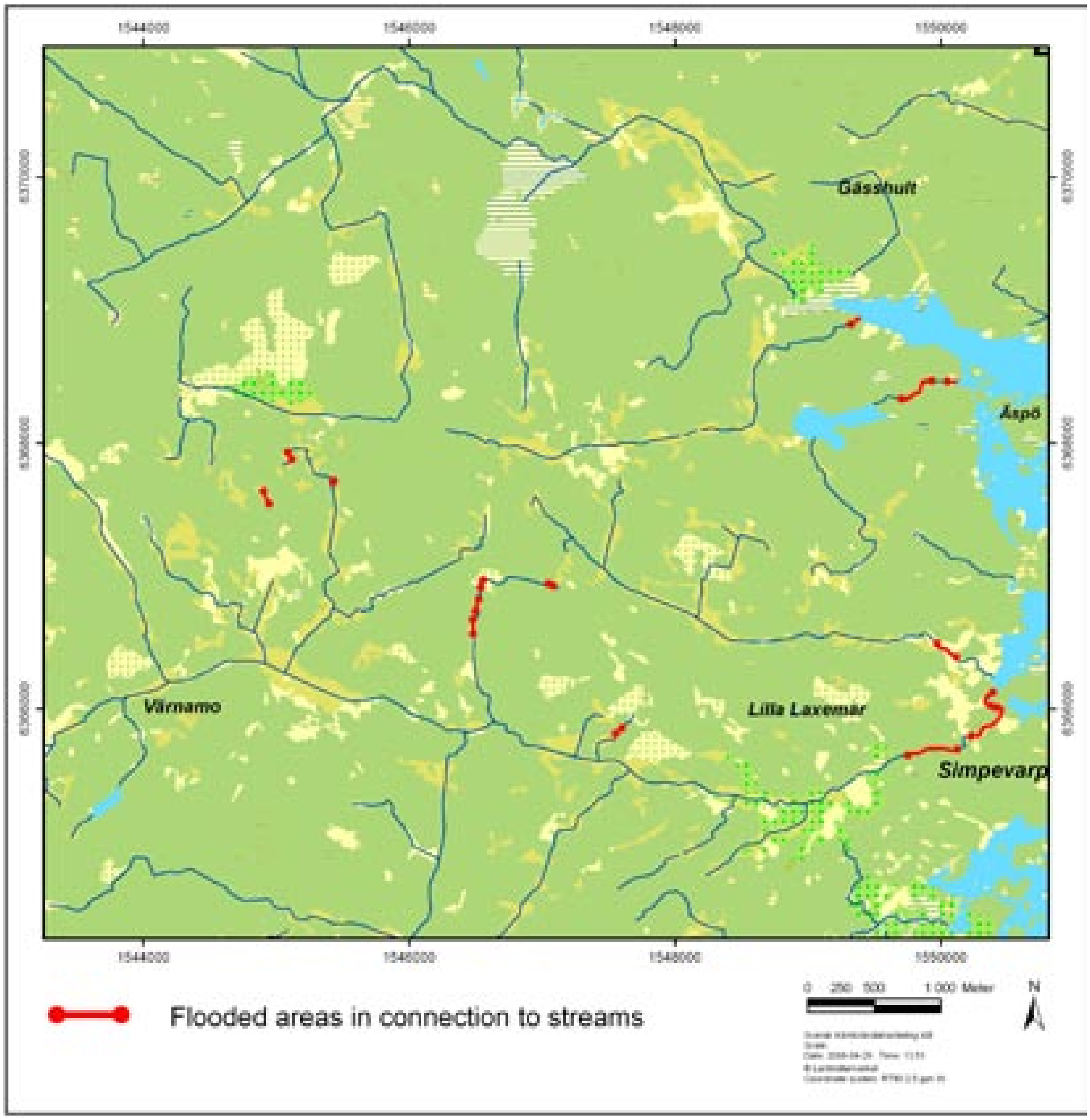


Figure 4-7. Stream stretches where flooding occurs in catchment 6, 7, 9 and 10 in the Laxemar-Simpevarp area.

4.4 Climate

4.4.1 Air temperature

The mean annual temperature in the Laxemar-Simpevarp area is 6–7°C /Werner et al. 2008/. The mean temperature in January is –2°C and the mean temperature in July is 16–17°C. By comparison, the mean annual temperature in Stockholm is 6.6°C, in Malmö 8.2°C and in Östersund 2.5°C /Larsson-McCann et al. 2002/.

4.4.2 Precipitation

The mean annual precipitation during the period 2005–2007 was 580 mm in Äspö and 620 mm in Plittorp, so the average precipitation for Laxemar-Simepvarp is estimated at 600 mm /Werner et al. 2008/. Results from meteorological measurements in Äspö and Plittorp are available from the time period 2003 to 2007 and are presented in Figure 4-8, together with meteorological measurements at 6 SMHI stations nearby. Long-term measurements from Oskarshamn are available from SMHI for the period 1961 to 2007. Monthly precipitation in Oskarshamn for the period 2003 to 2007 is compared with monthly precipitation for the period 1961–2007 in Figure 4-9. The precipitation in 2003–2007 is within the range for the long-term measurements, so the precipitation from Äspö and Plittorp can also be assumed to be representative for a longer time period.

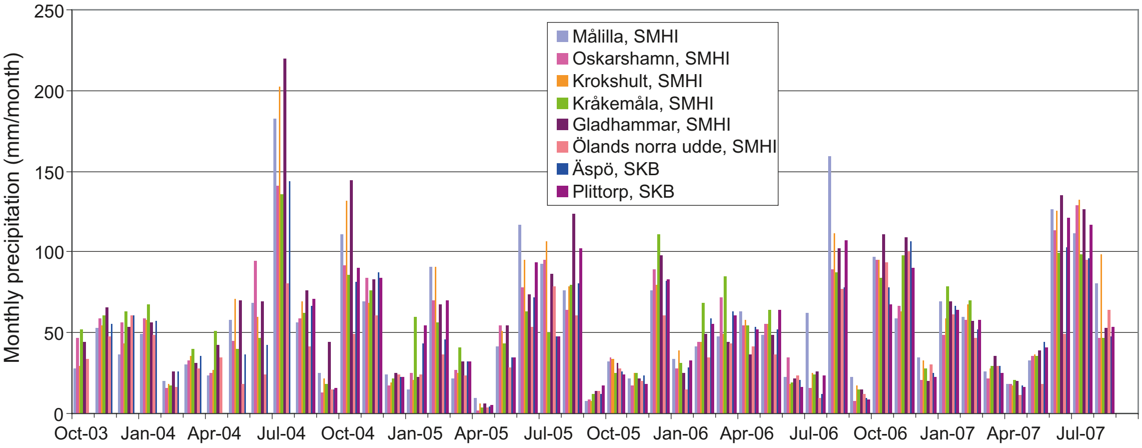


Figure 4-8. *Monthly precipitation at the SKB and SMHI stations Oct. 2003–Aug. 2007.*

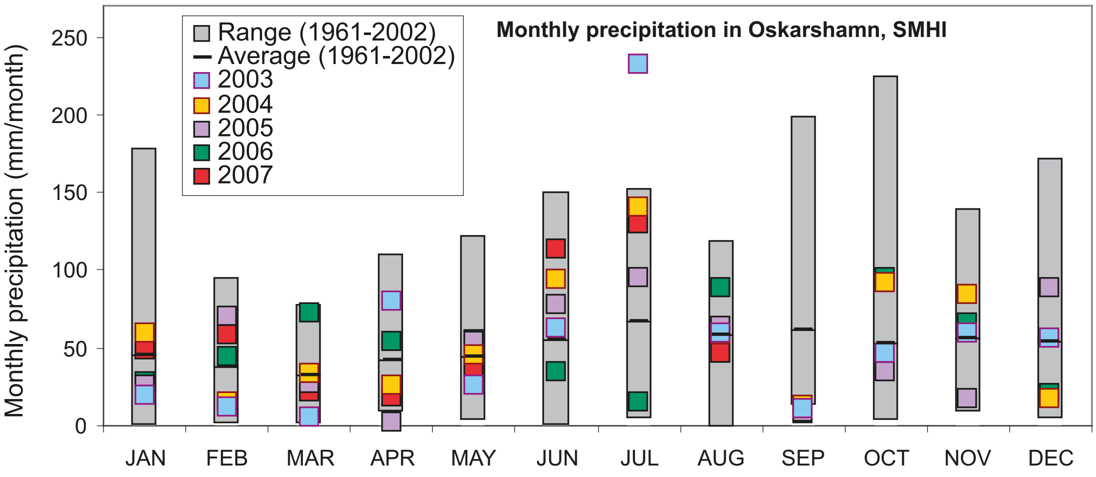


Figure 4-9. *Monthly precipitation at Oskarshamn 1961–2002, also displaying the monthly precipitation at Oskarshamn for each of the years 2003–2007. There are no data for Sep.–Dec. 2007.*

4.4.3 Snow cover

Approximately 17% of the accumulated precipitation during the period Sep. 9–Dec. 31, 2003, fell in the form of snow /Werner et al. 2008 /. Snow cover was measured approximately biweekly during the period 2002/03 to 2006/07 at station ASM100224, Grillplatsen, Äspö. Generally, there was a snow cover from December/January until March/April. However, short periods of snow were recorded as early as October, and late snow cover was recorded at the end of April. The period of snow cover at ASM100224 agrees well with the measured snow cover at four SMHI stations (Figure 4-10). Snow cover has been measured at the SMHI stations since 1994, making it possible to estimate snow cover for longer time periods for the Laxemar-Simpevarp area.

4.4.4 Ice cover

Ice cover recordings were made in Jämsen (ASM100229) from 2002 to 2007. Ice freeze-up occurred at the end of November in three of the seasons, while in the 2003/2004 and 2006/2007 seasons freeze-up did not occur until January. On average, Jämsen was covered by ice for 96 days, but the range was great, 37–147 days (Table 4-5). In Lake Gnötteln, located inland c. 30 km west of Jämsen, ice cover has been measured continuously since 1957. In Gnötteln as well, there is a large range in the period of ice coverage, varying between 10 days and a maximum period of almost 6 month (time period 1957–2000) /Larsson-McCann et al. 2002/. On average, Gnötteln is ice-covered for a somewhat longer period than Jämsen (c. 4 months from the beginning of December to the beginning of April).

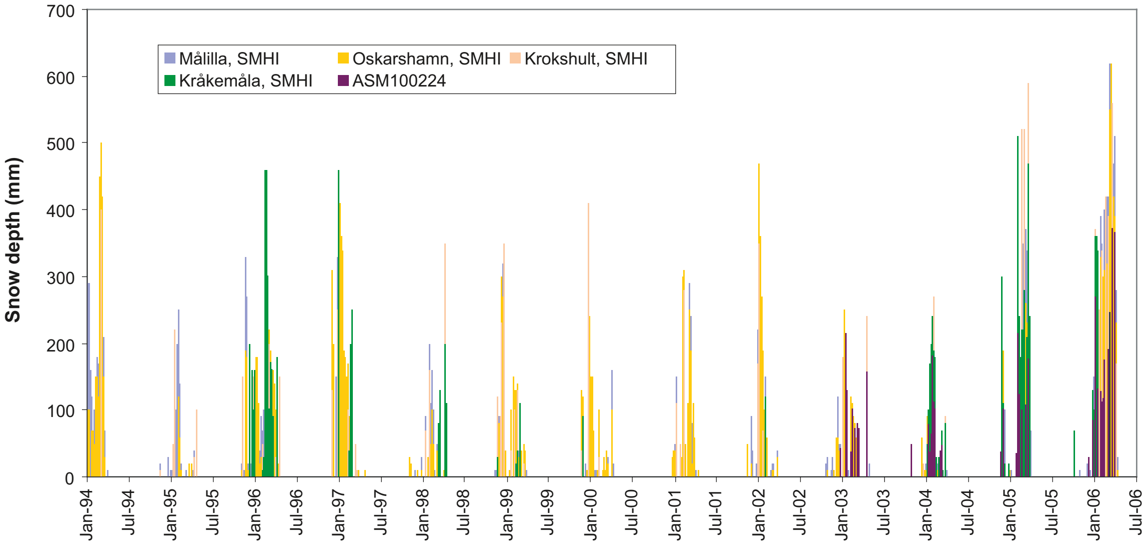


Figure 4-10. *Snow cover in the Laxemar-Simpevarp area (ASM100224) since 2002/03 and at nearby SMHI stations from 1994/95.*

Table 4-5. Periods of ice cover for Jämsen in Laxemar-Simpevarp 2002/03–2006/07, from /Werner et al. 2008/.

Winter season	Date for ice freeze-up	Date for ice break-up	Period of ice cover (days)
2002/03	2002-11-19	2002-11-22	3
	2002-12-19	2003-03-28	100
2003/04	2004-01-07	2004-03-10	64
2004/05	2004-11-22	2005-04-01	129
2005/06	2005-11-22	2006-04-18	147
2006/07	2007-01-23	2007-03-01	37
Average 2002/03–2006/07			96

4.4.5 Global radiation

Global irradiance has been measured in the Laxemar-Simpevarp area at Äspö since September 2003 /Sjögren et al. 2007/. The mean annual radiation was 1,021 kWh·m^{-2} (SD 47). This is in agreement with /Raab and Vedin 2007/, where it is stated that global irradiation in Sweden normally varies within 15% of the normal value of 800–1,100 kWh·m^{-2}. Global radiation is highest in June followed by July and May (Figure 4-11). Daily values vary between 0.8 W m^{-2} (in November 2003) and 346 W m^{-2} (in June 2005).

4.5 Lake bathymetry

The lakes in the Laxemar-Simpevarp area are small, but they generally have larger mean depths than the Forsmark lakes. Accordingly, the volumes of the Laxemar lakes are generally much larger than those of the Forsmark lakes. The retention time of the lakes varies between 218 days and as much as 829 days /Brunberg et al. 2004b/. In Table 4-6 some morphometric parameters are presented for the lakes in the area. Bathymetric maps illustrating the depths in the five lakes in the Laxemar-Simpevarp area is shown in Figure 4-12.

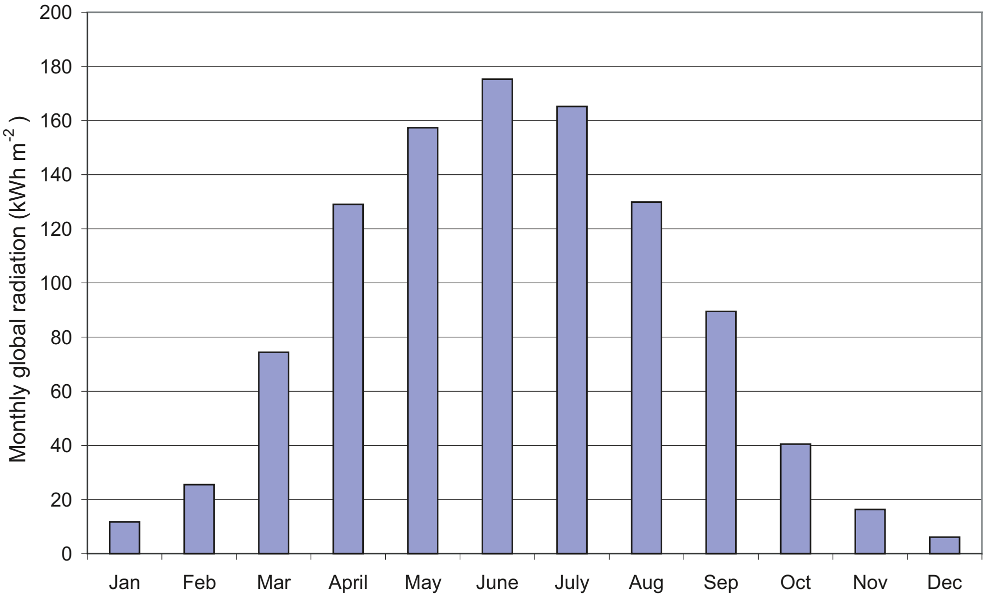


Figure 4-11. *Monthly averages (2004–2007) of global radiation at Äspö in the Laxemar-Simpevarp area.*

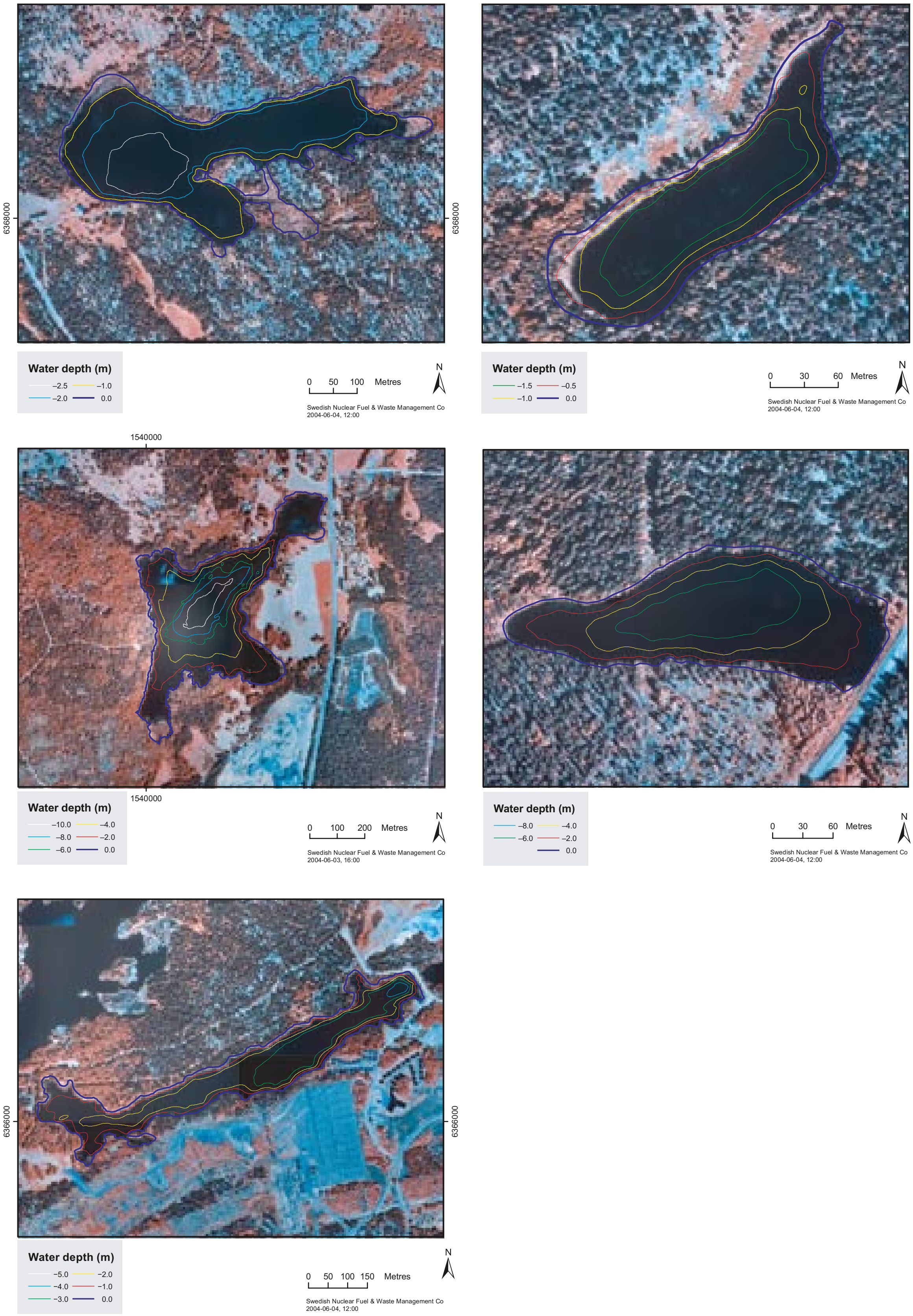


***Figure 4-12.** Bathymetric maps for the five lakes in the Laxemar-Simpevarp area; Frisksjön (upper left), Fjällgöl (upper right), Jämsen (middle left), Plittorpsgöl (middle right) and Söråmagasinet (lower left). From /Brunberg et al. 2004b/.*

Table 4-6. Morphometry parameters for the 5 lakes in the Laxemar-Simpevarp area (data from [1]/Brunberg et al. 2004b/, [2]data from the database SICADA April 2008 and [3]calculated from SKB's GIS database).

Catchment Lake	Simpevarp 7 Frisksjön	Simpevarp 10 Fjällgöl	Simpevarp 10 Plittorpsgöl	Simpevarp 10 Jämsen	Simpevarp 11 Söråmagasinet
Threshold elevation [m a RHB70][2]	1.29	–	24.69	24.65	–
Area [km^2][1]	0.13	0.03	0.03	0.24	0.10
Max depth [m] [1]	2.8	2.0	7.2	10.9	4.9
Mean depth [m] (Littoral I included) [1]	1.7	1.1	3.7	3.7	2.0
Mean depth [m] (Littoral I excluded) [3]	2.0	1.7	4.4	4.4	2.3
Volume [Mm^3] (Littoral I included) [1]	0.223	0.029	0.124	0.877	0.199
Volume [Mm^3] (Littoral I excluded) [3]	0.206	0.008	0.120	0.843	0.183
Shore length [m] [1]	2,632	864	933	4,036	2,992
Mean discharge [m^3/s] [1]	0.010	0.002	0.004	0.369	0.003
Retention time [days] [1]	264	218	399	275	829
Fetch [m] [1, A]	705	116	349	959	936
Width [m] [1, B]	248	55	119	603	184

[A] Fetch [m] Maximum length, the longest straight line over the water surface.
[B] Width [m] Maximum width, the longest straight line perpendicular to the length line.

4.6 Lake sediments

In this section the sediments of four lakes in the Simpevarp-Laxemar area are described. The bays around the island Äspö are sheltered areas, and the physical conditions are in many respects similar to those in lakes. Some of the data from these sheltered bays are therefore also presented below.

4.6.1 Stratigraphy

All lakes in the area comprise a development stage in the transition from a marine environment into a terrestrial area (further described in Chapter 8). Accumulation of sediments starts already before isolation from the Baltic Sea, so some of the sediments in a lake are older than the lake itself. The stratigraphical distribution of the regolith is more or less the same in areas covered by lake or sea water as in terrestrial areas /Sohlenius and Hedenström 2008/. The general stratigraphy observed from the ground surface and down is gyttja, clay gyttja, sand and gravel, glacial clay underlain by till, which rests directly upon the bedrock surface (Table 4-7). The postglacial clay studied in the area contains organic matter and is therefore referred to as clay gyttja (6–20% organic matter). Some of these clay sediments may, however, have an organic content lower than 6% (gyttja clay). Gyttja is the sediment currently accumulating in lakes. For further description of the different sediment layers, see section 3.6. In this report we have chosen to concentrate on the upper sediment layers, which contain most of the organic matter.

The sediments in the Laxemar-Simpevarp lakes are often very thick. The thickest recorded layer of gyttja sediments, more than 10 metres, was found in Frisksjön. Several metres of gyttja sediments have been recorded in other lakes as well. In a study of four lakes in the area (Frisksjön, Jämsen, Söråmagasinet and Plittorpsgöl), the clay layer was only penetrated in one of the lakes, indicating thick sediment layers (Table 4-8).

Table 4-7. Sediment stratigraphy in Frisksjön (SSM000242) /Johansson et al. 2007/.

Layer	Depth (m)
Water	0–2.90
Gyttja	2.90–13.00
Clay	13.00–16.80
Till	16.80–17.40
Bedrock	17.40–

Table 4-8. Maximum investigated sediment depth in 4 lakes in the Laxemar-Simpevarp area. Each lake was sampled with three sediment cores. The sediment sampling did not reach bedrock except for in Jämsen and thus maximum depth is presented as values > metres for three of the lakes /Nilsson 2004/. *Data from the database SICADA, April 2008, **/Brunberg et al. 2004b/.

Sampling site	Elevation (m.a.s.l.)	Maximum thickness of sediment column (m)	Underlying material	Sediment strata in which the investigation ended
PSM006573–75 Jämsen	24.65*	5.1 meter	Sand layer	Sand layer
PSM006576–78 Söråmagasinet	1.94**	> 5.4 meter	Unknown	Gyttja
PSM006579–81 Plittorpsgöl	24.69*	> 4 meter	Unknown	Clay gyttja
PSM006570–72 Frisksjön	1.29*	> 7 meter	unknown	Gyttja

4.6.2 Redox zone

Sediments can be divided into aerobic (oxygenated) and anaerobic (oxygen-free) layers. The aerobic or anaerobic state affects the chemical environment and habitat for biota. Sediments containing organic material have a high oxygen demand due to intense microbial (and other consumers) respiratory metabolism. Moreover, elements such as Fe^{2+} accumulate in reduced form when released into the sediments from decomposing biota, and these elements react with oxygen leading to high oxygen consumption in the sediments. Even during circulation periods in the lake (spring and autumn), well oxygenated lake water only penetrates a few centimetres into the sediment due to slow diffusion rates in sediments. /Wetzel 2001/ reported oxygenated conditions to a depth of 5 mm during summer stratification and 10–12 mm during autumn and spring circulation in Lake Windermere. In Frisksjön, no data are available on the depth of the oxygenated zone, but based on the observations by /Wetzel 2001/ the top 1 cm was assumed to be aerobic. The assumption that the surface sediment in Frisksjön is aerobic is strengthened by observation of the sediments (Sohlenius, personal communication). Surface sediments in anaerobic environments are often laminated with the seasonal sediment accumulation, resulting in different layers due to different sedimenting matter during the year. In anaerobic environments, bioturbation does not occur and the lamination persists, whereas in aerobic environments bioturbation mixes the upper sediment and no seasonal dynamics in the surface sediments can be detected. The sediments in Frisksjön do not show any lamination, and this, together with the low water depth of the lake, indicates that the surface sediments are oxygenated at least during circulation periods.

4.6.3 Carbon content, accumulation rate and chemical composition

Chemical composition of sediments has been analyzed in several studies /Nilsson 2004, Sternbeck et al. 2006, Fredriksson 2004b, Engdahl et al. 2006/. Chemical characterization of 64 elements in the upper 4.4 m of the sediments from Frisksjön in the Laxemar area has been performed by /Engdahl et al. 2006/. Data from this study are presented in Appendix 9. The studies by /Nilsson 2004, Sternbeck et al. 2006, Fredriksson 2004b/ include fewer elements (C, N, S) but more sites in the Laxemar-Simpevarp area. The results from the two studies concerning carbon, nitrogen and sulphur in the clay gyttja agree relatively well with each other (Table 4-9).

Table 4-9. The average contents (% of dry weight) of organic carbon (Org. C), nitrogen (N) and sulphur (S) in sediments in Frisksjön. From */Nilsson 2004 and Sternbeck et al. 2006/ and from **/Engdahl et al. 2006/.

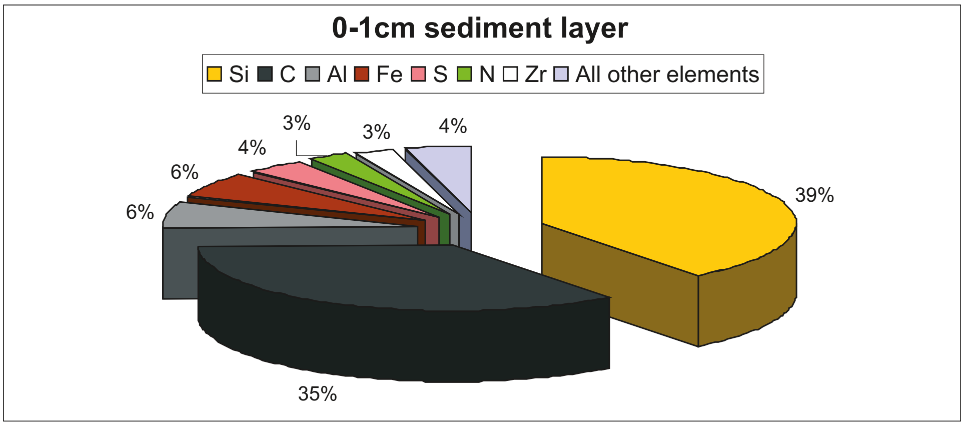
	n (C,N)	n (S)	Org. C	Max. C	Min. C	Tot. S	Max. S	Min. S	Tot. N	Max. N	Min. N
Clay gyttja in Frisksjön*	13	9	20.2±4.0	26.8	15.1	2.3±0.8	3.4	1.1	2.1±0.3	2.6	1.6
Clay gyttja in Frisksjön 0–2 cm **	1	1	12.0	12.0	12.0	1.9	1.9	1.9	1.3	1.3	1.3
Clay gyttja in Frisksjön 2–100 cm**	7	7	11.4±2.0	14.0	8.4	2.3±0.8	4.1	1.7	1.6±0.2	2.0	1.4
Clay gyttja in Frisksjön 100–440 cm**	4	4	11.8±1.7	14.0	10.0	2.5±0.2	2.7	2.2	2.1±0.3	2.3	1.7

The study by /Nilsson 2004/ shows that the concentrations of C, S and N increase with decreasing sediment age in lakes. The gyttja in Jämsen and Frisksjön had organic carbon contents of c. 20% and gyttja from Plittorpsgöl had organic carbon contents higher than 30%. The total contents of all these elements are relatively low in the glacial clay. The sediments deposited in lakes generally have a higher organic carbon content than sediments deposited in bays /Nilsson 2004/.

The relative amounts of the 64 studied elements in the upper 4.4 m of the sediments in Frisksjön are shown in Figure 4-13 (data from /Engdahl et al. 2006/). The upper aerobic sediment has been assigned a separate pool in the lake. The distribution of elements in the upper (0–0.01 m) and lower sediments (0.01–4.40 m) is almost the same. Silicon is the most common element followed by carbon (Figure 4-13). Aluminium, iron, sulphur and nitrogen also comprise relatively large portions of the weight in both sediment layers. Oxygen and hydrogen are commonly occurring elements in the sediment as many of the elements above are found in oxygen complexes, and organic compounds often contain hydrogen. However, oxygen and hydrogen were not analyzed in the study by /Engdahl et al. 2006/ and are thus not shown in Figure 4-13 or included in the comparison of most common elements in the sediment.

The sediment in Frisksjön has a lower carbon content and higher content of silicon and aluminium than the gyttja layer in the Forsmark lakes (section 3.6). The calcium content in Forsmark is higher than in Laxemar-Simpevarp. This is a result of the calcareous deposits in the Forsmark area. The sediment from Frisksjön more closely resembles the deeper clay gyttja layer of the Forsmark lakes. The chemical composition of sediments as well as other parts of the limnic ecosystems in the Laxemar-Simpevarp area is further discussed in Chapter 7.

Porosity and bulk density for sediments in the Laxemar-Simpevarp area have been calculated using data for the carbon and water contents from /Nilsson 2004/ and /Fredriksson 2004b/ (Table 4-10). Recent and long-term rates of sediment accumulation in the Laxemar-Simpevarp area have been studied by /Sternbeck et al. 2006/ (Table 4-11). The results were used to calculate the accumulation rates of carbon, nitrogen and phosphorus in Frisksjön and two coastal bays (Table 4-12). The average long-term accumulation covers a period of several thousands of years and the accumulation rates have probably varied considerably throughout that period. Frisksjön is today situated at 1.3 m.a.s.l., indicating that the lake was isolated from the Baltic at 1200 AD (see Chapter 8). However, the lake threshold has been lowered by man by at least 1 m, and probably more, during the last centuries. This means that Frisksjön was isolated from the Baltic Sea much earlier, possibly already before year 0 BC/AD. The long-term accumulation rates shown in Table 4-11 and Table 4-12 reflect a period when the present lake probably was connected to the Baltic Sea. The accumulation rates for other elements have been calculated and are presented in Chapter 7.



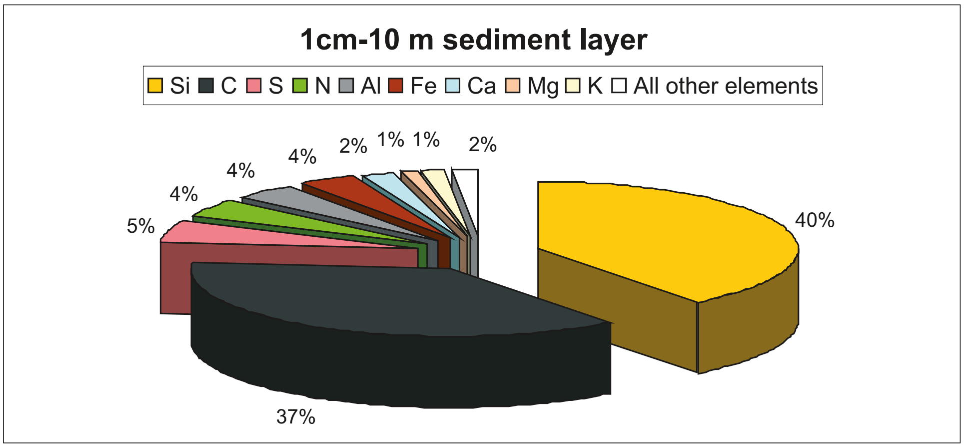


Figure 4-13. *Relative amounts of investigated elements (%) in the two sediment layers in Frisksjön: upper (0–1 cm) and lower (1 cm–10 m).*

Table 4-10. The average physical properties of the sediments in the Oskarshamn area /data from Sohlenius and Hedenström 2008/.

	No. of obs.	Depth (m)	Water content (%)	Porosity (%)	Bulk density (kg/m^3)	Reference	Comments
Top sediment (clay gyttja, organic)	58	0–0.05	90.8±1.6	94.7±0.9	1,043±9	/Fredriksson 2004b/	Sheltered sea areas
Clay gyttja	42	0–6	83.4±5.4	90.0±3.4	1,081±33	/Nilsson 2004/	Data from lake, bays and peat areas

Table 4-11. Average mass accumulation rates (g dw m^{-2} yr^{-1}) in Frisksjön and in the two marine bays Borholmsfjärden and Norrefjärd. The ^{210}Pb record covers the 20th century and the ^{14}C dates have been used to calculate the long-term accumulation rate /from Sternbeck et al. 2006/.

	Mass accumulation rate (g dw m^{-2} yr^{-1})			
Site	Average short term, ^{210}Pb	^{210}Pb, range	Average long term, ^{14}C	Long term cal (years ago)
Frisksjön	410	300–600	400±30	2,600–4,060
Borholmsfjärden	680	470–1,000	680±100	3,300–4,400
Norrefjärd	740	200–1,100		

Table 4-12. Average accumulation rates of carbon, phosphorus and nitrogen in Frisksjön and in the two marine bays Borholmsfjärden and Norrefjärd /from Sternbeck et al. 2006/. The long-term averages are shown in bold.

Depth, cm	Organic carbon accumulation rate (g C m^{-2} yr^{-1})		Phosphorus accumulation rate (g P m^{-2} yr^{-1})		Nitrogen accumulation rate (g N m^{-2} yr^{-1})	
	Average	SD	Average	SD	Average	SD
Frisksjön						
20–22	79	14	0.63	0.13	6.3	0.9
188–431	**74**	**13**	**0.36**	**0.13**	**9.3**	**1.7**
Borholmsfjärden						
20–22	67	8	0.86	0.15	7.8	0.7
280–560	**95**	**18**	**0.49**	**0.07**	**13.6**	**2.1**
Norrefjärd						
2–4	151	22	1.82	0.35	19.3	2.2
10–12	151	22	1.66	0.32	18.1	2.2
20–22	108	16	1.13	0.22	12.5	1.5
32–34	47	7	0.40	0.08	5.6	0.6

4.7 Habitat distribution in the lakes

Lakes may be divided into five different habitats, Littoral I, II, and III, Pelagic and Profundal habitat. The areal distribution of each habitat has been investigated by /Brunberg et al. 2004b/. The habitat definitions are found in section 3.7. All 5 habitats were found in four of the five investigated lakes (Table 4-13 and 4-14). Later investigations in Frisksjön revealed that the area defined as Littoral III was in fact profundal, since the light climate was too poor to sustain photosynthetic activity and no photosynthesizing organisms were found there. Due to the brown water colour in the lakes, little light reaches the benthic habitat and profundal covers on average 47% of the lake areas. The dominating littoral habitat differs between lakes. In Söråmagasinet Littoral III dominates, whereas in Fjällgöl, Plittorpsgöl and Jämsen (and also Frisksjön with the new habitat distribution) Littoral I dominates. Littoral II is present, although covering small areas, in all lakes except for in Fjällgöl, where only 4 habitats were found. The habitat distribution in Frisksjön is illustrated in Figure 4-14.

Table 4-13. Distribution (m^2) of habitats in the lakes in the Laxemar-Simpevarp area /Brunberg et al. 2004b/.

Catchment	Lake	Littoral I (m^2)	Littoral II (m^2)	Littoral III (m^2)	Profundal (m^2)	Pelagial (m^2)	Total lake area (km^2)
7	Frisksjön	24,200	1,430	49,130[1]	52,250	107,270	0.13
10	Fjällgöl	21,580	–	1,440	3,240	4,680	0.03
	Plittorpsgöl	6,630	290	4,260	22,800	27,340	0.03
	Jämsen	48,500	1,550	12,650	177,300	187,700	0.24
11	Söråmagasinet	20,430	740	39,690	39,140	82,700	0.10
Average		24,268	802	21,434	58,946	81,864	0.11
SD		15,168	682	21,635	68,656	72,071	0.09
Median		21,580	740	12,650	39,140	82,330	0.10
Min.		6,630	0	1,440	3,240	4,680	0.03
Max.		48,500	1,550	49,130	177,300	187,700	0.24

[1] Based on later investigations in Frisksjön this area is now defined as profundal since the light climate is too poor to sustain photosynthetic activity and no photosynthesizing organisms are found there.

Table 4-14. Relative distribution (%) of the different habitats in the lakes in the Laxemar-Simpevarp area /Brunberg et al. 2004b/.

Catchment	Lake	Littoral I (%)	Littoral II (%)	Littoral III (%)	Profundal (%)	Pelagial (%)
7	Frisksjön	18	<2	38[1]	42	82
10	Fjällgöl	82	–	6	12	18
	Plittorpsgöl	20	<1	13	67	80
	Jämsen	21	<1	5	75	79
11	Söråmagasinet	20	<1	40	38	80
Average		32		20	47	68
Standard deviation		28		17	25	28
Median		20		13	42	80
Min		18	0	5	12	18
Max		82	<2	40	75	82

[1] Based on later investigations in Frisksjön this area is now defined as profundal since the light climate is too poor to sustain photosynthetic activity and no photosynthesizing organisms are found there.

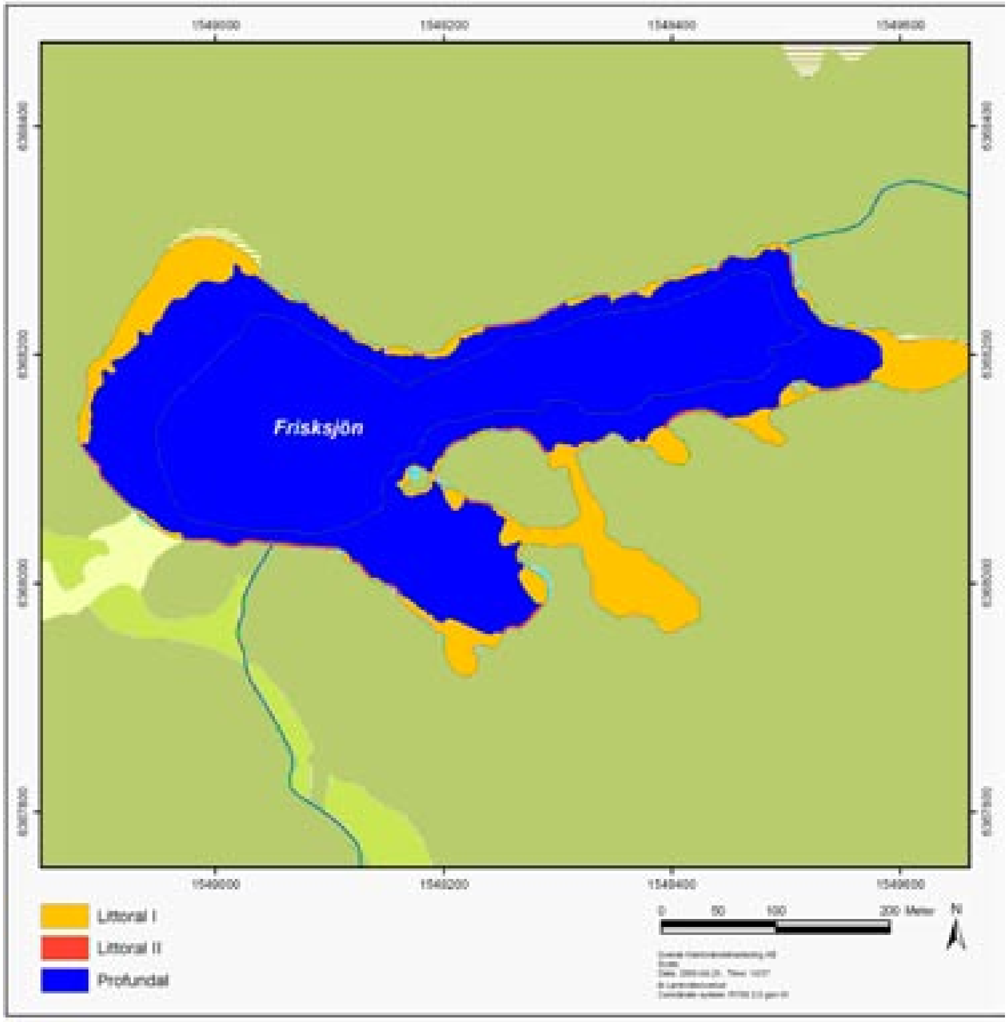


Figure 4-14. Distribution of major habitats in Frisksjön. The line in the profundal habitat illustrates the border between Littoral III and Profundal in an earlier investigation /Brunberg et al. 2004b/. Based on later investigations in Frisksjön, areas earlier defined as Littoral III are now defined as Profundal since the light climate is too poor to sustain photosynthetic activity and no photosynthesizing organisms are found there /Aquilonius 2005/.

4.8 Physical characteristics of streams

Streams in parts of the Simpevarp regional model area have been investigated using the same methods as in the Forsmark area (section 3.8) /Carlsson et al. 2005a/. Bottom substrate, water velocity, bottom vegetation, shading from terrestrial vegetation and technical encroachments were studied in 8 different catchments, and the total length of the investigated stretches was c. 20 kilometre long (Figure 4-2). Some of the streams are very small (e.g. four catchments on the island Ävrö) while others are larger. The largest is Laxemarån for which the entire stretch has not been investigated. Instead two stretches of totally c. 9.5 km have been examined. Three streams of medium size have also been investigated: Mederhultsån, Kåreviksån and Ekerumsån. In Mederhultsån, Kåreviksån and the four streams on Ävrö, all investigated stretches are of stream order 1. In Ekerumsån and Laxemarån stretches of stream order 1, 2 and 3 have been investigated.

The morphometry of the watercourses has also been investigated /Strömgren et al. 2006/. This investigation did not include the four small streams on Ävrö. Instead, additional stretches in Laxemarån were included. For Mederhultsån, Ekerumsån and Kåreviksån the same stretches as in /Carlsson et al. 2005a/ were investigated.

Of the investigated stretches most were of stream order 1 (49%) followed by stream order 3 (38%), whereas stream order 2 was the least represented in the investigated stretches (13% of total investigated stretch).

4.8.1 Bottom substrate

In the smaller streams, fine organic detritus or clay dominates as bottom substrate (Table 4-15), while conditions are different in Laxemarån, where clay or cobble is the dominant bottom substrate in stretches with stream order 1, fine organic detritus dominates stretches of stream order 2, and coarse organic detritus is most frequent in stretches of stream order 3.

Table 4-15. Distribution of different bottom substrates (%) in the investigated stream stretches in the Simpevarp regional model area (data from /Carlsson et al. 2005a/).

Stream name	**Meder-hultsån**	**Kåreviks-ån**	**Streams on Ävrö**	**Ekerumsån**			**Laxemarån**			**Total**			
Stream order	**1**	**1**	**1**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**Total**
Fine organic detritus	57	25	–	100	100	48		80	9	32	86	21	35
Coarse organic detritus	0	0	20						45	6	0	0	3
Clay	26	61	70			29	51	7		48	5	40	39
Sand	9	5	4			2		1	11	5	1	8	6
Gravel	3	4	0			4		1	9	2	1	8	4
Cobble	2	4	4			15	49	10	24	5	7	21	12
Boulder	1	0	2			1			3	1	0	2	1
Bedrock	2	–	–							1	0	0	0

4.8.2 Morphometry

Mederhultsån

Mederhultsån starts at roughly 13 m above sea level. The altitude gradient is quite steep at the beginning, but gradually becomes more moderate and after about 2,300 m it is hardly noticeable. At the time of the investigation, no flooded areas were found along Mederhultsån. The water flows partly in underground pipes, sometimes as long as several hundred metres.

Kåreviksån

Kåreviksån starts around 10 m above sea level and enters into the Baltic Proper after a little more than 2,800 m. Kåreviksån flows through Frisksjön on its way down to the Baltic Proper. The slope is relatively gentle, except for a stretch after approximately 300 m, a stretch close to the inlet into Frisksjön and a short stretch from the outlet from Frisksjön. The geometry of the stream channel is mostly clearly defined. The exception is a 300 m long section between Frisksjön and the Baltic Proper where the water overflows the bank.

Ekerumsån

Ekerumsån starts almost 13 m above sea level. The altitude gradient is low the first 3,000 m. Then it becomes very steep and the vertical drop is more than 6 m over only 300 m. After this stretch, the terrain flattens out all the way down to the Baltic Proper. There is an area where the water overflows the bank, close to the outlet into the Baltic Proper. This stretch is around 200 m long. Ekerumsån flows partly through pipes in the uppermost and lowermost parts.

Laxemarån

The stream Laxemarån begins south of Jämsen around 25 m above sea level and the total length down to the Baltic Proper is almost 15 km. The slope is steep the first 650 m, where the altitude decreases almost 10 m. After this section the slope becomes gentler. The exceptions are a 100 m stretch between 3,300 and 3,400 m, where the altitude decreases 2.5 m, and a 1,000 m long section from around 8,000 m where the terrain is very flat.

The geometry of the stream channel is generally clearly defined. After around 600 m the stream flows through a 1 km long, marsh area where the geometry of the stream channel is indistinct. The last kilometre is characterized by a very flat terrain where the stream overflows the bank. Laxemarån drains in pipes over only a couple of short sections near the outflow from Jämsen.

Eight tributaries to Laxemarån have been investigated. They are of different sizes and depths. In three of the tributaries the water overflows the bank in short stretches (tributary 10:5, 10:7 and 10:10). The highest altitude is recorded in tributary 10:7, which starts at 17 m.a.s.l. and enters Laxemarån at 6 m.a.s.l. All tributaries have a gentle slope except for short stretches with steeper conditions.

4.8.3 Shading

Terrestrial shading is highly dependent on catchment use. In areas with forest there are often densely shaded areas, whereas stream stretches passing agricultural land are not shaded at all.

In Mederhultsån most stretches are low to moderately shaded. There are some stretches passing through pipes, however, and these are totally shaded. Large parts of Kåreviksån passes through agricultural lands and these stretches are not shaded at all, but other parts pass through forest and these stretches are densely shaded (>50%). Ekerumsån and Laxemarån also have alternating stretches with dense shade and little shade. Most stretches of the streams on Ävrö are moderate to densely shaded.

4.9 Hydrochemical characteristics of lakes, streams and shallow groundwater

Surface water sampling was performed in a monitoring programme by SKB starting in March 2002. The sampling has been performed predominantly on a monthly basis. Four lakes belonging to separate catchments were monitored and 22 stations for running waters (Figure 4-15). The description of major constituents in water chemistry includes data from October 2002 to May 2005 for the Simpevarp regional model area /Tröjbom and Söderbäck 2006a/. Longer time series are available but no major difference in the data set can be seen. The water chemistry is compared with regional and national data from the national survey of lakes and watercourses /cf. Wilander et al. 2003/ (data available for downloading from http://info1.ma.slu.se/db.html). The data were also compared with Swedish Environmental Quality Criteria (EQC) /Naturvårdsverket 2000/. Some of the comparison of the chemical composition in the lakes with regional and national reference data is presented in box plots. (Explanation of box plots are presented in Figure 3-22).

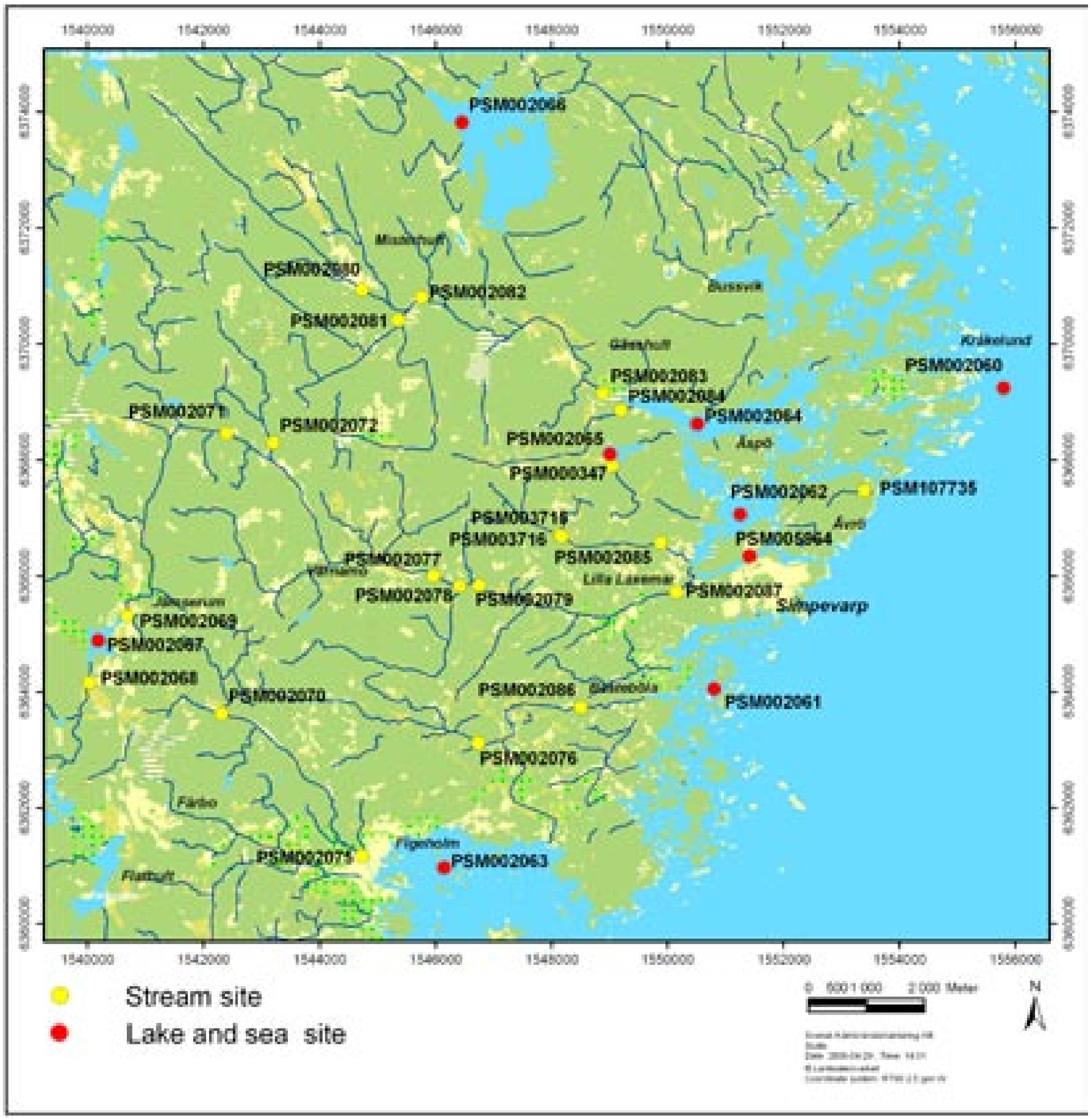


Figure 4-15. Monitored stream (yellow), lake and sea sites (red) in the Simpevarp regional model area. The SKB ID codes for each sampling site are given.

Concentrations of major elements and major ions, pH, temperature, oxygen and water colour in lakes, streams and groundwater are presented below and in Appendices 7 and 8. Water chemistry for minor elements is presented in Appendices 7 and 8 and in /Tröjbom and Söderbäck 2006a, Engdahl et al. 2008/.

4.9.1 Water chemistry in lakes

In the Simpevarp regional model area, the lakes are characterised as mesotrophic brown-water systems with the exception of Götemar, which is a clear-water lake. Most freshwaters are strongly coloured due to high amounts humic substances, leading to very high concentrations of dissolved organic carbon. The lakes are also relatively rich in nitrogen and phosphorus.

Acidity and alkalinity

The ***pH values*** are close to neutral (mean for all lakes 6.9 in surface water) and somewhat higher than the regional mean pH value (Table 4-16). The ***alkalinity*** is very good according to EQC and there is little sensitivity to acidification.

Table 4-16. Mean water chemistry (October 2002–May 2005) for major elements in the investigated lakes in the Simpevarp regional model area. Percentiles, mean, minimum, and maximum values have been calculated for all the monitored lakes. Values for surface water samples (0.5 m water depth), pH and conductivity have been measured in the field, while the other parameters are from laboratory analyses.

Element	N obs	Min.	25-p	Median	75-p	Max.	Mean	SD
pH (unit)	97	6.22	6.79	7.04	7.26	8.01	7.01	0.34
Conductivity (mS m^{-1})	102	9.4	11	12	15	18	13	3
Tot-P (mg L^{-1})	112	0.0054	0.015	0.018	0.023	0.043	0.019	0.008
POP (mg L^{-1})	111	0.0023	0.0064	0.0092	0.012	0.028	0.0097	0.005
PO_4-P(mg L^{-1})	112	<0.0005	0.00050	0.00080	0.0012	0.0050	0.00099	0.0008
Tot-N (mg L^{-1})	112	0.52	0.82	0.95	1.0	1.3	0.92	0.2
NH_4-N (mg L^{-1})	112	0.0013	0.0059	0.023	0.066	0.25	0.047	0.05
NO_2+NO_3-N (mg L^{-1})	112	0.00040	0.045	0.12	0.21	0.43	0.14	0.1
PON (mg L^{-1})	112	0.0084	0.048	0.081	0.11	0.28	0.087	0.05
TOC (mg L^{-1})	112	8.6	12	16	17	25	15	4
DOC (mg L^{-1})	111	8.6	12	15	17	24	15	4
POC (mg L^{-1})	112	0.077	0.43	0.70	0.89	5.5	0.78	0.6
SO_4-S (mg L^{-1})	112	2.7	3.6	4.3	5.5	8.4	4.7	1
Si (mg L^{-1})	112	0.33	2.1	3.9	4.6	6.4	3.4	2
Fe (mg L^{-1})	112	0.031	0.63	0.88	1.2	2.0	0.86	0.5
Mn (mg L^{-1})	112	<0.003	0.014	0.041	0.081	0.22	0.051	0.05
Cations								
Ca (mg L^{-1})	112	6.3	7.4	8.6	10	13	8.8	2
Mg (mg L^{-1})	112	1.9	2.2	2.3	2.9	4.3	2.6	0.6
Na (mg L^{-1})	112	2.7	8.7	9.6	11	17	10	2
K (mg L^{-1})	112	0.86	1.3	1.5	1.8	2.9	1.7	0.5
Anions								
Cl (mg L^{-1})	112	7.6	11	13	15	24	14	4
HCO_3 (mg L^{-1})	112	11	12	14	17	48	18	9
F (mg L^{-1})	110	<0.2	0.48	0.63	0.79	1.5	0.69	0.3
Br (mg L^{-1})	112	<0.2	<0.2	<0.2	<0.2	0.50	<0.2	0.05
I (mg L^{-1})	20	0.0040	0.0078	0.021	0.026	0.033	0.019	0.010

Major elements

The ***phosphorus*** concentrations are according to EQC moderate in Frisksjön, Jämsen and Söråmagasinet and low in Götemar (Figure 4-16). The phosphorus concentrations are elevated compared with the majority of Swedish lakes. Particulate phosphorus is coupled to primary production and shows elevated concentrations in the presence of phytoplankton. Phosphate phosphorus, on the other hand, shows low levels during the growing season, indicating that phosphorus may become limiting for primary production.

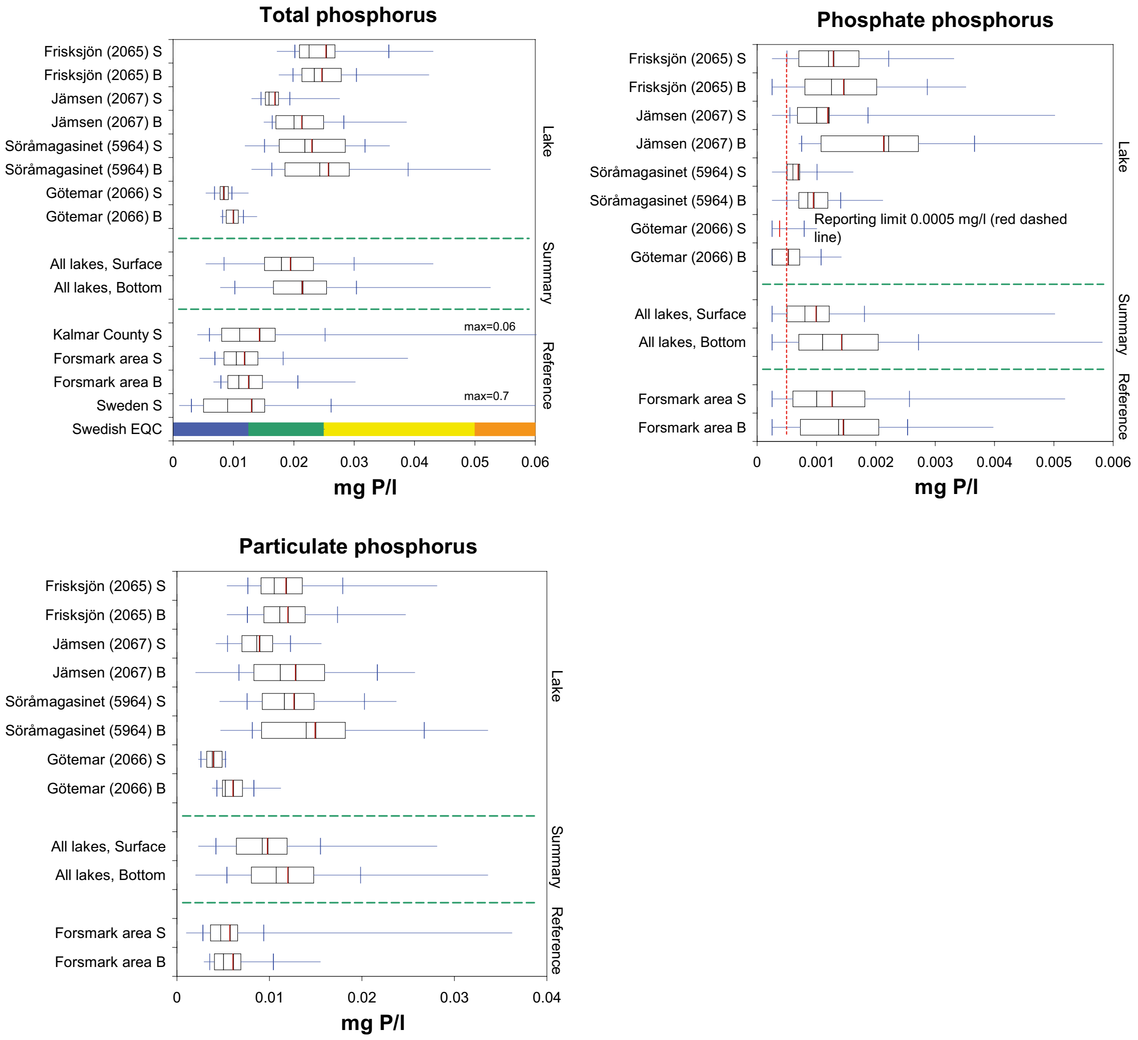


Figure 4-16. *Concentrations of total, phosphate and particulate phosphorus species in surface (S) and bottom (B) water in lakes in the Laxemar-Simpevarp area. For an explanation of the box plots, see Figure 3-22. Numbers within brackets represent the last digits in the ID code used in the database SICADA. Data from /Tröjbom and Söderbäck 2006a/.*

The ***nitrogen*** concentrations are high according to EQC and compared with the majority of Swedish lakes (Figure 4-17). Götemar, which has low phosphorus concentrations, also has slightly lower nitrogen concentrations than the rest of the investigated lakes. There is seasonality in nitrogen fractions, and in the summer the particulate nitrogen levels are high whereas the inorganic fractions (NH_4, NO_3) are higher during winter.

The concentrations of total organic ***carbon*** (TOC) are very high according to EQC and high compared with the majority of Swedish lakes (Figure 4-18). The only deviating lake is Götemar with moderately high concentrations. About 90% of TOC is made up by dissolved organic carbon (DOC). The TOC concentrations in Frisksjön and Jämsen show a clear seasonality with higher concentrations during the warm season. Söråmagasinet and Götemar have only minor seasonal variations in TOC concentrations.

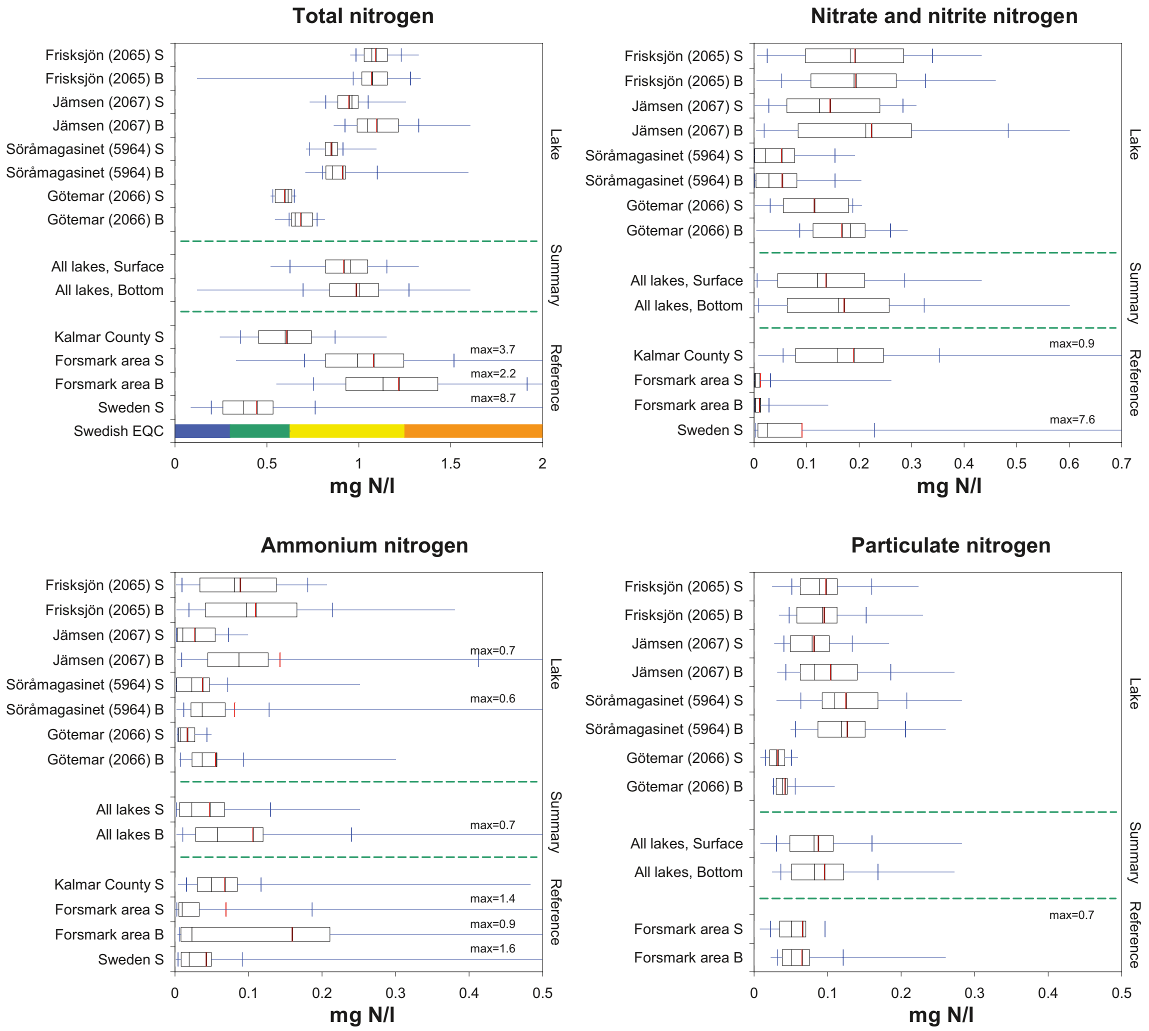


Figure 4-17. *Concentrations of total, nitrate and nitrite, ammonium and particulate nitrogen species in surface (S) and bottom (B) water in lakes in the Laxemar-Simpevarp area. For an explanation of the box plots, see Figure 3-22. Numbers within brackets represent the last digits in the ID code used in the database SICADA. Data from /Tröjbom and Söderbäck 2006a/.*

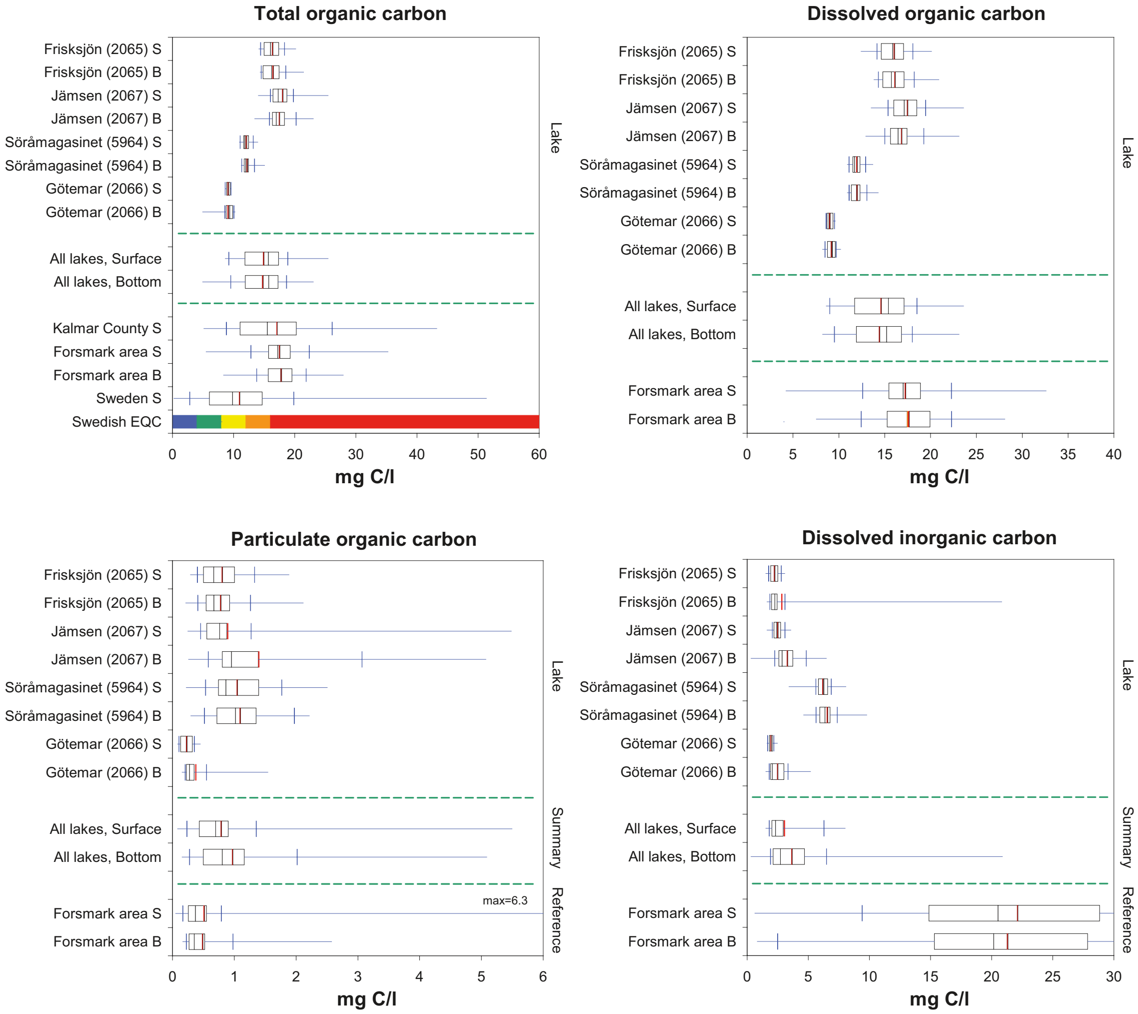


Figure 4-18. *Concentrations of total, dissolved and particulate organic carbon species, as well as contents of dissolved inorganic carbon, in surface (S) and bottom (B) water in lakes in the Laxemar-Simpevarp area. For an explanation of the box plots, see Figure 3-22. Numbers within brackets represent the last digits in the ID code used in the database SICADA. Data from /Tröjbom and Söderbäck 2006a/.*

The ***sulphur*** concentrations in the lakes in the Simpevarp regional model area, as in the rest of the region, are elevated compared with the majority of Swedish lakes. There is a seasonal pattern with lower summer values. The high sulphate concentrations in most lakes can be attributed to leaching from the catchments, as atmospheric deposition in the region is the same as in many other parts of the country.

Concentrations of ***silicon*** (Si) in Frisksjön and Jämsen are markedly elevated compared with most lakes in Sweden. Si is bioregulated and there is a clear seasonal pattern with low summer values when uptake by diatoms occurs. There was no diatom bloom recorded in the phytoplankton investigation. However, that investigation only included 8 samples over the entire year, so a diatom bloom may well have occurred between samplings.

Dissolved ions and conductivity

The total amount of dissolved ions, the ***electrical conductivity***, is somewhat elevated compared with most Swedish lakes (Table 4-16). However, it is much lower than in the Forsmark lakes.

Cations consist mainly of calcium, magnesium, sodium and potassium. These ions have slightly elevated concentrations compared with most Swedish lakes but are similar to those in the regional lakes. The concentrations are fairly constant on a seasonal basis.

Anions consist mainly of chloride, bicarbonate and sulphate. Fluoride and bromide occur at much lower concentrations and iodine only occurs at trace levels. Both chloride and fluoride concentrations are higher than in most Swedish lakes. Fluoride is also elevated compared to concentrations in regional lakes.

Iron concentrations are very high in Frisksjön, Jämsen and Söråmagasinet compared with most Swedish lakes. Götemar deviates from the rest of the lakes and has low iron concentrations. Götemar is a clear-water lake whereas the others are brown-water lakes. The high humic content in the brown-water lakes is most probably the reason for the high iron concentrations. ***Manganese*** occurs in moderately elevated concentrations in Frisksjön, Jämsen and Söråmagasinet whereas Götemar has lower concentrations.

Dissolved oxygen

The concentration of dissolved oxygen is dependent on mixing of the water column, temperature, inflow of oxygen-rich water, inflow of oxygen-depleted ground water, and the balance between primary production and decomposition of organic matter. In connection with primary production, dissolved oxygen is released to the water and the concentrations increase. In connection with decomposition, oxygen is consumed and concentrations decrease. The lakes in the Simpevarp area show recurrent episodes of low oxygen levels in the bottom water in both the summer and winter when the water column is stratified. When the water is completely mixed again in the spring and autumn, but also at other times (probably as a consequence of strong winds) the oxygen levels rises rapidly (Figure 4-19).

Temperature

Water temperature has been measured in 4 of the Laxemar-Simpevarp for different time periods (the longest is for Frisksjön 2002–2007). The water temperatures varied between a few tenths of a degree above zero in the winter up to above 20°C in the summer (Figure 4-20). The same pattern is seen for all four lakes (data from the database SICADA, October 2007).

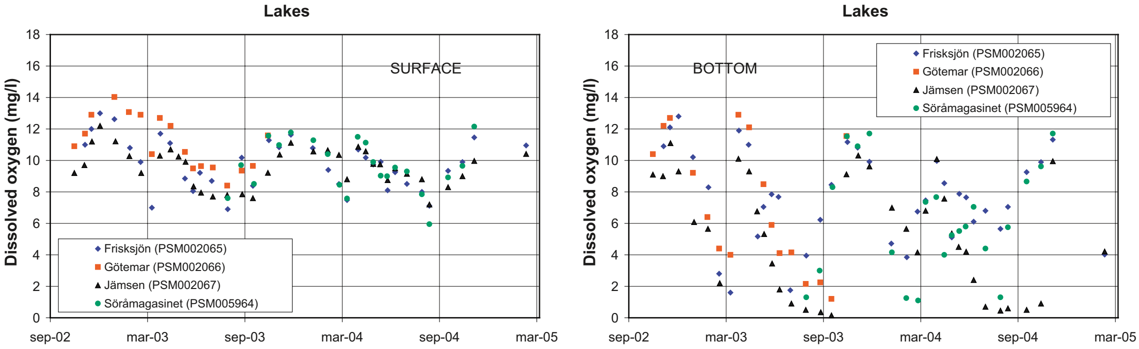


Figure 4-19. *Oxygen concentrations in four of the lakes in the Laxemar-Simpevarp area.*

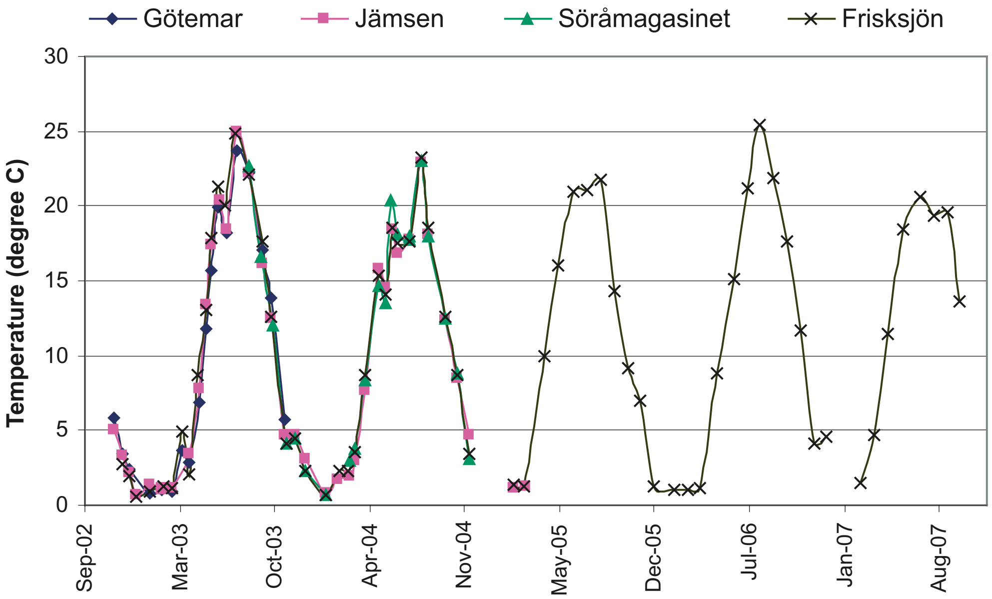


Figure 4-20. *Water temperature in surface water of four lakes in the Laxemar-Simpevarp area. (Data from the database SICADA, October 2007).*

Water colour

The water colour has been measured as absorbance at 420 nm in two lakes in the Laxemar-Simpevarp area, Frisksjön and Jämsen. The water colour varies over the year, with the highest values in the spring and autumn (Figure 4-21) (data from the database SICADA, April 2008). The annual mean water colour for Frisksjön varies somewhat between the two years when measurements were performed: in 2005 the annual average was 0.15 and in 2006 it was 0.12. This indicates a moderate water colour. For comparison, the mean absorbance measured in 8,000 lakes in Sweden was 0.14 and for lakes in Kalmar County 0.26 (data from the national survey of lakes /cf. Wilander et al. 2003/.

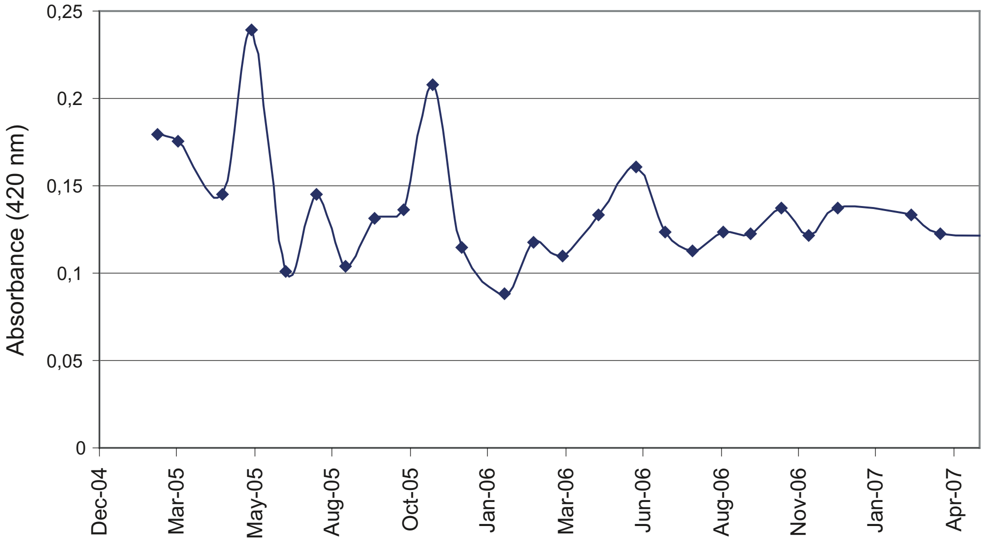


Figure 4-21. *Water colour, measured as absorbance at 420 nm, in Frisksjön. (Data from the database SICADA, April 2008).*

4.9.2 Water chemistry in streams

The streams in the Laxemar-Simpevarp area are characterized as mesotrophic brown-water systems. Most freshwaters are strongly coloured due to high amounts humic substances, leading to very high concentrations of dissolved organic carbon. The streams are also relatively rich in nitrogen and phosphorus.

The concentrations of most elements show more or less variation, due to both dilution effects caused by variations in runoff and to seasonal variations coupled to primary production and mobility of for example carbon species. In the winter when the water in the superficial soil layers is frozen, the contents of carbon and carbon-related elements are usually low in the flowing water. The seasonal variations of dissolved ions are less accentuated and probably mainly governed by variations in water flow.

Acidity and alkalinity

Most freshwater sampling sites show “moderately acid” to “slightly acid” **pH values** and an alkalinity corresponding to “good buffering capacity” according to the EQC (Table 4-17) /Naturvårdsverket 2000/. There are, however, a few stream sampling sites which show “very acid” pH values and “no or negligible” buffering capacity, indicating presence of acid and maybe also acidified waters in the Simpevarp regional model area. A substantial proportion of the Simpevarp regional model area is covered by a very thin Quaternary layer or bedrock, creating conditions for acidification in small streams draining the catchments, which are dominated by thin soils.

Major elements

The concentrations of total ***phosphorus*** in the streams in the Simpevarp regional model area range from “moderately high” to “very high” according to the EQC (Figure 4-22, Table 4-17) /Naturvårdsverket 2000/. Also according to data from the National Survey /cf. Wilander et al. 2003/, the phosphorus levels are elevated. For all three phosphorus species studied (total, phosphate and particulate phosphorus) there is a general tendency toward increasing concentrations downstream in the watercourses (Figure 4-22). The highest phosphorus levels coincide with areas with the highest proportion of arable land. Nevertheless, two stream sites in the northern part of the area show elevated phosphorus levels despite a low proportion of arable land in the catchment. The reason for these elevated levels is unclear.

The concentrations of total ***nitrogen*** in the streams in the Simpevarp regional model area are “high” according to the Swedish EQC /Naturvårdsverket 2000/, and according to data from the National Survey /cf. Wilander et al. 2003/ as well, the nitrogen levels are elevated (Figure 4-23, Table 4-17). As with phosphorus, the highest nitrogen concentrations are observed in streams that drain catchments containing a large proportion of arable land (Figure 4-23). The nitrogen levels are elevated in a catchment in the northern part of the area (compare with phosphorus). The ammonium fraction in particular is occasionally elevated. The total nitrogen content is fairly constant throughout the year, whereas the different nitrogen species show considerable seasonal variation. Nitrate, ammonium and particulate organic nitrogen comprise only a minor part of the observed total nitrogen contents.

The content of total organic ***carbon*** in the fresh waters of the Simpevarp regional model area is “very high” according to the EQC /Naturvårdsverket 2000/. According to data from the national survey /cf. Wilander et al. 2003/ as well, the organic carbon levels are markedly elevated (Figure 4-24, Table 4-17). The high organic carbon content in the Simpevarp area is fairly uniformly distributed (Figure 4-24). The content of organic carbon shows a clear seasonal variation, with generally higher values in the warmer season. The variation is probably coupled to the mobility of water and transport of humic acids and other carbon compounds originating from the terrestrial ecosystems. Both particulate and dissolved organic carbon show similar seasonal patterns.

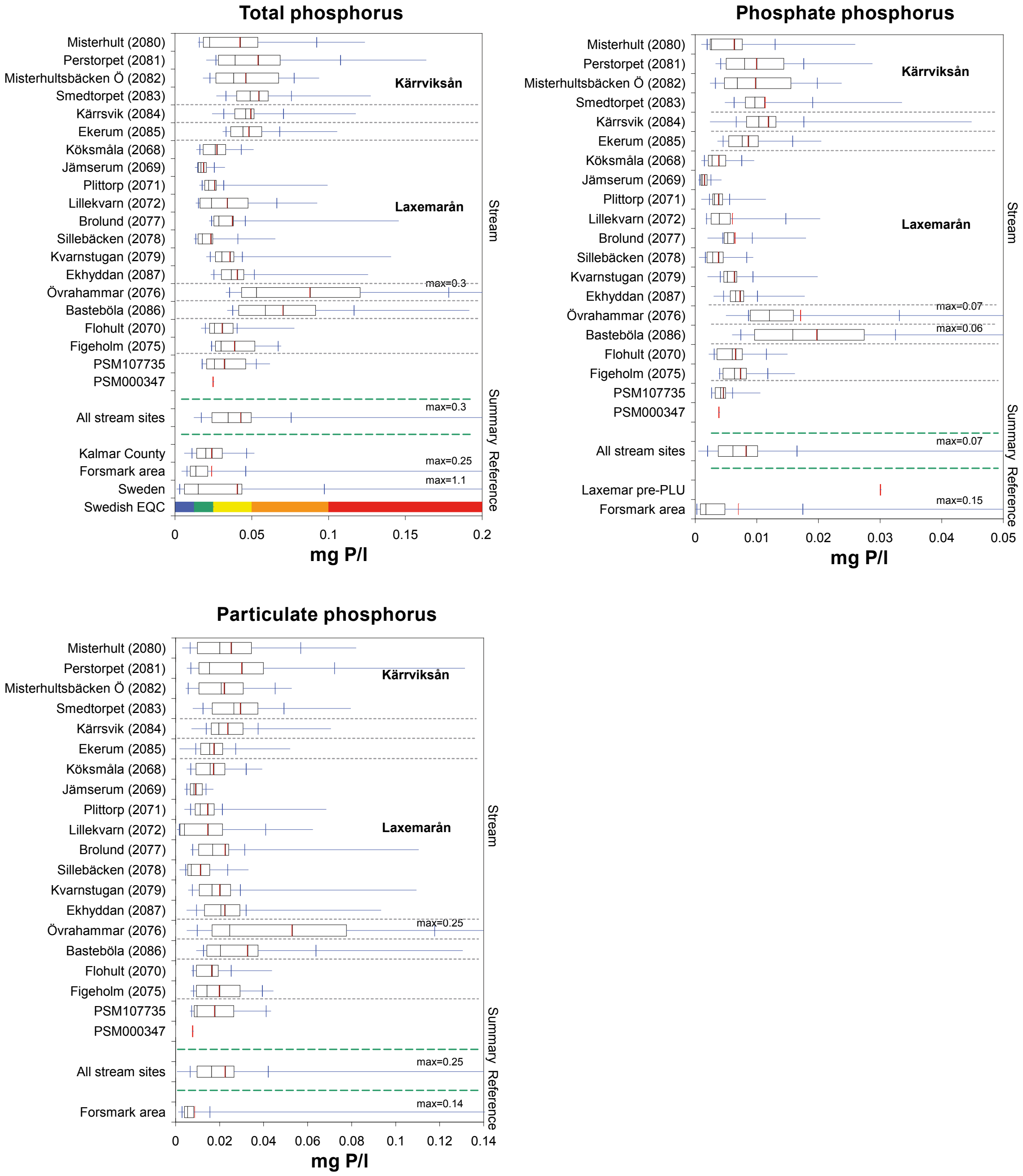


Figure 4-22. *Concentrations of total, phosphate and particulate phosphorus species in streams in the Laxemar-Simpevarp area. For an explanation of the box plots, see Figure 3-22. Numbers within brackets represent the last digits in the id-code used in the database SICADA. Data from /Tröjbom and Söderbäck 2006a/.*

The ***sulphur*** concentrations in the streams in the Simpevarp regional model area are, as in the rest of the region, elevated compared with most Swedish streams (Table 4-17). There is a general tendency for increasing sulphur concentrations along the watercourses in the area. As for phosphorus, the highest values are found nearest the outlets and coincide with the highest concentrations of arable land. These areas presumably have sulphur-containing sediments, which is probably an important reason for the elevated levels. A seasonal pattern with lower concentrations during summer is seen in most of the streams.

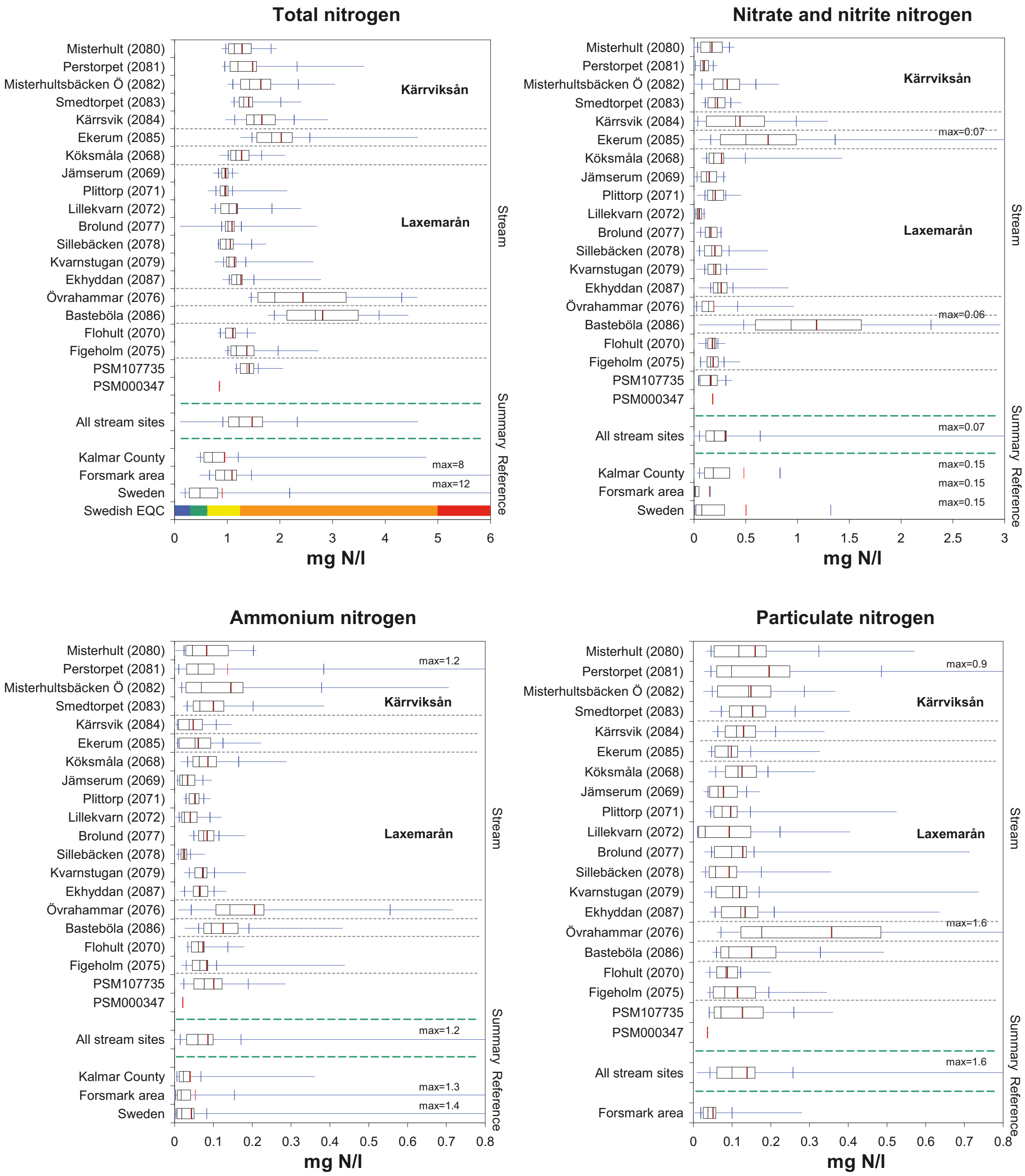


Figure 4-23. Concentrations of total, nitrate and nitrite, ammonium and particulate nitrogen species in streams in the Laxemar-Simpevarp area. For an explanation of the box plots, see Figure 3-22. Numbers within brackets represent the last digits in the ID code used in the database SICADA. Data from /Tröjbom and Söderbäck 2006a/.

Most Simpevarp regional model area streams show significantly elevated concentrations of ***silicon*** compared with normal levels in Sweden (Table 4-17). The area also deviates from the region. The lowest silicon concentrations occur in the western part of the area, whereas the highest occur in the eastern part, especially in the catchments containing a lot of arable land and fine-grained sediments.

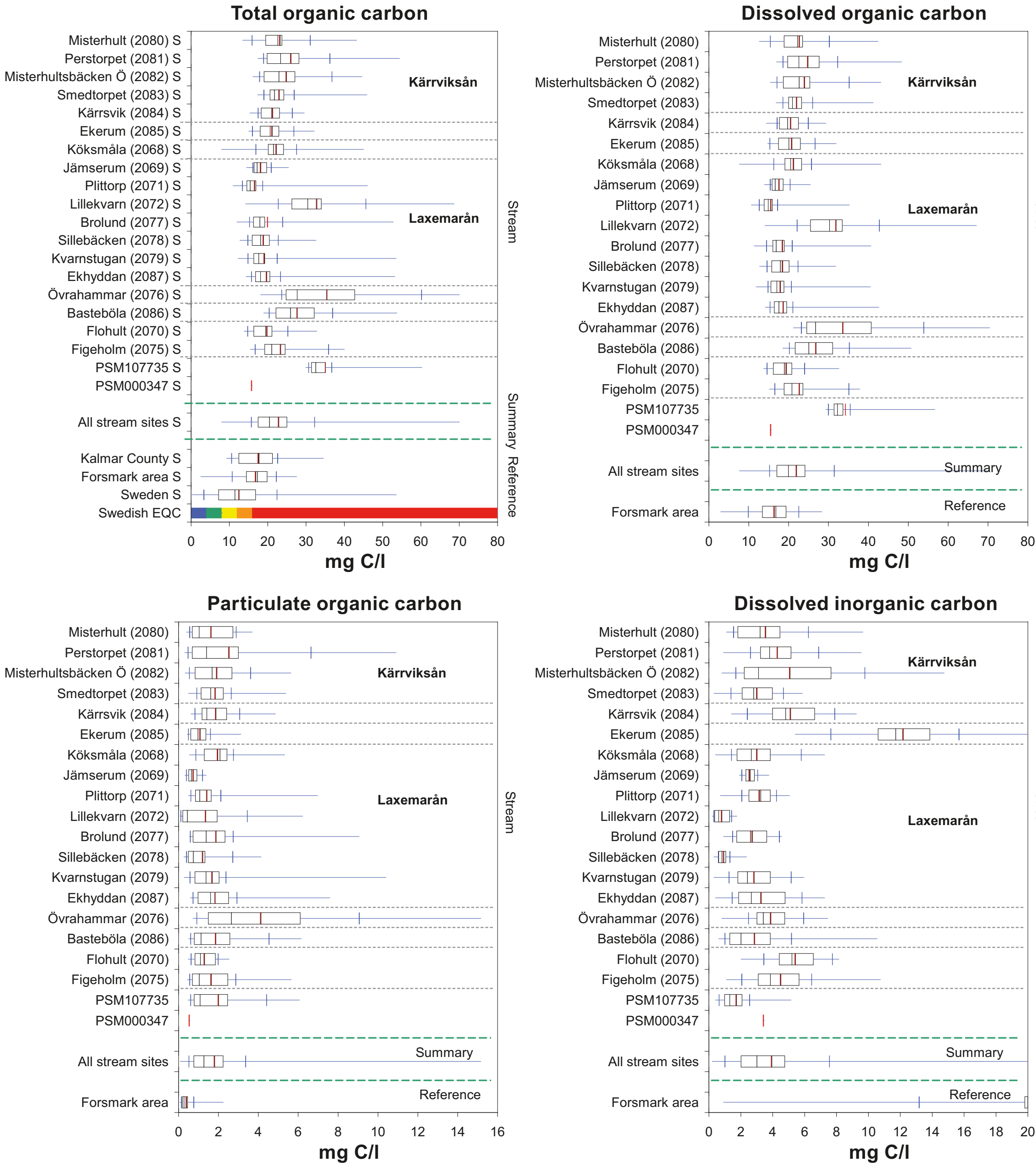


***Figure 4-24.** Concentrations of total, dissolved and particulate organic carbon species, as well as contents of dissolved inorganic carbon, in streams in the Laxemar-Simpevarp area. For an explanation of the box-plots, see Figure 3-22. Numbers within brackets represent the last digits in the ID code used in the database SICADA. Data from /Tröjbom and Söderbäck 2006a/.*

Dissolved ions

In conformity with the lake water chemistry, the total amount of dissolved ions in streams in the Laxemar-Simpevarp area lead to a somewhat elevated ***electrical conductivity*** compared with the situation in most Swedish freshwater bodies (Table 4-17). The electrical conductivity show high variability in streams. This variation, which shows no clear seasonal pattern, is probably caused by climatic variations in precipitation and runoff.

Cations consist mainly of calcium, magnesium, sodium and potassium (Table 4-17). These ions have slightly elevated concentrations compared with most Swedish streams but are similar to those in the regional streams. There is a general tendency for the highest concentrations of calcium, magnesium, sodium and potassium to be found in the streams near the coast, and the lowest concentrations in the western part of the Simpevarp regional model area. The concentrations are fairly constant on a seasonal basis. Many streams show very similar temporal patterns regarding these cations, even though they belong to different catchments. This may indicate that cation concentrations are mainly governed by climatic factors as precipitation and runoff.

In the streams in the Simpevarp regional model area, as well as in the lakes in the area, ***anions*** consist mainly of chloride, bicarbonate and sulphate (Table 4-17). Fluoride and bromide occur at much lower concentrations and iodine only occurs at trace levels. Both chloride and fluoride concentrations are higher than in most Swedish streams. Fluoride is also elevated compared with concentrations in regional lakes.

For ***iron*** and ***manganese,*** no national data are available for comparison. Compared with data from Forsmark streams, the values for streams in the Simpevarp regional model area are high (Table 4-17).

Table 4-17. Mean water chemistry (October 2002–May 2005) for major elements in the investigated streams in the Simpevarp regional model area. Percentiles, mean, minimum, and maximum values have been calculated for all the monitored streams.

Element	N obs	Min.	25-p	Median	75-p	Max.	Mean	SD
pH (unit)	570	5.01	6.12	6.42	6.65	7.85	6.40	0.46
Conductivity (mS/m)	571	5.8	11	13	17	34	14	5
Tot-P (mg L^{-1})	563	0.012	0.024	0.035	0.049	0.30	0.043	0.03
POP (mg L^{-1})	561	0.00060	0.0097	0.016	0.026	0.25	0.022	0.02
PO_4-P (mg L^{-1})	564	0.00050	0.0037	0.0061	0.0100	0.073	0.0082	0.008
Tot-N (mg L^{-1})	563	0.10	1.0	1.2	1.7	4.6	1.5	0.7
NH_4-N (mg L^{-1})	564	<0.0005	0.031	0.060	0.097	1.2	0.085	0.1
NO_2+NO_3-N (mg L^{-1})	564	0.0021	0.11	0.19	0.30	3.5	0.30	0.4
PON (mg L^{-1})	562	0.0087	0.060	0.099	0.16	1.6	0.14	0.1
TOC (mg L^{-1})	562	7.9	17	20	25	70	23	9
DOC (mg L^{-1})	564	7.6	17	20	24	70	22	8
POC (mg L^{-1})	560	0.080	0.75	1.3	2.2	15	1.8	2
SO_4-S (mg L^{-1})	573	0.92	8.6	13	18	66	16	10
Si (mg L^{-1})	555	2.9	6.5	8.2	10.0	20	8.4	3
Fe (mg L^{-1})	555	0.23	0.91	1.2	1.8	11	1.6	1
Mn (mg L^{-1})	555	0.0068	0.045	0.067	0.11	0.90	0.097	0.1
Cations								
Ca (mg L^{-1})	556	3.5	8.6	11	15	38	13	6
Mg (mg L^{-1})	556	0.90	2.0	2.4	3.2	5.8	2.6	0.9
Na (mg L^{-1})	556	2.7	6.1	8.6	11	31	8.9	4
K (mg L^{-1})	556	<0.4	0.95	1.3	1.7	7.8	1.5	0.9
Anions								
Cl (mg L^{-1})	573	2.0	6.0	10	14	51	11	6
HCO_3 (mg L^{-1})	572	<0.2	12	18	29	120	23	20
F (mg L^{-1})	565	<0.2	0.37	0.53	0.77	2.7	0.66	0.5
Br (mg L^{-1})	573	<0.2	<0.2	<0.2	<0.2	1.3	<0.2	0.2
I (mg L^{-1})	87	0.0020	0.0060	0.010	0.020	0.10	0.016	0.02

Dissolved oxygen

As in lakes, the concentrations of dissolved oxygen show a typical seasonal pattern due to the temperature-dependent solubility of oxygen (Figure 4-25). The solubility is higher at low temperatures leading to generally higher values during winter. In addition to temperature, decomposition of organic matter and primary production affect the concentrations of dissolved oxygen. Discharging groundwater is naturally depleted of oxygen, and during dry periods the increased proportions of groundwater in the streams may lead to decreased levels of dissolved oxygen in flowing waters. There are several observations of low oxygen concentrations in the summer in the streams in the Simpevarp regional model area, probably as a consequence of temperature, decomposition of organic matter and discharging groundwater.

Temperature

Water temperature has been measured in several of the streams in the Laxemar-Simpevarp area but the measurement period varies widely. The temperature in five streams is shown in Figure 4-26. The water temperatures varied between zero in the winter up to between 15 and 20°C in the summer.

Water colour

Water colour is measured as absorbance at 420 nm and varies over the year (Figure 4-27) (data from the database SICADA, April 2008). The highest values are measured in the spring and autumn, which correlates with high runoff. Annual water colour measured for the time period 2005–2006 is 0.19 for Laxemarån (upper part) (2005=0.22 and 2006=0.16), 0.20 for Laxemarån (lower part) (2005=0.23 and 2006=0.18), and 0.23 for Kärrviksån (2005=0.28 and 2006=0.19). The water colour of the streams in the Laxemar-Simpevarp area has been measured in several of the streams in the Laxemar-Simpevarp area during different measurement periods. The longest time series are from two sites in Laxemarån (PSM002079 (upper part) and PSM002087 (lower part)) and from Kärrviksån (PSM002083) (Figure 4-27).

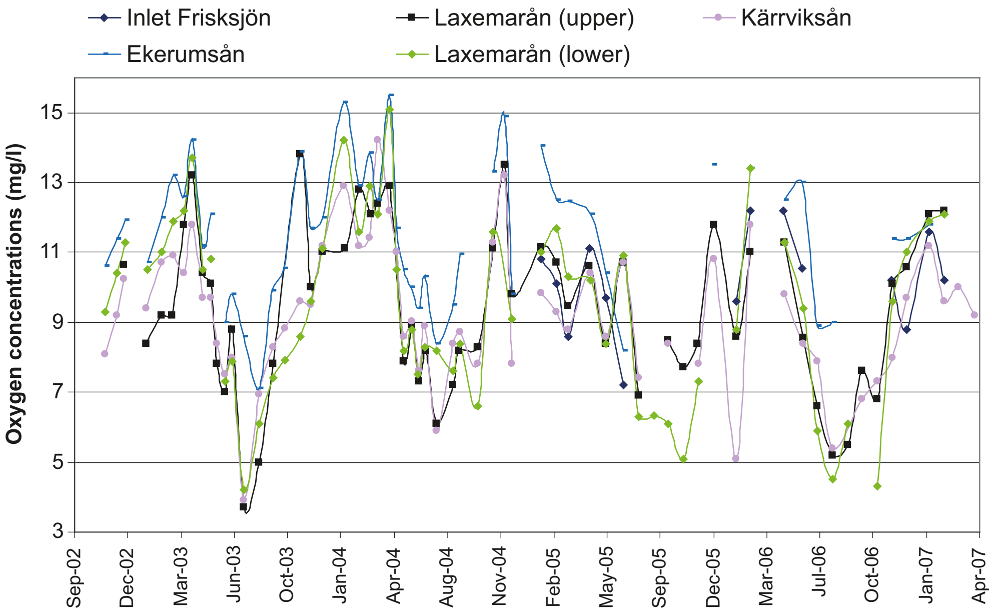


Figure 4-25. Concentrations of dissolved oxygen in streams in the Laxemar-Simpevarp area. ID codes for the sampling locations are Inlet Frisksjön: PSM000347, Laxemarån (upper): PSM002079, Kärrviksån: PSM002083, Ekerumsån: PSM002085 and Laxemarån (lower): PSM002087. For location, see Figure 4-14.

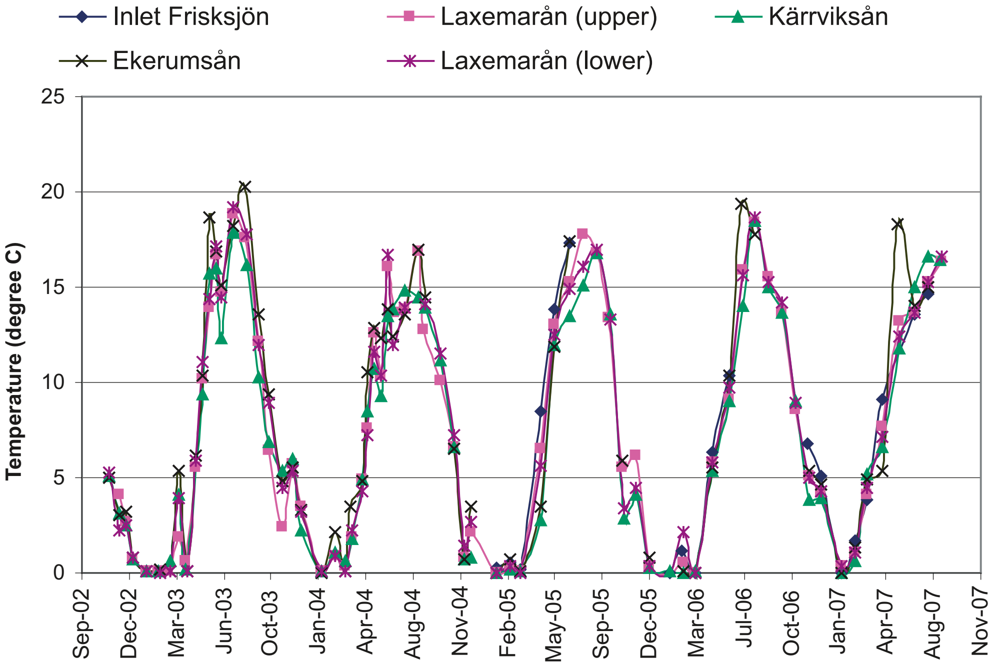


Figure 4-26. *Water temperatures in streams in the Laxemar-Simpevarp area. ID codes for the sampling locations are Inlet Frisksjön: PSM000347, Laxemarån (upper): PSM002079, Kärrviksån: PSM002083, Ekerumsån: PSM002085 and Laxemarån (lower): PSM002087. For location, see map in Figure 4-14.*

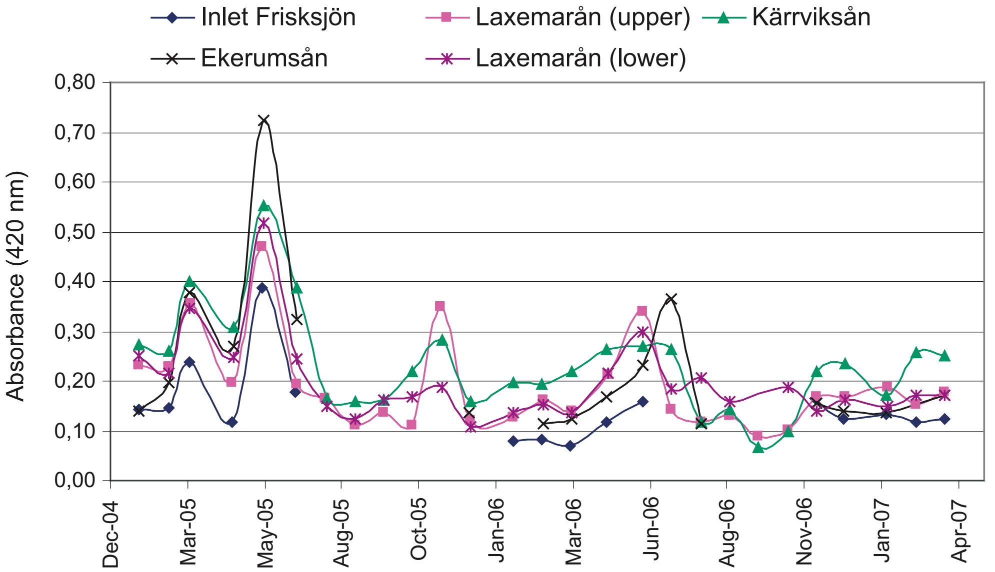


Figure 4-27. *Water colour, measured as absorbance at 420 nm, in streams in the Laxemar-Simpevarp area. ID codes for the sampling locations are Inlet Frisksjön: PSM000347, Laxemarån (upper): PSM002079, Kärrviksån: PSM002083, Ekerumsån: PSM002085 and Laxemarån (lower): PSM002087. For location, see map in Figure 4-14.*

4.9.3 Chemistry in groundwater

The shallow groundwater in the Laxemar-Simpevarp area is characterized by neutral or slightly acid pH values, a normal content of major constituents, and alkalinity ranging from high to very low. Marine relicts influence groundwater in the area, resulting in elevated concentrations of e.g. chloride and sulphate. Several parameters show large deviation compared with national reference data. Iron and manganese show markedly elevated concentrations of about one order of magnitude. Fluoride, iron and strontium also show elevated concentrations compared to national references.

Acidity and alkalinity

The shallow groundwater is characterized by neutral or slightly acid pH values with a majority of observations between pH 6 and 7 (Table 4-18). Most alkalinity measurements are classified as high or very high according to EQC. However, there are a few observations with pH below 6 and with low or very low alkalinity. The low pH values are found in small, topographically elevated catchments where exposed bedrock and clay gyttja-covered peat dominate the overburden. Alkalinity is generally higher in shallower groundwater than in surface waters.

Major elements (C, N, P)

Limited data are available concerning the elements carbon, nitrogen and phosphorus in groundwater and the compilation presented here is for a single soil tube in the area (SSM000240) located beneath a marine bay and for a relatively short time period (March 2006–September 2007). Total organic ***carbon*** concentrations consist almost entirely of dissolved organic carbon (Table 4-18). The concentrations of dissolved inorganic carbon are much higher than the organic concentrations. The mean and median values for the single soil tube SSM000240 are higher than the concentrations for a number of soil tubes in the Laxemar-Simpevarp area as well as for private wells in the Laxemar-Simpevarp area and in Kalmar County /Tröjbom and Söderbäck 2006a/. Most of the ***phosphorus*** occurs as phosphate, and in general only a minor fraction of total phosphorus consists of particulate species. The phosphate concentrations are somewhat higher than in private wells in the Laxemar-Simpevarp area and Kalmar County. The dominant ***nitrogen*** form is as ammonium, while nitrate and nitrite (NO_3 and NO_2) concentrations are low. The ammonium concentrations are much higher than those in private wells in the Laxemar-Simpevarp area and in Kalmar County, and the reverse is true for the concentrations of nitrate and nitrite. However, the concentrations are of the same order of magnitude as in soil tubes in lakes and sea in the Forsmark area.

Major constituents

Major constituents of the groundwater are generally calcium, chloride, magnesium, silica, sodium, sulphate, carbonate and bicarbonate (Table 4-18). Calcium, magnesium, sodium and potassium show normal levels compared with national reference data. Chloride, sulphate and silicon, however, show elevated levels compared with national references. The groundwater in the soil tubes can be classified as Ca-HCO_3 to Na-Cl type, i.e. dominated by either calcium ions or sodium ions. The Ca-HCO_3 type probably indicates recently infiltrated water and recharge areas. Higher localities are classified as Ca-HCO_3 type, whereas lower situated soil tubes are classified as Ca-CHO_3 or Na-Cl type.

Calcium concentrations are on the same level or lower than in private wells in Sweden. There are generally higher concentrations in the groundwater than in streams and lake water.

Magnesium and ***sodium*** concentrations are normal compared with regional and national wells. There is a tendency for the lowest concentrations to be found in topographically high-situated soil tubes. There is a difference between magnesium and sodium, however. The ratio between "lower" and "higher" soil tubes differs, the ratios being 1.5 for Mg and 4 for Na, indicating

Table 4-18. Mean water chemistry (October 2002–May 2005) for major elements in the shallow groundwater in the Laxemar-Simpevarp area /Tröjbom and Söderbäck 2006a/. Percentiles, mean, minimum and maximum values have been calculated for all the monitored locations. *Samples from soil tube SSM000240 (March 2006–September 2007) (data from the database SICADA April 2008).

Element	N obs	Min.	25-p	Median	75-p	Max.	Mean	SD
pH (unit)	63	5.17	6.33	6.68	6.95	7.97	6.68	0.58
Conductivity (mS/m)	63	4.0	19	29	57	120	42	30
Tot-P* (mg L^{-1})	5	0.078	0.13	0.13	0.24	1.8	0.48	0.75
POP* (mg L^{-1})	5	0.0005	0.0015	0.0078	0.0078	0.011	0.0056	0.0044
PO_4-P* (mg L^{-1})	5	0.036	0.040	0.13	0.20	2.2	0.51	0.92
Tot-N (mg L^{-1})*	5	1.2	1.6	1.9	2.1	2.9	2.0	0.65
NH_4-N* (mg L^{-1})	5	0.92	1.4	1.6	1.7	2.9	1.7	0.71
NO_2+NO_3-N* (mg L^{-1})	5	0.00040	0.00040	0.00050	0.00060	0.0022	0.00082	0.00078
PON* (mg L^{-1})	5	0.0065	0.0093	0.055	0.087	0.091	0.050	0.041
TOC* (mg L^{-1})	5	10	10	10	11	11	10	0.29
DOC* (mg L^{-1})	5	10	10	10	11	11	10	0.26
POC* (mg L^{-1})	5	0.011	0.055	0.42	0.75	0.85	0.42	0.38
DIC* (mg L^{-1})	5	244	261	265	273	276	264	13
SO_4-S (mg L^{-1})	41	0.26	5.2	8.7	20	59	14	10
Si (mg L^{-1})	41	4.3	8.5	11	15	26	12	5
Fe (mg L^{-1})	41	0.33	2.3	5.8	9.4	42	7.7	8
Mn (mg L^{-1})	41	0.082	0.22	0.49	0.61	6.1	0.58	0.9
Cations								
Ca (mg L^{-1})	41	6.1	23	34	47	100	38	20
Mg (mg L^{-1})	41	1.3	5.1	8.2	11	45	10	8
Na (mg L^{-1})	41	4.6	7.5	12	39	230	39	60
K (mg L^{-1})	41	1.1	2.5	4.8	7.0	46	7.7	10
Anions								
Cl (mg L^{-1})	55	3.2	5.4	7.4	24	200	36	50
HCO_3 (mg L^{-1})	63	2.0	52	93	190	550	130	100
F (mg L^{-1})	55	<0.2	0.82	1.4	2.2	5.4	1.6	1
Br (mg L^{-1})	55	<0.2	<0.2	<0.2	0.32	1.5	0.29	0.4
I (mg L^{-1})	17	0.0030	0.0060	0.010	0.016	0.050	0.013	0.01

differences in mechanisms governing the concentrations of these elements. The concentrations of sodium in shallow groundwater are usually comparable to those in streams and lakes. The concentrations of magnesium, on the other hand, are 3–4 times higher than those found in lakes and streams.

Potassium concentrations are normal compared with regional and national wells but 3–4 times higher than concentrations in streams and lakes. As with magnesium, there is a tendency for the lowest concentrations to occur in the highest topographical locations in the western area.

Chloride concentrations in shallow groundwater in the Laxemar-Simpevarp area are slightly elevated compared with those in Swedish wells. The highest concentrations are found on the island of Ävrö and near the brackish basins. The concentrations are comparable to concentrations in streams and lakes.

Sulphate concentrations are elevated, almost twice the mean concentration for Swedish wells. The concentrations are also twice the concentrations in streams and lakes in the area.

The concentrations of ***silicon*** in shallow groundwater are quite high, twice the concentrations found in Forsmark. There is a high variation in concentrations of silicon (Si) within soil tubes.

Bicarbonate (HCO_3) concentrations show a large range from 500 to almost 0 mg L^{-1}, indicating very low alkalinity in some groundwater. Most observations however, are slightly elevated compared with those in Swedish wells.

Redox potential

No calculations based on redox pairs have been performed to evaluate the redox potential. However, a simplified classification based on iron, manganese and sulphate is presented /Tröjbom and Söderbäck 2006a/. Soil tubes in the Simpevarp area are classified as having a low redox potential.

Both ***iron*** and ***manganese*** concentrations (Table 4-18) are clearly elevated compared with median values for undisturbed shallow groundwater /Naturvårdsverket 1995/. Iron concentrations are generally higher in shallower groundwater than in both lakes and streams.

4.10 Biota

4.10.1 Biota in lakes

The biomass of biota in lakes in the Laxemar-Simpevarp area is dominated by consumers, particularly by benthic bacteria. Due to the brown water colour of the lakes, the distribution of primary producers is restricted leading to dominance of heterotrophic biota.

All functional groups are represented in the site investigation of the biomass of biota. Some samplings of biomasses have been spread over the year but concentrated in the summer period. In those cases, an average for each month was calculated and an annual average was estimated from the monthly average values. Primary production estimates for reeds and one respiration measurement have been performed in Frisksjön. All species of biota found during the site investigations are listed in Appendix 4. A description of biomass, primary production and respiration measured in the lakes follows below.

Biomass of primary producers

The annual mean ***phytoplankton*** biomass investigated by microscopic counts was 0.3 mg C L^{-1} (n=8) and the community was dominated for most of the year by truly autotrophic species (Table 4-19, Figure 4-28) /Sundberg et al. 2004/ (E. Andersson unpublished). Two phytoplankton blooms were recorded. The first one in July was mainly composed of the mixotrophic *Peridinium* (*Dinophyceae*) and had a total phytoplankton biomass of 0.7 g C m^{-3}. The second bloom was larger with a total phytoplankton biomass of 2.1 g C m^{-3} and was composed of the algae *Gonyostomum semen* (*Chloromonadophyceae*). The algae *G. Semen* can cause problems in bathing waters as it produces a slime that can cause skin reactions in sensitive persons. The biomass of *G. semen* in Frisksjön during 2003 however, was moderate according to Swedish Environmental Criteria (EQC, /Naturvårdsverket 2000/). The seasonal mean phytoplankton biomass from May to October was high and indicates eutrophic conditions in Frisksjön according to EQC.

The phytoplankton biomass was also estimated as concentrations of chlorophyll a. There was good correspondence with microscope counts and chlorophyll measurements and the phytoplankton blooms are detected by both methods. According to EQC, the chlorophyll a concentration in Frisksjön also indicates that the phytoplankton biomass is high. Nevertheless, the median chl a concentration of 5.5 µg L^{-1} is very close to the median chl a concentration in 206 coloured lakes (5.1 µg L^{-1}) in a review by /Nürnberg and Shaw 1999/.

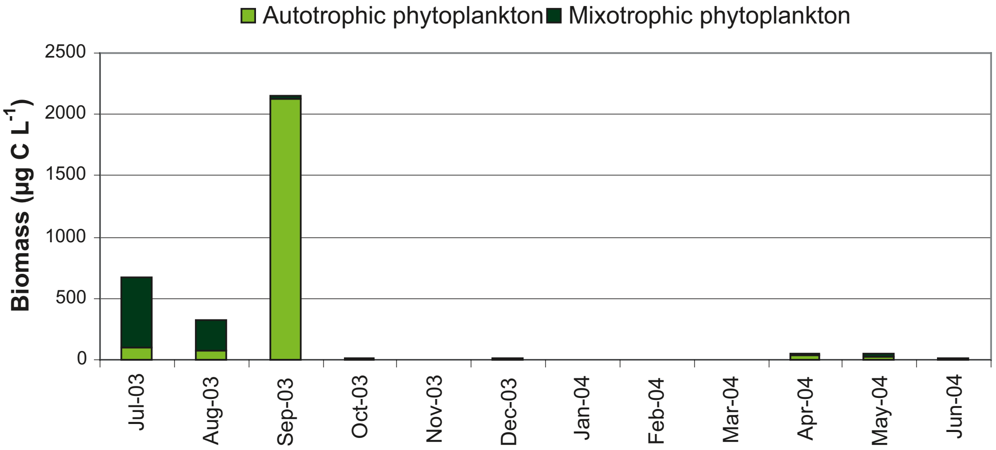


Figure 4-28. *Phytoplankton biomass in Frisksjön during 2003 and 2004 /Sundberg et al. 2004/ (Eva Andersson unpublished).*

Table 4-19. Phytoplankton biomass measured in Frisksjön 2003 and 2004 /[1]Sundberg et al. 2004/ ([2]Eva Andersson unpublished).

Year	Month	Biomass (µg C L^{-1})		
		Autotrophic phytoplankton	Mixotrophic phytoplankton	Sum
2003	July[1]	96	575	671
	August[2]	69	255	324
	September[2]	2,133	15	2,148
	October[2]	12	1	14
	December[1]	9	1	10
2004	April[1]	34	11	45
	May[2]	27	22	49
	June[2]	8	11	18

In total, 21 species of ***macrophytes*** were noted in a qualitative investigation of macrophytes in Frisksjön (Table 4-20) /Aquilonius 2005/. Quantitative investigations of macrophytes show that in Littoral I, reed is clearly the dominant macrophyte. The above-ground biomass (measured in August) was 287 g C m^{-2} and the below-ground biomass was almost eight times higher, 2,242 g C m^{-2} (Table 4-21) /Andersson et al. 2006/. In comparison, other macrophytes in Littoral I were negligible with a biomass < 10 g C m^{-2} /Aquilonius 2005/. The biomass of macrophytes in Littoral II was very low, 0.8 g C m^{-2} /Aquilonius 2005/. The above-ground biomass of reed is higher than the biomass in the Forsmark lakes (181 g C m^{-2}) and the straw density (94 m^{-2}) is higher than that reported from a lake in Netherlands (53 m^{-2}) /Meulemanns 1988/ but biomass was lower than that reported from a lake in northern Germany (687 g C m^{-2} /Gessner et al. 1996/) and thus the biomass estimate was within reported literature values.

Primary production

The annual above-ground production of reed in Frisksjön was assumed to be equal to the maximum biomass in August, i.e. 287 g C m^{-2} /Andersson et al. 2006/. No other data on primary production in the Simpevarp regional model area are available.

Table 4-20. Macrophytes found in a qualitative inventory in Frisksjön /Aquilonius 2005/.

Latin name	Swedish name	English name
Alisma plantago-aquatica	Svalting	Water-plantain
Carex nigra	Hundstarr	Common sedge
Carex rostrata	Flaskstarr	Bottle Sedge
Carex vesicaria	Blåsstarr	Bladder-sedge
Equisetum fluviatile	Sjöfräken	Water Horsetail
Iris pseudacorus	Gul svärdslilja	Yellow Iris
Juncus conglomerates alt. J. effesus	Knapptåg alt. Veketåg	Compact Rush or Soft-Rush
Lysimachia thyrsiflora	Topplösa	Tufted Loosestrife
Lysimachia vulgaris	Videört (strandlysing)	Yellow Loosestrife
Lythrum salicaria	Fackelblomster	Purple-loosestrife
Menyanthes trifoliata	Vattenklöver	Bogbean
Nuphar lutea	Gul näckros	Yellow Water-lily
Nymphea alba	Vit näckros	White Water-lily
Oenanthe aquatica	Vattenstäkra	Fine-leaved Water-dropwort
Phragmites australis	Bladvass	Common Reed
Potamogeton natans	Gäddnate	Broad-leaved Pondweed
Schoenoplectus lacustris	Säv	Common Club-rush
Sparganium angustifolium	Plattbladig igelknopp	Floating Bur-reed
Sparganium emersum	Vanlig igelknopp	Unbranched Bur-reed
Typha latifolia	Bredkaveldun	Bulrush

Table 4-21. Biomass of primary producers in different habitats in Frisksjön. Data from /Andersson et al. 2006, Aquilonius 2005/.

Habitat	Biomass (g C m^{-2})
Littoral I	
Above-ground biomass of reed	287
Below-ground biomass of reed	2,242
Littoral II	0.8

Biomass of consumers

The biomass of ***bacterioplankton*** in Frisksjön was investigated in June and August 2006 (one replicate on each occasion) and the biomass of ***benthic bacteria*** was investigated on one occasion in June 2006 (3 replicates) /Andersson et al. 2006/. The bacterioplankton biomass was 18 mg C m^{-3} in June and 34 mg C m^{-3} in August. Benthic bacterial biomass was 5.3 g C m^{-2} (standard deviation 1.0 g C m^{-2}). The biomass of bacterioplankton (1.6×10^{7} cells ml^{-1}) may be considered somewhat low compared to the median cell number (2.7×10^{7} cells ml^{-1}) for 73 coloured lakes reviewed by /Nürnberg and Shaw 1999/. However, the number of cells is well within the range for the coloured lakes (0.02–9.6 cells ml^{-1}). The number of sediment bacteria can vary within a wide span, but typically ranges between 10^{8} and 10^{10} cells per ml sediment /Schallenberg et al. 1989/. Thus the bacterial cell number in Frisksjön 5×10^{9} is also within the range reported in the literature.

The biomass of ***zooplankton*** in Frisksjön was measured on three occasions. The biomass was very high in July (1.68 g dw m^{-3}), while it was much lower in December (0.16 g dw m^{-3}) and April (0.14 g dw m^{-3}) (Figure 4-29) /Sundberg et al. 2004/. /Sundberg et al. 2004/ concluded that the zooplankton community in Frisksjön is typical of a small lake on the east coast of southern Sweden. However, the very high biomass in July was considered to be unrepresentative of the total summer value. Instead, the median zooplankton biomass in another humic lake, included in the Swedish national monitoring programme (Älgsjön; /SLU 2005 (www)/), was used for the period June–September to estimate the annual mean biomass. The annual mean biomass was estimated to be 0.11 g C m^{-3}. The zooplankton biomass is somewhat low compared with that in 81 European shallow lakes /Gyllström et al. 2005/. In July the zooplankton community was dominated by cladocerans (mainly *Daphnia cucullata*). In December and April copepods dominated (mainly *Eudiaptomus*). Smaller zooplankton such as heterotrophic flagellates and ciliates were not included in the estimate of zooplankton since water was filtered through a 64 µm mesh.

Benthic fauna was investigated in the Frisksjön, Jämsen, Söråmagasinet and Plittorpsgöl /Ericsson and Engdahl 2004/ (Table 4-22). In all lakes, the biomass increased with depth and was lowest in Littoral I, intermediate in Littoral II and III and highest in the Profundal habitat. The species richness, on the other hand was highest in Littoral I. In most lakes detritus feeders were the dominant benthic fauna in Littoral I, followed by predators and shredders (Table 4-23). In Littoral II and III, predators were the dominant benthic fauna in all lakes except for in Jämsen where detritus feeders were the most common benthic fauna (Table 4-24). In Frisksjön, a large mussel was excluded from the biomass estimate in Littoral III since mussels are very scattered and the probability of catching one is extremely low and has an undue influence on the biomass estimate due to the very low number of samples in the study. Excluding the single mussel found in Frisksjön, filter feeders, scrapers and shredders made insignificant contribution to the biomass of benthic fauna in the lakes. In the Profundal habitat the most common benthic fauna in all lakes consisted of predators, representing 92% of the total biomass (Table 4-25). The predators mainly consisted of the phantom midge *Chaoborus flavicans*, which is able to migrate through the water column at night to feed on zooplankton but stays in the benthic habitat during day to avoid predators. The benthic fauna in Littoral I was sampled with a hand net (opening 0.25×0.25 m, mesh size 0.5×0.5 mm). An area of 0.25 m^2 was disturbed by the foot and the net was slowly swept over the area to collect the animals. In Littoral III, and in the Profundal, an Ekman grabber was used to collect the animals which were sieved through a 0.5 mm mesh.

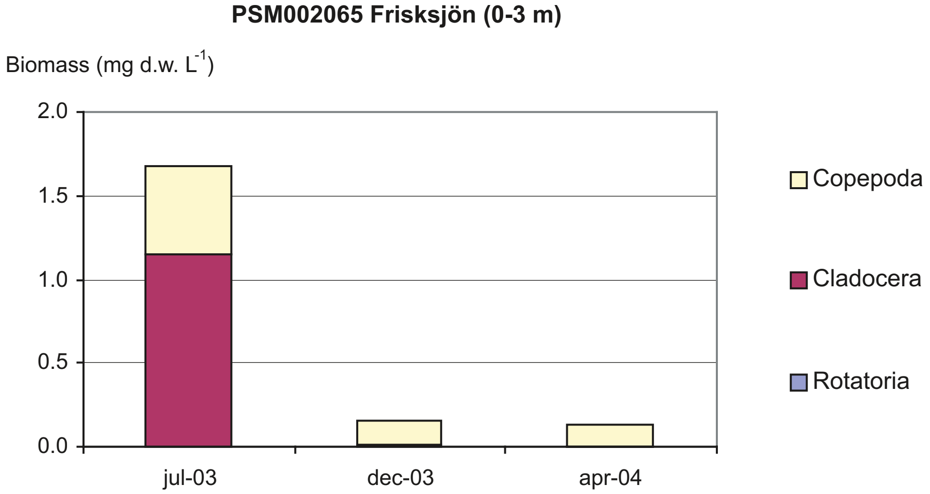


Figure 4-29. *Biomass of different zooplankton groups in the whole water column in the centre of Frisksjön (0–3 m) /Sundberg et al. 2004/.*

Table 4-22. Biomass of benthic fauna (in g ww m^{-2}) in the Littoral and Profundal habitats in four lakes in the Simpevarp area (n=5 in all habitats).

	Frisksjön	Jämsen	Söråmagasinet	Plittorpsgöl
Littoral I	1.7	0.9	2.2	2.7
Littoral II+III	5.0*	3.7	3.6	8.8
Profundal	7.0	11.7	2.8	8.6

* One large mussel (Anodonta anatina) is excluded from this biomass estimate. Including the mussel the biomass would be 185 g ww m^{-2}.

Table 4-23. Biomass of different functional groups of benthic fauna in Littoral I (mean values n=5) in four different lakes.

Functional groups	Frisksjön		Jämsen		Söråmagasinet		Plittorpsgöl		Average	
	g ww m^{-2}	%	g ww m^{-2}	%	g ww m^{-2}	%	g ww m^{-2}	%	g ww m^{-2}	%
Filter feeders	0.03	2	0	0	0.13	6	0.08	3	0.06	3
Detritus feeders	0.48	29	0.35	37	0.79	36	1.76	66	0.85	42
Predators	0.73	44	0.12	13	0.89	41	0.64	24	0.60	31
Scrapers	0.04	2	0.05	5	0.32	15	0.03	1	0.11	6
Shredders	0.34	20	0.33	35	0.01	<1	0.11	4	0.20	20
Other unknown	0.04	2	0.09	10	0.05	2	0.06	2	0.06	4
Sum	1.66		0.94		2.18		2.68		1.87	

Table 4-24. Biomass of different functional groups of benthic fauna in Littoral II and Littoral III (mean values n=5) in four different lakes.

Functional groups	Frisksjön		Jämsen		Söråmagasinet		Plittorpsgöl		Average	
	g ww m^{-2}	%	g ww m^{-2}	%	g ww m^{-2}	%	g ww m^{-2}	%	g ww m^{-2}	%
Filter feeders	0.30	6	0	0	0	0	0.14	2	0.11	2
Detritus feeders	1.37	1	2.56	69	0.69	19	3.68	42	2.08	39
Predators	3.64	2	1.12	30	2.87	81	5.01	57	3.16	59
Scrapers	0	0	0	0	0	0	0	0	0	0
Shredders	0	0	0	0	0	0	0	0	0	0
Other unknown	0.002	<1	0.003	<1	0	0	0.01	<1	0	<1
Sum	5.31		3.68		3.56		8.8		5.34	

Table 4-25. Biomass of different functional groups of benthic fauna in the Profundal habitat (mean values n=5) in four different lakes.

Functional groups	Frisksjön		Jämsen		Söråmagasinet		Plittorpsgöl		Average	
	g ww m^{-2}	%	g ww m^{-2}	%	g ww m^{-2}	%	g ww m^{-2}	%	g ww m^{-2}	%
Filter feeders	0	0	0	0	0	0	0	0	0	0
Detritus feeders	0.38	5	1.76	15	0.16	6	0.62	7	0.73	8
Predators	6.67	95	9.87	84	2.62	94	7.98	93	6.79	92
Scrapers	0	0	0	0	0	0	0	0	0	0
Shredders	0	0	0	0	0	0	0	0	0	0
Other unknown	0	0	0.10	1	0	0	0	0	0.03	<1
Sum	7.05		11.73		2.77		8.60		7.54	

A total of 7 species of ***fish*** were caught in a fish survey 2004 in 4 of the lakes in the Laxemar-Simpevarp area /Engdahl and Eriksson 2004/. The most species were found in Jämsen (7), followed by Frisksjön (6), Söråmagasinet (6) and Plittorpsgöl (3). The catch per unit effort (CPUE = kg fish per net) differed between the lakes. Frisksjön and Söråmagasinet showed similar CPUE whereas Jämsen and Plittorpsgöl had much lower CPUE (Table 4-26). The low CPUE in Jämsen and Plittorpsgöl could be due to the fact that several nets were placed at low depths where the oxygen levels were probably low. In all lakes, perch (*Perca fluviatilis*, sw. *abborre*) dominated in terms of number of individuals as well as CPUE. Length and weight distribution diagrams for different species in the different lakes are presented in Appendix 5.

Fish were classified into the functional groups zooplanktivore fish (Z-fish), benthivore fish (B-fish) and piscivore fish (P-fish), based on the weight of individual fish according to /Holmgren and Appelberg 2000/ (Table 4-26). All the lakes were dominated by fish feeding on benthic fauna (B-fish). The fish survey was conducted using multi-mesh gillnets according to standardized methods /Fiskeriverket 2001, Naturvårdsverket 1999a, Naturvårdsverket 2000/. The species, length and weight of all fish were determined. A conversion factor of 33 kg fish ha^{-1} $CPUE^{-1}$ (i.e. 1 kg fish in the net represents 33 kg fish ha^{-1} in the lake) was used to calculate the total fish biomass (proposed by Per Nyberg at Fiskeriverket, Örebro).

Respiration

Respiration was measured once in the Profundal habitat /Wijnbladh and Plantman 2006/. The measured values varied a lot. The average respiration during the day (c. 9 am to 16 pm) was found to be 39 mg C m^{-2} h^{-1}, and during the evening (c.16 pm–20 pm) an average value of 1 mg C m^{-2} h^{-1} was measured. The respiration was calculated from measured differences in oxygen concentrations in experimental chambers (n=5) at one location in the lake on one occasion (July 2005) /Wijnbladh and Plantman 2006/.

Table 4-26. Fish species in different lakes, categorized according to functional groups in Catch Per Unit Effort (kg ww), and total fish biomass.

Functional group	Species	Frisksjön	Jämsen	Söråmagasinet	Plittorpsgöl
Z-fish		0.044	0.037	0.003	0.009
	Perch	0.044	0.009	0.003	0.009
	Bleak	–	0.028	–	–
B-fish		0.891	0.307	1.44	0.318
	Bream	0.272	0.138	0.602	–
	Ruffe	0.008	0.010	0.018	–
	Perch	0.267	0.084	0.326	0.054
	Roach	0.312	0.068	0.480	0.264
	Rudd	0.032	0.007	0.015	–
P-fish		0.835	0.312	0.704	0.477
	Perch	0.112	0.203	0.565	0.344
	Pike	0.723	0.109	0.14	0.134
Total CPUE		1.77	0.66	2.15	0.80
Total fish biomass per hectare (kg ww ha^{-1})		58.4	21.6	70.8	26.5
Total fish biomass in lake (kg ww)		627	406	583	72

4.10.2 Biota in streams

Abundance of primary producers

Chlorophyll *a* (Chl *a*), which is a measure of the ***phytoplankton*** biomass, was measured in two different streams in the Laxemar-Simpevarp area (n=64) /Tröjbom and Söderbäck 2006a/: in the lower parts of Laxemarån and Kärrviksån. The chl *a* concentrations were low with a median for both streams of 1.8 µg chl *a* L^{-1}. This is what could be expected as the phytoplankton biomass is generally low in small streams /Wetzel 2001/. No identification of species was done but the phytoplankton composition was most probably similar to the ones found in the upstream lakes.

Streams in 8 catchments were investigated for vegetation in 2004 using the same method as in Forsmark, see section 3.10.2 /Carlsson et al. 2005a/. Altogether, 42 species of ***macrophytes*** were noted in the streams. The abundance of vegetation fluctuated throughout the streams and was linked to the amount of shade. In Mederhultsån and Ekerumsån, more than half of the investigated stretches were classified as having "intense growth", while vegetation was lacking in c. 40% of the stretches in Kåreviksån and the four streams on the island Ävrö. In Laxemarån, 58% of the investigated stretches of stream order 1 had substantial growth, whereas in stretches of stream order 2, 30% had substantial growth and 29% had intense growth. For the stretches of stream order 3, 38% lacked vegetation while 30 % had moderate growth (Table 4-27). Dominant species and coverage of the stream sections for the investigated catchments are described below:

The upstream part of Mederhultsån was dominated by *Lemna minor* (common duckweed, sw. *vanlig andmat*). This free-floating species are an indicator of relatively nutrient rich water conditions. Further downstream commonly dominating species were *Alisma plantago-aquatica* (water plain-tail, sw. *svalting*), *Juncus effusus* (soft-rush, sw. *veketåg*) and *Sparganium sp.* (bur-reed, sw. *igelknopp*). Large areas of Mederhultsån had intense growth (Figure 4-30).

In the most upstream parts of Kåreviksån *Alisma plantago-aquatica* was the dominating species, but there were also sections with substantial amounts of *Lemna minor*. *A. plantago-aquatica* was also among the dominant species in the lower part of Kåreviksån, downstream of Frisksjön, but *Potamogeton polygonifilus* (bog pondweed, sw. *bäcknate*) and *Lysimachia thyrsiflora* (tufted loosestrife, sw. *topplösa*) also dominated in some parts. Large parts of Kåreviksån were not investigated and still others lacked vegetation.

Table 4-27. Total abundance of vegetation (%) growing in each section of the investigated stream stretches in the Simpevarp area. Numbers in bold indicates the most common class of vegetation.

Stream name	Mederhultsån	Kåreviksån	Streams at Ävrö	Ekerumsån			Laxemarån			Total			
Stream order	**1**	**1**	**1**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**Total**
Vegetation lacking	5	40	42	7	4	9	4	6	38	17	6	29	21
Single plants (<5% cov.)	4	4	10	–	4	5	21	9	22	7	8	16	12
Moderate growth (5–50% cov.)	10	22	23	–	8	10	17	25	30	13	20	23	19
Substantial growth (50–75% cov.)	28	17	10	4	13	18	58	30	9	23	25	12	18
Intense growth (75–100% cov.)	53	7	15	89	72	59	–	29	2	40	41	20	30

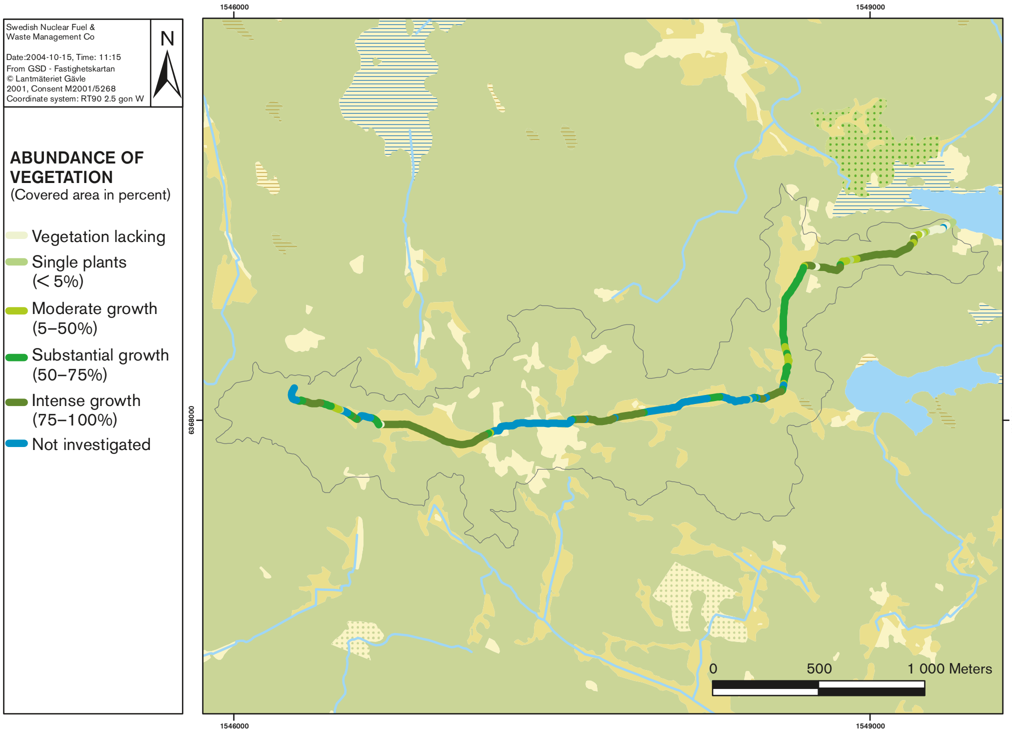


Figure 4-30. *Vegetation in Mederhultsån.*

In Ekerumsån the vegetation was substantial in most parts. Among the dominant species were *Alisma plantago-aquatica* (water plain-tail, sw. *svalting*) and *Juncus effusus* (soft-rush, sw. *veketåg*). Large parts of Ekerumsån had intense growth (Figure 4-31).

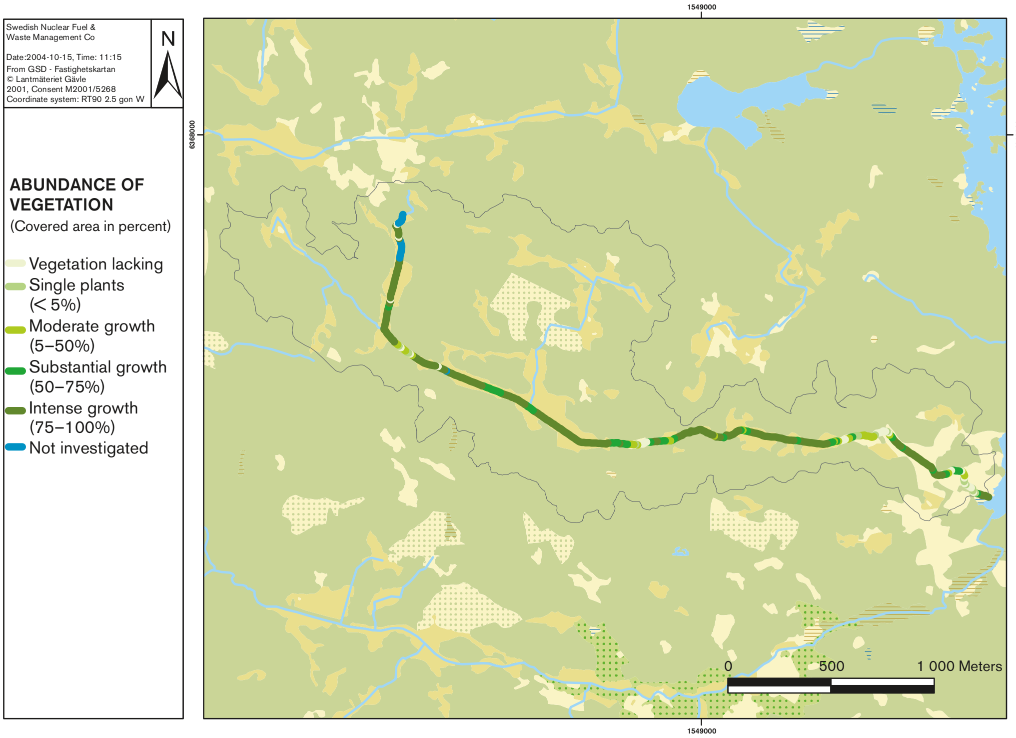


Figure 4-31. *Vegetation in Ekerumsån.*

Species that frequently dominated the investigated sections in Laxemarån along the entire stream were *Alisma plantago-aquatica* (water plain-tail, sw. *svalting*) and *Nymphaeaceae* (water lily, sw. *näckros*). In the upstream part, sections dominated by *Typha latifolia* (bulrush, sw. *bredkaveldun*) were often found, while dominance of *Phragmites australis* (common reed, sw. *vass*) was commonly found in the most downstream part. The upstream part of Laxemarån had longer sections with intense growth than the lower stream stretches, where there were also sections lacking vegetation (Figure 4-32a and b).

In the four tiny streams on the island of Ävrö, most parts were dry and therefore no aquatic vegetation was found. The few sections containing vegetation contained *Equisetum fluviatile* (water horsetail, sw. *sjöfräken*) and *Lysimachia thyrsiflora* (tufted loosestrife, sw. *topplösa*) (in Vadeviksbäcken), *Typha latifolia* and *Fontinalis antipyretica* (common water moss, sw. *stor näckmossa*) (in Gloebäcken) and *Typha latifolia* and *Sparganium sp.* (bur-reed, sw. *igelknopp*) (in Skölkebäcken). Vegetation was lacking in large parts of the streams at Ävrö.

Biomass of consumers

Benthic fauna was sampled at three stream locations: downstream of the outlet from Frisksjön and at two different locations in Laxemarån /Ericsson and Engdahl 2004/. The site downstream of Frisksjön had a much larger biomass than the other two sites in Laxemarån as well as much larger proportion of filter feeders (Table 4-28). The difference is probably due to the proximity to Frisksjön and to the influx of plankton from the lake. Dominance of filter feeders, higher abundance and higher biomass are normal traits of stream sites close to lake outlets. The total number of taxa found differed between the sites with the highest number at the downstream site in Laxemarån. The benthic fauna was sampled with a hand net (opening 0.25×0.25 m, mesh size 0.5×0.5 mm). An area of 0.25 m^2 was disturbed by the foot and the net was slowly swept over the area to collect the animals.

Signal crayfish (*Pacifastacus leniusculus*) have been observed at a site in Laxemarån (Åby, LSM0000570). The observation was made during electrofishing /Andersson 2006/. Moreover, one specimen of the native noble crayfish (*Astacus astacus*) was observed in Kåreviksån, just downstream of the outlet of Frisksjön in 2006 (Erik Wijnbladh, pers obs).

The biomasses of ***bacteria and zooplankton*** were not investigated in the streams in the Laxemar-Simpevarp area. The bacterial biomass in streams can be high, especially in small streams that receive high inputs of allochthonous carbon sources /Wetzel 2001/. The zooplankton biomass in streams tends to be lower than in lakes /Wetzel 2001/. The zooplankton biomass also tends to be positively correlated to the phytoplankton chl *a* biomass. Thus, the low chl *a* concentrations in the two streams investigated in the area indicate that the zooplankton biomass was also low.

Table 4-28. Biomass of different functional groups of benthic fauna in streams in the Laxemar-Simpevarp area.

Functional group	Downstream Frisksjön		Laxemarån, upstream		Laxemarån, downstream		Average	
	g ww m^{-2}	%	g ww m^{-2}	%	g ww m^{-2}	%	g ww m^{-2}	%
Filter feeders	4.072	55.2	0.392	13.6	0.265	10.3	1.576	26.4
Detritus feeders	1.759	23.9	0.546	18.9	1.186	46.1	1.164	29.6
Predators	0.353	4.8	0.700	24.2	0.506	19.7	0.520	16.2
Scrapers	0.077	1.0	0.002	0.1	0.056	2.2	0.045	1.1
Shredders	0.913	12.4	1.222	42.3	0.476	18.5	0.870	24.4
Other unknown	0.195	2.7	0.027	0.9	0.086	3.3	0.103	2.3
Sum	7.370	100	2.888	100	2.575	100	4.278	100

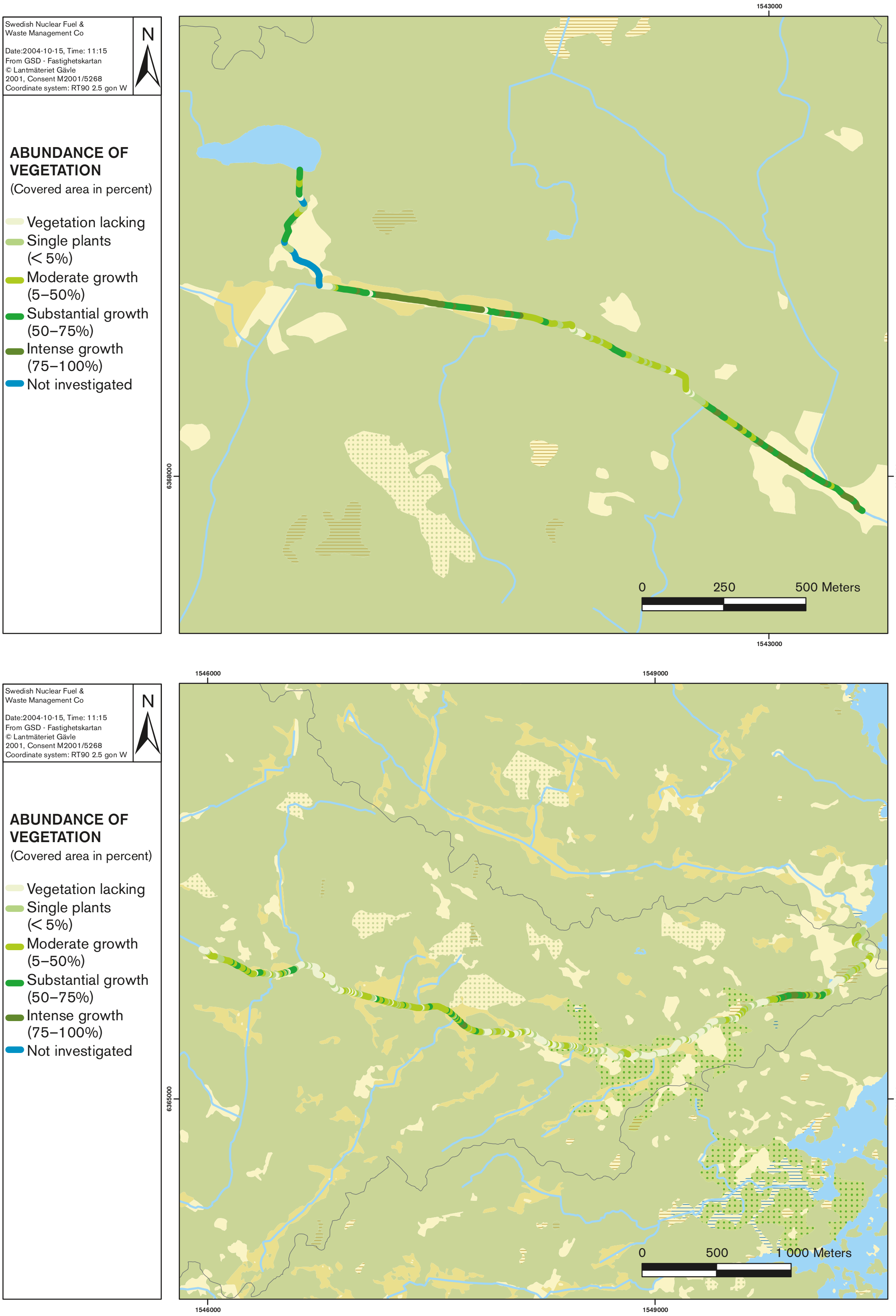


***Figure 4-32.** Vegetation in the upstream parts of Laxemarån (upper) and vegetation in the downstream sections of Laxemarån (lower).*

The occurrence of ***fish*** was investigated in two of the streams: Laxemarån and Ekerumsån, in May and August 2006 /Andersson 2006/. In this survey the only stretch that had properties required for salmonid spawning – fast-flowing water, a varied bottom structure and a relative stable water level – was in Laxemarån at the site LSM000569, Ekhyddan. However no trout (the most probable salmonid to find) were observed. Instead the survey indicated that Laxemarån may be an important spawning area for both ide and roach. Both species were observed spawning at the site LSM000569. The fact that no juvenile individuals of these species were observed in August indicated that the fry migrated to the Baltic Sea soon after hatching. Altogether five fish species were observed in Laxemarån (ide *Leuciscus idus*, roach *Rutilus rutilus*, burbot *Lota lota*, pike *Esox lucius* and ruffe *Gymnocephalus cernua*). The lower part of Ekerumsbäcken was of some importance as a feeding area for small pike. Later in the season, plant growth and low water levels made this stream an unsuitable habitat for fish. Altogether, two species were observed in Ekerumsbäcken (pike and tench *Tinca tinca*). The study was performed using electrofishing on four occasions in the spring (April and May) and on one occasion in the late summer (August).

Primary production

No estimations of primary production have been performed in the Simpevarp streams.

4.10.3 Edible biota in lakes and streams

It is of importance for the safety assessment to estimate the production of edible biota. Today, the use of biota in lakes is assumed to be negligible as fishing is assumed to take place predominantly in the coastal marine areas. Nevertheless, the production of food that can be sustainably produced by the limnic ecosystem has been estimated to provide input data for the models of the safety assessment since the future usage of the lakes as food source may be higher than today.

Food production was categorized as food normally consumed and edible products /SKB 2006a/. Food normally consumed for a lake includes fish, while edible products are everything that has some potential to be consumed by humans. Edible products could be worms, larvae, molluscs as well as fish etc above a certain practical size. In SR-Can this size was set at 1 mm (i.e. macrofauna).

Production was estimated for species or taxa of fish and crayfish. Production for most species was estimated by means of production per biomass ratios (P/B) from the literature. Some estimates (for e.g. fish) were based on calculations of the mass balance from metabolic demands and consumption using literature values /Kautsky 1995, Lindborg 2005/. Production was estimated as the weight of organic carbon (g C m^{-2} $year^{-1}$). This partly compensates for the energetic quality of food by that structural components such as bones, shells etc which normally are not eaten also contain a low fraction of organic carbon.

The P/B ratios are dependent on fish size (weight and length), and an allometric relationship has been established from studies of 79 freshwater species in Canada /Randall and Minns 2000/ Several of the fish species are similar to the Scandinavian species, and as this paper and other papers show, the P/B ratio is well correlated to size for most animals /Banse and Mosher 1980, Downing and Plante 1993, Randall and Minns 2000/.

The maximum lengths of the fish species caught in the surveying gillnets were taken from the site study at Laxemar-Simpevarp /Engdahl and Eriksson 2004/. These ranges were compared with the data from /Randall and Minns 2000/ and for each species a mean P/B was estimated for this range (Table 4-29). This P/B ratio was multiplied by the estimated biomass per m^2 to obtain the area specific fish production for each tabulated species in each of the studied lakes: Frisksjön, Jämsen, Söråmagasinet and Plittorpsgöl. The total sum of fish production for each lake was used to obtain an average fish production estimate for the area, which is 0.3 g C m^{-2} $year^{-1}$.

Table 4-29. Biomass, B (g C m^{-2} year^{-1}), and production, P (g C m^{-2} year^{-1}), of different fish species in Forsmark area, based on average P/B ratios (1/y) of size range from /Randall and Minns 2000/. Biomass and size estimates from /Lindborg 2005/ and /Borgiel 2004b/, respectively.

Species	Size (mm)	P/B	Frisksjön		Jämsen		Sörå-magasinet		Plittorpsgöl		Mean
			B	P	B	P	B	P	B	P	P
Perch *Perca fluvialtilis*	300–400	0.5	0.30	0.15	0.09	0.04	0.26	0.13	0.12	0.06	0.098
Bleak *Alburnus alburnus*	100–200	1.5	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.003
Bream *Abramis brama*	200–400	0.9	0.08	0.07	0.04	0.03	0.17	0.15	0.00	0.00	0.063
Ruffe *Gymnocephalus cernua*	100–200	1.5	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.004
Roach *Rutilus rutilus*	200–300	1.0	0.09	0.09	0.02	0.02	0.14	0.14	0.08	0.08	0.080
Rudd *Scardinius erythrophthalmus*	50–150	1.6	0.01	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.006
Pike *Esox lucius*	700–1,300	0.2	0.03	0.01	0.03	0.01	0.04	0.01	0.04	0.01	0.008
Total			0.51	0.34	0.19	0.12	0.62	0.44	0.23	0.14	0.26

Although crayfish has been noted in the area today (see section 4.10.2), there are probably no large colonies of crayfish in the lakes. The lakes could contain larger amounts of crayfish in the future. A generic yield of a good crayfish lake is about 50 kg ha^{-1} /Fiskeriverket 2003/, which corresponds to a production of 0.4 g C m^{-2} y^{-1}. Thus, a maximum total food production from a lake is less than 0.7 g C m^{-2} y^{-1}.

If the range is extended to other theoretical food items, molluscs and insect larvae could be eaten. There is no evidence that insect larvae from aquatic habitats are eaten on a regular basis, while molluscs are at least utilized in marine environments. Freshwater mussels of the family Unionidae (e.g. *Anodonta anatina*, duck mussel, sw. *allmän dammmussla*) are found in Frisksjön, although there are no biomass estimates. Comparing with production in the River Thames, a theoretical upper estimate of production is 132 kg FW ha^{-1} y^{-1} /Negus 1966/. The abundance of mussels in the Thames is about 100 times higher compared with semiquantitative estimates from Lake Mälaren in Sweden /Lundberg and Proschwitz 2007/. Thus, probably a very high estimate of the production of large molluscs is 0.3 g C m^{-2} year^{-1}. There are no records of humans eating unionids on a regular basis, and general discussion of the edibility of unionids seems to rate them as distasteful /Bourquin 2008 www/.

Thus the maximum production of food from lakes similar to future lakes in the Laxemar-Simpevarp area is composed of fish and crayfish and is less than 0.7 g C m^{-2} year^{-1}.

4.10.4 Chemical characteristics of biota

The chemical composition of biota in Frisksjön was investigated in the autumn 2004 /Engdahl et al. 2006/. In total 21 samples from limnic environments were analyzed (Table 4-30). In addition to the content of the macronutrients carbon, nitrogen and phosphorus, the concentrations of 61 other elements were determined in the samples. No chemical data were available for biota in the Laxemar-Simpevarp streams.

Table 4-30. Description of biota samples analyzed for chemical composition /Engdahl et al. 2006/. When several replicates of the same sample were analyzed, this is indicated by (repl). Muscle samples were used for fish and benthic fauna. All sampled were stored in the frozen state before analysis.

	Sampling site/ID code	Number and description of samples	Individual/ sample
Fish	Frisksjön		
	ASM000192	Roach (benthivorous), 3 repl	4–5
	ASM000192	Perch (piscivorous), 3 repl	2
Aquatic vegetation	Frisksjön		
	ASM000110	Reed (standing crop and rhizome, respectively), 2 repl	At least 5
	ASM000110	Water lily (leaf and root, respectively), 2 repl	At least 3
	ASM000111	Reed (standing crop and rhizome, respectively), 2 repl	At least 5
	ASM000111	Water lily (leaf and root, respectively), 2 repl	At least 3
	ASM000112	Reed (standing crop and rhizome, respectively), 2 repl	At least 5
	ASM000112	Water lily (leaf and root, respectively), 2 repl	At least 3
Benthic fauna (mussel)	Frisksjön		
	ASM000110	Duck mussel	5
	ASM000111	Duck mussel	5
	ASM000112	Duck mussel	5

Data on four different functional groups were analyzed: macrophytes, benthic fauna, benthivorous fish and piscivorous fish. Two macrophyte species were represented: reed and water lily, which are present in different parts of the lake (Littoral I and III, respectively). Both the above-ground and below-ground parts of macrophytes were analyzed. The concentrations of carbon, nitrogen, phosphorus, iodine and uranium in different functional groups are presented in Table 4-31. The compiled data for all analyzed elements are presented in Appendix 10, while primary data are provided in /Engdahl et al. 2006/. For many of the trace elements (and sometimes also for other elements), the results of the analyses are below the detection limit. In these cases, a value equal to half of the detection limit was used in the calculation of mean concentrations.

The carbon content was quite constant between different functional groups and deviated only by a factor of 1.2. Comparing above-ground parts of macrophytes with roots reveals different patterns for water lily and reed: for the former the concentrations are somewhat higher in above-ground parts, while the opposite is true for reed.

The concentrations were more uneven for nitrogen. The highest concentrations of this element are found in fish and the lowest in macrophytes. For both macrophyte types, the nitrogen concentrations are lower in the roots than in the above-ground parts. The differences in concentrations between functional groups are even more pronounced for phosphorus. The highest concentrations were found in benthic fauna followed by fish, and the lowest values were found in macrophytes. The phosphorus concentrations are significantly lower in reed than in water lily. In water lily higher concentrations are found in the roots than in the above-ground parts, while the opposite is true for reed.

Two elements that are not main constituents of biota are also shown in Table 4-31, i.e. iodine and uranium. In the case of iodine, the highest concentrations were found in water lily followed by benthic fauna while the lowest concentrations were recorded in piscivorous fish. The levels in benthivorous fish were somewhere in between, in the same order as the concentrations in reed. In both macrophyte species, the iodine concentrations were higher in the roots than in the above-ground parts. The same pattern is seen for uranium. The concentrations in fish were very much lower than in the other sample types. The values for two of the piscivorous fish samples were below the detection limit. A difference of about one order of magnitude is seen for benthivorous and piscivorous fish as well as for water lily and reed. As uranium is toxic to biota, there may be an active avoidance of this element in higher biota such as fish, either through blocking of uptake and/or through effective excretion of this element.

Table 4-31. Concentrations of a number of selected elements in biological samples from Frisksjön /Engdahl et al. 2006/.

Element	Sample type	Count	Mean	Median	Min.	Max.	Sdev
Total carbon (g/kg dw)	Macrophyte, (Water lily) above	3	413	411	408	420	6.57
	Macrophyte, (Water lily) root	3	373	366	365	388	12.9
	Macrophyte, (reed) above	3	411	404	399	432	17.6
	Macrophyte, (reed) root	3	427	430	408	443	17.5
	Total producers	*12*	*406*	*408*	*365*	*443*	*24.2*
	benthic fauna	3	380	380	380	380	0
	benthivorous fish	3	426	426	421	430	4.75
	piscivorous fish	3	422	423	415	429	6.67
	Total consumers	*9*	*409*	*421*	*380*	*430*	*22.4*
Total nitrogen (g/kg dw)	Macrophyte, (Water lily) above	3	20.5	20.0	19.3	22.0	1.40
	Macrophyte, (Water lily) root	3	12.0	12.2	9.05	14.7	2.83
	Macrophyte, (reed) above	3	14,5	11.8	11.3	20.3	5.08
	Macrophyte, (reed) root	3	3.59	3.82	3.09	3.86	0.433
	Total producers	*12*	*12.6*	*12.0*	*3.09*	*22.0*	*6.82*
	benthic fauna	3	80.8	79.5	77.8	85.2	3.90
	benthivorous fish	3	139	139	137	142	2.77
	piscivorous fish	3	128	141	101	142	23.5
	Total consumers	*9*	*116*	*137*	*77.8*	*142*	*29.4*
Total P (g/kg dw)	Macrophyte, (Water lily) above	3	2.86	2.56	2.18	3.84	0.870
	Macrophyte, (Water lily) root	3	3.27	3.87	2.04	3.91	1.07
	Macrophyte, (reed) above	3	1.17	0.744	0.566	2.20	0.896
	Macrophyte, (reed) root	3	0.383	0.382	0.265	0.502	0.119
	Total producers	*12*	*1.92*	*2.11*	*0.265*	*3.91*	*1.43*
	benthic fauna	3	28.3	29.6	23.2	32.0	4.55
	benthivorous fish	3	13.3	13.3	13.1	13.4	0.153
	piscivorous fish	3	11.8	12.1	11.3	12.1	0.462
	Total consumers	*9*	*17.8*	*13.3*	*11.3*	*32.0*	*8.21*
Iodine (mg/kg dw)	Macrophyte, (Water lily) above	3	10.2	10.3	6.69	13.6	3.46
	Macrophyte, (Water lily) root	3	19.0	13.3	11.4	32.2	11.5
	Macrophyte, (reed) above	3	2.68	2.63	1.53	3.89	1.18
	Macrophyte, (reed) root	3	3.69	3.84	1.08	6.15	2.54
	Total producers	*12*	*8.88*	*6.42*	*1.08*	*32.2*	*8.58*
	benthic fauna	3	7.21	7.16	6.43	8.03	0.801
	benthivorous fish	3	1.40	1.34	1.23	1.63	0.21
	piscivorous fish	3	3.55	3.35	2.91	4.38	0.75
	Total consumers	*9*	*4.05*	*3.35*	*1.23*	*8.03*	*2.60*
Uranium (mg/kg dw)	Macrophyte, (Water lily) above	3	0.180	0.169	0.100	0.271	0.086
	Macrophyte, (Water lily) root	3	1.78	1.49	1.32	2.53	0.655
	Macrophyte, (reed) above	3	0.014	0.012	0.009	0.023	0.007
	Macrophyte, (reed) root	3	0.476	0.409	0.137	0.882	0.377
	Total producers	*12*	*0.613*	*0.220*	*0.009*	*2.53*	*0.794*
	benthic fauna	3	0.926	0.905	0.793	1.08	0.145
	benthivorous fish	3	0.002	0.002	0.002	0.003	0.001
	piscivorous fish	3	0.0001[1]	0.0001[1]	0.0001[1]	0.0002[1]	0.0001[1]
	Total consumers	*9*	*0.309*	*0.002*	*0.0001*	*1.08*	*0.468*

[1] 2 of 3 values below detection limit varying between 0.0001–0.0002 mg/kg dw.

A comparison between data from Laxemar-Simpevarp and Forsmark reveals that, as expected, the concentration of carbon, nitrogen and phosphorus did not differ for the same kind of functional groups between the two sites. Different kinds of primary producers were analyzed: in Forsmark macroalgae were investigated and in Laxemar-Simpevarp macrophytes, and some differences could be seen between these two groups. The carbon concentration was slightly higher in macrophytes than in macroalgae, and the same pattern was seen for the nitrogen and phosphorus concentrations. The microalgae in Forsmark had a carbon content on the same order of magnitude as the macrophytes in Laxemar-Simpevarp, while the nitrogen concentrations were much higher. The phosphorus content of microalgae was higher than that of reed but lower than the concentrations found in water lily.

The concentrations of iodine differed between the two sites. In fish, the concentrations in Laxemar-Simpevarp were about 10 times higher than those recorded in Forsmark. The concentrations were also somewhat higher in benthic fauna. The iodine concentrations in macro- and microalgae (Forsmark) were higher than in reed but lower than the concentrations recorded in water lily (Laxemar-Simpevarp). As regards uranium, the concentrations in fish were about the same in the two areas. In benthic fauna, somewhat higher concentrations were recorded in Laxemar-Simpevarp, while the macroalgae (Forsmark) had a higher uranium content than the macrophytes (Laxemar-Simpevarp).

4.11 Land use and human impact

Human settlement can affect limnic systems via e.g. water use and pollution. In the Laxemar-Simpevarp area, examples of important human impact on the limnic systems are the excavation and ditching of streams, which affects most streams in the area, and the construction of a new lake by damming of a sea bay. Moreover, water levels have been lowered in some of the lakes, and the names of some wetlands and minor fields in the area indicate that a number of former lakes have disappeared during the last centuries due to human activities, probably with the aim of gaining farmland.

4.11.1 Human impact on lakes

Some major impacts on the limnic ecosystems in Laxemar-Simpevarp are the creation of the Söråmagasinet reservoir and the pumping of water between lakes and streams in the area (Figure 4-33). Söråmagasinet was originally a coastal bay, which was transformed into a lake in the seventies to ensure freshwater supplies for the nuclear power plant /Werner et al. 2008/. Occasionally, on the order of a few days each year or every second year, water is pumped from Ström in Laxemarån into Söråmagasinet in order to maintain the available water storage in the lake. Since 1983, drinking and process water for the nuclear power plant has been pumped from Lake Götemar (situated north of the Laxemar subarea) in a pipeline to a water works operated by OKG. At present, approximately 150,000–200,000 m^3 of water is pumped each year. Historically (up to 1987), water was pumped from Lake Trästen (situated west of the Laxemar subarea, upstream of Lake Fårbosjön) into Lake Jämsen, which discharges to the north into the Laxemarån in order to compensate for the pumping from Laxemarån. Past and present pumping activities in the Laxemar-Simpevarp area are further described in /Werner et al. 2008/.

Many of the lakes in the area have been subjected to lowering of the water level in order to gain farmland. For example, Frisksjön has been artificially lowered over the past few centuries, and the lowering may be 1 m or even more. Table 4-32 summarizes identified drainage operation /Werner et al. 2008/.

Figure 4-33. *Pumping station in the Söråmagasinet reservoir pumping freshwater into the reservoir from Laxemarån.*

An attempt has been made to restore one of the lakes that disappeared due to previous drainage operations, Lake Gästern. The water level of Gästern was lowered in several stages during the 19th and early 20th centuries. The last lake-lowering operation was carried out in 1920. A project has recently (mid-2008) been finalized to raise the lake-water level up to the pre-1920 level. The new outlet is located in the north-eastern part of the wetland. Prior to the lake restoration, the low- and high water levels were 3 and 4.5 m.a.s.l., respectively, and the lake threshold was 2.4 m a. s. l. Subsequent to the restoration, the low- and high water levels are 2.5 and 5 m.a.s.l., with a spillway level of 4.2 m.a.s.l. /Werner et al. 2008/.

The coastal area in the Laxemar-Simpevarp area is extensively used for recreational purposes such as fishing and bathing. There is probably less recreational use of the limnic environment. Someone may use Frisksjön for skating and Laxemarån for fishing, but to a very small extent. Bathing places are available in Götemaren and Fårbosjön (Kristina Dahlström, SKB, pers. com.). In section 4.10.3 the amount of biota in lakes that can theoretically be used as food is described. This figure is certainly larger than actual food outtake from the lakes today. Theoretically lake organisms could also be harvested as food supply to cultivated animals but this does not occur today and is an unlikely scenario also for the future.

Table 4-32. Identified drainage operations in the Laxemar-Simpevarp area, from /Werner et al. 2008/.

Drainage operation	Area concerned	Year
Simpevarp drainage operation	Simpevarp peninsula	1955
Gässhult	The stream Kärrviksån, immediately upstream of the stream outlet to the Baltic Sea	1955
Lake Gäster	Lowering of Lake Gäster in Gässhult, also involving Kärrviksån	1918
Lake Götemar	Lowering of Lake Götemar	1933
Jämserum drainage operation	Lowering of Lake Jämsen and associated drainage operations	1937
	An area east of Lake Jämsen and downstream to stream Släthultebäcken. The drain depth was somewhat larger than in the other operations (c. 1.50–1.70 m)	1937
Köksmåla drainage operation	Part of the stream between the lakes Jämsen and Trästen, and an elongation south of the Jämserum drainage operation	1943
Lilla Laxemar and Mederhult drainage operations	Parts of the stream Ekerumsån	1933 and 1935
Mederhult drainage operation	The westernmost parts of the stream Mederhultsån	1949
Plittorp-Stora Basthult drainage operation	Part of Laxemarån	1944
Plittorp drainage operation	An area that drains into the stream Laxemarån	1939
Släthult drainage operation	The stream Släthultebäcken	1927
Stora Laxemar drainage operation	An area that drains into the stream Laxemarån	1922
Ström-Åby drainage operation	The stream Laxemarån, from Kvarnstugan in the west to Ström in the east	1933

4.11.2 Human impact on streams

Most of the stream stretches in the Laxemar-Simpevarp area are affected by human activities in that they have been extensively excavated (Table 4-33). Kåreviksån is somewhat less affected than the others. Man-made technical encroachments in the stream such as installation of pipes (of the necessary diameter, length and height for water to descend to the substrate), construction of dams and filling of channels are described in detail in Appendix 5 in /Carlsson et al. 2005a/.

The largest impact of human activities on the stream today is probably the pumping of water between Laxemarån and the Söråmagasinet reservoir (further discussed in section 4.12.1 and in /Werner et al. 2008/).

Table 4-33. Technical encroachments in the investigated stream stretches in the Simpevarp area (%). From /Carlsson et al. 2005a/.

Stream name	Meder-hultsån	Kåreviks-ån	Streams at Ävrö	Ekerumsån			Laxemarån			Total			
Stream order	**1**	**1**	**1**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**Total**
Natural, no excavation	6	11	4			5				6	0	0	3
Moderate excavation	–	14	4	100	100	95	100	100	100	4	0	2	3
Substantial excavation	94	76	93							90	100	98	94

4.12 Lakes in the region

In order to put the lakes in the Laxemar-Simpevarp area in a broader context, the lakes in the region of Kalmar County are described. Regional lake size, catchment areas and catchment composition have been compared with data from 3,044 lakes included in the national survey of lakes in 2002 /cf. Wilander et al. 2003/. Water chemistry in the lakes in the Laxemar-Simpevarp area was compared with regional and national lakes in section 4.8 and will only briefly be discussed in the section below.

The median lake size in the Kalmar County is 1.2 km^2, which is close to the median size for Swedish lakes (2.1 km^2). The lakes in the region vary in size between 0.05 and 16 km^2. The investigated lakes in the Laxemar-Simpevarp area are small (mean lake size 0.1 km^2, median 0.1 km^2) and among the smallest 10% of lakes in Sweden.

The median catchment in the region is of the same size as the typical catchment in the national database (medians 116 and 114 km^2, respectively) (Table 4-34). The catchments in the Laxemar-Simpevarp area on contrary are very small (mean size 2.1 km, median 0.7 km^2). The catchments in the region are clearly dominated by forest (mean 81% coverage of total). On average, 10% of the catchment areas consist of open land and 8% of water. The catchments in the Laxemar-Simpevarp area are also dominated by forest (88%), but open land has a smaller impact on these lakes (mean 3% of total catchment areas). The mean Swedish catchment is also dominated by forest but to a much smaller degree (68%). The mean Swedish catchment contains more wetlands than the Kalmar regional catchments. Moreover, nearly 8% of the national mean catchment consists of bare mountain and glacier, land types not present in this region.

Table 4-34. Characteristics of the catchments in Sweden, in the Kalmar County and in the Laxemar-Simpevarp area.

	Size (km^2)	Land use				
		Forest (%)	Open land (%)	Wetland (%)	Water (%)	Built-up area (%)
Lakes in Sweden (N=3044)						
Average	926	68	5	7	9	1
Median	114	74	1	4	8	0
Min	0.1	0	0	0	0	0
Max	46,881	100	79	58	43	50
Number of observations	3,044	3,044	3,044	3,044	3,044	3,044
Lakes in Kalmar County (N=122)						
Average	253	81	10	1	8	1
Median	116	82	10	0	7	0
Min	4	41	0	0	1	0
Max	1,359	98	37	6	20	13
Number of observations	122	122	122	122	122	122
Lakes in the Laxemar-Simpevarp area (N=5)						
Average	2.1	88	3	0	9	0
Median	0.7	91	0	0	7	0
Min	0.3	74	0	0	3	0
Max	7	95	7	0	20	0
Number of observations	5	5	5	5	5	5

The dominance of forest in the catchments influences the water chemistry in the lakes, and many of the lakes in the region can be described as brown-water lakes influenced by humic substances. The influence of humic substances is reflected in such aspects of the water chemistry as high water colour, high concentrations of TOC and high iron concentrations. The lakes in the region have high iron concentrations and somewhat higher water colour than the average Swedish lake. The concentrations of TOC are high, and the lakes in the region belong to the 25% of lakes with the highest TOC concentrations in Sweden.

4.13 Confidence and uncertainties in site data

The amount of data from the limnic ecosystems in the Laxemar-Simpevarp area is quite large. It is quite uncommon to have such a large dataset from the same site, and this ensures good confidence in the characterization of the lake and stream ecosystems in Laxemar-Simpevarp today. A detailed description of confidence and uncertainties follows below.

Catchment characteristics

The size and land use of the catchments have been investigated mainly with GIS and aerial photos. The delimitation of some of the subareas has been validated by field investigations in the area. In our opinion the updated catchment delimitation is of good quality and acceptable for area descriptions and further use in e.g. mass balances. The delimitation of land use and soil characteristics within the catchments is more uncertain, since that data has not been validated.

Hydrological measurements

Hydrological measurements have been performed in several ways. The water flow in streams has been measured since March 2003, whereas data on lake water level are available from June 2004. As the site investigations have been performed during a relatively short time period, the time series are not of impressive length but the spatial density is quite good.

The extent of periodically flooded areas adjacent to streams has been investigated in four of the catchments in Laxemar-Simpevarp. The length and flooded area were measured but the sizes were not estimated. These measurements were performed in the course of one year and different weather conditions between years may lead to different sizes of the flooded areas. However, the investigation gives an indication of the distribution and occurrence of flooded areas.

Climate parameters

Climate parameters have been measured locally since May 2003. Measurements have been performed at two stations within the area which show very similar data. Climate data also agree well with long-term measurements by SMHI, indicating that the data are valid for a longer time period as well.

Lake bathymetry

The lake bathymetry has been measured with good precision. The shorelines were digitized from ortophotos and, if necessary, checked in the field, and the water depths were measured by means of echo sounding. The distance between the measuring points differs /Brydsten et al. 2004/. However, this must be considered as acceptable spatial precision.

Physical characters of the streams

The physical characters of the streams in the Laxemar-Simpevarp area have been investigated in the field in stretches of 10 m each and this must be considered as very good spatial precision.

Bottom substrate, water velocity, bottom vegetation, shading from terrestrial vegetation and technical encroachments were investigated, so that a large amount data are available to describe the stream character. The entire investigation was performed by the same person so differences within the data as a consequence of different judgments of the somewhat subjective parameters can be excluded. However, this also means that the correctness of the investigation results cannot be validated since no stretches have been investigated independently by two persons.

Sediment

The amount of sediment data for Frisksjön in the Laxemar-Simpevarp area is substantial, including stratigraphical data, water content and concentrations of carbon and other elements as well as long-term sediment accumulation rate. In addition to Frisksjön, stratigraphical data are available for another three lakes. However, there is uncertainty associated the stratigraphical data as bedrock was only reached in one of the four investigated lakes. Thus, the depth of the sediment is somewhat uncertain, although one investigation in Frisksjön has shown depth down to 10 m. Except for the description of bottom substrate, no sediment data are available from streams in the area and this gives rise to some uncertainties. However, in general the sediment data provide a reliable estimate of the sediments and sediment characteristics in the Laxemar-Simpevarp area.

Lake habitats

The lake habitats have been delimited in the field using D-GPS equipment and must be considered to be of good quality. The problem with the habitat delimitation is rather the delimitation between limnic and terrestrial ecosystems. The shoreline used in the lake investigation is the highest water level, which has the consequence that wetlands in direct contact with the lake are also included in the lake, as discussed earlier (see section 2.3.1). As the water level is not constant, the impact of these wetland areas on the rest of the lake varies over time and we have no information about the exchange of substances between the wetlands and the lakes. There can be expected to be a flow of substances from the wetland to the lake. In this report, all wetlands bordering on the lakes have been considered to be terrestrial areas (wetlands). The inflow of carbon from these areas is addressed in the chapter dealing with carbon mass balance calculations (Chapter 5).

Chemistry data

The amount of water chemistry data from limnic environments in the Laxemar-Simpevarp area is unusually large in distribution, in space as well as in time, even though the data set is certainly not unique. The amount of data differs between different parameters, i.e. isotopes of certain elements have been measured only once every four month, compared with most other elements, which have been measured every month.

The sampling and measurements have been performed by qualified personal and the analyses have been performed by accredited laboratories when possible which should guarantee high data quality.

Chemistry data for sediments are less extensive. However, analyses of carbon, nitrogen and sulphur content in Frisksjön from different studies provide similar results, providing good confidence in the data on the chemical composition of the sediments.

Chemical characteristics of limnic biota in the Laxemar-Simpevarp area have been investigated once. The number of species is restricted (fish, mussel, macrophytes) and the number of replicates differs and hence, the reliability of the data differs between functional groups. Overall, the chemical distribution between biota can be viewed as reliable with regard to orders of magnitude of elements in different functional groups, although absolute figures may be more uncertain.

Biota in lakes

The data set from biota in Laxemar-Simpevarp is large. Data are not as extensive as for the Forsmark lakes, but biomass data on almost all functional groups are available. Data on biomass of functional groups in the Laxemar-Simpevarp area are within values reported from literature, which is an indication of accuracy in the dataset.

For biota one weak point is that most of the information is on biomass and little effort has been spent on the quantification of biological processes. Respiration has been measured on one occasion in the benthic habitat in Frisksjön and macrophyte production has been estimated, but other than that, data on primary production, respiration and consumption from the area are lacking. However, an unrealistic effort is required to measure the respiration and consumption of biota in Laxemar-Simpevarp area, and it is unclear whether site-specific studies would provide a greater understanding of the sites than the literature data on respiration and consumption for functional groups we have used in this report.

In Frisksjön, the phytoplankton biomass has been measured 8 times in the course of one year, and the result can be considered to be a good estimate of the annual mean. The biomasses of bacterioplankton, benthic bacteria, zooplankton, benthic fauna and macrophytes have been measured with lower frequencies (2, 1, 3, 1, 1 measurements each, respectively) and annual means are more uncertain. However, as biomasses of all functional groups have been measured in the lake, the magnitudes of the annual means should be correct. The results of one of the samples from the zooplankton study in Frisksjön were considered to be unrepresentative of the entire summer, so that zooplankton biomass data estimated in a nearby humic lake were used together with some of the site-specific results. In the benthic fauna estimate, small meiofauna is not included and it is therefore likely that the biomass of benthic fauna is somewhat underestimated. Benthic fauna has been measured in another three lakes in the area in addition to Frisksjön, which gives an estimate of the variation between the lakes.

The fish biomass has been investigated in Frisksjön, Jämsen, Söråmagasinet and Plittorpsgöl. The fish biomass was only investigated once in each lake, which gives no information about between-year variations. The most important uncertainty associated with this data is the conversion factor used to estimate the fish biomass from the CPUE (catch per unit effort) obtained from the standardized gillnet fishing. The conversion factor we use was recommended by a Swedish fish expert, but no conversion factors have been published in the scientific literature. The classification of fish species into different functional groups according to their size may also be somewhat uncertain. The conversion from zooplanktivore to piscivore may not be total and may differ between lakes depending on food resources and competition.

Since respiration was only measured on one occasion, this estimate is too uncertain to use for longer time periods. However, it can be used as an estimate of the magnitude of summer respiration and agrees well with modelled summer respiration in Chapter 5.

Biota in streams

The information on biota in the Laxemar-Simpevarp streams consists of data on vegetation, benthic fauna and fish. No measurements of primary production or respiration have been performed. This may be seen as a weak point, but as the streams are mainly small and long stretches are dry during part of the vegetation period this should not be an important information gap.

Vegetation in streams has been investigated in 10 m sections (in total c. 20 km stream length). The spatial distribution of data must therefore be regarded as very good, although parts of the streams were not investigated. The investigation was performed by one person, so differences within the data as a consequence of different judgements of the somewhat subjective parameters can be excluded. This also means that results cannot be validated since no stretches have been investigated independently by two persons.

Benthic fauna was measured at three localities at one occasion. Thus, the investigation provides estimates of variation in space but not in time. Fish were investigated by electrofishing on 5 occasions, providing reliable results on annual variation.

Land use and human impacts

Land use and human impacts on limnic environments have been recorded during the two characterization studies of lakes and streams in the Laxemar-Simpevarp area. In the lake characterization, no extra effort was made to find such information and only conditions known to the authors were recorded. Some human impact may therefore have been overlooked, but considering the relative young age of the area this may be less likely. The presence of barriers to migratory fish and human impacts in streams are well documented for the stretches that have been investigated. Information for other stretches is lacking.

Conclusions

In general, an impressive amount of data has been gathered from the area. The data quality is most often judged as high whereas the spatial and/or temporal density in the available data varies.

5 The lake ecosystem – conceptual and quantitative carbon models

From an ecosystem perspective lakes can be described in several ways. One common way to describe lakes in a general way is with the mass balance concept. In a mass balance, the major flows to and from the lake are described, but no information is given about the dynamics within the system, e.g. the flows between organisms. Instead, the results of in-lake processes are described as net fluxes out of or into the system. The mass balance approach is very useful for describing the role of lake ecosystems in biogeochemical processing of organic matter at a landscape level. If the interest is in the food web itself, an ecosystem model, including major functional groups and the flows of elements or energy between them, is more appropriate. The latter may be essential when performing e.g. risk assessments. To get the whole view of pools and fluxes within the lake ecosystem, both these concepts are relevant. /Andersson and Sobek 2006/ suggested that a mass balance should be included when calculating ecosystem models to strengthen the conclusion of the ecosystem model.

Ecosystem models and mass balances can be developed for any element. In this chapter, models and mass balances for carbon are presented. This element can be seen as the main constituent of biomass and carbon has often been used in literature when constructing ecosystem models /e.g. Gessner et al. 1996, Jansson et al. 1999, Wetzel 2001, Andersson and Kumblad 2006, Sobek et al. 2006/. Another aspect is that a lake model based on carbon can be used to estimate the fate of radioactive carbon (C-14) in the lake environment. Of course, many other elements besides carbon are also of interest for the modelling of transport of radionuclides, and conceptual models for the transport of a number of other elements are described in Chapter 7.

In this chapter, mass balances and ecosystem models for carbon have been calculated for five lakes: Eckarfjärden, Bolundsfjärden, Gunnarsbo-Lillfjärden and Labboträsket in the Forsmark area, and Frisksjön in the Laxemar-Simpevarp area. The data presented in Chapter 3 and 4 were used as quantitative input when the mass balances and ecosystem models were set up. The lakes in Forsmark have been divided into larger and smaller lakes. The larger lakes are somewhat deeper and contain a relatively large area of submerged vegetation, whereas the smaller lakes are shallower and have a small water surface compared with the surrounding reed belts. Some lakes in the area have a thick microbial mat in the benthic habitat, while others lack a microbial mat (see section 3.10). In order to describe more than one kind of lake, we decided to create quantitative models for two larger lakes (Bolundsfjärden and Eckarfjärden) and two smaller lakes (Gunnarsbo-Lillfjärden and Labboträsket). Of the two smaller lakes, one contains a microbial mat, whereas the other has none. The two large lakes are situated within the same catchment (no. 8), and Labboträsket and Gunnarsbo-Lillfjärden in a neighbouring catchment (no. 1, see Figure 3-1). In catchment 2, Eckarfjärden is situated upstream, whereas Bolundsfjärden is one of the most downstream lakes in the system. This means that Eckarfjärden was isolated from the sea before Bolundsfjärden. In catchment 1, Labboträsket is situated upstream of Gunnarsbo-Lillfjärden. The amount of data available from the different lakes has been an important factor in selecting candidates for the larger and the smaller lakes. Frisksjön is one of the five lakes situated within the Laxemar-Simpevarp area and is the only lake situated within the Laxemar subarea. Most of the lakes in the region are shallow brown-water lakes, and Frisksjön was chosen as a representative of all the lakes in the area.

5.1 Conceptual models

5.1.1 Carbon mass balances

The aim of the mass balance calculations in this report is to provide an overview of the major fluxes of different elements to and from the lake ecosystem. Carbon enters lakes with water through inlets, direct flow from the catchment and via groundwater inflow. The flow in the inlets is relatively easily assessed, whereas direct drainage to lakes is more difficult to measure directly *in situ*. Carbon also enters the lake from the atmosphere via direct deposition on the lake surface and there is also a constant carbon dioxide gas exchange via the air-water surface. The exchange with the atmosphere may be of limited importance for most elements, but for carbon an important part of the total export from lakes may be the emission of carbon dioxide to the atmosphere /Algesten et al. 2003/. Under certain conditions there may also be an influx of carbon gas to the lake /Andersson and Brunberg 2006a/, and the direction of the flow is an indication of whether the lake is a net heterotrophic or autotrophic system.

Beside the atmospheric exchange, carbon exits the lake ecosystem via the lake outlets and via sediment accumulation. The flow in the outlets is relatively easily assessed. Sedimentation is the process where particulate matter within the lake water sinks down to the lake floor. Some of the matter will be resuspended up to the water phase again, while the rest stays in the sediment, becomes buried and becomes part of the sediment for the rest of the lake phase. In a long-term perspective, the accumulation of carbon and other elements in the sediment is the most interesting process, whereas the sedimentation and resuspension processes may be interesting in a shorter time perspective. No site-specific estimations of sedimentation and resuspension have been performed at the two sites, but long-term accumulation has been investigated.

A conceptual mass balance model was set up (Figure 5-1) and in the calculations the following equation was applied:

TOCIN + DICIN + DOCDEP = TOCOUT + DICOUT + CO_2 FLUX + TCSED + TCBIRD

where:

TOCIN represents the inflow of Total Organic Carbon via inlets and via direct drainage to the lake. The concentrations of organic carbon in groundwater are small /Tröjbom and Söderbäck 2006ab/, so the flow of organic carbon via groundwater is considered negligible.

DICIN represents the inflow of Dissolved Inorganic Carbon to the lake via inlets, direct drainage and groundwater inflow to the lake.

DOCDEP represents Dissolved Organic Carbon entering the lake through wet deposition.

TOCOUT represents the outflow of Total Organic Carbon from the lake via the outlet. The flow of organic carbon via groundwater is small and is considered negligible.

DICOUT represents the outflow of Dissolved Inorganic Carbon from the lake via the outlet.

CO_2 FLUX represents the flux of CO_2 across the air-water interface as a result of the balance between carbonic acid dissolved in the lake water and CO_2 present in the atmosphere.

TCSED represents the long-term accumulation of Total Carbon within the lake.

TCBIRD represents the outflux of carbon from the system via birds feeding in the lakes.

Three identified processes which may potentially influence the mass balance, but which are not included in the equation, are the swarming of hatching of insects, migration of fish and fishing by humans. The influence of these processes on carbon dynamics in the Forsmark lakes is assumed to be minor. The reasons for not including them in the mass balance are described below.

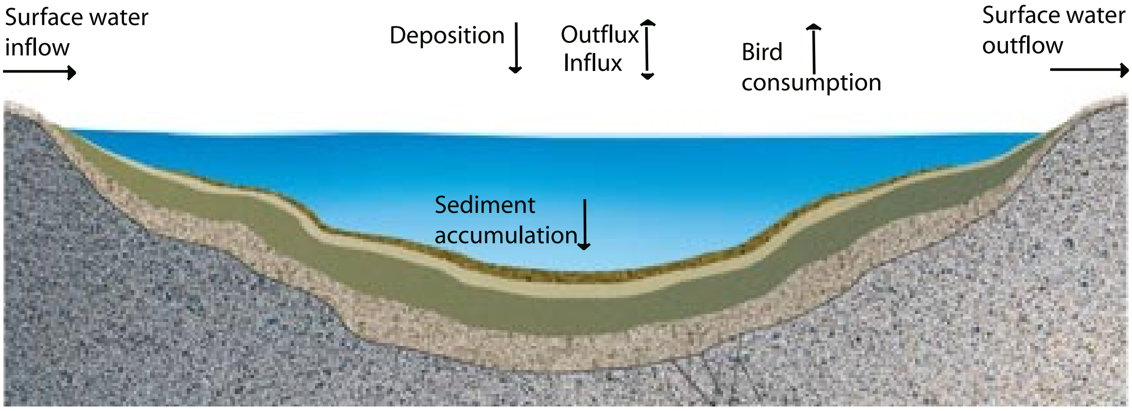


Figure 5-1. *Transport processes considered in the carbon mass balance of lake ecosystems.*

Swarming of hatching insects is a potential outflux of carbon from the lake. We have no information about how much of the biomass that potentially could be involved in this process, but assuming that the whole pool of benthic fauna in Bolundsfjärden should leave the lake this carbon outflow is only about 1% of the TOC outflow via the outlet. We therefore consider this process insignificant.

The contribution of carbon from fish migrating into Bolundsfjärden is assumed to be negligible. Ruffe (*Gymnocephalus cernua*) is the dominant fish species migrating into the lake /Loreth 2005/. This is a small species compared to many of the fish in the lake (i.e. tench), so in terms of biomass the migration is small compared to the stationary population in the lake. Moreover, the spawning fish are present within the lake for only a very short period (days) and even though they may lay large amounts of eggs, only a small fraction of them will actually hatch into fry that grow to the size where they can migrate out to the Baltic Sea. In the safety assessment of a future repository, the assumption that migrating fish are not relevant to include in the carbon model leads to a conservative estimate of radionuclide concentrations in the fish stock in the lake, as the small "dilution" of radionuclides per biomass from the (uncontaminated) migrating fish is not accounted for. In the investigation by /Loreth 2005/, the migration upstream from Bolundsfjärden was shown to be small and, accordingly, fish migration is assumed to be negligible for Eckarfjärden and Labboträsket as well.

Fishing in the lakes should be of minor importance for the mass balances. Some fishing may occur, but it is likely that most of the recreational fishing takes place in the nearby coastal areas today.

5.1.2 Ecosystem carbon models

The aim of the ecosystem model is to provide an overview of major pools and fluxes within the ecosystem. To do so, habitats, pools, and relationships between them have been identified as described below. Fluxes from abiotic pools to biotic pools are included in the ecosystem, but the main focus of the models is the biological processes, i.e. no effort has been made to quantify the fluxes between abiotic pools.

Habitats

The lakes are divided into three major habitats: the pelagic, littoral and profundal (Figure 5-2). The pelagic habitat is defined as the open water body. The littoral habitat is defined as the benthic zone reached by enough light to enable photosynthesis (comparable to the sum of Littoral II and III, see section 3.7). The profundal habitat is the benthic habitat where light penetration is less than needed to sustain a permanent vegetation of primary producers.

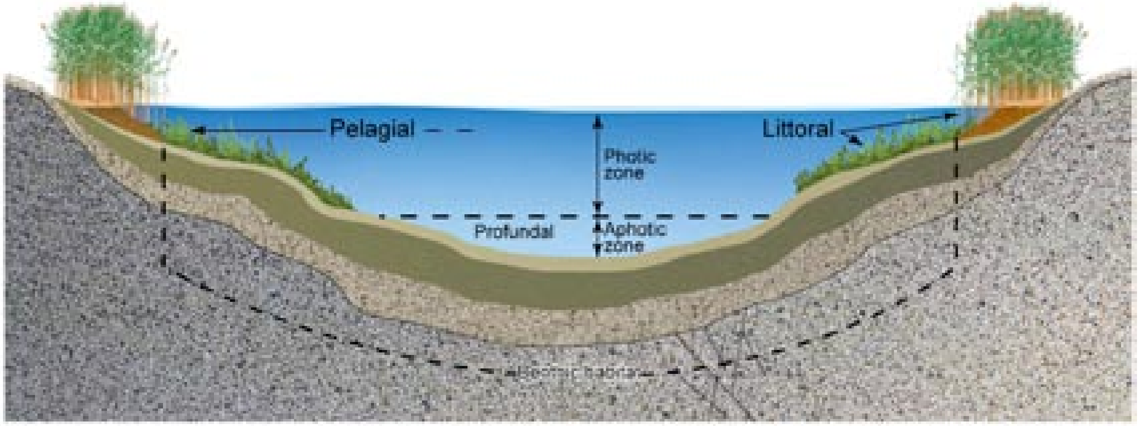


Figure 5-2. Lake habitats used in the ecosystem carbon models.

The reed belts surrounding the lakes (comparable to Littoral I in section 3.7) are dry in the summer and trees are found in them, hence the reed belts are to be considered as wetlands rather than parts of the lake. Thus, although it may seem controversial, Littoral I is classified as terrestrial area and is further described in /Löfgren 2008/. The main reason for this is to treat all kinds of wetlands within the areas in a similar way. The interface zones have to be considered as a transient stage in the succession of lakes turning into land. In the safety assessment of a repository for spent nuclear fuel, fluxes of elements are interesting on a landscape level and the models for the three ecosystem types (terrestrial, limnic and marine) will be linked together to model the overall fluxes. In this step it is not of specific importance how these areas are defined, the important thing is that these areas are included somewhere and later on linked in a convincing manner.

Biotic carbon pools

The biota is divided into 7 functional groups according to food and habitat preferences (Table 5-1). Some functional groups occur within more than one habitat, for example benthic bacteria are present in both littoral and profundal habitats. Moreover, some functional groups, such as fish, were further divided into subgroups in the calculations based on their specific food preferences.

Primary producers

Primary producers consist of all autotrophic organisms, and these are divided into the functional groups phytoplankton (autotrophic and mixotrophic) and benthic primary producers (microphytobenthos, macroalgae emergent and submerged macrophytes). Phytoplankton is assumed to be evenly distributed within the pelagic habitat, whereas benthic primary producers occur in the littoral habitat.

Table 5-1. Functional groups in the lake ecosystems.

	Pelagic	Littoral	Profundal
Primary producers	Phytoplankton	Benthic primary producers	
Consumers	Bacterioplankton	Benthic bacteria	
	Zooplankton	Benthic fauna	
	Fish		

Consumers

Consumers are defined as all heterotrophic organisms in the lake. Consumers are divided into the functional groups bacterioplankton, zooplankton, benthic bacteria, benthic fauna and fish. Bacterioplankton, zooplankton and fish are assumed to be evenly distributed within the pelagic habitat. Benthic fauna and benthic bacteria are assumed to be present in the littoral habitat and in the profundal habitat.

Birds feeding on vegetation or fauna in lakes are also consumers linked to the limnic ecosystems. They do not live entirely on food produced in the lake and their importance for the ecosystem is limited. Therefore, birds using the lakes for feeding are not treated as a functional group in the ecosystem model. Instead, bird feeding is treated as an outflux in the mass balance calculations (section 5.2.5).

Abiotic carbon pools

In the ecosystem models four abiotic pools were identified: inorganic carbon dissolved in water (DIC), organic carbon dissolved in water (DOC), particulate organic carbon in water (POC) and carbon in the sediments (sediment C).

Food web interactions

Phytoplankton and benthic primary producers are assumed to consume dissolved inorganic carbon (DIC) from the water (Figure 5-3). Due to the exchange at the air-water surface, DIC is assumed to always be available for primary production. In addition to photosynthesis, mixotrophic phytoplankton utilize bacterieplankton as a food source. Mixotrophic phytoplankton is capable of vertical migration /Smayda 1997/, so it is reasonable to assume that they can migrate and also utilize bacteria in the uppermost parts of the microbial mat on the sediment surface. It is therefore assumed that mixotrophic phytoplankton consume bacterioplankton and benthic bacteria from the top 0.5 mm of the microbial mat. Moreover, in Forsmark, benthic bacteria have been observed to be suspended in the water column during certain periods /Andersson 2005/, which would make the benthic bacteria available to mixotrophic phytoplankton.

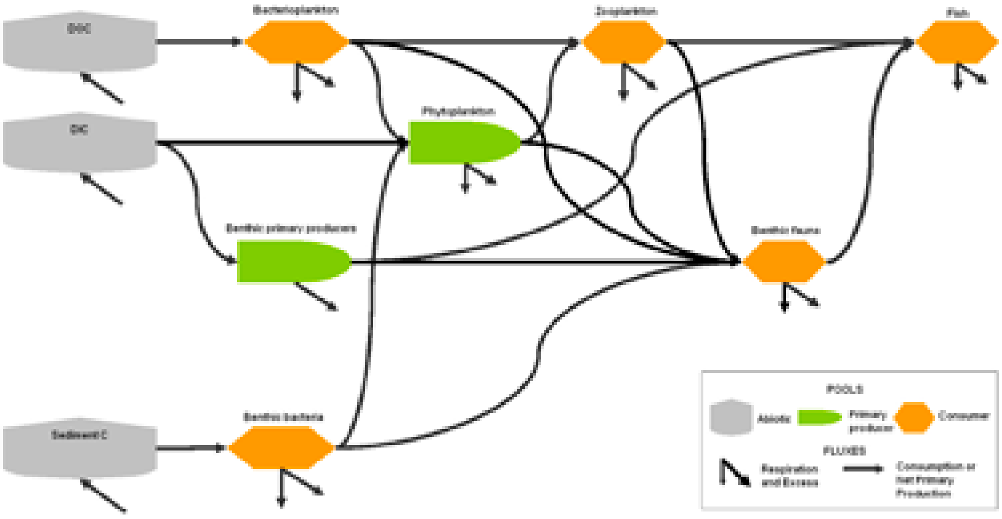


Figure 5-3. *Food web relationships in the conceptual model of the lake ecosystem.*

Bacterioplankton consume DOC and to some extent also POC as bacteria can be associated with particulate matter in the lake water. However, bacterioplankton dissolves the particulate carbon into smaller substances before utilising it, so for simplicity bacterioplankton was assumed to consume only DOC. Benthic bacteria consume organic carbon in the sediment.

In the model calculations, zooplankton is assumed to feed on phytoplankton, bacterioplankton and to some extent also on other zooplankton. Since we have no detailed information on feeding preferences of zooplankton we assume that 50% of the zooplankton community is available as a food source for zooplankton.

Benthic fauna is composed of functionally different groups, such as filter feeders, detritus feeders, scrapers, shredders and predators, but these were treated as one group in the model calculations. Benthic fauna is assumed to consume phytoplankton, bacterioplankton, zooplankton, benthic primary producers, benthic bacteria from the top 1 cm of the microbial mat, and in addition also other benthic fauna. In reality, benthic fauna also consumes dead particulate organic carbon. However, the excess of organisms, i.e. production/consumption minus respiration and grazing/predation, is assumed to contribute to the POC and DOC pool. Thus, POC consumption is already accounted for in the consumption of live organisms.

Fish are divided into three subclasses in the calculations: zooplanktivores (Z-fish), benthivores (B-fish) and piscivores (P-fish), according to feeding preferences /Holmgren and Appelberg 2000/. Z-fish were assumed to consume metazooplankton, whereas B-fish were assumed to feed on benthic fauna and benthic primary producers. The only primary producer consumed by fish in Swedish lakes is the epiphytic growth on macroalgae/macrophytes, so the major part of the benthic primary producers is not consumed. The extent of epiphytic growth is not known, but it is included in the biomass estimates of the macrophtyes/macroalgae. We assume that 20% of the total biomass of macrophytes and macroalgae is available as a food source for the benthivores. Piscivores are assumed to feed on all three subclasses: Z-, B-, and P-fish.

Excess

Carbon that is not consumed or respired is assumed to contribute to the excess pool. Some of the excess will leave the lake through the lake outlet, but a large part of the excess may also contribute to the sediment accumulation in the lakes. By using the same values for carbon influx/outflux via inlets, outlets and atmospheric deposition as in the carbon mass balances described above, an estimate of sediment accumulation is derived. Thus the excess can be used to compare the results from the ecosystem model and the mass balance.

5.2 Model parameterization for the mass balances

Site-specific data in combination with literature data have been used to develop quantitative models from the conceptual models. A detailed description of the model parameterization done for mass balances follows below. The different transport processes identified in section 5.1.1 have been calculated using different model assumptions described below. Most influxes and outfluxes are based on site- or lake-specific data (Table 5-2).

Table 5-2. Site- (S) or Lake- (L) specific data used for mass balance calculations for the four modelled lakes in Forsmark (Fm) and Laxemar-Simpevarp (Lm).

Process	Eckarfjärden (Fm)	Bolundsfjärden (Fm)	Gunnarsbo-Lillfjärden (Fm)	Labboträsket (Fm)	Frisksjön (Lm)
Inflow via inlets, groundwater and direct flow from catchment (TOC_{IN}, DIC_{IN})	L	L	L	L	L
Influx via wet deposition from atmosphere (DOC_{DEP})	S	S	S	S	S
Outflow via outlets (TOC_{OUT}, DIC_{OUT})	L	L	L	L	S
Outflow to atmosphere ($CO_{2\ FLUX}$)	L	L	L	L	L
Sediment accumulation (TC_{SED})	L	S	S	S	L
Bird consumption	S	S	S	S	S

5.2.1 Carbon influx from the catchment via water (TOC_{IN}, DIC_{IN})

Forsmark

For the Forsmark lakes, the total transport of elements from the catchment was estimated based on simultaneous measurements of concentrations and discharge in streams over a period of two years /Tröjbom et al. 2007, section 5.3/. Daily transport was calculated by multiplying total daily discharge by a concentration representative of the same time period, and these daily estimates were further added to obtain monthly and yearly transport. These values include water in- and outflow to/from lakes via in/outlets as well as diffusive in- and outflow of elements directly to the lake from the catchment as well as via groundwater. The mean value of the two years has been used as the best estimate, whereas the two individual values are presented as the range (minimum and maximum values) in Appendix 12. As only data from 2 years are available, the true range may of course be larger.

Extrapolations in both time and space had to be performed to compensate for the mismatch between concentration and discharge measurements. For Bolundsfjärden, which has a relatively large surface area, transport of carbon from areas draining directly into the lake was added to the calculated transport in the inlet stream by multiplying the area-specific transport rate (kg C km^{-2} y^{-1}) in the measuring point just upstream of the lake (PFM000068) (data from Table E-2 in Appendix E in /Tröjbom et al. 2007/), by the area draining directly into the lake. For Labboträsket, the area-specific transport of carbon in the upstream measuring point (PFM000066) was applied to the whole catchment (excluding the lake area) and was thus used to calculate total transport of carbon into the lake.

For Eckarfjärden, simultaneous measurements of concentrations and discharge were only available for the outlet stream during the period 2004 to 2006. However, monthly chemical measurements were performed in both the inlet (PFM000071) and outlet (PFM000070) streams during the period 2002 to 2004. To calculate annual transport of TOC and DIC into the lake, the ratio between concentrations in the inlet and the outlet streams was first calculated for each sampling occasion during the period 2002–2004 (data from SICADA, October 2007). These ratios were added to obtain monthly averages, and the monthly averages were used to calculate annual mean ratios. These annual mean ratios were then used to estimate concentrations in the inlet stream during the period 2004–2006 from measured concentrations in the outlet. Finally, the estimated concentrations were assumed to be representative of all water draining into the lake, and were thus used together with area-specific discharge in the downstream hydrological discharge station (PFM002668, cf. /Tröjbom et al. 2007/) to calculate the total annual transport of carbon into the lake.

Laxemar-Simpevarp

For Frisksjön, the total transport of elements from the catchment was estimated based on simultaneous measurements of concentrations and discharge in streams over a period of one year /Tröjbom et al. 2008, section 5.3.3/. Extrapolations in both time and space had to be performed to compensate for the mismatch among the measurement stations. Daily transport was calculated by multiplying total daily discharge by a concentration representative of the same time period, and these daily estimates were further added to obtain monthly and yearly transport. These values include water in- and outflow to/from lakes via in/outlets as well as diffusive in- and outflow of elements directly to the lake from the catchment as well as via groundwater. In order to estimate a range, the lowest and highest area-specific transports (kg C km^{-2} y^{-1}) calculated for different catchments in Laxemar-Simpevarp area were used together with the catchment area of the lake to estimate minimum and maximum values (presented in Appendix 12).

5.2.2 Carbon influx/exchange with the atmosphere (DOC$_{DEP}$ and CO_2 $_{FLUX}$)

Forsmark

For the Forsmark lakes, the annual deposition of carbon, DOC$_{DEP}$, was calculated from mean concentrations in precipitation from two stations in the Forsmark area /Tröjbom and Söderbäck 2006b/ and from annual precipitation (calculated as an annual mean from two years: 2004 and 2005) /Johansson et al. 2008/. Minimum (0.8 g C m^{-2}) and maximum (2.3 g C m^{-2}) values are based on literature data /Dillon and Molot 1997, Willey et al. 2000/.

The CO_2 flux across the air-water surface was calculated from chemical equilibriums. There is equilibrium of CO_2 between air and surface waters as a response to the partial pressure of the gas within the lake water resulting in a flux of carbon dioxide across the air-water interface of lakes. The partial pressure of CO_2 (pCO_2) in the surface water of each lake was calculated from DIC, pH, temperature and air pressure at each sampling occasion using equilibrium constants /Stumm and Morgan 1996/ and Henry's constant according to /Weiss 1974/. Atmospheric pCO_2 was assumed to be 365 µatm (corresponds to 365 ppmv). The flux of CO_2 across the air-water interface (CO_2 $_{FLUX}$) was calculated from the difference between lake pCO_2 and atmospheric pCO_2, and wind speed /Cole and Caraco 1998/. In Forsmark, wind was measured at the meteorological station Högmasten, situated 3 km north of Eckarfjärden. In the winter, the ice cover prevents gas exchange with the atmosphere, and the accumulating CO_2 is rapidly degassed during the spring melt /Striegl et al. 2001/. We accounted for the spring melt emission of CO_2 by subtracting the CO_2 concentration measured shortly after ice-out from the CO_2 concentration prior to ice-out, and by adding the resulting flux to the flux estimate for the open-water period. Dates for ice-on and ice-out are based on observations from the site investigations /Aquilonius and Karlsson 2003, Heneryd 2004, 2005, 2006 and 2007/. The CO_2 flux across the air-water interface was calculated for the years for which data are available (four years for Eckarfjärden, three years for Bolundsfjärden and Labboträsket and one year for Gunnarsbo-Lillfjärden), and the average annual CO_2 flux (best estimate) was calculated as the mean of these years. The lowest and highest annual flux values for each lake have been assumed to represent the range (minimum and maximum values).

Laxemar-Simpevarp

For Frisksjön, the annual deposition of dissolved organic carbon, DOC$_{DEP}$, was based on concentration in precipitation from station Rockneby Kalmar /Phil-Karlsson et al. 2008/ and from mean precipitation in Laxemar-Simpevarp /Werner et al. 2008/. Minimum (0.8 g C m^{-2}) and maximum (2.3 g C m^{-2}) values are based on literature data /Dillon and Molot 1997, Willey et al. 2000/.

The CO_2 flux across the air-water surface in Laxemar-Simpevarp was calculated in the same way as for Forsmark (see above). The wind speed in Laxemar-Simpevarp was measured at the meteorological station in Plittorp, c. 8 km west of Frisksjön. Dates for ice-on and ice-out are based on observations from the site investigations (from the database SICADA, April 2008, cf. section 4.4.4). The CO_2 flux across the air-water interface was calculated for the years for which data are available (4 years), and the average annual CO_2 flux (best estimate) was calculated as the mean of these years. The lowest and highest annual flux value have been assumed to represent the range (minimum and maximum values).

5.2.3 Carbon outflux by sediment accumulation (TC_{SED})

Forsmark

In Forsmark, long-term accumulation of dry matter has been estimated to be 1 mm $year^{-1}$ in sediments from Eckarfjärden /Hedenström and Risberg 2003/. The accumulation rate of carbon within the lake sediment has been estimated using data from the study /Hedenström and Risberg 2003/ on accumulation rate of dry matter combined with the average carbon content of the gyttja layer in Eckarfjärden (27% of dry weight), together with data from /Nordén 2007/ on the average water content of that sediment layer. Further, the density of minerals was assumed to be 2,650 kg m^{-3} (the commonly used density factor for quartz) and that the amount of organic matter was calculated by multiplying the carbon content by 1.7 /Hedenström and Sohlenius 2008/. For Bolundsfjärden, lake-specific data on water content in the gyttja layer (90%) /Nordén 2007/ have been used together with the average carbon content for the gyttja layer in three lakes in the area (Eckarfjärden /Hedenström and Risberg 2003/, Fiskarfjärden and Puttan /Hedenström 2004/) and the accumulation rate of dry matter from Eckarfjärden. No lake-specific sediment data are available for Gunnarsbo-Lillfjärden and Labboträsket. Instead the same data on carbon content and accumulation rate as for Bolundsfjärden were used together with the average water content of the gyttja layer from three lakes in the area (Eckarfjärden, Bolundsfjärden and Puttan) /Nordén 2007/. In the calculations, it is assumed that the sediment accumulation is evenly spread over the entire lake area (reed belts excluded).

The carbon concentration of 27% /Hedenström and Risberg 2003/ that is used in the calculation of sediment accumulation deviates slightly from the 35% carbon reported in /Hannu and Karlsson 2006/. The study by /Hannu and Karlsson 2006/ is used in the estimation of the sediment carbon pool below, in order to use data from the same sampling event as in the estimations of pools for all other elements (presented in Chapter 7). However, the study by /Hedenström and Risberg 2003/ includes more replicates and is supposed to give a more accurate estimate of the sediment accumulation.

In this report, different estimates of the accumulation of dry matter, water and carbon content of the gyttja layer were used to estimate the minimum and maximum carbon accumulation rate in lake sediments. Sediment accumulation rates for four oligotrophic hardwater lakes in the region (including Eckarfjärden) are presented in /Hedenström and Risberg 2003/, showing a range between 0.2 and 4 mm $year^{-1}$. The lowest value is for Barsjö (a small lake resembling Labboträsket) before isolation, while the highest value is for the lagoon surface in Landholmssjön (larger lake resembling the larger lakes in the Forsmark area).

Data on water content in lake sediments are available from three lakes in the Forsmark area: Eckarfjärden, Bolundsfjärden and Puttan /Nordén 2007/. The lowest and highest values for this parameter in gyttja samples from these three lakes (78% in Bolundsfjärden and 98% in Puttan) are assumed to represent the range. Data on the carbon content of the gyttja layer are available in /Hedenström and Risberg 2003/. The range presented for Eckarfjärden is 10–45% and for Barsjön 8–45% of dry weight. The latter range is used for this parameter. There is a clear positive correlation between the carbon and water content of lake sediments (see e.g. Figures 4-3, 4-6, 4-9 and 4-13 in /Hedenström and Risberg 2003/), so minimum and maximum values for these two parameters have been combined with minimum and maximum values for sediment accumulation rates in order to find minimum and maximum carbon accumulation rates. The minimum carbon accumulation rate was thereby estimated using high carbon and water content in combination with low accumulation rate. The maximum carbon accumulation rate was estimated using low carbon and water content combined with high accumulation rate.

Laxemar-Simpevarp

In Laxemar-Simpevarp, the long-term accumulation rate of carbon has been estimated in Frisksjön by dating of sediment cores /Sternbeck et al. 2006/. The study reveals an average rate of 79 g C m^{-2} y^{-1} (SD = 14 g C m^{-2} y^{-1}) in the upper part of the sediment layer (20–22 cm sediment depth) that represents the lacustrine phase of the lake. The estimation is based on two sediment cores (one used for analysis of sediment age and the other for carbon content) from the deepest part of the lake. When calculating the permanent sediment accumulation (TCSED) it was assumed that the whole lake area (excluding the reed belt) functions as an accumulation bottom and that the accumulation rate is the same over the whole area.

The minimum accumulation rate was estimated using a carbon accumulation rate 2 standard deviations lower than the mean value together with a smaller area of accumulation bottoms (52,000 m^2 which is the area classified as profundal in /Brunberg et al. 2004b/). The maximum accumulation rate was estimated using a carbon accumulation rate 2 standard deviations higher than the mean value and the same accumulation area as for the best estimate (the whole lake area, excluding the reed belt).

5.2.4 Carbon outflow via water (TOCOUT + DICOUT)

Forsmark

For the Forsmark lakes, the outflow of carbon *via surface water* was estimated from simultaneous measurements of concentrations in the lake and discharge in streams over a period of two years (data from Table E-1 in Appendix E in /Tröjbom et al. 2007/). For Eckarfjärden, the concentrations measured in the sampling point downstream of the lake were used, while the concentrations in lake water were used for Bolundsfjärden, Gunnarsbo-Lillfjärden and Labboträsket. Daily transports were calculated by multiplying total daily discharge by a concentration representative of the same time period, and these daily estimates were further added to obtain monthly and yearly transports. Extrapolations in both time and space had to be performed to compensate for the mismatch among the measurement stations. The outflow of TOC and DIC via the outlets was estimated using measured water flow and concentrations for two years. The mean value of the two years is used as best estimate value, whereas the two individual values are assumed to represent the range (minimum and maximum values).

Laxemar-Simpevarp

The outflow of carbon via surface water from Frisksjön was estimated from concomitant measurements of concentrations in lake water (surface) and discharge in streams during three years (2005–2007). Since the discharge estimates from the gauging station downstream Frisksjön most likely are erroneous /cf. Werner et al. 2008/, we used instead monthly mean values for specific discharge from the gauging station just upstream Frisksjön (PSM000347) (discharge data are presented in /Werner et al. 2008/). The monthly means were combined with monthly measurements of TOC and DIC in lake water to calculate monthly transport of carbon via the outlet, and these estimates were further summarized to calculate yearly transport. For a few months, missing chemical data was replaced by the mean value of data from the previous and the succeeding months. The mean value of the three years is used as a best estimate, and minimum and maximum are assumed to represent the range.

5.2.5 Carbon outflux by birds feeding in the lake (TCBIRD)

Forsmark and Laxemar-Simpevarp

Bird consumption (g C m^{-2} year^{-1}) has been estimated using data on bird territories in the two areas (Green unpubl.) and the metabolic rate in birds, calculated from an equation given in /Nagy et al. 1999/. The calculations are described in /Löfgren 2008, section 4.2.2/. It may be argued that birds also contribute to the carbon pool in lakes through deposition of faeces. As the species of birds in question use the lakes only for feeding and do not nest in the lakes, this influx is assumed to be negligible.

In the Forsmark and Laxemar-Simpevarp areas, the outflow of carbon from the aquatic systems via consumption by birds feeding in lakes and shallow bays (0–5 m depth) is dominated by herbivorous species (contribute 52% of total outflux via consumption by birds). Given that the dominant bottom vegetation in the Forsmark lakes is stoneworts, a group of plants consumed by very few bird species (mainly ducks which have not been observed in the lakes), we have assumed that birds are mainly feeding in the shallow bays in the area and that the outflow of carbon via herbivorous birds is negligible. Likewise, macrophytes in Frisksjön are practically absent except for reed, which is not utilised by birds. Hence, the same assumptions as for Forsmark have been used when calculating the consumption by birds feeding in Frisksjön. The consumption in lakes by birds is thereby dominated by piscivorous bird species (72%), followed by omnivorous birds (23%) and insectivorous birds (5%). No estimates of variation are available for this data. An estimate of minimum consumption was achieved by considering only bird species specifically feeding in lakes (the above estimates include birds feeding in both lake and marine habitats). An estimate of maximum consumption was achieved by also including the herbivorous birds occurring in the lakes.

5.3 Model parameterization for ecosystem models

5.3.1 Abiotic carbon pools

All abiotic pools in the water phase can be assumed to be available for the biotic pools. The sediment carbon, on the other hand, is a very large pool in most lakes and it is reasonable to assume that only the uppermost part of the sediment is available for biota. In the ecosystem models, no effort has been made to quantify the size of the carbon sediment pool available for biota, but sediment carbon is assumed to be available in excess for the functional groups that utilize that pool.

The concentrations of ***DOC*** in Bolundsfjärden, Eckarfjärden Gunnarsbo-Lillfjärden and Labboträsk have been measured in the site investigation and data from 2004-06-01 to 2006-05-31 were used in this evaluation (data from SICADA, October 2006). Data on ***POC*** is also available for the time period 2004-06-01 to 2006-05-31 (SICADA, October 2006).

The carbon content of the ***sediment*** in Eckarfjärden was derived from Appendix 1 in /Hannu and Karlsson 2006/. The available samples were divided into three deposit layers: gyttja, clay gyttja and clay. In Bolundsfjärden, the carbon content was not analyzed but the depth of the different sediment layers are measured /Hedenström 2004/. In Gunnarsbo-Lillfjärden and Labboträsk no measurements on the sediments have been performed. Instead, sediment depths were estimated from other lakes in the area situated at the same altitude (i.e. isolated from the Baltic Sea at approximately the same time and thus lakes of similar age). In the case of Gunnarsbo-Lillfjärden (1.92 m.a.s.l.) data from Gällsboträsket (1.47 m.a.s.l.) was used, and in the case of Labboträsket (2.7 m.a.s.l.) data from Stocksjön (2.65 m.a.s.l.) was used. For Bolundsfjärden, Gunnarsbo-Lillfjärden and Labboträsk, the carbon content in different sediment layers was assumed to equal the carbon content in the sediment layers of Eckarfjärden.

The abiotic pool DIC is assumed to always be available for biota due to a continuous exchange of CO_2 between the air and water. Therefore this pool is not quantified.

5.3.2 Biomass

Forsmark

Most biomass data used in the ecosystem carbon models are site specific (Table 5-3). Much of the site-specific biomass data used were available in grams wet or dry weight and this has been converted into grams C using conversion factors presented in Table 5-4. Site data from Eckarfjärden /Blomqvist et al. 2002, Andersson et al. 2003/ were used together with chlorophyll *a* concentrations in surface waters (0.5 m) /Tröjbom and Söderbäck 2006b/ to calculate ***phytoplankton*** biomass in Bolundsfjärden, Gunnarsbo-Lillfjärden and Labboträsket (Table 5-3). The mean monthly biomass (g C m^{-3}) in Eckarfjärden was divided by the mean monthly chl *a* concentration in Eckarfjärden, and this ratio was multiplied by the chl *a* concentrations in the other lakes to achieve the biomass there. The biomass was measured in Bolundsfjärden during 2001 /Franzén 2002/, but the replicates were few and there were only autumn values. The phytoplankton biomass in Bolundsfjärden was therefore calculated from Eckarfjärden data. The calculated autumn values agreed well with the measured autumn values.

Benthic primary producers consist of microphytobenthos, submerged vegetation and emergent macrophytes. Site data on the microphytobenthos biomass from Eckarfjärden /Andersson et al. 2003/ was used also for Bolundsfjärden and Gunnarsbo-Lillfjärden (Table 5-3). Only autumn values of the microphytobenthos biomass were available for Bolundsfjärden /Franzén 2002/, so values from Eckarfjärden were used for this lake as well. The few measured data from Bolundsfjärden agree well with autumn values from Eckarfjärden. Since only 1 of 23 samples in Labboträsket contained a microbial mat (section 3.9.1), the biomass of the microphytobenthos there was assumed to be negligible. The biomass of submerged vegetation (mainly the macroalgae *Chara sp.*) was taken from site-specific investigations in Bolundsfjärden 2006 (Table 5-3) /Karlsson and Andersson 2006/. Biomass estimates of *Chara sp.* were also available from Bolundsfjärden and Fiskarfjärden from 2004 /Huononen 2005/. However, that investigation included few replicates and only autumn values, so the biomass values of submerged vegetation from the study in 2006 were also used for Eckarfjärden, Gunnarsbo-Lillfjärden and Labboträsket. The biomass of emergent macrophytes is very small compared to submerged macrophytes. It is therefore assumed to be negligible and is not included in the model calculations.

Table 5-3. Biomass and primary production values used for the different functional groups in the lake ecosystem models. E-fjärden=Eckarfjärden, B-fjärden= Bolundsfjärden, GL-fjärden= Gunnarsbo-Lillfjärden and L-träsk = Labboträsket.

Functional group	Biomass (*g C m^{-2}, ** g C m^{-3})				Primary production /Respiration (* g C m^{-2} y^{-1}, ** g C m^{-3} y^{-1})			
	E-fjärden	B-fjärden	GL-fjärden	L-träsk	E-fjärden	B-fjärden	GL-fjärden	L-träsk
Phytoplankton**	0.04	0.04	0.03	0.03	16.2	18.6	13.1	10.2
Benthic primary producers*:					87.0	87.0	87.0	87.0
Macroalgae	22.23	22.23	22.23	22.23	55.7	55.7	55.7	–
Microphytobenthos	3.82	3.82	3.82	–				
Emergent macrophytes	–	–	–	–				
Bacterioplankton**	0.05	0.05	0.05	0.05				
Zooplankton**	0.07	0.07	0.07	0.07				
Benthic bacteria*	3.68	3.68	3.68	3.68				
Benthic fauna*	0.43	0.56	0.43	0.43				
Z-fish*	0.03	0.001	0.002	–				
B-fish*	0.74	0.62	0.77	0.68				
P-fish*	0.31	0.11	0.26	–				

Table 5-4. Conversion factors used for converting biomass in grams wet or dry weight into grams carbon (C).

Available data	Conversion factor (ww to dw)	Conversion factor (g C g dw^{-1})
Primary producers		
Benthic primary producers		
Submerged macroalgae		0.268 (a)
Consumers		
Zooplankton		0.48 (b)
Benthic fauna		0.435 (c)
Fish		
Planktivorous	0.198 (a)	0.440 (a)
Benthivorous	0.203 (a)	0.445 (a)
Piscivorous	0.203 (a)	0.432 (a)

a) /Hannu and Karlsson 2006/
b) /Anderson and Hessen 1991/
c) average of conversion factors for different taxa given in /Liess and Hillebrand 2005/.

The estimated biomass of ***bacterioplankton, benthic bacteria,*** and ***zooplankton*** from studies in Eckarfjärden were used for all the lakes in the area /Blomqvist et al. 2002, Andersson et al. 2003, Andersson 2005, Andersson and Brunberg 2006a/.

Site-specific data on the biomass of ***benthic fauna*** were used for Bolundsfjärden /Huononen 2005/. Two methods were used for sampling and an average of the results from the two methods was used in the model. The average biomass of benthic fauna from Bolundsfjärden and Fiskarfjärden was used to model Eckarfjärden, Gunnarsbo-Lillfjärden and Labboträsket. The biomass of benthic fauna was measured once in Eckarfjärden, but was most probably underestimated on this occasion since only areas lacking submerged vegetation were sampled /Andersson et al. 2003/. Benthic fauna have been shown to correlate with benthic vegetation /van den Berg et al. 1997/ and large areas of Eckarfjärden are covered by *Chara sp.*, which makes estimates from the survey in Fiskarfjärden and Bolundsfjärden more accurate. The benthic fauna was sorted into subgroups according to feeding preferences.

Site-specific biomass data have been used for ***fish*** biomass in Eckarfjärden, Bolundsfjärden and Gunnarsbo-Lillfjärden /Borgiel 2004b/. No biomass data are available for fish in Labboträsket, but it is known that only small Crucian carp live there (see section 3.10.1). It was assumed that Crucian carp are mainly benthic feeders and the biomass of zooplanktivorous and carnivorous fish was therefore set at zero in Labboträsk. The biomass of benthivorous fish in Labboträsket was estimated using the mean biomass per unit area of benthivorous fish in Eckarfjärden and Bolundsfjärden.

Laxemar-Simpevarp

Most of the assumptions used in the quantitative lake models for the lakes in the Forsmark area are also valid for Frisksjön. The text below therefore includes site-specific information and, when appropriate, references to the descriptions in the Forsmark text. As for Forsmark, most biomass data in the Laxemar-Simpevarp ecosystem carbon models are site-specific (Table 5-5). For conversion from wet weight to carbon weight for biota, the same conversion factors as for Forsmark were used for data from Laxemar-Simpevarp (Table 5-4).

Site-specific data on the ***phytoplankton*** biomass in Frisksjön were used in the calculations /Sundberg et al. 2004/ (E. Andersson unpublished).

Table 5-5. Biomass, primary production, respiration and consumption values used for the different functional groups in the ecosystem model for Frisksjön. Some of the phytoplankton are mixotrophic, so this functional group has both primary production and respiration.

Functional group	Biomass (*g C m^{-2}, **g C m^{-3})	Primary production (g C m^{-2} y^{-1})	Respiration (*g C m^{-2} y^{-1}, ** g C m^{-3} y^{-1})	Consumption (* g C m^{-2} y^{-1}, ** g C m^{-3} y^{-1})
Phytoplankton**	0.28	40	14.5	28.9
Benthic primary producers*				
Macrophytes	0.81	1.0	–	–
Microphytobenthos	–	–	–	–
Submerged vegetation	–	–	–	–
Bacterioplankton**	0.03	–	58.7	78.3
Zooplankton** [a]	0.11	–	2.9	8.8
Benthic bacteria*	5.32	–	63.6	84.8
Benthic fauna*				
Littoral	0.43	–	2.5	7.5
Profundal	0.60	–	3.5	10.5
Z-fish*	0.01	–	0.1	0.1
B-fish*	0.29	–	1.7	2.9
P-fish*	0.27	–	1.6	2.7

[a] 2 of 3 measured values have been used together with values from another lake, see text for details.

Benthic primary producers consist of the microphytobenthos emergent and submerged macrophytes. In Frisksjön submerged macrophytes (i.e. nymphea) are found in a small area comparable to Littoral II in section 3.7 /Aquilonius 2005/. The biomass of the microphytobenthos is assumed to be negligible due to the poor light climate of the entire benthic area.

Site-specific data were used for the biomasses of ***bacterioplankton, benthic bacteria, benthic fauna and fish*** /Andersson et al. 2006, Ericsson and Engdahl 2004, Engdahl and Eriksson 2004/. Site-specific data on ***zooplankton*** were only available for three dates, so, in addition to site-specific data, data from Lake Älgsjön were used to estimate the annual mean zooplankton biomass (see section 4.10.1).

5.3.3 Primary production

Forsmark

Primary production data used in the ecosystem carbon models are compiled in Table 5-3.

Site data from Eckarfjärden /Blomqvist et al. 2002, Andersson et al. 2003, Andersson and Brunberg 2006a/ were used together with chlorophyll *a* concentrations to calculate production of ***phytoplankton*** in Bolundsfjärden, Gunnarsbo-Lillfjärden and Labboträsket. The production per litre and month was divided by the mean monthly chl *a* concentration in the surface water of Eckarfjärden. The production in Bolundsfjärden, Gunnarsbo-Lillfjärden and Labboträsket was then calculated by multiplying the production per chl *a* in Eckarfjärden by the mean monthly chl *a* concentration in the lakes. Annual production (Table 5-3) was achieved by adding together the monthly means.

The production of ***benthic primary producers*** was calculated as the sum of the production of microphytobenthos and macroalgae. *Microphytobenthos* production estimates for Eckarfjärden, Bolundsfjärden and Gunnarsbo-Lillfjärden were taken from site-specific data in Eckarfjärden /Blomqvist et al. 2002, Andersson et al. 2003, Andersson and Brunberg 2006a/. Labboträsket lacks a microbial mat, so the production by the microphytobenthos was assumed to be negligible there. Higher biomass and production of phytoplankton in Bolundsfjärden could potentially lead to less light reaching the microphytobenthos and thus lower primary production by the microphytobenthos. However, the shallower depth in Bolundsfjärden probably enables as much light to reach the benthic habitat as in Eckarfjärden, so the same production has been assumed.

Net primary production and respiration of *macroalgae* was obtained from site-specific investigations in Bolundsfjärden /Karlsson and Andersson 2006/. We assume the same respiration rate under dark and light conditions, resulting in a night respiration by the macroalgae in the summer of approximately 20% of their net primary production. Respiration by *Chara sp.* in the winter was assumed to be negligible due to the low temperature and biomass. The same value of primary production by macroalgae was used for all 3 lakes in the area.

Laxemar-Simpevarp

Primary production data used in the ecosystem carbon models are compiled in Table 5-5.

Phytoplankton production was estimated using literature data based on investigations in a number of humic lakes together with phosphorus and chl *a* concentrations in the lake /Nürnberg and Shaw 1999/.

Submerged macrophytes, which are the only ***benthic primary*** producers of significance in Frisksjön, were assumed to lose part of their annual production during the growing season (e.g. due to grazing), and it was therefore assumed that the August biomass measured in the lake constituted 80% of the total annual production. Like biomass, the production of submerged microphytobenthos was assumed to be negligible.

5.3.4 Respiration

Forsmark

Respiration data used in the ecosystem carbon models are compiled in Table 5-6. As respiration has not been measured for any functional group in the Forsmark lakes, we have no site-specific data for this process. Instead, respiration has been estimated using conversion factors.

The ***phytoplankton*** in Eckarfjärden is to a large extent made up of mixotrophic species which, in addition to performing photosynthesis, are able to consume bacteria /Blomqvist et al. 2002, Andersson et al. 2003/. Therefore, both respiration and consumption have been calculated for phytoplankton. The mixotrophic phytoplankton was assumed to contribute to the primary production in proportion to its biomass. The mixotrophic phytoplankton was assumed to achieve 2/3 of its carbon assimilation from consumption of bacteria /Jansson et al. 1999/ and its growth efficiency was assumed to be 50%. The same proportion of mixotrophic phytoplankton to total phytoplankton biomass as in Eckarfjärden was assumed for Bolundsfjärden, Gunnarsbo-Lillfjärden and Labboträsk.

The commonly used growth efficiency of 25% /del Giorgio et al. 1997/ was used for calculating ***bacterioplankton*** respiration. Secondary production by bacterioplankton (n= 24) was measured by thymidine incorporation in situ in Eckarfjärden during 2001 and 2002 /Blomqvist et al. 2002, Andersson et al. 2003, Andersson and Brunberg 2006a/. The annual respiration was calculated from an annual mean production calculated from these measurements (13.1 g C m^{-3} y^{-1}, n=2 years, min 12.4 g C m^{-3} y^{-1}, max 13.7 g C m^{-3} y^{-1}).

Respiration of ***benthic bacteria, zooplankton***, ***benthic fauna***, and ***fish*** was calculated using conversion factors from biomass (Table 5-7), together with temperature variation over the year measured in the investigated lakes, and assuming a direct linear response of respiration to temperature. The biomasses of benthic bacteria and zooplankton were investigated in Eckarfjärden, the biomass of benthic fauna in Bolundsfjärden and Fiskarfjärden, and the biomass of fish in Eckarfjärden and Bolundsfjärden. The temperature data used for Eckarfjärden and Bolundsfjärden are based on measurements from April 2002 to December 2005, whereas the same temperature data for Fiskarfjärden are based on measurements from January to December 2004 (data from the database SICADA, October 2006).

Table 5-6. Respiration and consumption values used for the different functional groups in the lake ecosystem models. E-fjärden=Eckarfjärden, B-fjärden= Bolundsfjärden, GL-fjärden= Gunnarsbo-Lillfjärden and L-träsk = Labboträsket. Note that phytoplankton contains mixotrophic species with both primary production and respiration.

	Respiration (*g C m^{-2} y^{-1}, ** g C m^{-3} y^{-1})				Consumption (* g C m^{-2} y^{-1}, ** g C m^{-3} y^{-1})			
Functional group	**E-fjärden**	**B-fjärden**	**GL-fjärden**	**L-träsk**	**E-fjärden**	**B-fjärden**	**GL-fjärden**	**L-träsk**
Phytoplankton**	8.4	8.7	6.8	5.4	16.8	17.5	13.5	10.9
Benthic primary producers*								
Macrophytes	87.0	87.0		87.0				
Microphytobenthos	55.7	55.7		–				
Submerged vegetation								
Bacterioplankton**	39.2	39.2	39.2	39.2	52.3	52.3	52.3	52.3
Zooplankton**	1.0	1.0	1.0	1.0	3.2	3.2	3.2	3.2
Benthic bacteria*	44.7	44.7	44.7	44.7	84.1	84.1	84.1	84.1
Benthic fauna*	2.4	3.3	2.4	2.4	7.3	9.8	7.3	7.3
Z-fish*	0.16	0.01	0.01	–	0.28	0.01	0.02	–
B-fish*	4.4	3.7	4.7	4.1	7.6	6.5	8.1	7.0
P-fish*	1.9	0.6	1.6	–	3.2	1.1	2.7	–

Table 5-7. Conversion factors derived from /Kautsky 1995/ for calculation of respiration from biomass.

Functional group	Respiration g C g C^{-1} day^{-1}
Zooplankton	0.115
Benthic bacteria	0.069
Benthic fauna	
Benthic filter feeders	0.028
Benthic detritivores	0.032
Benthic herbivores	0.029
Benthic carnivores	0.033
Fish	0.033

Laxemar-Simpevarp

Respiration data used in the ecosystem carbon models are compiled in Table 5-5. The ***phytoplankton*** in Frisksjön was to a large extent (40%) composed of mixotrophic species (see section 4.10.1), which in addition to photosynthesis are able to consume bacteria. Therefore, both respiration and consumption have been calculated for phytoplankton. The mixotrophic phytoplankton were assumed to achieve 2/3 of its carbon assimilation from consumption of bacteria /Jansson et al. 1999/. The growth efficiency was assumed to be 50%, and thus respiration was assumed to be half of consumption (see the section "Consumption" below).

Bacterioplankton respiration was calculated from the literature. /del Giorgio et al. 1997/ showed a correlation between bacterial cells per ml and bacterial respiration for a number of lakes, estuaries and marine areas. We applied the summer value for bacterial abundance in Frisksjön to the respiration graph presented by /del Giorgio et al. 1997/, and obtained the respiration value 9 µg C L^{-1} day^{-1}. To estimate the annual respiration we corrected for temperature measured in Frisksjön assuming a direct linear response of respiration to temperature and assuming that the summer respiration was valid for 20°C.

Respiration of ***benthic bacteria, zooplankton***, ***benthic fauna***, and ***fish*** was calculated using conversion factors from biomass (Table 5-7), together with the temperature variation over the year measured in Frisksjön, and assuming a direct linear response of respiration to temperature (temperature data from the database SICADA, October 2007).

5.3.5 Consumption

Forsmark

Consumption data used in the ecosystem carbon models are compiled in Table 5-6. In the model calculations it was assumed that consumption is equal to the sum of secondary production, respiration and egestion (unassimilated food/faeces). The biomass was considered to be constant on an annual basis, i.e. there are variations in biomass within the year but there is no increase or decrease in biomass between years. The sum of secondary production and egestion was here treated as one unit, excess. All functional groups of heterotrophic biota are assumed to consume their different food sources in proportion to the available biomass of the food sources.

The mixotrophic phytoplankton are assumed to achieve 2/3 of their carbon assimilation from consumption of bacteria and 1/3 from primary production /Jansson et al. 1999/. In primary production measurements in Eckarfjärden, primary production was measured on a community level and there was no distinction between autotrophic and mixotrophic primary production. In this report we have assumed the same proportion for primary production as for biomass of mixotrophic phytoplankton to total phytoplankton.

Bacterial consumption (both pelagic and benthic) was calculated as the sum of bacterial secondary production and bacterial respiration. Secondary production by bacterioplankton was measured in Eckarfjärden /Blomqvist et al. 2002, Andersson et al. 2003, Andersson and Brunberg 2006a/ (see the section "Respiration" above). Secondary production by benthic bacteria was been measured in Eckarfjärden during 2001 and 2002 /Blomqvist et al. 2002, Andersson et al. 2003, Andersson and Brunberg 2006a/. Mean annual benthic bacterial production was calculated from these measurements (39.5 g C m^{-3} y^{-1}, n=2 years, min 35.3, max 43.7 g C m^{-3} y^{-1}).

Consumption by zooplankton and benthic fauna was assumed to be 3 times respiration /Elmgen 1984/. For fish, consumption was assumed to be 1.74 times respiration according to the results of probabilistic modelling of ecosystem parameters by /Kumblad et al. 2006/.

Laxemar-Simpevarp

Consumption data used in the ecosystem carbon models are compiled in Table 5-5. In almost all cases, the assumptions made concerning consumption in Frisksjön are the same as those for the Forsmark lakes. The only exception is bacterial consumption which, due to lack of data on secondary bacterial production, was calculated from respiration, assuming a growth efficiency of 25%. For the other functional groups, consumption was calculated in the same way as for Forsmark.

5.4 Quantitative mass balances and ecosystem carbon models

The ecosystem model and mass balance approaches are two ways of describing the lake ecosystem. The mass balances describe the flows to and from lakes, whereas the ecosystem models describe the flows within the lakes. Both models can be used to estimate whether a lake is a net sink or source of carbon (i.e. a heterotrophic or autotrophic system). Thus, although the models mainly cover different aspects of the ecosystem, parts of the models can be compared with each other. The amount of site-specific data in the models is great, but the data have been sampled during a short time period, so one should be aware of the uncertainties of the absolute numbers presented in this chapter. The most important result is the general picture: the important in- and outflows to and from the lakes, the important flows and pools within the lakes, and whether the lakes sources or sinks of carbon (i.e. heterotrophic or autotrophic systems). The results of the ecosystem carbon models as well as the mass balances are presented for each lake in the following text, together with short comments on the agreement of the results obtained from the two models. The best estimates are presented in the text below whereas the range of the fluxes are presented in Appendix 12.

5.4.1 Lakes in Forsmark

Quantitative models for Eckarfjärden, Bolundsfjärden, Gunnarsbo-Lillfjärden and Labboträsket are described in this section. Eckarfjärden and Bolundsfjärden represent the larger lakes in the area and Gunnarsbo-Lillfjärden and Labboträsket represent the smaller ones.

Eckarfjärden

Eckarfjärden is one of the larger lakes in the Forsmark area. It is the deepest (maximum depth 2.1 m) and highest situated lake in the regional model area. Eckarfjärden is a clear-water lake surrounded by reed, with bottoms covered by the macroalgae *Chara sp.* and a thick microbial mat (Figure 5-4).

Mass balance

According to the mass balance for Eckarfjärden, the influx of carbon is dominated by the DIC and TOC inflow from the catchment (10,400 and 3,500 kg C y^{-1}, respectively). The atmospheric deposition of dissolved organic carbon (230 kg C y^{-1}) makes a minor contribution to the carbon influx to the lake. The major outflux of carbon is the downstream flow of DIC and TOC (6,800 and 5,700 kg C y^{-1}, respectively), followed by sediment accumulation (3,700 kg C y^{-1}), while birds feeding in the lake (300 kg C y^{-1}) are less important.

Figure 5-4. *Lake Eckarfjärden, one of the larger lakes in the Forsmark area. Eckarfjärden is a shallow oligotrophic hardwater lake surrounded by reed. Photo: Eva Andersson, April 2005*

The flux of carbon dioxide across the lake-air interface is negative, indicating an uptake of about 900 kg C y^{-1} and a net autotrophic metabolism (Figure 5-5).

There is an imbalance in the mass balance in that outfluxes exceed influxes by c. 1,400 kg C y^{-1}. This is equivalent to 8% of the carbon outflux and 9% of the total carbon influx. There are large ranges in some of the flows, and the mass balance can be balanced by using other estimates within the ranges of flows.

Ecosystem carbon model

Based on the conceptual model, the annual mean *biomass* in Eckarfjärden is estimated to be 5,900 kg C and is concentrated in the littoral habitat (96% of total biomass is found in the littoral, Figure 5-6a, Table 5-13). Primary producers comprise most of the total mean biomass in the lake, and the dominant group is benthic primary producers (comprising 83% of the total biomass). Benthic bacteria contribute 12% of the total biomass, while each of the other functional groups comprises 3% or less of the total biomass.

According to the model, annual *primary production* is 30,600 kg C y^{-1} and is, like the biomass, concentrated in the littoral habitat where the benthic primary producers contribute 88% of total primary production (Figure 5-5, Table 5-13). Annual *respiration* is 21,100 kg C y^{-1} and thereby smaller than primary production. This indicates that the lake is a net autotrophic system with a positive net ecosystem production (NEP) of 9,500 kg C y^{-1}. In contrast to biomass and production, a large part of the respiration occurs in the pelagic habitat (58% of the total respiration). Benthic bacteria and bacterioplankton dominate respiration, together comprising 82% of the total respiration. Other important functional groups in terms of respiration are mixotrophic phytoplankton and fish, comprising 9 and 6% of the total respiration, respectively. The other functional groups make only small contributions to the total respiration.

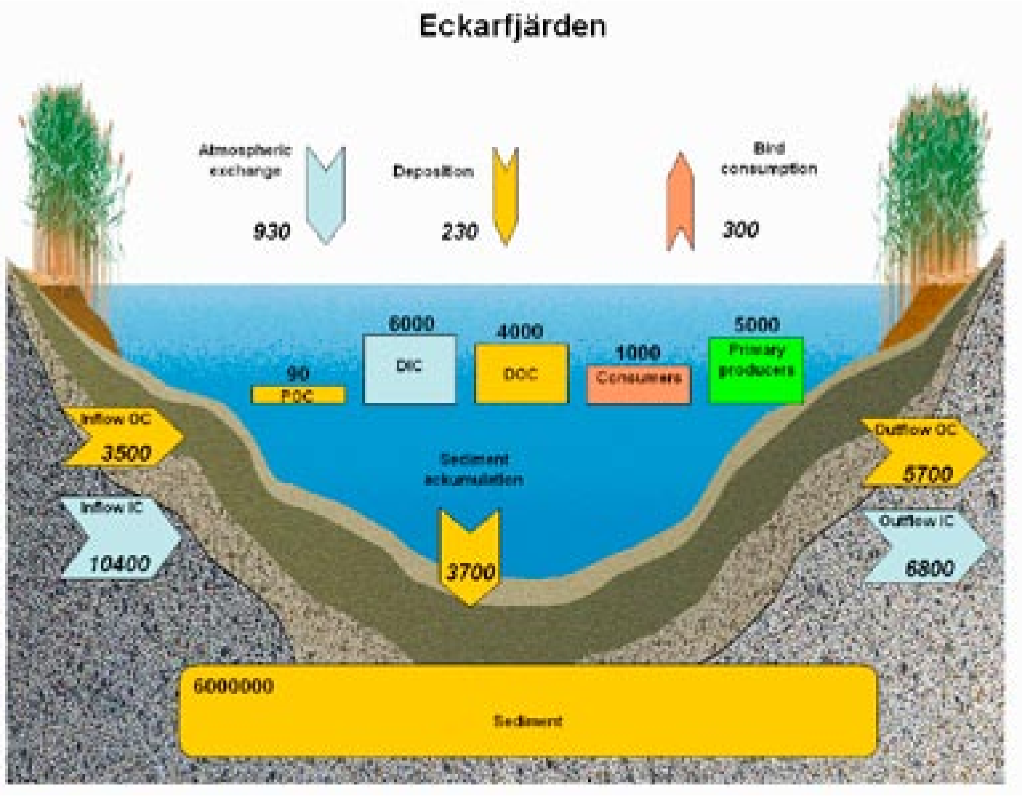


Figure 5-5. *Carbon mass balance for Eckarfjärden, components in kg C, and fluxes in kg C y^{-1}.*

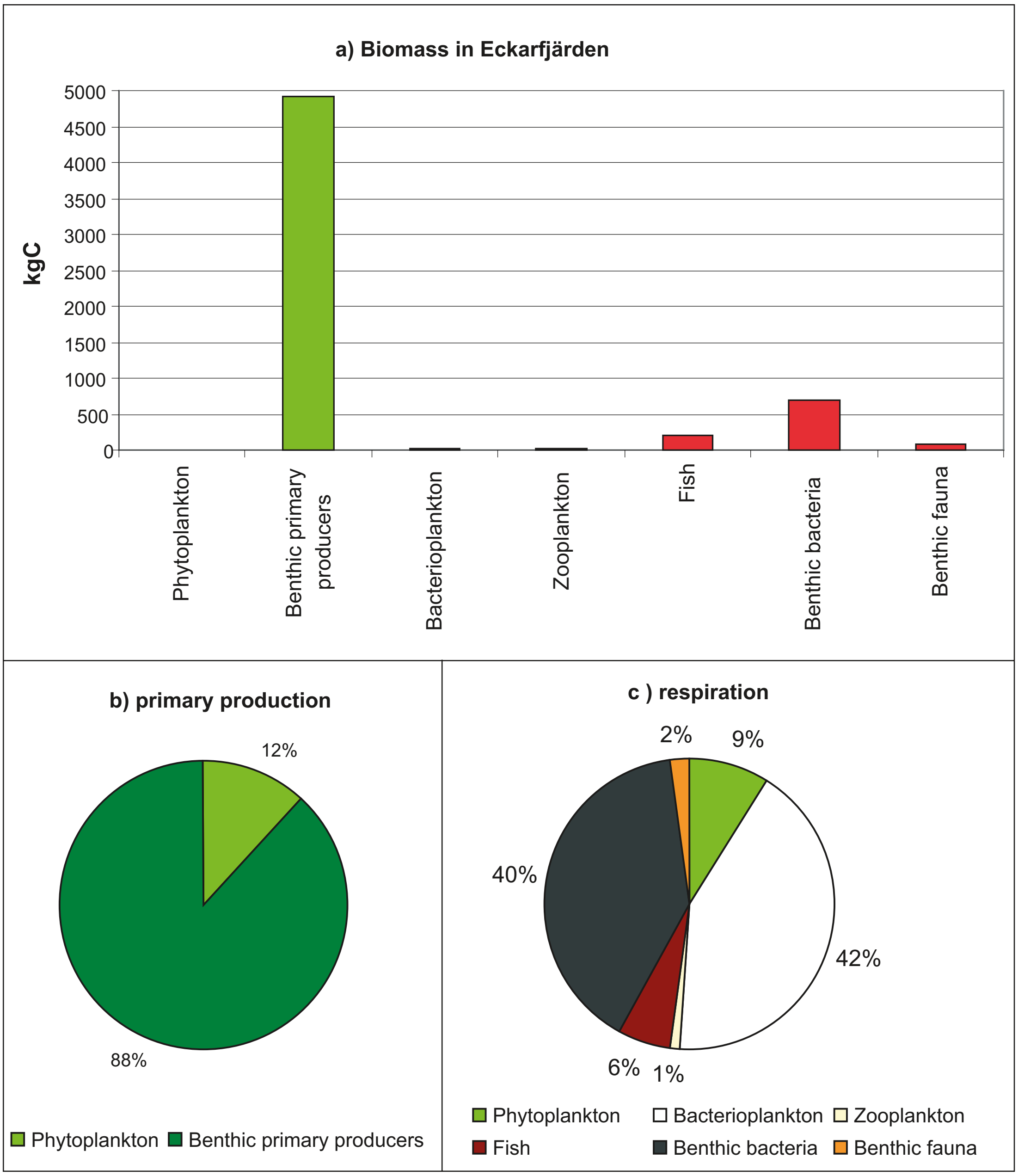


Figure 5-6. *Distribution of a) biomass, b) primary production and c) respiration among functional groups in the benthic and pelagic habitats in the ecosystem model for Eckarfjärden.*

With the food web structure and feeding rates assumed in the conceptual model, only about 7% of the carbon fixed through primary production was directly consumed by higher organisms. Instead, most carbon was consumed in the form of DOC and POC. Bacterioplankton and benthic bacteria, which are the two functional groups that consume most DOC and POC, comprise 77% of the total carbon consumption (Table 5-13). Mixotrophic phytoplankton comprised another 11% of the total carbon consumption in the lake, whereas fish, benthic fauna and zooplankton represented only a small fraction of the total carbon consumption. Many organisms are sustained by carbon from adjacent habitats, for example the pelagic habitat needs support from the littoral habitat. To sustain bacterioplankton, DOC produced by primary producers in the littoral needs to be used. To sustain mixotrophic phytoplankton, benthic bacteria from the top of the microbial mat in the littoral habitat need to be utilized. Fish are mainly composed of species/sizes feeding on benthic fauna from the littoral habitat. In turn, the pelagic habitat contributes POC to the littoral habitat. The largest carbon flow to the top predator fish goes from benthic primary producers via benthic fauna to fish (Figure 5-7).

Table 5-13. Total mean biomass (kg C) and annual metabolic rates (kg C y⁻¹) of functional groups in Eckarfjärden. Phytoplankton includes both autotrophic and mixotrophic species, so net primary production, heterotrophic respiration and consumption have been reported.

Functional group	Biomass kg C	 %	Net Prim. Prod. kg C y⁻¹	 %	Respiration kg C y⁻¹	 %	Consumption kg C y⁻¹	 %
Pelagic habitat	**239**	4	**3,670**	12	**12,220**	58	**18,411**	52
Phytoplankton	9	<1	3,670	12	1,900	9	3,800	11
Bacterioplankton	12	<1			8,876	42	11,800	33
Zooplankton	15	<1			235	1	719	2
Fish	203	3			1,209	6	2,092	6
Littoral habitat	**5,683**	96	**26,900**	88	**8,878**	42	**17,272**	48
B. primary producers	4,910	83	26,900	88				
B. bacteria	693	12			8,421	40	15,900	44
Benthic fauna	80	1			457	2	1,372	4
Total	**5,922**		**30,570**		**21,099**		**35,683**	

On an annual basis, all organisms with the exception of benthic fauna show a carbon excess when grazing is subtracted from production/consumption. As the abundance of benthic fauna is similar from year to year, it is clear that the assumed feeding pressure on benthic fauna is somewhat overestimated by the model. Assuming a small change in the food choice of fish and that a larger share of the fish consumption consists of zooplankton, the benthic fauna will also show carbon excess.

The carbon excess will contribute to sediment accumulation in the lake, as well as to outflow through the outlet. Using the calculated values in the mass balance for carbon influx (influx via water and carbon deposition) and carbon outflux (outflux through outlet, sediment accumulation, and bird consumption), the ecosystem carbon model for Eckarfjärden has a shortage of c. 1,100 kg carbon. However, this mismatch is small compared with the flows of carbon in the model. For example it constitutes only 3 and 5% of total primary production and respiration, respectively.

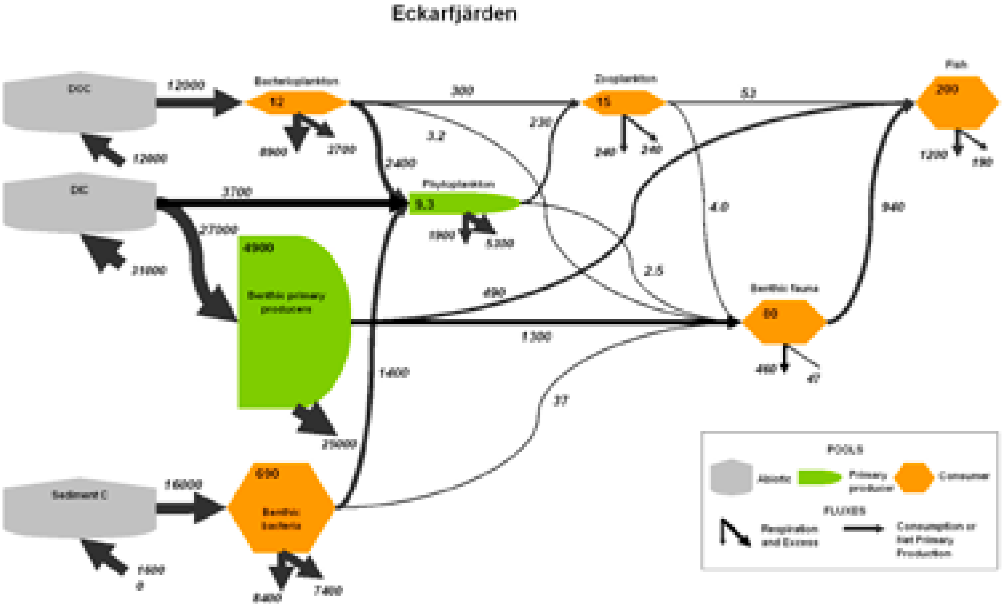


Figure 5-7. Carbon flow (kg C y⁻¹) in the ecosystem model for Eckarfjärden. Sizes of arrows and boxes for biota are scaled relative to each other. The consumption of phyto-, zoo- and bacterioplankton by benthic fauna is included in the consumption of sediment carbon in the figure. Note that consumption within the same functional group is not shown, e.g. the consumption of fish by carnivorous fish.

Bolundsfjärden

Bolundsfjärden is the largest lake in the Forsmark area, with an area about 3 times larger than Eckarfjärden (Figure 5-8). It is somewhat shallower than Eckarfjärden (maximum depth 1.8 m) and is situated near sea level (0.64 m.a.s.l.). Under extreme weather conditions, brackish water enters the lake from the sea. The water is therefore sometimes more brackish than what is normal for limnic conditions. Bolundsfjärden is a clear-water lake surrounded by reed and with bottoms covered by the macroalgae *Chara sp.* and a thick microbial mat.

Mass balance

According to the mass balance for Bolundsfjärden, the influx of carbon to the lake is dominated by the DIC and TOC inflow from the catchment (32,000 and 22,500 kg C y^{-1}, respectively) (Figure 5-9). Atmospheric deposition of dissolved organic carbon (500 kg C y^{-1}) makes only a small contribution to the carbon influx to the lake. The major outflux of carbon is the downstream flow of DIC and TOC (32,000 and 21,900 kg C y^{-1}, respectively), followed by carbon accumulation in the sediments (9,000 kg C y^{-1}), whereas the outflux by birds feeding in the lake (700 kg C y^{-1}) is of minor importance.

The flux of carbon dioxide across the lake-air interface is negative, indicating an uptake of about 2,800 kg C y^{-1} and a net autotrophic metabolism.

There is an imbalance in the mass balance: the outflux exceeds the influx by 5,400 kg C y^{-1}. This corresponds to 10 and 9% of the total carbon influx and outflux, respectively. The imbalance in the mass balance can therefore be considered small.

Figure 5-8. *Lake Bolundsfjärden is the largest lake in the Forsmark area. The smaller lake at the front edge is Lake Graven.*

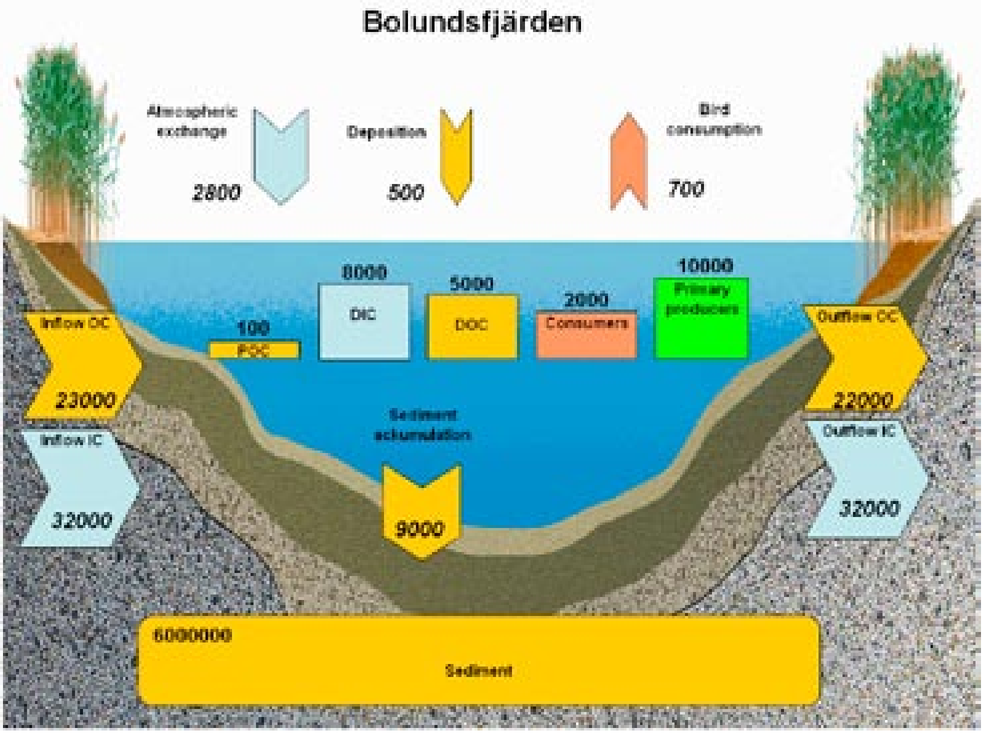


Figure 5-9. Carbon mass balance for Bolundsfjärden, components in kg C, and fluxes in kg C y^{-1}.

Ecosystem carbon model

Based on the conceptual model, the annual mean *biomass* in Bolundsfjärden is estimated to be 12,600 kg C and is concentrated in the littoral habitat (97% of the total biomass, Figure 5-10a, Table 5-14). Primary producers make up the major part of the total biomass in the lake, and the dominant functional group is benthic primary producers (comprising 84% of the total biomass). Benthic bacteria comprise 12% of the total biomass, while each of the other functional groups comprises 2% or less of total biomass.

According to the model, *primary production* is 63,700 kg C y^{-1} and it is concentrated in the littoral habitat, where benthic primary producers comprise 91% of the total primary production (Figure 5-10b, Table 5-14).

According to the model, annual *respiration* (37,000 kg C y^{-1}) is less than primary production. In contrast to primary production, a large part of the respiration occurs in the pelagic habitat (48%). The most important functional groups in terms of respiration are benthic bacteria (49%), followed by bacterioplankton (34%) and mixotrophic phytoplankton (8%, Figure 5-10c, Table 5-14).

With the food web structure and feeding rates assumed in the conceptual model, only about 8% of the carbon fixed through primary production is directly consumed by higher organisms. Instead, most carbon is consumed in the form of DOC and POC. Bacterioplankton and benthic bacteria, which are the two functional groups that consume most DOC and POC, comprise 79% of the total carbon consumption. Mixotrophic phytoplankton makes up another 9% of the total consumption, whereas fish, benthic fauna and zooplankton represent only a minor share of the total carbon consumption in the lake. Many organisms get part of their food supply from other habitats than the habitat where they live. For example, organisms in the pelagic habitat are dependent on carbon produced in the littoral habitat. To sustain bacterioplankton, DOC produced by primary producers in the littoral needs to be used. To sustain mixotrophic phytoplankton, benthic bacteria from the top of the microbial mat in the littoral habitat need to be

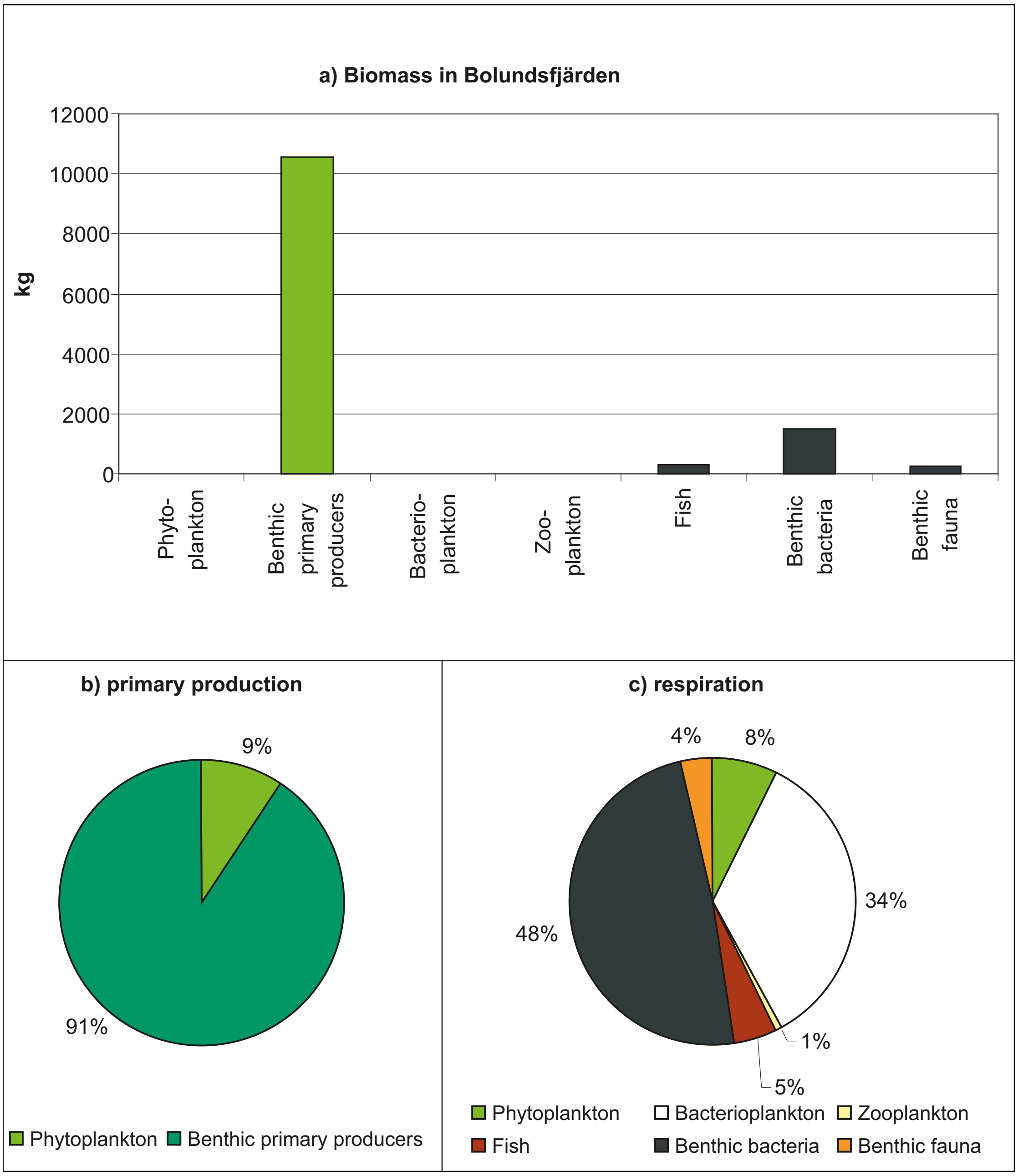


Figure 5-10. *Distribution of a) biomass, b) primary production and c) respiration among functional groups in the benthic and pelagic habitats in the ecosystem model of Bolundsfjärden.*

utilized. Fish feed to a large extent on benthic fauna from the littoral habitat. In turn, the pelagic habitat contributes POC to the littoral habitat. The largest carbon flow to the top predator fish goes from benthic primary producers via benthic fauna to fish (Figure 5-11).

On an annual basis, all organisms show a carbon excess when grazing is subtracted from production/consumption. The carbon excess will contribute to sediment accumulation in the lake, as well as to outflow through the outlet. Using the calculated values in the mass balance for carbon influx (influx via water and carbon deposition) and carbon outflux (outflux through outlet, sediment accumulation, and bird consumption), the ecosystem carbon model for Bolundsfjärden still has an excess of c. 18,100 kg C y^{-1}. This excess is larger for Bolundsfjärden than for e.g. Eckarfjärden, and it is also relatively large compared with the total primary production (28%) and respiration (29%) in Bolundsfjärden.

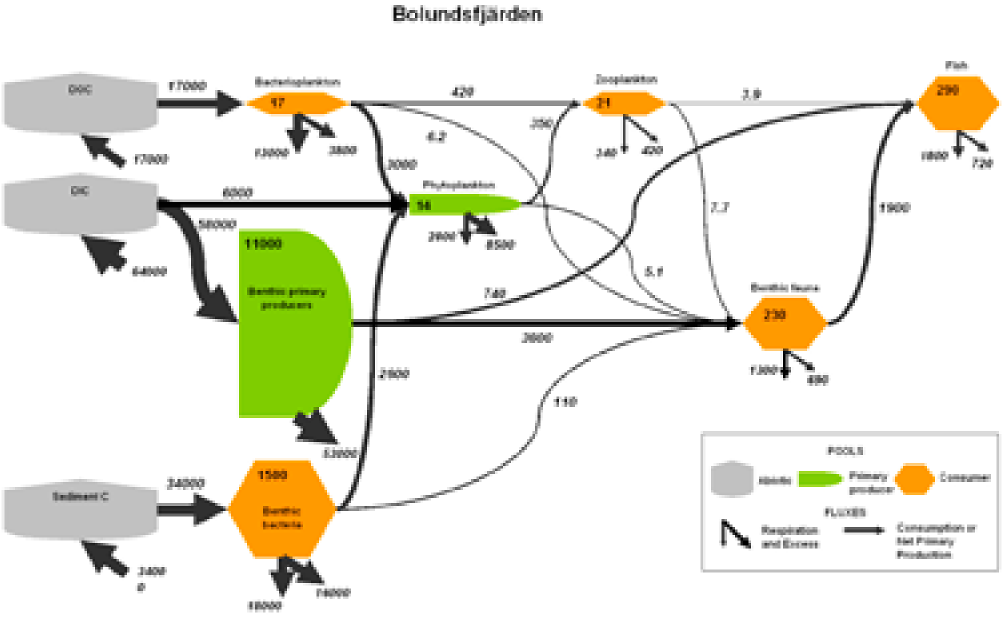


Figure 5-11. *Carbon flow (kg C y^{-1}) in the ecosystem model for Bolundsfjärden. Sizes of arrows and boxes for biota are scaled relative to each other. The consumption of phyto-, zoo- and bacterioplankton by benthic fauna is included in the consumption of sediment carbon in the figure. Note that consumption within the same functional group is not shown, e.g. the consumption of fish by carnivorous fish.*

Table 5-14. Total mean biomass (kg C) and annual metabolic rates (kg C y^{-1}) of functional groups in Bolundsfjärden. Phytoplankton includes both autotrophic and mixotrophic species, so net primary production, heterotrophic respiration and consumption have been reported.

Functional group	Biomass		Net Prim. Prod.		Respiration		Consumption	
	kg C	%	kg C y^{-1}	%	kg C y^{-1}	%	kg C y^{-1}	%
Pelagic habitat	**348**	3	**6,034**	9	**17,628**	48	**26,669**	41
Phytoplankton	14	<1	6,034	9	2,825	8	5,650	9
Bacterioplankton	17	<1			12,699	34	16,932	26
Zooplankton	21	<1			337	1	1,029	2
Fish	294	2			1,768	5	3,059	5
Littoral habitat	**12,256**	97	**57,698**	91	**19,395**	52	**38,007**	59
B. primary producers	10,540	84	57,698	91				
B. bacteria	1,487	12			18,072	49	34,037	53
Benthic fauna	229	2			1,323	4	3,970	6
Total	**12,604**		**63,732**		**37,023**		**64,676**	

Gunnarsbo-Lillfjärden

Gunnarsbo-Lillfjärden (south basin) is one of the smaller lakes in the area (0.03 km^2), although its maximum depth is relatively deep, 2.2 m. The lake is situated 1.6 m.a.s.l. Gunnarsbo-Lillfjärden is a clear-water lake surrounded by reed and with bottoms covered by the macroalgae *Chara sp*. and a thick microbial mat. A high proportion of fish species resistant to low oxygen conditions indicates that low oxygen conditions prevail in the winter.

Mass balance

According to the mass balance for Gunnarsbo-Lillfjärden, the influx of carbon to the lake is strongly dominated by DIC inflow via water (26,700 kg C y^{-1}, c. 67% of total influx) (Figure 5-12). The second largest influx is TOC inflow via water (13,100 kg C y^{-1}). In comparison, the carbon influx by atmospheric deposition (22 kg C y^{-1}) is negligible. The major outflux of carbon is the downstream flow of DIC (26,200 kg C y^{-1}, c. 64% of total outflow) followed by TOC outflow via water (13,100 kg C y^{-1}), while carbon accumulation in the sediments (400 kg C y^{-1}) and birds feeding on fish (30 kg C y^{-1}) are of less magnitude.

The flux of carbon dioxide across the lake-air interface is positive, indicating an outflow of about 1,400 kg C y^{-1} and a net heterotrophic metabolism.

There is a small imbalance in the mass balance in that outflux exceeds influx by 3,200 kg C y^{-1}. This corresponds to 2% of the total carbon outflux and 2% of the total carbon influx; hence, the imbalance can be considered small.

Ecosystem carbon model

Based on the conceptual model, the annual mean *biomass* in Gunnarsbo-Lillfjärden is estimated to be 560 kg C and is concentrated in the littoral habitat. Only 4% of the biomass occurs in the pelagic habitat (Figure 5-13a). Benthic primary producers comprise 83% of the total biomass and benthic bacteria comprise 12%. The other functional groups comprise 3% or less of the total mean biomass. Benthic primary producers constitute 92% of the total *primary production* (2,800 kg C y^{-1}) (Figure 5-13b, Table 5-15).

According to the model, *respiration* (1,800 kg C y^{-1}) is smaller than primary production, indicating net autotrophic conditions in the lake. The respiration is almost evenly distributed between the pelagic and littoral habitats, with 53% of the respiration occurring in the pelagic habitat. The most important functional groups in terms of respiration are benthic bacteria and bacterioplankton, comprising 45 and 39% of total respiration, respectively (Figure 5-13c, Table 5-15).

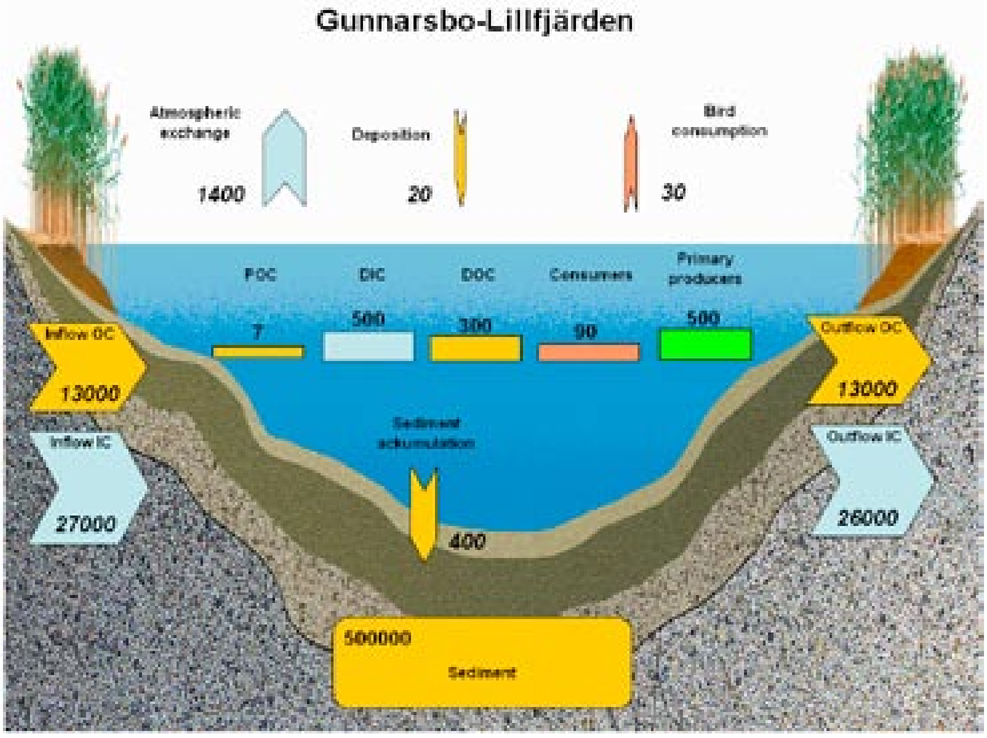


Figure 5-12. *Carbon mass balance for Gunnarsbo-Lillfjärden, components in kg C, and fluxes in kg C y^{-1}.*

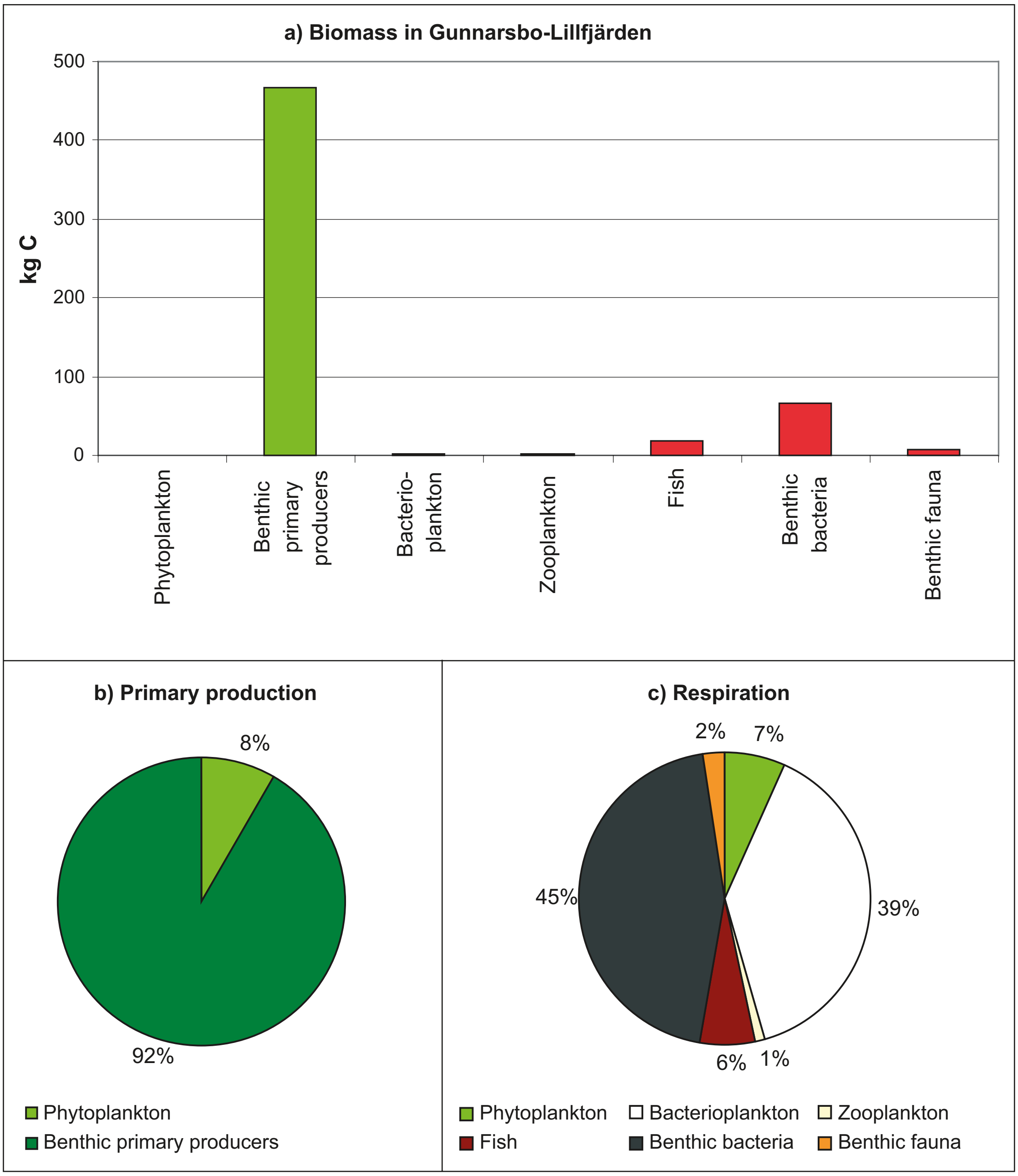


Figure 5-13. *Distribution of a) biomass, b) primary production and c) respiration among functional groups in the benthic and pelagic habitats in the ecosystem model of Gunnarsbo-Lillfjärden.*

With the food web structure and feeding rates assumed in the conceptual model, only about 7% of the carbon fixed through primary production is consumed by higher organisms. Instead, most carbon is transferred via the pools of DOC and POC. Bacterioplankton and benthic bacteria, which are the two functional groups that consume most DOC and POC, comprise 80% of the total carbon consumption (Table 5-15). Mixotrophic phytoplankton comprises 8% of the total consumption and fish comprises 6% of the total consumption. All other functional groups comprise 4% or less of the total consumption. Many organisms feed from adjacent habitats, for example fish feed to a large extent on benthic fauna from the littoral habitat. In turn, the pelagic habitat contributes POC to the littoral habitat. The largest carbon flow to the top predator fish goes from benthic primary producers via benthic fauna to fish (Figure 5-14).

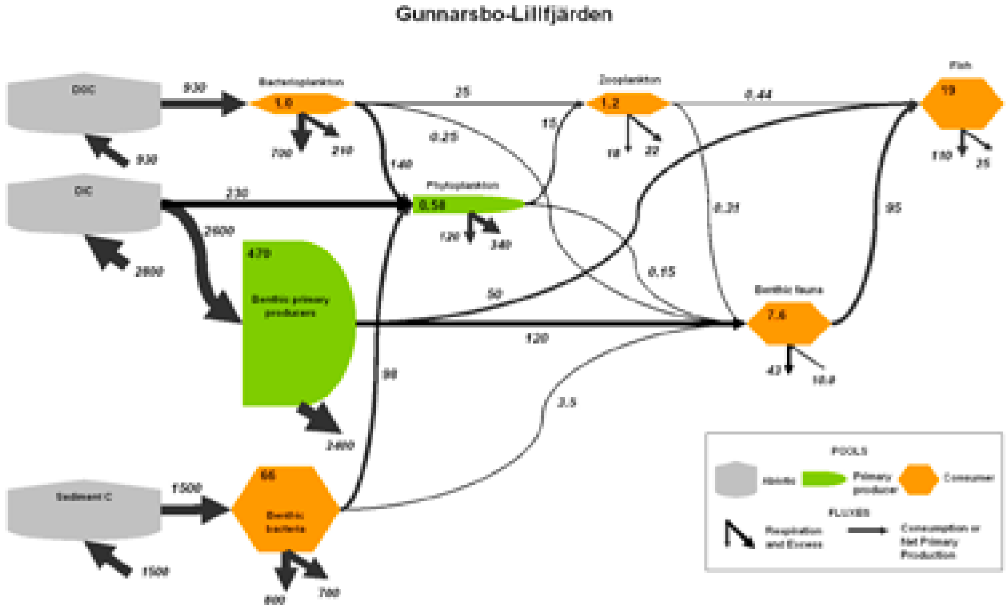


Figure 5-14. *Carbon flow (kg C* y^{-1}*) in the ecosystem model for Gunnarsbo-Lillfjärden. Sizes of arrows and boxes for biota are scaled relative to each other. The consumption of phyto-, zoo- and bacterioplankton by benthic fauna is included in the consumption of sediment carbon in the figure. Note that consumption within the same functional group is not shown, e.g. the consumption of fish by carnivorous fish.*

On an annual basis, all organisms with the exception of benthic fauna show a carbon excess when grazing is subtracted from production/consumption. As the abundance of benthic fauna is similar from year to year, it is clear that the assumed feeding pressure on benthic fauna is somewhat overestimated by the model. Assuming a small change in the food choice of fish and that a larger share of the fish consumption consists of zooplankton, the benthic fauna will also show carbon excess. The carbon excess will contribute to the sediment accumulation in the lake as well as outflow through the outlet or to the atmosphere. Using the calculated values in the mass balance for carbon influx (influx via water and deposition directly on lake surface) and carbon outflux (outflow through outlet, sediment accumulation, and bird consumption), the ecosystem carbon model for Gunnarsbo-Lillfjärden still shows an excess of c. 2,600 kg C y^{-1}.

Table 5-15. Total mean biomass (kg C) and annual metabolic rates (kg C y⁻¹) of functional groups in Gunnarsbo-Lillfjärden. Phytoplankton includes both autotrophic and mixotrophic species, so net primary production, heterotrophic respiration and consumption have been reported.

Functional group	Biomass		Net Prim. Prod.		Respiration		Consumption	
	kg C	%	kg C y^{-1}	%	kg C y^{-1}	%	kg C y^{-1}	%
Pelagic habitat								
Phytoplankton	1	0.1	232	8	120	7	240	8
Bacterioplankton	1	0.2			696	39	928	30
Zooplankton	1	0.2			18	1	56	2
Fish	19	3			112	6	194	6
Littoral habitat								
B. primary producers	467	83	2,557	92				
B. bacteria	66	12			801	45	1,508	49
Benthic fauna	8	1			43	2	130	4
Total	**562**		**2,789**		**1,791**		**3,058**	

Compared with total primary production and respiration, this excess is large (92 and 143%, respectively). Compared with the inflow and outflow via inlet and outlet, on the other hand, the excess is relatively small (6 and 7% of inflow and outflow via water, respectively). Thus, the models are very sensitive to the fluxes to and from the lake, whereas the in-lake processes have a minor impact on the result.

Labboträsket

Labboträsket is one of the smaller lakes in the Forsmark area, with an area about 10% of the area of Bolundsfjärden. It is much shallower than the two larger lakes: maximum depth is 1.1 m. Labboträsket is situated 3.56 m.a.s.l. Labboträsket is a clear-water lake surrounded by reed and with bottoms covered by the macroalgae *Chara sp*. In contrast to the three Forsmark lakes described above, Labboträsket lacks a microbial mat. Long periods with low oxygen conditions occur in the winter.

Mass balance

According to the mass balance for Labboträsket, the influx of carbon to the lake is dominated by the DIC and TOC from the catchment (19,200 and 9,200 kg C y^{-1}, respectively) (Figure 5-15). By comparison, the carbon influx by atmospheric deposition (3 kg C y^{-1}) is negligible. The major outflux of carbon is the downstream flow of DIC and TOC (21,000 and 9,500 kg C y^{-1}, respectively), while carbon accumulation in the sediments (45 kg C y^{-1}) and birds feeding on fish (4 kg C y^{-1}) are of less magnitude.

The flux of carbon dioxide across the lake-air interface is positive, indicating an outflux of about 400 kg C y^{-1} and a net heterotrophic metabolism.

There is a small imbalance in the mass balance in that outflux exceeds influx by 2,600 kg C y^{-1}. This corresponds to 8% of the total carbon outflux and 9 % of the total carbon influx; hence, the imbalance can be considered small.

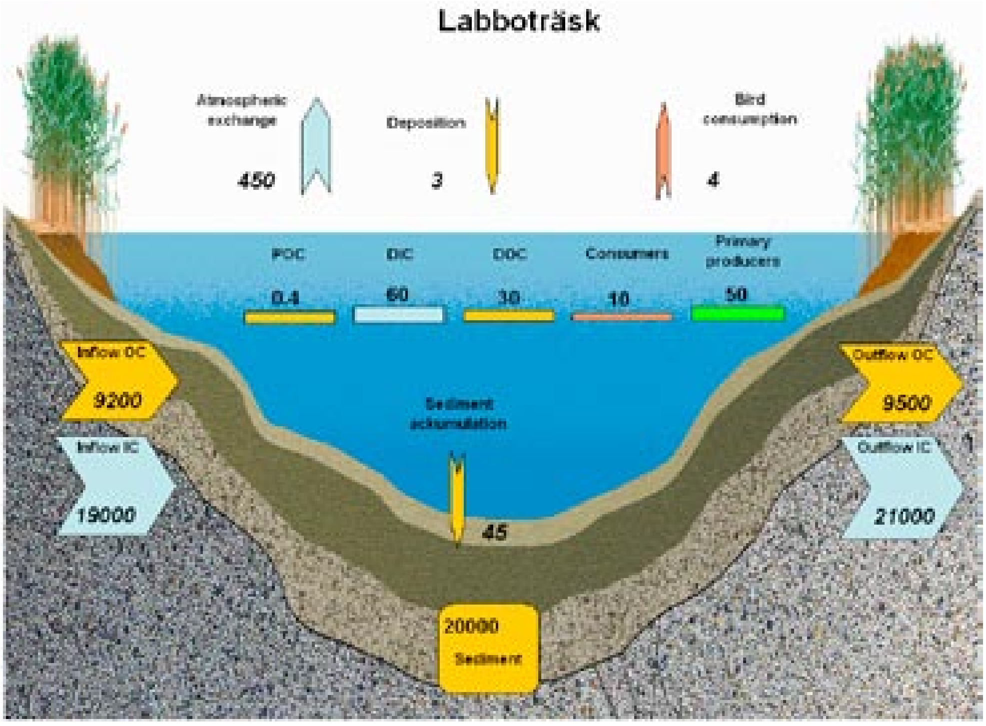


Figure 5-15. *Carbon mass balance for Labboträsket (kg C y^{-1}).*

Ecosystem carbon model

Based on the conceptual model, the annual mean *biomass* in Labboträsket is estimated to be 60 kg C and is concentrated in the littoral habitat. Only 3% of the biomass occurs in the pelagic habitat (Figure 5-16a). Benthic primary producers comprise 82% of the total biomass and benthic bacteria comprise 14%. The other functional groups constitute 2% or less of the total mean biomass. Benthic primary producers comprise 91% of the total *primary production* of 209 kg C y^{-1} (Figure 5-16b, Table 5-16).

According to the model, respiration (193 kg C y^{-1}) is similar in magnitude to primary production. The respiration is almost evenly distributed between the pelagic and littoral habitats, with 46% occurring in the pelagic habitat. The most important functional groups in terms of respiration are benthic bacteria and bacterioplankton, comprising 51 and 36% of total respiration, respectively (Figure 5-16c, Table 5-16).

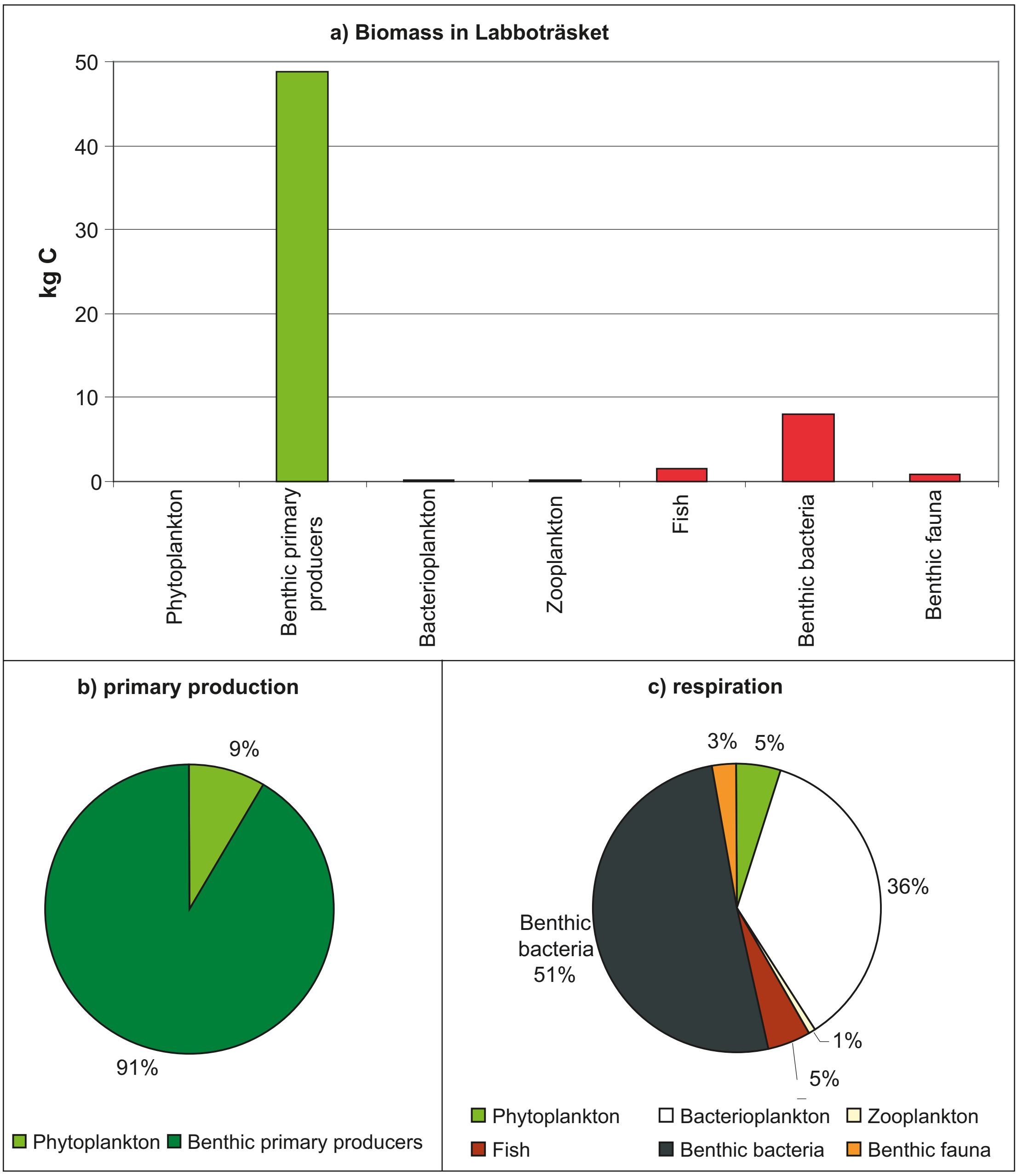


Figure 5-16. *Distribution of a) biomass, b) primary production and c) respiration among functional groups in the benthic and pelagic habitats in the ecosystem model of Labboträsket.*

With the food web structure and feeding rates assumed in the conceptual model, only about 10% of the carbon fixed through primary production is consumed by higher organisms. Instead, most carbon is transferred via the pools of DOC and POC. Bacterioplankton and benthic bacteria, which are the two functional groups that consume most DOC and POC, comprise 84% of the total carbon consumption (Table 5-16). All other functional groups comprise 6% or less of the total consumption. Many organisms feed from adjacent habitats, e.g. fish consist to a large extent of individuals feeding on benthic fauna from the littoral habitat. In turn, the pelagic habitat contributes POC to the littoral habitat. The largest carbon flow to the top predator fish goes from benthic primary producers via benthic fauna to fish (Figure 5-17).

Table 5-16. Total mean biomass (kg C) and annual metabolic rates (kg C y^{-1}) of functional groups in Labbotråsket. Phytoplankton includes both autotrophic and mixotrophic species, so net primary production, heterotrophic respiration and consumption have been reported.

Functional group	Biomass		Net Prim. Prod.		Respiration		Consumption	
	kg C	%	kg C y^{-1}	%	kg C y^{-1}	%	kg C y^{-1}	%
Pelagic habitat	**2**	3	**18**	9	**89**	46	**132**	40
Phytoplankton	<1	<1	18	9	10	5	19	6
Bacterioplankton	<1	<1			69	36	92	28
Zooplankton	<1	<1			2	1	6	2
Fish	1.5	3			9	5	15	5
Littoral habitat	**58**	97	**190**	91	**104**	54	**206**	60
B. primary producers	49	82	190	91				
B. bacteria	8	14			98	51	190	56
Benthic fauna	1	2			5	3	16	5
Total	**60**		**208**		**193**		**338**	

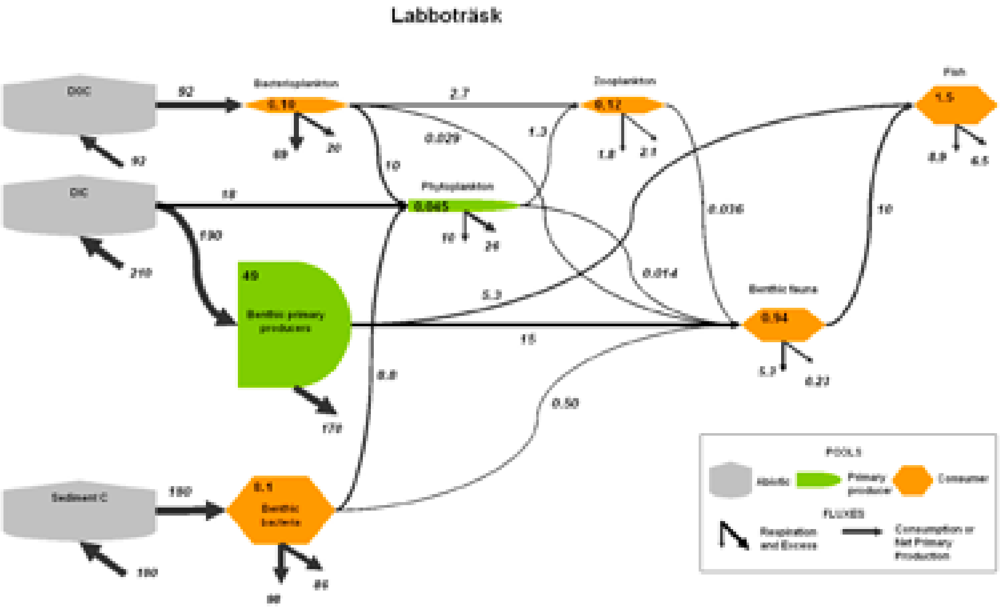


Figure 5-17. Carbon flow (kg C y^{-1}) in the ecosystem model for Labbotråsket. Sizes of arrows and boxes for biota are scaled relative to each other. The consumption of phyto-, zoo- and bacterioplankton by benthic fauna is included in the consumption of sediment carbon in the figure. Note that consumption within the same functional group is not shown, e.g. the consumption of fish by carnivorous fish.

On an annual basis, all organisms show a carbon excess when grazing is subtracted from production/consumption. The carbon excess will contribute to the sediment accumulation in the lake as well as outflow through the outlet or to the atmosphere. Using the calculated values in the mass balance for carbon influx (influx via water and carbon deposition) and carbon outflux (outflux via water, sediment accumulation, and bird consumption), the ecosystem carbon model for Labboträsket has a deficit of c. 2,100 kg C y^{-1}. Compared with total primary production and respiration, this deficit is very large (1,000% and 1,100%, respectively). Compared with the inflow and outflow via inlet and outlet, on the other hand, the shortage is small, only 8 and 7%, respectively. This illustrates that the lake model is very sensitive to the flows to and from the lake, whereas the in-lake processes have a minor impact on the main result.

5.4.2 Lakes in Laxemar-Simpevarp

Frisksjön

Frisksjön is shallow and of medium size compared to other lakes in the region. It is situated 1.37 m.a.s.l. and is humic-rich with strongly coloured water (Figure 5-18).

Mass balance

According to the mass balance, the largest influx of carbon to Frisksjön is the inflow of TOC via water (8,300 kg C y^{-1}, Figure 5-19). The most important carbon outflux from Frisksjön is sediment accumulation (8,000 kg C y^{-1}). Other important outfluxes are the emission of carbon dioxide to the atmosphere (4,500 kg C y^{-1}), followed by the downstream outflow of TOC (4,300 kg C y^{-1}). Other carbon fluxes, such as DIC inflow and outflow via water, atmospheric wet deposition and bird consumption in the lake, are of minor importance.

Figure 5-18. *Frisksjön in Laxemar-Simpevarp.*

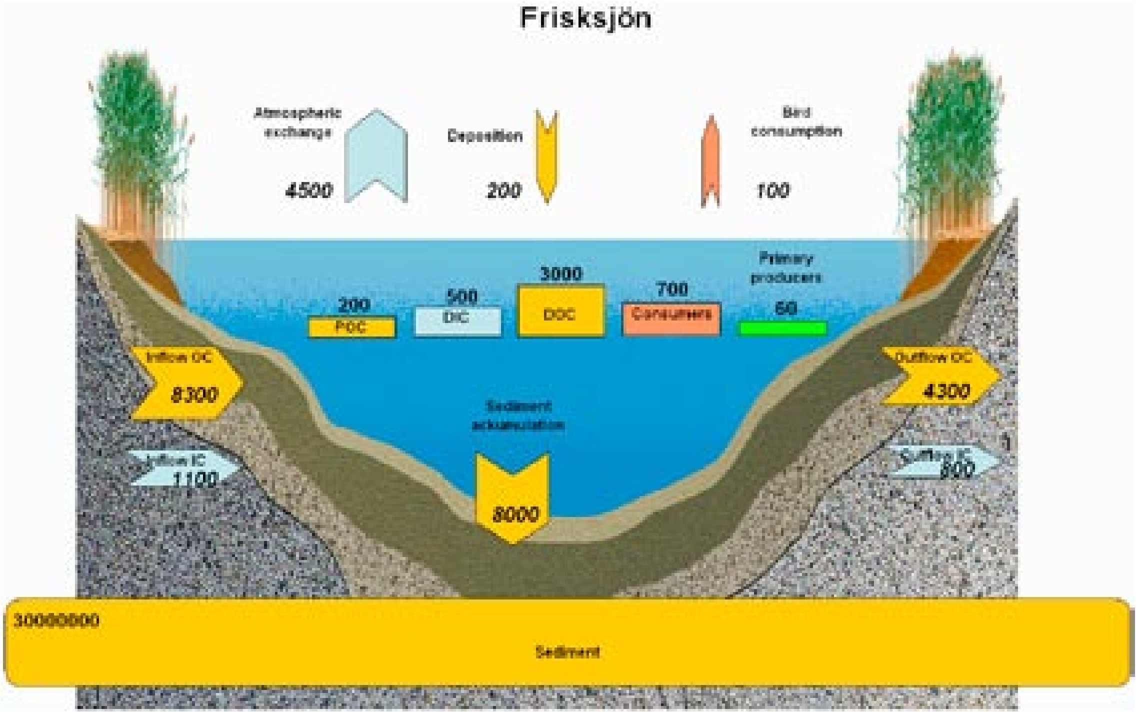


Figure 5-19. *Carbon mass balance for Frisksjön (kg C y^{-1}).*

There is a positive flux of carbon dioxide across the lake-air interface of 4,500 kg C y^{-1}, indicating a net heterotrophic metabolism. This is in agreement with the results of the carbon ecosystem model of Frisksjön, which show much higher respiration than primary production.

The mass balance is heavily imbalanced with 8,100 kg C y^{-1} lower influx than outflux of carbon. This corresponds to 85% of total carbon influxes or 46% of total carbon outfluxes. There is a large uncertainty in some of the fluxes, especially the larger fluxes: TOC inflow, CO_2 emission and sediment accumulation. If values in the higher range of TOC inflow from the catchment and values in the lower range of sediment accumulation and CO_2 emission are used, the mass balance will instead indicate higher influx than outflux of carbon. Thus, the wide span in estimates of different parameters leads to uncertainties in the mass balance, and the calculated flows should be seen as indicators of magnitude rather than absolute numbers.

Ecosystem carbon model

Based on the conceptual model, the annual mean *biomass* in Frisksjön is estimated to be 750 kg C and the biomass is concentrated in the littoral and profundal habitat. Benthic bacteria is the dominant functional group (73% of total biomass), followed by phytoplankton, fish and benthic fauna (7–8% each of total biomass), while the other functional groups each contributed 3% or less to the total biomass (Figure 5-20a, Table 5-17).

According to the model, annual *primary production* is 4,300 kg C y^{-1} and is totally dominated by phytoplankton production. Benthic primary producers accounted for less than 1% of primary production (Table 5-17). Annual *respiration* is 12,600 kg C y^{-1} and is thus much higher than primary production, indicating a negative net ecosystem production (NEP). Despite the low biomass in the pelagic habitat (20% of total biomass), a large share of total respiration occurs there (46% of total respiration). Benthic bacteria contribute most to total respiration (52%) followed by bacterioplankton (26%) and mixotrophic phytoplankton (12%) (Figure 5-20b). All other functional groups each contribute 5% or less to total respiration.

With the food web structure and feeding rates assumed in the conceptual model, a relatively large portion (c. 34%) of the carbon fixed through primary production is directly *consumed* by higher organisms. Thus, any radionuclides incorporated into the food web through primary production may be transported upwards in the food chain. The rest of the primary produced carbon is incorporated into the DOC and POC pools. Bacterioplankton and benthic bacteria, the two functional groups that consume most DOC and POC, comprise 67% of the total carbon consumption in the lake (Figure 5-20c, Table 5-17). DOC and POC consumption by bacteria is larger than primary production, which means the lake is dependent on allochtonous carbon entering the lake from the catchment.

Carbon is transported to the top predator fish mainly through benthic bacteria via benthic fauna to fish (Figure 5-21). When grazing is subtracted from production/consumption for the different functional groups on an annual basis, most groups show a carbon excess. The exceptions are fish, bacterioplankton and macrophytes which all show a small carbon deficit. Obviously, these

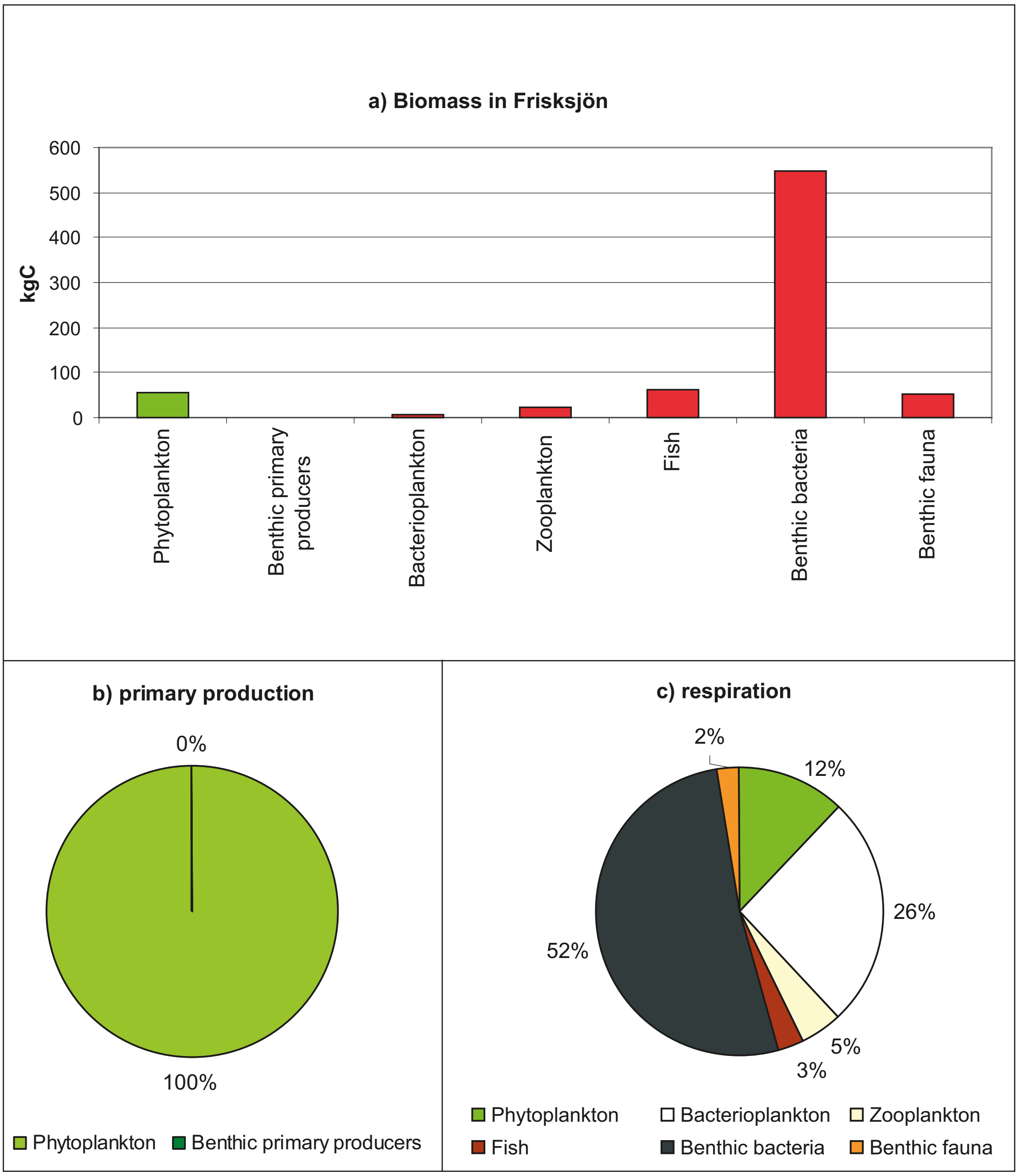


***Figure 5-20.** Distribution of a) biomass, b) respiration and c) consumption among functional groups in the benthic and pelagic habitats in the ecosystem model of Frisksjön.*

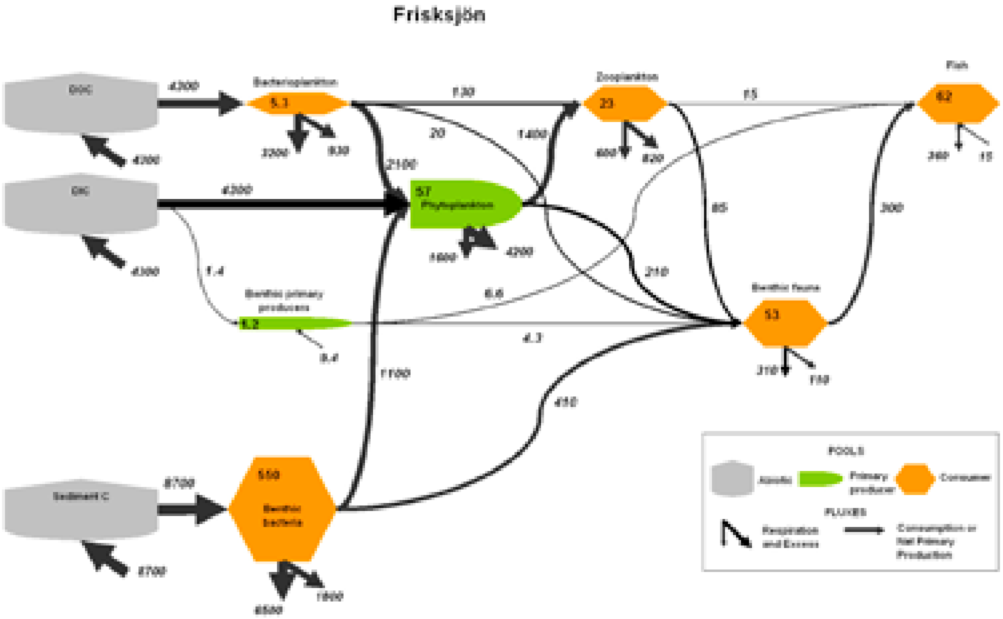


Figure 5-21. *Carbon flow (kg C y^{-1}) in the ecosystem model for Frisksjön. Sizes of arrows and boxes for biota are scaled relative to each other. The consumption of phyto-, zoo- and bacterioplankton by benthic fauna is included in the consumption of sediment carbon in the figure. Note that consumption within the same functional group is not shown, e.g. the consumption of fish by carnivorous fish.*

Table 5-17. Total mean biomass (kg C) and annual metabolic rates (kg C y^{-1}) of functional groups in Frisksjön. Phytoplankton includes both autotrophic and mixotrophic species and, hence, net primary production, heterotrophic respiration and consumption has been reported.

Functional group	Biomass		Net Prim. Prod.		Respiration		Consumption	
	kg C	%	kg C y^{-1}	%	kg C y^{-1}	%	kg C y^{-1}	%
Pelagic habitat	**147**	20	**4,291**	100	**5,744**	46	**9,839**	51
Phytoplankton	57	8	4,291	100	1,553	12	3,105	16
Bacterioplankton	5	1			3,233	26	4,310	22
Zooplankton	23	3			603	5	1,809	9
Fish	62	8			355	3	615	3
Littoral and profundal	**602**	80	**1**	0.03	**6,846**	54	**9,641**	49
B. primary producers	1	0.2	1	0.03				
B. bacteria	547	73			6,539	52	8,718	45
Benthic fauna	53	7			308	2	923	5
Total	**749**		**4,292**		**12,590**		**19,480**	

functional groups will not go extinct but some assumptions in the model may be inaccurate. For example, if the food choice of carnivorous fish is altered by assuming more grazing of zooplankton and benthic fauna, fish will also show carbon excess.

Theoretically, on an annual basis, the result of subtracting grazing from production/consumption for all functional groups should give rise to a carbon excess. The carbon excess will contribute to the sediment accumulation in the lake, as well as to outflow through the outlet or to the atmosphere. When the calculated values are included in the mass balance for carbon influx (influx via water and carbon deposition) and carbon outflux (outflux via water, sediment accumulation, and bird consumption), the ecosystem carbon model for Frisksjön indicates a large deficit of c. 12,000 kg C y^{-1}. This deficit is mainly caused by the large imbalance in the mass balance and is not a measure of the robustness of the ecosystem carbon model.

5.5 Conclusions from the carbon models

5.5.1 Forsmark

In the larger lakes Eckarfjärden and Bolundsfjärden in Forsmark, the annual flows to and from the lakes are small compared to the in-lake processes, indicating that the lakes may be important sites for biogeochemical processing of carbon in the landscape (Table 5-18). Due to the great demand for inorganic carbon by primary producers and the demand for organic carbon by bacteria, there is a high probability that carbon entering the lakes will be incorporated into the food web. In the smaller lakes Labboträsket and Gunnarsbo-Lillfjärden, on the other hand, the biological processes within the lake are small compared with carbon flowing to and from the lake via inlets and outlet. For example, in Labboträsket the carbon incorporated into biota via primary production is, on an annual basis, only 2% of the flow of organic carbon via the inlet and outlet (Table 5-18). However, this may not be the case for all small lakes in the area, but the relationship between fluxes to and from the lake, and the internal processes within the lake are also affected by the relationship between lake volume and catchment area. Both Labboträsket and Gunnarsbo-Lillfjärden have relatively large carbon inflows via water, but many other small lakes in the area have more moderate influxes of carbon via water. For these lakes, internal processes may be of similar size as the fluxes to and from the lakes.

The mass balances show that the largest influx of carbon to the Forsmark lakes is the inflow via the inlets. The largest outflux is the outflow via the outlet in all lakes. However, sediment accumulation is also relatively large in Bolundsfjärden and Eckarfjärden (14 and 22% of total outflux, respectively). Thus, these lakes may function as sinks of carbon, which may be incorporated either into biota or into the sediments. In Gunnarsbo-Lillfjärden and Labboträsket, on the other hand, sediment accumulation is negligible compared with the outflow via the outlet, and the lake may be regarded as a flow-through system. There are also examples in the Forsmark area of small lakes where outflows are of small magnitude, and in these lakes sediment accumulation constitutes a relatively large portion of total outflux (for example Lake Puttan, further described in Chapter 7). That kind of lake cannot be considered a flow-through system, although the amount that may be trapped in these small lakes is small compared with the larger lakes.

In all Forsmark lakes, biomass is concentrated in the littoral habitat, where between 96% and 97% of the total biomass in the lake is found. Primary production is concentrated in the littoral habitat, where between 88% and 92% of the total primary production occurs. This is expected in the shallow hardwater lakes, where bottoms to a large extent are covered by macroalgae and benthic production may be large.

In contrast to biomass and primary production, a large part of the respiration and consumption in all four lakes occurs in the pelagic habitat. The deepest lake, Eckarfjärden, has a higher proportion of respiration in the pelagic habitat compared with the shallower lakes Bolundsfjärden, Gunnarsbo-Lillfjärden and Labboträsket. The dominant functional group in terms of respiration in Eckarfjärden is bacterioplankton, while the dominant functional group in Bolundsfjärden, Gunnarsbo-Lillfjärden and Labboträsket is benthic bacteria.

For both Eckarfjärden and Bolundsfjärden, the ecosystem models show that the dominant process within the lake is primary production, which clearly exceeds respiration. In the case of Gunnarsbo-Lillfjärden as well (the smaller lake with a microbial mat), the ecosystem model indicates that primary production is much larger than respiration. In contrast, the ecosystem model for Labboträsket (the lake lacking a microbial mat) indicates that primary production and respiration are equally important processes. The ecosystem models thus indicate that the largest impact on the net ecosystem production (NEP) is the presence of microphytobenthos in the benthic habitat. Another factor influencing the NEP is the depth of the water column, since the pelagic habitat is net heterotrophic and the benthic habitat is net autotrophic. The mass balance for the larger lakes Eckarfjärden and Bolundsfjärden show results consistent with the ecosystem models, indicating net autotrophic conditions. For both the smaller lakes Gunnarsbo-Lillfjärden and Labboträsket, the mass balances indicate net heterotrophic conditions. The ecosystem model and mass balance model for Gunnarsbo-Lillfjärden thereby does not show consistent results.

Table 5-18. Carbon flows to/from lakes compared with biotic processes and pools within the lakes for Eckarfjärden, Bolundsfjärden and Labboträsk in the Forsmark area and for Frisksjön in the Laxemar-Simpevarp area.

Flows to/from the ecosystem

	Eckarfjärden	Bolundsfjärden	Gunnarsbo-Lillfjärden	Labboträsket	Frisksjön
	kg (% of influxes/ outfluxes)	kg (% of influxes/ outfluxes)	kg (% of influxes/ outfluxes)	kg (% of influxes/ outfluxes)	kg (% of influxes/ outfluxes)
Inflow via inlet					
Organic carbon	+3,500 (+41)	+23,000 (+39)	13,100 (+33)	+9,200 (+32)	+8,300 (+87)
Inorganic carbon	+10,400 (+49)	+32,000 (+55)	26,700 (+67)	+19,200 (+68)	+1,082 (+11)
Inflow via deposition	+230 (+2)	+500 (+1)	20 (0.1)	+3 (+0.01)	+160 (+2)
Atmospheric exchange	+930 (+8)	+2,800 (+5)	–1,400 (–3)	–450 (–1)	–5,700 (–25)
Outflow via outlet					
Organic carbon	–5,700 (–35)	–22,000 (–34)	–13,100 (–32)	–9,500 (–31)	–4,300 (–24)
Inorganic carbon	–6,800 (–41)	–32,000 (–50)	–26,200 (–64)	–21,000 (–68)	–800 (–5)
Sediment accumulation	–3,650 (–22)	–9,000 (–14)	–400 (–1)	–45 (–0.1)	–8,000 (–45)
Bird consumption	–300 (–2)	–700 (–1)	–30 (–0.1)	–4 (–0.01)	–100 (–1)
Total influxes	15,100	58,300	39,800	28,400	9,600
Total outfluxes	16,500	63,700	41,100	31,000	17,700

Processes within the ecosystems

	Eckarfjärden	Bolundsfjärden	Gunnarsbo-Lillfjärden	Labboträsket	Frisksjön
	kg C y^{-1}	kg C y^{-1}	kg C y^{-1}	kg C y^{-1}	kg C y^{-1}
Primary production	30,600	63,700	2,800	209	4,300
Respiration	21,100	37,000	1,800	193	12,600

Biotic and abiotic pools in the ecosystem

	Eckarfjärden	Bolundsfjärden	Gunnarsbo-Lillfjärden	Labboträsket	Frisksjön
	kg C (% of total)	kg C (% of total)	kg C (% of total)	kg C (% of total)	kg C (% of total)
Primary producers	5×10^3 (0.1)	1×10^4 (0.2)	5×10^2 (0.1)	5×10^1 (0.2)	6×10^1 (0.0002)
Consumers	1×10^3 (0.02)	2×10^3 (0.03)	9×10^1 (0.02)	1×10^1 (0.05)	7×10^2 (0.003)
DIC	6×10^3 (0.1)	8×10^3 (0.1)	5×10^2 (0.1)	6×10^1 (0.3)	5×10^2 (0.002)
DOC	4×10^3 (0.1)	5×10^3 (0.1)	3×10^2 (0.1)	3×10^1 (0.1)	3×10^3 (0.01)
POC	1×10^2 (0.002)	1×10^2 (0.002)	7×10^0 (0.001)	4×10^{-1} (0.002)	2×10^2 (0.001)
Sediment carbon	6×10^6 (99.7)	6×10^6 (99.6)	5×10^5 (99.7)	2×10^4 (99.4)	3×10^7 (99.99)

The mass balances indicate that the relative sizes of primary production and respiration are not the same in the smaller and larger lakes, as both the smaller lakes show net heterotrophic conditions. Moreover, many of the smaller lakes in the area have lower chlorophyll *a* concentrations than the larger lakes, which may be an indication of lower primary production in the smaller lakes and a lower net ecosystem production.

Most of the primary produced carbon in the lakes is incorporated into the DOC and POC pools in the system, and only a small portion (7–10%) is directly consumed by higher organisms. Thus, any pollutant incorporated into organic matter during primary production would to a large extent circulate within the microbial loop and would not be transported upwards in the food web.

However, a large proportion of the consumption by the top predator fish is derived from the benthic habitat, so any pollutants settling on the sediments could easily be reincorporated into the food web.

Overall, the main conclusion of the mass balance and carbon ecosystem model is that the larger lakes may be important sites in the landscape for biogeochemical processes, whereas the smaller lakes should function more as flow-through systems. In the larger lakes, primary production and respiration are processes that involve much larger carbon fluxes than after in- and outfluxes. There is therefore a large potential for elements entering the large lakes from the surrounding to be incorporated into the lake food web. In some of the smaller lakes in the area, primary production and respiration are much smaller than the inflow and outflow of carbon to/from the lake and elements entering the small lakes should to a large degree be transported further downstream in the water system.

5.5.2 Laxemar-Simpevarp

The mass balance shows that Frisksjön is a site of intense processing of organic matter. The lake receives large influxes of organic matter from the catchment, and these influxes are to a large extent mineralized to CO_2 and emitted to the atmosphere. Furthermore, a substantial part of the organic carbon is permanently buried in the sediments. Hence, it is evident that Frisksjön significantly alters the terrestrial export of organic carbon to the sea.

The mass balance show that the largest influx of carbon to Frisksjön is the inflow via the inlets. The largest outflux is sediment accumulation (Table 5-17). Thus, these lakes may function as sinks of carbon, which may be incorporated either into biota or into the sediments.

Biomass and respiration are concentrated in the littoral habitat and benthic bacteria. The ecosystem model shows that respiration is much larger than primary production and the system is net heterotrophic. This result is supported by the mass balance model, which indicates a large outflux of carbon dioxide from the water to the air.

A relatively large portion (34%) of the primary produced carbon is consumed by higher organisms. Thus, any pollutant incorporated into organic matter during primary production would to a large extent be transported upwards in the food web. Moreover, a large proportion of the consumption by the top predator fish is derived from the benthic habitat, so any pollutants settling on the sediments could easily be reincorporated into the food web.

5.5.3 Comparison between Forsmark and Laxemar-Simpevarp

The lakes in Forsmark differ considerably from Frisksjön in the Laxemar-Simpevarp area. The Forsmark lakes are hardwater lakes dominated by high primary production and at least the larger lakes are net autotrophic systems. Frisksjön, on the other hand, is a brown-water lake dominated by respiration and a net heterotrophic system. Labboträsket, and potentially other lakes lacking a microbial mat in Forsmark, have a higher share of respiration than lakes with a microbial mat, and the mass balance for Labboträsket indicates that it is a heterotrophic system. However, Labboträsket still shows high primary production in comparison with Frisksjön and resembles the larger Forsmark lakes more than Frisksjön.

In the Forsmark lakes, a small portion (7–10%) of the primary produced carbon is directly consumed by higher organisms, indicating that pollutants incorporated into primary producers would to a large extent circulate within the microbial loop. In Frisksjön, on the other hand, as much as 34% of primary produced carbon is directly consumed by higher organisms. Thus, in Frisksjön, pollutants incorporated by primary producers have a larger probability of being transported upwards in the food web than in the Forsmark lakes. Moreover, there is a large secondary production in Frisksjön by bacteria utilizing organic carbon, and according to the models a large portion of the organic carbon entering the system from the catchment will be incorporated into bacteria. As bacteria to are to a great extent utilized by higher organisms, this is another possible pathway for pollutants to travel upwards in the food web.

There are also similarities between the lakes in the two areas. The larger lakes in Forsmark, as well as Frisksjön, are important sites in the landscape for biogeochemical processing. In the larger lakes in Forsmark, the in-lake processes (primary production and respiration) involve larger carbon masses than are transported into or out of the systems, indicating that there is a high probability for elements entering the lake to be incorporated into the food web. In Frisksjön, a large part of the carbon entering the system is processed by bacteria and thereby incorporated into the food web or emitted to the atmosphere as carbon dioxide. The smaller lakes Gunnarsbo-Lillfjärden and Labboträsket in Forsmark differ both from the larger lakes in Forsmark and from Frisksjön in the sense that the in-lake processes are of small importance compared with the carbon flow to and from the system.

Other similarities between lakes in the two areas are that phytoplankton plays a minor role as a primary producer and that the main food web to the top predator fish goes from benthic fauna to fish. However, there are also differences in the food web between the two areas. For example, in the Forsmark lakes the benthic fauna obtains most of its carbon from benthic primary producers, whereas the benthic fauna in Frisksjön obtains most of its carbon from benthic bacteria.

In conclusion, there are both similarities and differences between the lakes in Forsmark and Laxemar-Simpevarp. The most important similarity between the areas is that the larger lakes in both areas are important for biogeochemical processing and can alter the fate of carbon transported in the landscape. The most important difference between the areas is the dominance of primary production in Forsmark and of respiration in Frisksjön, which leads to different pathways for carbon. In addition, the fate of pollutants incorporated into the food web by primary production probably differs between the areas since a considerably smaller share of the primary produced carbon is directly consumed by higher organisms in Forsmark compared with Frisksjön.

5.6 Confidence and uncertainties

5.6.1 Forsmark

Both the mass balances and the ecosystem models for Forsmark rely on extraordinary amounts of data, site-specific as well as generic. Generally, the models are close to balanced which may indicate that the results are correct. On the other hand, the models for one of the lakes, Gunnarsbo-Lillfjärden, show contradictory results when compared with each other, indicating that there are uncertainties in the models. As in all models, some simplifications of the systems have been made and some parameters are associated with a higher degree of uncertainty than others. A description of the confidence and major uncertainties of the two models follows below.

Mass balances

Most influxes and outfluxes of carbon have been measured at the sites and can be considered to be relatively reliable estimates. The most important carbon fluxes are the inflow from the catchment and the outflow through the outlet. Sediment accumulation is of intermediate importance in Eckarfjärden and Bolundsfjärden but of small importance in Gunnarsbo-Lillfjärden and Labboträsket, while other carbon flows are of minor importance in the mass balances of all lakes. Generally, the carbon outflow via the outlet is well constrained, whereas the estimates of TOC and DIC inflow from the catchment and of sediment accumulation are associated with a higher degree of uncertainty. A discussion of the confidence of separate carbon flows in the mass balances follows below.

Carbon influxes

One of the largest influxes, TOC_{IN}, is most probably underestimated. Water chemistry data have been used together with discharge data to estimate the transport of different elements within the landscape. Extrapolation has been employed to estimate the diffusive inflow from the catchment and, as an example, estimated concentrations in the water from the inlet to Eckarfjärden were assumed to be representative for all water draining into the lake. However, TOC concentrations in water draining directly from the reed belts to the lake are probably higher than in the drainage from an average boreal catchment. A higher influx of carbon from the reed belts probably contributes to the imbalance in the mass balances. Macrophytes decompose slowly /Gessner et al. 1996, Gessner 2001/, but 30–40% of the annual reed production in lakes is assumed to be released as DOC and incorporated into the heterotrophic lake metabolism /Bertilson and Jones 2003/. During high water levels, large parts of the DOC in the reed surrounding the lakes should enter the lakes. Thus, the reed production in Littoral I is probably contribution to the TOC influx and balance in the mass balances can be achieved by assuming a TOC influx from the macrophytes. As an example, if as little as 8% of the reed production in Littoral I (section 3.10.1) enter Eckarfjärden the mass balance of the lake will be balanced. The inflow of TOC via groundwater is assumed to be negligible compared with the amounts reaching the lake water from other sources. The assumption is realistic since TOC concentrations measured in shallow groundwater are about 10% of the DIC concentrations (Appendix 1 and 2 in /Tröjbom and Söderbäck 2006b/). Overall, the annual TOC inflow (1.7–3.9 g C m^{-2} y^{-1}) is well within reported values (1.2–8.75 g C m^{-2} y^{-1}) of TOC export from boreal catchments /Algesten et al. 2003, Matsson et al. 2005, Hope et al. 1994/. Thus, the estimates are, although probably somewhat low, still most probably of the right order of magnitude.

The inflow of DIC via inlets is reliable, as it has been measured once a month over a period of two years. The annual mean DOC deposition (1.03 g C m^{-2} y^{-1}) has been measured at the site and is within the range of reported literature values (1 and 1.4 g C m^{-2} y^{-1}) for Sweden and Southern Finland /Willey et al. 2000, Lindroos et al. 2001/.

During some years there are occasions with sea water intrusion to Bolundsfjärden which may potentially lead to an influx of carbon. The effect of these occasions on the mass balances has not been assessed. However, as we detect no major differences between the mass balances for Bolundsfjärden (where salt water intrusion occurs) and Eckarfjärden (with no salt water intrusion), we assume that the salt water intrusions are of minor importance for the carbon mass balances.

CO_2 flux

The exchange of CO_2 between the lake and the atmosphere is well constrained, as the calculations are based on chemical equilibrium constants, and because wind speed, which strongly affects the gas flux between the air-water interface, is usually low above small lakes (Eckarfjärden and Bolundsfjärden are also considered small in a wider perspective). The calculations are based on site specific data on water chemistry covering several years and the variation between years is rather small values in the same order of magnitude.

Carbon outfluxes

The largest outfluxes of carbon in the mass balances, the outflow of TOC and DIC via the outlet (TOCOUT and DICOUT, respectively), can be considered to be reliable estimates as they have been calculated from measured discharge data and concentrations in the water at the site.

The estimated accumulation of carbon in sediments (TCSED), which is of intermediate importance for the larger lakes, is based on data from Eckarfjärden. The carbon accumulation rate in sediments is dependent on several parameters which vary between lakes in the area (e.g. water flow rate and organic content, depending on i.e. lake morphometry, in-lake biological processes and catchment area), and accordingly accumulation may vary substantially between lakes in the same area. As mentioned earlier (section 3.6), the estimated range for this parameter for lakes in the region is quite large (minimum c. 10% of mean value and maximum value c. 4 times the mean). The estimated accumulation in Eckarfjärden is somewhat higher than was found for small lakes in Finland /Pajunen 2000/ (19 g C m^{-2} y^{-1} in Eckarfjärden, compared with 6 g C m^{-2} y^{-1} for lakes in the size class <1 km^2 in /Pajunen 2000/). However, the estimate for Eckarfjärden is in good agreement with carbon accumulation rates estimated for the coastal area of Forsmark (14 g C m^{-2} y^{-1}) /Sternbeck et al. 2006/. Thus, the carbon accumulation rate in sediments in Eckarfjärden is probably of the correct order of magnitude.

The estimate of consumption by birds is relatively uncertain. It is difficult to determine how large a percentage of birds in the area that actually feed in the lakes, and the feeding rates of birds are estimated from literature studies. On the other hand, bird consumption comprises c. 1% of total carbon outflux in the mass balances, so the uncertainty of this estimate is of minor importance. The confidence and uncertainty of the bird consumption data is further described in /Löfgren 2008/.

Ecosystem carbon models

Overall, biomass in the ecosystem carbon models is based on site-specific data, while most of the processes (excluding primary production) have been estimated using conversion factors found in the literature. The model is therefore strongly dependent on the choice of conversion factors.

A major objection to the ecosystem models may be that all data are not lake-specific. Most of the data on biota and processes in the Forsmark lakes are site-specific and have been obtained from measurements in the larger lakes Eckarfjärden and Bolundsfjärden. In the model calculations, the data have also been applied to the smaller lakes Gunnarsbo-Lillfjärden and Labboträsket. In contrast to Eckarfjärden and Bolundsfjärden, Labboträsket has a much more trivial fish fauna, containing only species resistant to low oxygen levels. Moreover, the benthic microbial mat, which is very thick in the two larger lakes, is almost absent in Labboträsket. Moreover, results from the mass balances indicate that the smaller lakes are net heterotrophic, although ecosystem models based on data from the larger lakes indicate net autotrophic conditions. Thus, there may be significant differences between smaller and larger lakes. However, similar water chemistry, a high abundance of *Chara* vegetation and relatively low chlorophyll a concentrations (a measure of phytoplankton biomass) in all lakes indicate that the biota is similar and that the results are reliable for the small lakes as well.

Biomass

The biomasses of all functional groups have been measured in at least one lake in Forsmark. Overall, the number of site-specific biomass estimates is quite unique, and although data for some functional groups are based on few replicates, the biomasses of most functional groups are based on extensive datasets and the biomass estimates can be considered well constrained. The confidence of the biomass data is further discussed in section 3.13.

Primary production

Primary production has been measured for all functional groups of primary producers in Forsmark. While some studies (microphytobenthos and phytoplankton) have good coverage over the year, other studies (macroalgae) have few replicates over the year, leading to higher uncertainties of the annual primary production. Dark respiration by primary producers is somewhat uncertain since only daytime respiration has been measured, which also lead to some uncertainties in the annual net primary production. However, dark respiration should not affect the net result by more than c. 20%. Overall, the primary production estimates in the model can be considered reliable. Even if the absolute figures are somewhat uncertain, the order of magnitude should be correct since site-specific data are available for all functional groups. The confidence in primary production data is further discussed in section 3.13.

Respiration

Overall, respiration must be regarded as being heavily dependent on the choice of conversion factors. Benthic and pelagic bacteria are the most important functional groups in terms of respiration and together comprise between 84 and 88% of total respiration in the lakes. Therefore, the conversion factors used to calculate bacterial respiration from bacterial biomass and production play a significant role for the overall model calculations. In Eckarfjärden, secondary production by bacterioplankton has been measured in situ for two years (n=24) and can be considered reliable /Blomqvist et al. 2002, Andersson et al. 2003/. This production can be used together with a range of growth efficiencies to estimate a range of possible respiration by bacteria. In the models, the commonly used bacterial growth efficiency (BGE) of 25% /del Giorgio et al. 1997/ was used to calculate bacterioplankton respiration. However, /Andersson and Brunberg 2006a/ suggested that bacteria in the Forsmark lakes should assimilate algal exudates and the BGE on algal exudates is often above 50% /del Giorgio and Cole 1998/. A BGE of 50% results in considerably lower respiration than calculated in this model, and our estimate may well be too high. Benthic bacterial respiration was calculated with a biomass conversion factor. This results in a BGE of close to 50%, which can be considered realistic considering the extremely high density of algae surrounding the bacteria in the microbial mats.

For other functional groups, respiration was calculated using conversion factors from biomass and temperature in the lakes. The conversion factors lead to uncertainty in the results, but we have no estimates of the size of the error. Since most biomass estimates are reliable, the respiration estimates should be of the correct order of magnitude even if the absolute numbers are more uncertain.

Consumption

The consumption estimates are entirely based on conversion factors from literature, which of course leads to some uncertainty in the results. As for respiration, benthic bacteria and bacterioplankton are the most important functional groups (contributing between 80% and 85% of total consumption). Therefore, the conversion factor for bacteria plays the most important role for the overall model. Bacterial consumption is calculated as the sum of production and respiration. Secondary production by bacteria has been measured in Eckarfjärden, so the consumption assumption is as good/bad as the estimation of respiration.

The conversion factor for calculating fish consumption is based on modelling of a marine area outside Forsmark and is probably of the right order of magnitude. All other functional groups of consumers have been assumed to have a consumption of 3 times the respiration /Elmgren 1984/, a rather rough conversion factor for which we have no verification of its correctness. Based on the uncertain respiration values (see above) this is also one of the most uncertain parameters in our models. However, although uncertain we can assume that it is of the right order of magnitude due to the fact that all estimates are based on site-specific biomass data.

5.6.2 Laxemar-Simpevarp

Both the mass balance and the ecosystem models for Frisksjön rely on large amount of site-specific data. Still, the models are heavily imbalanced, which suggests that they are associated with uncertainties. The most uncertain parameters are the influx of carbon to the lake from the catchment and sediment accumulation, which are parameters of the mass balance. A detailed description of the confidence and major uncertainties of the two models for Frisksjön follows below.

Mass balance

The largest flows in the mass balance are the carbon inflow from the catchment, the carbon outflow via the outlet, sediment accumulation, and CO_2 emission to the atmosphere. Of these flows, only CO_2 emission can be considered to be well constrained, while the others are associated with a high degree of uncertainty. The ranges of possible in- and outflow and sediment accumulation are large. Using values in the outer ranges of these flows ensures that the mass balance will be balanced. This, together with the fact that most flows are calculated from site-specific parameters, indicates that the magnitudes of the flows are correct, although the absolute numbers are associated with large uncertainties. A discussion of the certainties and uncertainties of separate carbon flows follows below.

Carbon influxes

The estimates of TOC export from the catchments in the Laxemar-Simpevarp area range from 3.5 to 7.3 mg C m^{-2} y^{-1} /Tröjbom et al. 2008/ (average 5.0 mg C m^{-2} y^{-1}). The estimated carbon influx is an extrapolation from measuring stations in the Laxemar-Simpevarp area and not specific data from Frisksjön. This makes the estimate uncertain, although it should be of the right order of magnitude. The estimated carbon inflow from catchment is within reported export rates of TOC from boreal catchments in literature (1.2–8.75 mg C m^{-2} y^{-1} /Algesten et al. 2003, Mattson et al. 2005, Canham et al. 2004/). Still, the carbon influx is probably an underestimate of the true influx due to underestimation of the carbon influx from the reed belt, which has not been included in the lake system (see discussion in the Forsmark section).

The accuracy of the estimated DIC inflow is the same as for the TOC inflow, i.e. the magnitude is certainly correct, although the absolute influx is uncertain. The DOC deposition, which is of minor importance for the mass balance, is considered a reliable estimate.

CO_2 flux

The exchange of CO_2 between the lake and the atmosphere is well constrained, as the calculations are based on chemical equilibrium constants, and because wind speed, which strongly affects the gas flux between the air-water interface, is usually low above small lakes. The calculations are based on site-specific data on water chemistry covering several years and the variation between years is rather small.

Carbon outfluxes

Estimates of TOC and DIC outflow are based on measurements in the Laxemar-Simpevarp area, although they are not specific for Frisksjön. Thus, the estimates are uncertain although the magnitude should be correct.

The estimate of organic carbon accumulation sediments is possibly somewhat high, as the sediment cores did not include the water-rich top 15–30 cm of sediments /Nilsson 2004/. Thus, our estimate of organic carbon accumulation in the sediments (79 g C m^{-2} y^{-1}) is very high compared with recent estimates of carbon accumulation rates in small Finnish lakes (4–13 g C m^{-2} y^{-1}) /Pajunen 2000/. On the other hand, the comparably high concentrations of inorganic nutrients in Frisksjön, together with substantial production of emergent macrophytes surrounding the lake, may contribute to an elevated carbon accumulation rate.

Bird consumption can be viewed as a relatively uncertain estimate as it is difficult to determine how large a percentage of the birds in the area that actually feed in the lakes, and as the feeding rates of birds are estimated from literature studies. Nevertheless, even with a wide range in the calculations, the contribution of bird consumption in the lakes to the overall carbon fluxes is minor, and thus this uncertainty in the actual number is of little importance for the mass balances.

Ecosystem carbon models

In general, the biomasses in the ecosystem carbon models are based on site-specific data, whereas the processes have been estimated using conversion factors found in the literature. The model is therefore to some extent dependent on the choice of conversion factors. Overall, the ecosystem model for Frisksjön is much more uncertain than the Forsmark models due to a much smaller data set. For most functional groups there are only few measurements of biomasses and no whole-year studies, which may be of importance when calculating a whole-year model. However, the single measurements available are nevertheless an asset as they indicate that the estimates are of the right order of magnitude.

Biomass

The biomasses of all functional groups have been measured at least once in Frisksjön. For phytoplankton, the annual mean is based on 8 replicates over the year, which can be considered a good estimate of the annual mean. For other functional groups, on the other hand, replicates are few and therefore the calculated annual means are more uncertain. However, since all estimates are based on actual measurements in the lake they are good indicators of the magnitude of the biomasses.

Primary production

Primary production by phytoplankton has not been measured in Frisksjön, but has been estimated from literature values for humic lakes. /Nürnberg and Shaw 1999/ showed correlations between phosphorus concentrations and annual production, as well as between chl *a* concentrations and annual production. Inserting our chl *a* concentration and phosphorus concentrations in these graphs independently gives an estimate of the phytoplankton production of c. 40 g C m^{-2} y^{-1}. The estimate it of course rough, but since it is based on in-lake phosphorus and chlorophyll concentrations we consider it to be realistic.

Respiration

Overall, respiration must be seen as heavily dependent on the choice of conversion factors. Bacteria are the most important functional groups in terms of respiration and are responsible for 86% of the total respiration in the lakes. Therefore, the conversion factors used to calculate bacterial respiration from bacterial biomass play a significant role in the overall model calculations. In Frisksjön, community respiration in the benthic habitat has been measured on one occasion. The measured respiration was found to be 40 mg C m^{-2} h^{-1}, which is twice the calculated benthic bacterial respiration during July (16 mg C m^{-2} h^{-1}). Considering the uncertainty of the conversion factors and the fact that the measured values are the result of a few replicates in a single day, we consider the measured respiration to be reasonably close to the modelled one, i.e. they are of the same order of magnitude.

In the pelagic habitat we have no respiration data to use for comparison. Bacterioplankton are responsible for most of the respiration in the lake. The literature on bacterioplankton respiration seldom includes whole-year studies, and many studies focus on bacterioplankton secondary production and not respiration. However, it is clear that the estimates of bacterial respiration in the literature span a wide range. The biomass estimates narrows the range of respiration down to two order of magnitudes (5×10^5 – 1×10^7 g C year $^{-1}$ /Mason 1977, del Giorgio et al. 1997, Nürnberg and Shaw 1999, Wetzel 2001, Boulion 2005/). We choose to use an estimate in the middle of the range (3×10^6 g C $year^{-1}$). Without biomass estimates there is an even larger range of bacterial respiration. Thus, pelagic respiration is subjected to a relatively high degree of uncertainty, but the biomass estimates give a respiration that is if not absolutely correct probably of the right order of magnitude.

Consumption

As for Forsmark, consumption is entirely based on literature conversion factors, which of course may lead to uncertainty in the results. Bacteria are the most important group, and since the respiration of bacteria is somewhat uncertain, so is their consumption. However, since biomass estimates are available, the order of magnitude is realistic.

6 The stream ecosystem – conceptual model and model assumptions for carbon

We have chosen a concept where stream ecosystems are treated as a special case of a lake. The habitats defined in a lake may also be present in streams. The same functional groups are also relevant for streams, see Table 6-1. One obvious difference between streams and lakes is the water flow, which is often much more rapid in streams than in lakes. Shading from terrestrial vegetation is often also more pronounced in streams than in large lakes, where the vegetation border on the shoreline can only shade a very limited fraction of the lake area. The small streams present in the Forsmark and Laxemar-Simpevarp areas are completely dry for part of the year. The lack of water means that stationary populations of most functional groups cannot be present in the streams.

6.1 Habitats and functional groups

The habitats defined for lakes (see section 5.2) are also used for the streams. With the data set available today a distinction between Littoral I (soft-bottoms with emergent and floating-leaved vegetation) and Littoral III (soft-bottom with submerged vegetation) cannot be made without a lot of data processing. These habitats have therefore been merged to one habitat called Littoral I/III in the sections dealing with streams.

The streams in Forsmark consists mostly of Littoral I/III (92% of investigated stretches), but there are also Littoral II habitats on short stretches (c. 8%). Littoral I/III is also the dominant habitat in the Laxemar area, but here there is a clear difference between small and larger streams. In the large Laxemarån, c. 40% of the stretches are composed of hard-bottom habitats (Littoral II), while the equivalent figure for the other smaller streams is c. 10% (7–17%). The pelagic habitat occurs temporarily, when water levels are high (spring and autumn flows). All streams in both areas are assumed to lack profundal habitats due to their shallow depth.

6.1.1 Primary producers

Large parts of the streams are dominated by benthic primary producers (see section 3.10.2 and 4.10.2. In Forsmark and Laxemar-Simpevarp streams the benthic primary producers are mainly made up by emergent macrophytes. Such vegetation has an annual cycle where the vegetation withers away in the autumn. The non-living matter can be transported downstream if the water flow is strong enough; otherwise the withering vegetation remains at the site and degradation processes start. As we see no filling up of the streams we assume that the matter that is initially deposited on the bottom when the macrophytes are withering is transported downstream by no later than the next spring flood. Thus, no long-term deposition of organic matter in stream sediments is assumed. The organic matter is assumed to be part of the particulate organic carbon

Table 6-1. Functional groups in the stream ecosystems.

	Pelagial	Littoral	Profundal
Primary producers	Phytoplankton		
		Benthic primary producers	
Consumers	Bacterioplankton	Benthic bacteria	
	Zooplankton	Benthic fauna	
	Fish		

pool in the water, first in the stream itself and later in the downstream lake or bay. When water from the stream enters a basin the water velocity often decreases drastically and sedimentation of particulate matter occurs, bringing at least some of the organic matter to the sediments.

Phytoplankton is of course present in the waters of the streams but is most likely of less importance (estimates from chlorophyll measurements indicate low amounts, see sections 3.10.2 and 4.10.2). In comparison with macrophytes, phytoplankton is also more dependent on the actual presence of water in the streams for its existence, whereas macrophytes can often withstand brief periods of draught, making the phytoplankton "growing season" in the small streams in these two areas somewhat shorter.

6.1.2 Consumers

The abundance and biomass of benthic fauna naturally varies geographically in streams, depending on the local conditions. In streams that periodically dry up, the populations are also temporary and we assume that no stationary communities of benthic fauna exist in large parts of the streams in any of the two areas.

The streams in Forsmark and Simpevarp may be of some importance for fish as feeding areas during periods of high water flow, but no stationary fish populations can be sustained in the small streams. It is possible that there are stationary fish populations in parts of the larger Laxemarån in Laxemar-Simpevarp, but that is not supported by the results from investigations (see section 4.10.2). Fish migration for spawning has been observed in streams in both the Forsmark and Simpevarp areas. The reproducing fish migrate back to the sea after spawning, so the time they spend in the stream is very short – a couple of weeks per year.

During the periods the streams have water in them, other consumers such as zooplankton, bacterioplankton and benthic bacteria are present in them. But as with benthic fauna and fish, if stationary populations of these groups are present in the smaller streams they are not active during the dry periods. The situation is somewhat different in the larger Laxemarån. Here species that can tolerate low oxygen levels may be permanently present in the stretches that do not dry out.

6.1.3 Importance of different processes

Taking into account the facts presented above, we reasoned that the biological processes in the streams in both areas are of little importance in the context of long-term dispersion of radionuclides from a deep repository, so no specific carbon models have been constructed for this kind of ecosystem. The most important process taking place in the streams is the movement of water and dissolved and particulate matter through the catchment. This movement is unidirectional, towards the sea. The biological processes (primary production, consumption, respiration and excretion) may delay this transport by uptake of elements or by physical retention of particles, but both these processes are thought to be temporary in a long-term perspective.

A special case when biological processes may be important for the long-term dispersion of radionuclides is when streams flood, which may occur in the spring (see sections 3.3.5 and 4.3.4). On such occasions larger areas are reached by the stream water and its content of dissolved elements and particles. Depending on local conditions, elements and particles may be retained in the flooded areas for longer periods. The biological processes of importance in such areas are better described by a terrestrial ecosystem model than in a stream model and are therefore not treated in this report. Instead, the reader is referred to /Löfgren 2008/.

7 Pools and fluxes of different elements into, out of and within lakes

The aim of this chapter is to visualize how other elements than carbon (described in Chapter 5) move and/or accumulate in the lake ecosystems in Forsmark and Laxemar-Simpevarp. Different elements have different properties and can be expected to behave differently in nature. Some will be transported rapidly through the lakes, accompanying the flowing water, while others may be incorporated into the food web and/or into the sediments and accumulate in the lake ecosystems. The fate of an element is dependent both on the properties of the actual element and on the character of the specific lake ecosystem. By estimating in- and outfluxes and accumulation in the ecosystems it is possible to visualize the fate of elements and thereby to identify hot spots in the ecosystems for e.g. pollutants and radionuclides.

7.1 Conceptual model and model assumptions

The same mass balance concept as for carbon (Chapter 5) is used to describe fluxes of elements into, within (accumulation in sediment) and out of the lake ecosystem. The processes (*fluxes*) considered in the mass balances are illustrated in Figure 7-1 and the following equation was set up:

TXIN + TXDEP = TXOUT + TXSED

where:

- TXIN is the inflow of element X from the catchment via the inlet and direct drainage to the lake and via groundwater inflow,
- TXDEP is the wet deposition of element X from the atmosphere directly onto the surface of the lake,
- TXOUT is the outflow of element X via surface water (through the outlet),
- TXSED is the long-term accumulation of element X in the lake sediment.

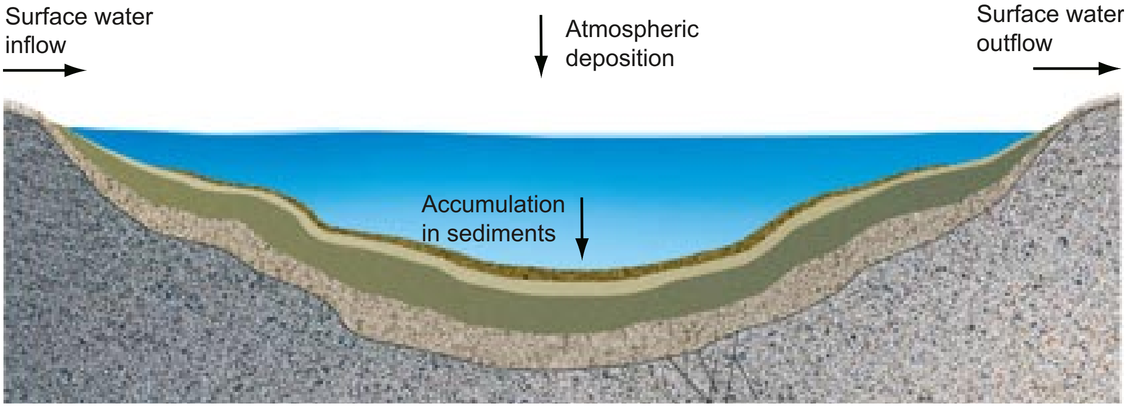


Figure 7-1. *Element fluxes considered in the mass balances.*

Compared with the mass balance concept used for carbon (Chapter 5), two fluxes have been neglected: in/outflux via atmospheric gas exchange and outflux from the lake systems via consumption by birds. Gas exchange with the atmosphere is of limited importance for most elements, but it can be an important process for e.g. nitrogen and carbon. Nitrogen is transported in gaseous form from the lake water to the atmosphere and vice versa as a result of nitrification/denitrification processes in the lake ecosystem. Other elements for which gas exchange with the atmosphere may be of importance are volatile elements such as iodine and mercury. We have no site data for estimating atmospheric exchange of other elements than carbon, but we assume that for most other elements this flux is negligible. The reason for not including the outflux via bird consumption is that this process is of minor importance for carbon (section 5.3) and can therefore also be neglected for other elements. The term long-term accumulation of elements in the sediments has been included to emphasize that this is the net result of sedimentation and resuspension/dissolution processes.

In the Forsmark area, mass balances have been set up for five lakes situated in the catchment "Forsmark 2": Eckarfjärden, Gällsboträsket, Bolundsfjärden, Puttan and Norra Bassängen. Of these lakes, Eckarfjärden and Bolundsfjärden are regarded as larger lakes, while the other three are smaller (like Labboträsket and Gunnarsbo-Lillfjärden in Chapter 5). The fluxes of elements among these five lakes illustrate the downstream transport of elements through the limnic ecosystem in the main part of the Forsmark area. The same catchment contains a couple of smaller ponds. They are not connected with the other limnic environments via streams and have not been included in the calculations since they are small parts of the whole catchment and data are lacking for these objects. The mean values for the five lakes are sometimes used as representative of a mean Forsmark lake to make comparison with e.g. Laxemar-Simpevarp easier. In the Laxemar-Simpevarp area, a mass balance has been set up for Frisksjön.

The construction of ecosystem models for other elements than carbon requires more data than are available. Instead, as a complement to the mass balances, the chemical compositions of important components in the lake ecosystem (i.e. biota, sediment, dissolved and particulate fractions in water) have been used to calculate the masses of the elements in each component. The description of elemental pools in the ecosystem components should not be viewed as a variant of the ecosystem models for carbon presented in Chapter 5, since flows between the different functional groups in the food web are not described, nor do we care about different habitats in the lake ecosystem. However, the description is a useful tool for understanding the distribution of elements in the ecosystem.

The ecosystem is divided into a biotic and an abiotic component. The former is divided into primary producers and consumers. Primary producers include phytoplankton and benthic primary producers (including benthic macrophytes, macroalgae and microphytobenthos). Consumers include bacterioplankton, zooplankton, benthic bacteria, benthic fauna (herbivores, filter feeders, detritivores, carnivores and omnivores) and fish (zooplanktivorous, benthivorous and piscivorous). Abiotic components for which the chemical composition was estimated include the dissolved and particulate phases of the lake water, as well as the lake sediment. In order to differentiate an oxygenated upper sediment layer, the first centimetre of the sediment has been recognized as a separate component in lakes that lack a microbial mat. For the other lakes, this oxygenated layer is part of the microbial mat and the underlying sediment is assumed to be anoxic. This is supported by the authors' own observations of purple sulphur bacteria in the microbial mat from lakes in the area (see section 3.6 and 4.6 for further information about the oxygenated layer). The anoxic sediment layer (denoted deeper sediment) is thus the largest sediment component, and for the lakes with a microbial mat the only sediment component that is recognized.

7.1.1 Elements considered in the evaluation

Elements can be divided according to physical and chemical characters into metalloids, metals, non-metals, lanthanides and actinides. The following 64 elements are considered in this chapter.

Metals: Ag, Al, Ba, Be,Ca, Cd, Cs, Co, Cr, Cu, Fe, Ga, Hf, Hg, K, Li, Mg, Mn, Mo, Na, Nb, Ni, Pb, Rb, Sc, Sn, Sr, Ta Ti, Tl, V, W, Y, Zn, Zr

Non-metalls: Br, C, Cl, F, I, N, P, S

Metalloids: As, B, Sb, Se, Si

Lanthanides: Ce, Dy, Er, Eu, Gd, Ho, La, Lu, Nd, Pr, Sm, Tb, Tm, Yb

Actinides: Th, U

Most elements are metals. **Metals** are shiny and are good conductors of heat and electricity. Metals lose electrons readily and corrode easily. **Non-metals** is the second most common category of elements. Their characteristics are opposite those of metals. Non-metals have a tendency for their atoms to gain a small number of electrons from metal atoms in order to acquire the electron configuration of an inert gas atom. The non-metals have a dull appearance and are poor conductors of heat and electricity. They have low density and melting point. Since metals tend to lose electrons and non-metals tend to gain electrons, metals and non-metals tend to form compounds with each other.

Metalloids have the appearance of metals but display non-metallic properties as well. They are solids that can be either shiny or dull. Metalloids conduct heat and electricity better than non-metals but not as well as metals.

Thirty rare earth elements comprise the **lanthanides** and the **actinides**. Most of the elements in the actinide series are called trans-uranium elements, which means they have atomic numbers greater than 92 (the atomic number of uranium). Several of the lanthanides are formed during the fission of uranium and plutonium. Lanthanides are relatively soft silvery-white metals that tarnish when exposed to air, forming oxides. They are very reactive and react with water or H^+ to liberate hydrogen (H_2). They react in an exothermic reaction with the H_2. They are strong reducing agents and their compounds are generally ionic. Actinides are highly electropositive. The actinides combine with most non-metals.

A detailed description is given for four of the 64 described elements: phosphorus, iodine, thorium and uranium. Phosphorus has been chosen since this is an important element for biota that is often a limiting factor in lakes, and the body of data available on this element is larger than for all other elements (except for carbon, which is dealt with in Chapter 5, and nitrogen, for which an equal amount of data is available). The other three elements have been selected since they are of special interest for the safety assessment to be performed by SKB. Iodine, uranium and thorium represent elements with different sorption properties in deposits. Iodine is representative of elements that are very mobile in the environment. The sorption coefficient of iodine, K_ds, tabulated in /Karlsson and Bergström 2002/ varies from 0.03 $m^3\ kg^{-1}$ (organic soil) to 0.3 $m^3\ kg^{-1}$ (soil and suspended matter in lakes and brackish environments). Thorium represents almost immobile elements, and the K_ds tabulated in /Karlsson and Bergström 2002/ varies from 10 $m^3\ kg^{-1}$ (soil) to 100 $m^3\ kg^{-1}$ (suspended matter in lakes and brackish environments). Uranium is representative of elements with sorption properties somewhere in between and the K_ds tabulated in /Karlsson and Bergström 2002/ varies from 0.1 $m^3\ kg^{-1}$ (soil) to 10 $m^3\ kg^{-1}$ (suspended matter in lakes and brackish environments). Uranium and thorium have no known biological role, while iodine appears to be a trace element essential to animal and vegetable life.

7.2 Model parameterization

7.2.1 Chemical composition of biotic and abiotic components

Forsmark

The chemical composition of the **dissolved** water phase in Bolundsfjärden, Eckarfjärden and Norra bassängen has been measured in the site investigation and data from 2004-06-01 to 2006-05-31 were used in this evaluation (Appendix 7, data from SICADA, October 2006). Chemistry data from Puttan and Gällsboträsket are lacking. For the former, data from Norra Bassängen was used instead, and for Gällsboträsket chemistry data from the Bolundsskogen station (stream water downstream of the lake) were used. When data from Bolundsskogen were missing, data from Bolundsfjärden (which is the closest downstream lake) were used instead. Long-term measurements are lacking for some elements (Ag, B, Be, Ga, Nb, Se, Sn, Ta, Ti, W), so data from one occasion in April 2008 were used (Appendix 7) /Engdahl et al. 2008/. These data includes site specific data for Bolundsfjärden and Eckarfjärden whereas in the case of Gällsboträsket, Norra bassängen and Puttan a mean from Eckarfjärden, Bolundsfjärden and Labboträsket was used. In the case of Ag, Sn, and Ta, concentrations were below detection limit and half the detection limit was used as an estimate.

Data on the **particulate** fractions of the macronutrients carbon, nitrogen and phosphorus are also available for the time period 2004-06-01 to 2006-05-31 (SICADA, October 2006). For other elements, one measurement was performed in the spring of 2008 to estimate the size of the particulate fraction (Appendix 8) /Engdahl et al. 2008/. Bolundsfjärden, Eckarfjärden and Labboträsket were sampled in the latter investigation. In the mass balances, data from Bolundsfjärden were also used for Puttan and Norra Bassängen. The mean particulate concentrations for the three investigated lakes were used for Gällsboträsket. Values for Au, In, Ir, Os, Pd, Pt, Rh and Ru were below the detection limit, and half the detection limit was used as an estimate in the model.

The chemical composition of lake **sediments** in two Forsmark lakes, Eckarfjärden and Stocksjön, was derived from Appendix 1 in /Hannu and Karlsson 2006/ and from Appendix 1 in /Strömgren and Brunberg 2006/. The available samples were divided into three deposit layers: gyttja, clay gyttja and clay. As described earlier, the first (upper) centimetre of the sediment (gyttja layer) was recognized as a separate component in the lakes that lack a microbial mat (Gällsboträsket), in order to differentiate a biologically active upper sediment layer. The deeper sediment component consists of the rest of the gyttja layer together with the clay gyttja and clay. For the lakes with a microbial mat, deeper sediment is the only sediment layer as a microbial mat belongs to the biotic component (microphytobenthos and benthic bacteria). The sand layer that is often present between the clay gyttja and clay layers has been omitted since it is often thin and has a much lower weathering capacity compared to e.g. clay. No chemical data concerning the chemical composition of sand in sediments are available from the Forsmark area.

The concentration of different elements in sediment samples has been correlated to the carbon content, measured in the same samples /Hannu and Karlsson 2006/. The carbon contents established in /Hannu and Karlsson 2006/ differ slightly from another study by /Hedenström and Risberg 2003/, e.g. 35% instead of 27% in gyttja and 9% instead of 8% in clay gyttja-gyttja clay (see section 3.6). The differences are small and may be the result of few replicates. The carbon and water contents of the different sediment layers in Eckarfjärden and the elemental contents from Eckarfjärden were therefore used for all lakes in the area, despite the differences presented above. The only lake-specific data used for other lakes was the thickness of each sediment layer (Table 3-10) and the lake area /Hedenström 2004, Brunberg et al. 2004a/. For nitrogen, data on the concentration in the "clay" was lacking; instead, concentrations in the clay gyttja were used for this layer.

Data on the chemical composition of the limnic **biota** from Forsmark is mainly derived from /Hannu and Karlsson 2006/ and /Kumblad and Bradshaw 2008/. The former study presents site-specific chemical data for the microphytobenthos (microbial mat), macroalgae (benthic submerged vegetation), benthic fauna (only filter feeders) and planktivorous, benthivorous and piscivorous fish (further described in section 3.10). For the chemical composition of the microphytobenthos, a combination of the data presented for the microbial mat in /Hannu and Karlsson 2006/ (Bolundsfjärden) and in /Strömgren and Brunberg 2006/ (Stocksjön) were used (average values when data for the same element is available for both datasets). For phytoplankton, zooplankton and herbivorous, detritivorous and carnivorous benthic fauna, data were taken from /Kumblad and Bradshaw 2008/. This study aims to characterize the brackish water ecosystem just outside the two islands Stor-Tixlan and Lill-Tixlan within the Forsmark regional model area. The use of data from a brackish ecosystem in this evaluation may introduce some uncertainty, but in the absence of site-specific limnic data we chose to use this site-specific data set. It contains an extensive chemical characterization (48 elements) for a number of functional groups sampled in the same area at the same time. Data for omnivorous benthic fauna were calculated as a mean of all analyzed species of benthic fauna. Concentrations of 15 elements (Ag, B, Be, Ga, Hf, La, Nb, Sb, Sc, Sn, Sr, Ta, Ti, W and Y) in benthic herbivores, benthic detrivores and benthic carnivores were lacking, but were assumed to be identical to the chemical composition of benthic filter feeders /Hannu and Karlsson 2006/.

Site-specific chemical data are lacking for bacterioplankton, but phosphorus, nitrogen and sulphur content in bacterioplankton have been estimated using conversion factors for brackish and freshwater aquatic bacteria (Baltic Sea and Norwegian lake) from the literature /Fagerbakke et al. 1996/. Site-specific data are lacking for benthic bacteria as well, and conversion factors from carbon to phosphorus and nitrogen for benthic bacteria from /Kautsky 1995/ are used. The C/P ratio used for bacterioplankton and benthic bacteria is of the same order of magnitude as that reported for Microcystis-associated bacteria in Lake Vallentunasjön (north of Stockholm) /Brunberg 1995/. The sulphur content of benthic bacteria was assumed to be equal to the sulphur content of bacterioplankton reported by /Fagerbakke et al. 1996/. For all other elements, bacterioplankton and benthic bacteria were not included.

To estimate the total pools of different elements in biotic components, we assumed that there is a constant relation between carbon content and the content of any other element. Accordingly, we calculated the element per carbon ratio for the biota samples available in /Hannu and Karlsson 2006, Kumblad and Bradshaw 2008/. For each lake, the element per carbon ratio was then multiplied by the total carbon pool in the biotic component, and finally the estimates for the different biotic components were summarized to estimate the total biotic pool of each element. No carbon content was reported for the microphytobenthos from Stocksjön /Strömgren and Brunberg 2006/. Instead, it was assumed that the carbon content of microphytobenthos was the same as in the microbial mat from Eckarfjärden /Hannu and Karlsson 2006/. The carbon pools for different biotic components (functional groups) in the five lakes were taken from the carbon ecosystem models described in Chapter 5.

Laxemar-Simpevarp

The chemical composition of the **dissolved** water phase has been measured in the site investigation and data was taken from the time period 2002-11-20 to 2007-07-24 (SICADA, October 2007). Long-term measurements are lacking for some elements (Ag, B, Be, Ga, Nb, Se, Sn, Ta, Ti, W), so data from one occasion in April 2008 were used /Engdahl et al. 2008/.

In the case of the macronutrients carbon, nitrogen and phosphorus, the **particulate** fractions of the elements in lake water have also been measured in the site investigation during the period 2002-11-20 to 2007-07-24 (SICADA, October 2007). For all other elements, the particulate fraction was analyzed in Frisksjön as suspended material on one occasion in April 2008.

For Au, In, Ir, Os Pd, Pt, Rh and Ru concentrations were below detection limit and half the detection limits were used as estimates of the concentration of these elements. The detection limit was not specified for Re, which resulted in negative concentration when the filter were subtracted in the analyses, so the concentration was set to 0.

The chemical composition of lake **sediments** from Frisksjön down to a depth of 4.4 m was taken from Appendix 2 in /Engdahl et al. 2006/. In the top 10 cm, layers were analyzed every two centimetres, after which a 2–3 cm layer was analyzed at depths of 0.25, 0.5, 1, 2, 3, 4 and 4.4 metres. There was a clear difference in chemical composition between sediments above and below a depth of 1.97 m, indicating the transition from marine to limnic conditions. In calculating the pools of elements in the sediment, the first centimetre of the sediment (gyttja layer) was recognized as a separate component in order to differentiate a biologically active upper sediment layer. Due to the different chemistry in the upper and lower sediments, the remaining deeper sediments were calculated as separate components, one from 0.01 to 1.97 m and one from 1.97 to 10 m. Although sediment depth in Frisksjön is estimated to be 10 m (section 3.6), the chemical composition is only available for the sediment down to a depth of 4.4 m. For the remaining sediment, the chemical composition was assumed to be the mean from the sediment layer 1.97–4 m.

As with the Forsmark lakes, the concentration of different elements in the sediments has been correlated to the content of carbon measured on the same sample at the same time /Engdahl et al. 2006/. This carbon content differs somewhat from other studies, e.g. 11–12% instead of 20% (section 4.6). However, this may be due to few replicates in the studies, and as we have no further information regarding which dataset is correct, the data set from /Engdahl et al. 2006/ that includes many elements has been used.

Site-specific data on the chemical composition of limnic **biota** is available for aquatic vegetation (roots/rhizomes and aboveground parts of water lily), benthic fauna (only filter feeders), and for benthivorous and piscivorous fish /Engdahl et al. 2006/. The same non-site specific data as were used for the Forsmark lakes have also been used in Laxemar-Simpevarp. For phytoplankton, zooplankton and herbivorous, detritivorous and carnivorous benthic fauna, the chemical composition was taken from /Kumblad and Bradshaw 2008/. The chemical composition of benthic herbivores, detrivores and carnivores with regard to 15 elements (Ag, B, Be, Ga, Hf, La, Nb, Sb, Sc, Sn, Sr, Ta, Ti, W and Y) was assumed to be identical to the chemical composition of benthic filter feeders /Engdahl et al. 2006/. For bacterioplankton conversion factors from the literature (Baltic Sea and Norwegian lake /Fagerbakke et al. 1996/) were used for converting from carbon to phosphorus, nitrogen and sulphur. Conversion factors from carbon to phosphorus and nitrogen from the literature were used for benthic bacteria as well /Kautsky 1995/. The sulphur content of benthic bacteria was assumed to be equal to the sulphur content of bacterioplankton reported by /Fagerbakke et al. 1996/.

The total biotic pools of elements in Frisksjön were calculated in the same way as the elemental pools in Forsmark (for further explanation, see above).

7.2.2 Mass balances

Forsmark

The transport of major elements in surface water has been estimated from simultaneous measurements of concentrations and discharge in streams (Appendix F in /Tröjbom et al. 2007/). These values include water in- (TXIN) and outflow (TXOUT) to/from lakes via in/outlets as well as diffusive in- and outflow of elements directly to the lake from the catchment as well as via groundwater. The transport of minor elements has been calculated by correlation of minor elements to the transport of major elements /Tröjbom et al. 2007/.

The contribution to the total influx of elements to lakes via wet deposition on the lake surface (TX_{DEP}) has been estimated using site-specific data on the chemical composition of precipitation from two sampling stations in the Forsmark area /Tröjbom and Söderbäck 2006b/ together with site-specific annual precipitation (calculated as an annual mean from two years: 2004 and 2005) /Johansson et al. 2008/. Site-specific precipitation data are only available for ten elements (P, Al, Fe, Na, K, Ca, Mg, Cl, DOC, SO_4^{2-}). Bromine, iodine and silicon were analysed but below detection limit and for these elements, half the detection limit was used as an estimate of concentration in precipitation. For iron, manganese, silicon and strontium, data on chemical composition in precipitation in Laxemar-Simpevarp were used. No site-specific data on deposition are available for uranium and thorium, but deposition has been assumed to equal estimates of atmospheric deposition during the winter period in a deciduous forest in southern Sweden /Tyler and Olsson 2006/. For nitrogen, concentrations in precipitation measured by /Pihl-Karlsson et al. 2003/ (Jädraås station) were used for Forsmark. For other elements this influx has not been included in the mass balance.

The accumulation of elements in lake sediments functions as a withdrawal of elements from the lake water. This outflux has been estimated using the average elemental composition of the gyttja layer in Eckarfjärden and Stocksjön (Appendix 1 in /Hannu and Karlsson 2006/, Appendix 1 in /Strömgren and Brunberg 2006/), the estimated dry weight content of the gyttja layer in the lake (section 3.6), the long-term accumulation rate estimated for Eckarfjärden (section 4.4 in /Hedenström and Risberg 2003/) and the area for sediment accumulation in the lake. The latter is assumed to be the whole lake area excluding the reed belts.

Laxemar-Simpevarp

The transport of major elements in surface water to/from Frisksjön has been estimated from simultaneous measurements of concentrations and discharge in streams (Appendix C in /Tröjbom et al. 2008/). These values include water in- (TX_{IN}) and outflow (TX_{OUT}) to/from lakes via in/outlets as well as diffusive in- and outflow of elements directly to the lake from the catchment as well as via groundwater. The transport of minor elements has been calculated by correlation of the minor elements to the flows of major elements /Tröjbom et al. 2008/

When available, TX_{DEP} has been estimated using site-specific data on the chemical composition of precipitation from two sampling stations in the Laxemar-Simpevarp area (SICADA, October 2007, ID code PSM002170 and PSM001516, the number of observations varies for different elements: n=29-105, Sep 2002–Nov 2007), together with site-specific annual precipitation (600 mm, calculated as an annual mean from the years 2005 and 2007 and the two stations Plittorp and Äspö) /Werner et al. 2008/. Site-specific data on wet deposition on the lake surface (TX_{DEP}) is available for eleven elements (Br, Na, K, Ca, Mg, Si, Fe, Mn, Sr, Cl, SO_4^{2-}). Data on phosphorus concentrations in precipitation have been taken from /Knape 2001/, where total phosphorus concentrations measured in precipitation at Äspö Island during the period 1997–1999 are presented. Data on the chemical composition of precipitation in Forsmark was used for aluminum. No site-specific data on deposition are available for uranium and thorium, but deposition has been assumed to equal estimates of atmospheric deposition during the winter period in a deciduous forest in southern Sweden /Tyler and Olsson 2006/. For carbon and nitrogen, concentrations in precipitation measured by /Pihl-Karlsson et al. 2008/ were used (Rockneby station in Kalmar County). For other elements this flux has not been included in the mass balance.

The accumulation of elements in lake sediments has been estimated using the average elemental composition of the gyttja layer in Frisksjön (Appendix 2 in /Engdahl et al. 2006/), the estimated amount dry weight content of the gyttja layer in the lake (section 4.6), the long-term accumulation rate estimated for Frisksjön /Sternbeck et al. 2006/ and the area for sediment accumulation in the lake. The latter is assumed to be the whole lake area excluding Littoral I (the reed belts).

7.3 Evaluation of elemental pools and fluxes for a number of elements in Forsmark

This section contains the main results of the mass balances for a number of elements in Forsmark. Pools and mass fluxes are presented in section 7.3.1 for a large number of elements. Detailed results for phosphorus, iodine, thorium and uranium for the five lakes Bolundsfjärden, Eckarfjärden, Gällsboträsket, Puttan and Norra bassängen are presented in section 7.3.2 and 7.3.3. Detailed results for separate elements in the five lakes are found in Appendices 11 and 12.

7.3.1 Chemical composition of different ecosystem components

The most abundant element in the Forsmark lakes (i.e. in all components, dissolved, particulate, biotic, and sediment, hydrogen and oxygen excluded) is silicon (41%), followed by carbon (17%), aluminium (13%), iron (8%) and calcium (8%) (Figure 7-2). The abiotic component has exactly the same distribution of elements, which is expected as the abiotic component constitutes 99.95% of total mass of investigated elements in the average lake. Moreover, the sediment in the average lake constitutes 99.7% of the total mass of investigated elements, which means that the sediment has the same distribution of elements as the total lake ecosystem (Figure 7-3).

In the abiotic components in lake water, elements are mainly present in the dissolved component, and amounts in the particulate component are considerably smaller (Figure 7-4). Only lanthanum and phosphorus are almost equally abundant in the particulate and the dissolved components. The dissolved and particulate components differ from each other in elemental composition: the dissolved component is dominated by chlorine, sodium, calcium and carbon (Figure 7-5), illustrating the dominance of the major ions in the water phase, while the particulate component is dominated by carbon, which comprises 72% of the particulate matter (Figure 7-6). The dissolved component differs somewhat among the 5 investigated lakes. In four of the lakes, calcium is more abundant than sodium in the dissolved component. In contrast, in Bolundsfjärden, the sodium concentration is much higher than the calcium concentration. The high sodium concentration in Bolundsfjärden is probably due to occasional salt-water intrusion. Nitrogen, calcium, silicon and sulphur contribute between 2 and 9% each to the particulate component in the average lake, while all other elements make minor contributions to the particulate component.

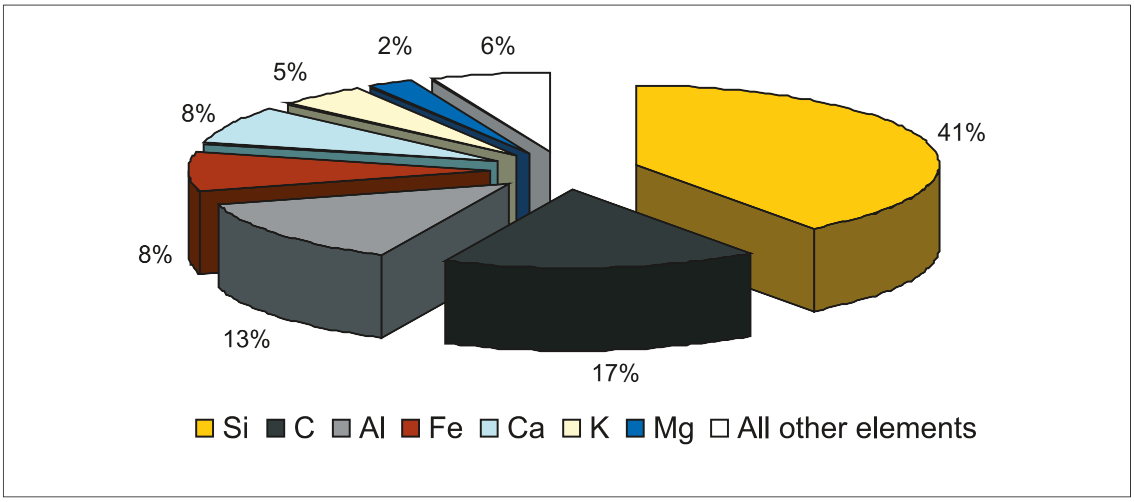


Figure 7-2. Distribution of elements (% of total investigated elements, based on mass) in the average lake (in all ecosystem components: dissolved, particulate, biotic and sediment). Note that not all elements are analyzed and that the elements of which water is composed, oxygen and hydrogen, are not included.

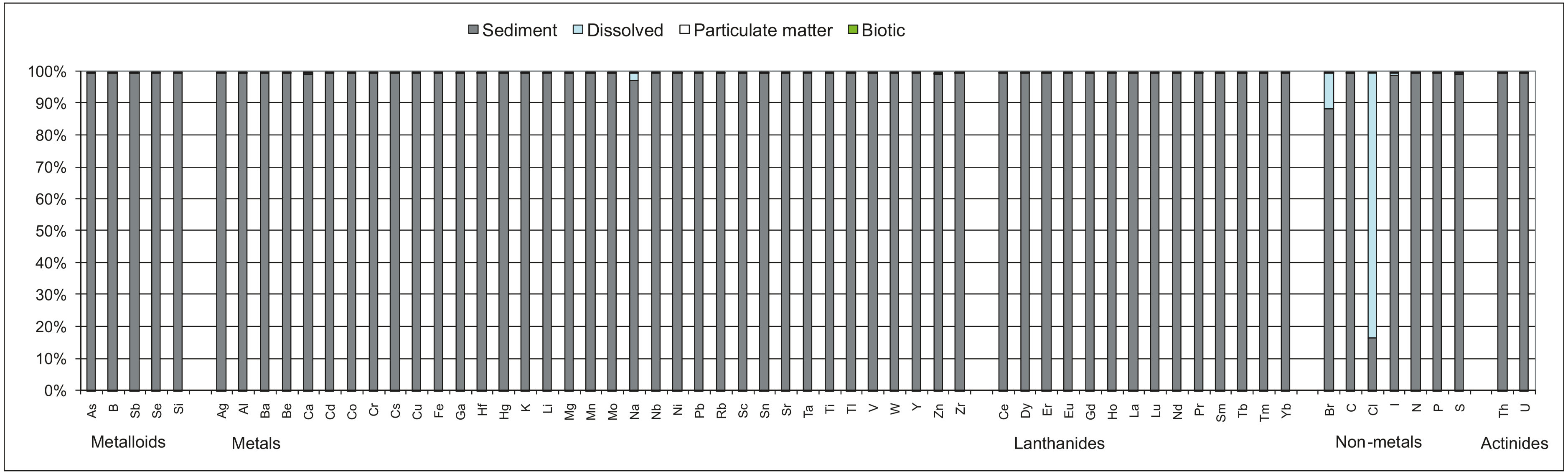


Figure 7-3. *Distribution of analyzed elements among the different components of the ecosystem in the mean lake in Forsmark: sediment (black), dissolved in water (blue), particulate (white) and biotic (green). Sediment is totally dominant and the biotic and particulate fractions are not visible in this figure.*

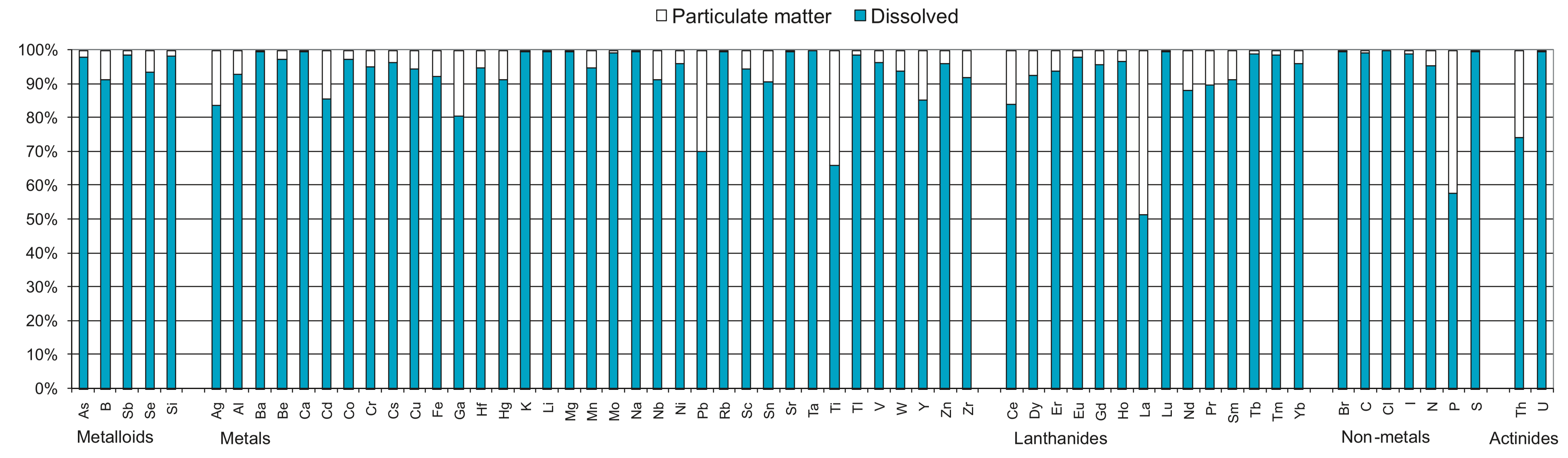


***Figure 7-4.** Distribution of analyzed elements between the dissolved and particulate components in lake water in the average lake in Forsmark.*

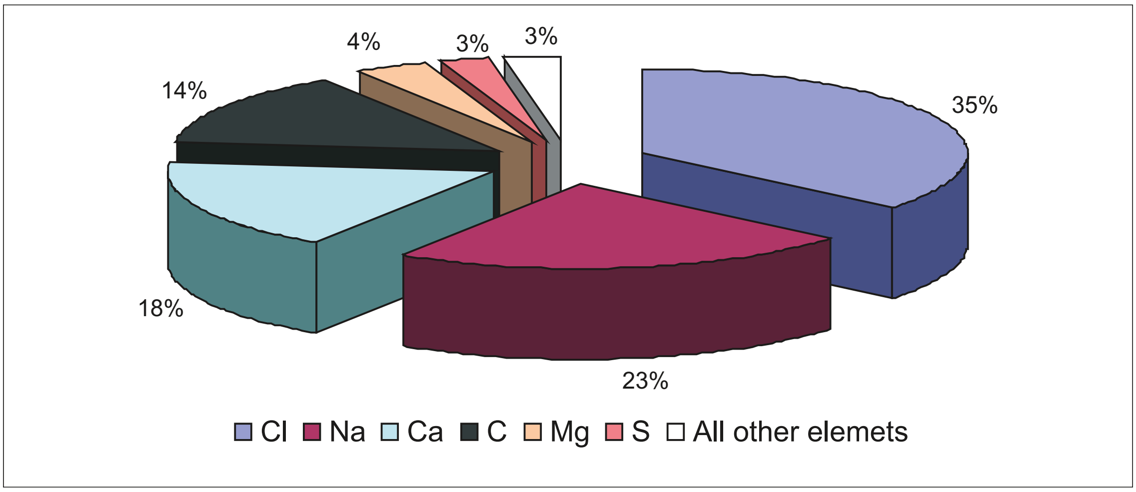


Figure 7-5. Distribution of elements (% of total investigated elements, based on mass) in the dissolved component in the average lake in Forsmark. Note that not all elements are analyzed and the elements of which water is composed, oxygen and hydrogen, are not included.

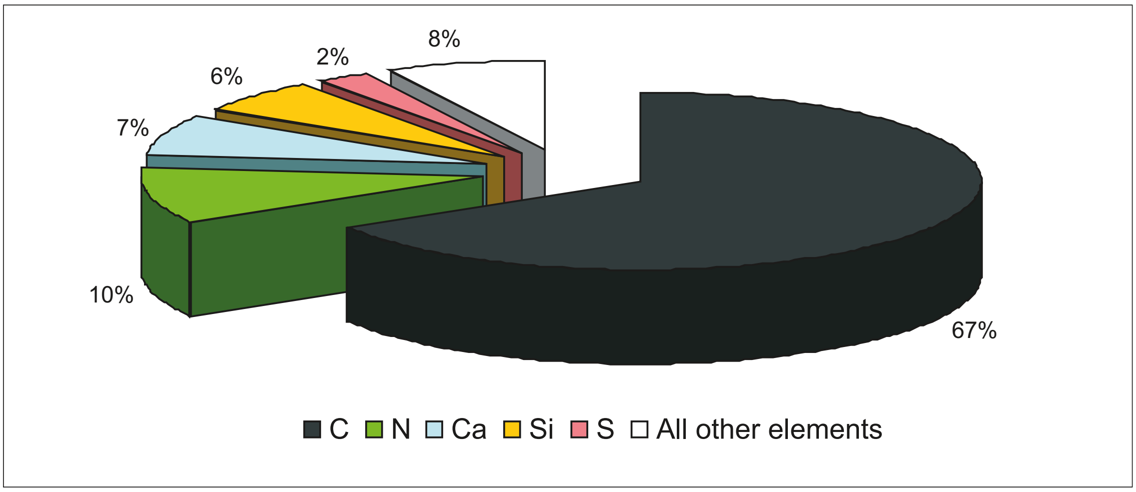


Figure 7-6. Distribution of elements (% of total investigated elements, based on mass) in the particulate component in the average lake in Forsmark. Note that not all elements are analyzed and the elements of which water is composed, oxygen and hydrogen, are not included.

The elemental composition of the biotic component differs from that of the total abiotic component, but somewhat resembles that of the particulate component. The biotic component is dominated by carbon (57% of total) and calcium (33% of total). Nitrogen, zinc and silicon comprise between 2 and 4% each of total mass of the biotic component, while all other elements comprise smaller fractions (Figure 7-7).

Within the biotic component, almost all the elements are most abundant in benthic primary producers (Figure 7-8). This is especially true of the lanthanides, which occur almost exclusively in the benthic primary producers. This may be accurate, but it may also be an artifact due to missing data on the chemical composition of bacteria. Data on the chemical composition of all functional groups except bacterioplankton and benthic bacteria are available for most elements (Appendix 6), but the composition of all functional groups is available only for phosphorus, nitrogen, carbon and sulphur. Bacteria are known to have a very high phosphorus content /Wetzel 2001/. Accordingly, 70% of all phosphorus in the biota is found in bacteria (average lake). Bacteria also contain considerable amounts of nitrogen, sulphur and carbon (34, 16 and 12% of the total biotic mass of each element in the average lake). Thus, most elements are

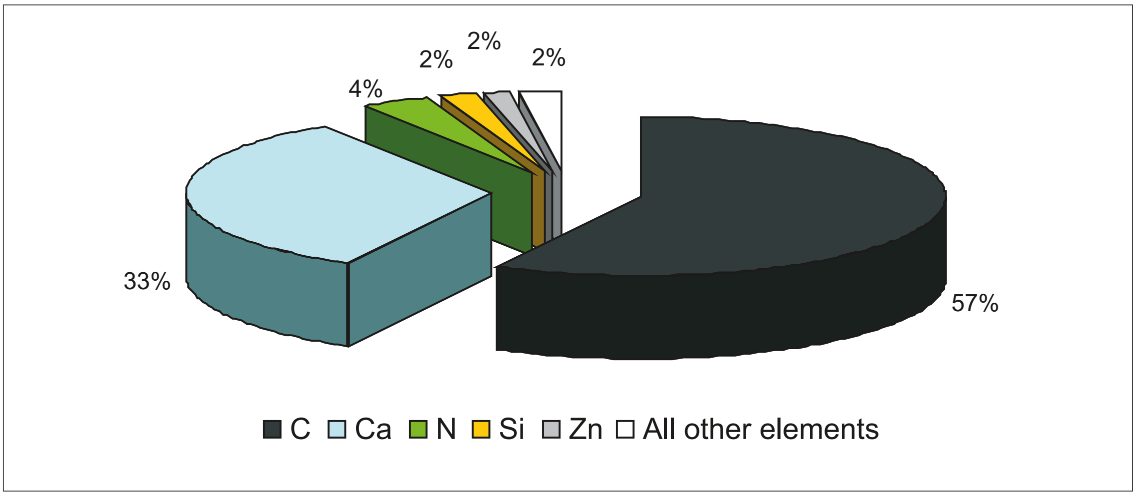


***Figure 7-7.** Distribution of elements (% of total investigated elements, based on mass) in the biotic component in the mean lake in Forsmark. Note that not all elements are analyzed and the elements of which water is composed, oxygen and hydrogen, are not included.*

probably present in consumers to a considerably larger degree than shown in Figure 7-8. Some elements are most common in consumers even without the contribution of bacteria: a significant fraction of mercury, potassium, sodium and bromine is found in the analyzed groups of consumers. Mercury, which is an element known for biomagnification, shows the highest concentration in fish. Potassium, rubidium and zinc are also present in large amounts in fish. For some unknown reason, bromine is found mainly in zooplankton, and the same pattern is seen in Frisksjön in Laxemar-Simpevarp and in the marine environment /Wijnblad et al. 2008/. The concentration of almost 30 of the analyzed elements in fish is below the detection limit of the method, and it is evident that the concentrations of most trace elements in fish are small.

7.3.2 Mass balances

Data to estimate all of the four major fluxes (inflow through water, outflow through water, atmospheric deposition and accumulation in sediment) are available for 16 elements (C, Ca, Cl, Fe, I, K, Mg, Mn, N, Na, P, S, Si, Sr, Th, U). However, for another 31 elements the only flux missing is atmospheric deposition. For phosphorus this flux is large for some of the lakes (31, 43, and 45% of total influx in Bolundsfjärden, Eckarfjärden and Puttan, respectively), while for the other 14 elements where all fluxes were measured, atmospheric deposition constitutes a minor fraction of total influx (mean value for the Forsmark lakes 1.7%, min. 0.01% max. 18% of total influx). Due to the small share represented by atmospheric influx for most elements, the mass balances for elements where data on atmospheric deposition are lacking are also discussed in this section. A summary of the estimated elemental fluxes for analyzed elements is given in Appendix 12.

In the average Forsmark lake, the inflow via water is the most important influx for all investigated elements. The most important outflux differs somewhat between elements. For metalloids, metals, and non-metals, outflow via water is the most important outflux, whereas for lanthanides the most important outflux is accumulation in sediments (Figure 7-9). There are some differences among the five studied lakes in the relative importance of different fluxes. In Bolundsfjärden, Eckarfjärden and Puttan, the influx of phosphorus, iron and manganese via atmospheric deposition is relatively large compared to the inflow via water. In the other two lakes, Gällsboträsket and Norra Bassängen, on the other hand, atmospheric influx of phosphorus, iron and manganese is small. This is an effect of the lake area and the position of the lake within the catchment (i.e. the size of the catchment area). Eckarfjärden and Bolundsfjärden have relatively large atmospheric influx due to their large lake area, whereas the smaller Puttan has a relatively large share of atmospheric deposition due to low inflow via water. The importance of

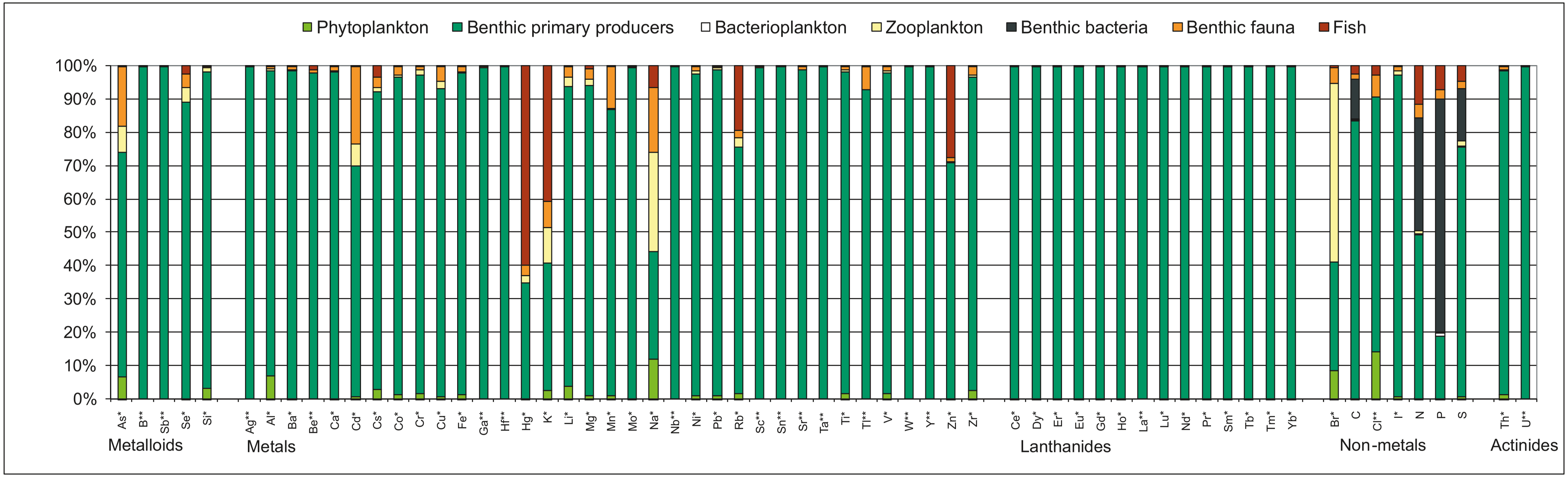


Figure 7-8. *Distribution of a number of elements among the biotic components of the ecosystem in the average lake in Forsmark. * indicates that data for bacterioplankton and benthic bacteria are missing. ** indicates that data are missing for one or more other groups besides bacteria*

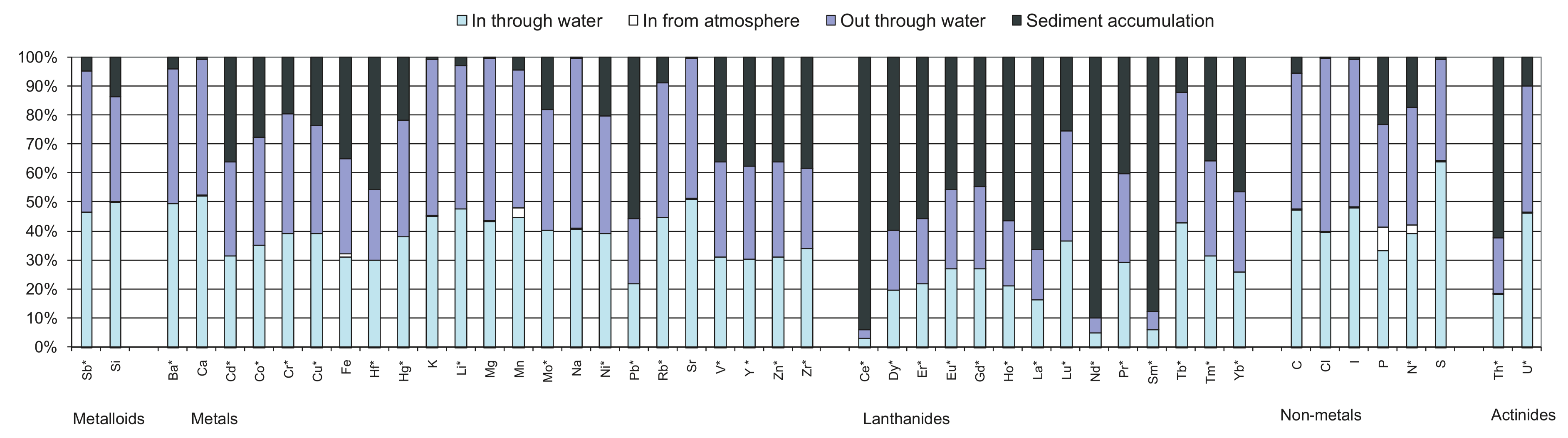


Figure 7-9. *Relative magnitude of different in- and outfluxes for a number of elements in the average lake in Forsmark. Elements included are those where all fluxes were determined or were only atmospheric deposition was lacking (indicated by *). All fluxes are estimated separately, i.e. sediment accumulation is estimated from sediment cores, in- and outflows are estimated from concentrations in inlets and outlets, and atmospheric deposition is estimated from concentrations in precipitation. The uncertainties in the estimated flows can lead to imbalance in the mass balances, e.g. higher outfluxes than influxes to the lake, which is the case for most lanthanides.*

different outfluxes differs among the lakes. In Gällsboträsket and Norra Bassängen, the outflow via water dominates for almost all elements, while in Bolundsfjärden, Eckarfjärden and Puttan, accumulation in sediment is the dominating outflux for many elements. Lake Puttan shows that in addition to lake size, the position of the lake within the catchment (i.e. the size of the catchment area) also influences the functioning of the lake. Properties of the elements also influence the flow pattern of the elements, and iodine, uranium and thorium are examples of this (further discussed in section 7.3.4).

The most and least abundant elements in the fluxes (based on mass) are shown in Table 7-1. The largest sediment accumulation was composed of elements common in biota (carbon, calcium, silicon, nitrogen, sulphur and iron), whereas mercury and lanthanides show the lowest accumulation rates in accordance with their uncommonness in biota and water. Among the 16 elements for which atmospheric deposition is available, some ions common in marine environments (chlorine, sodium, and sulphur) dominate along with carbon and nitrogen. The inflow as well as outflow via water is dominated by the same elements: carbon, chlorine, calcium, sodium and sulphur. The least common elements in inflow as well as outflow via water are mercury and some lanthanides.

The mass balances are associated with some uncertainties, and the mass balances are well balanced for only 14 elements (influxes vary between 75% and 110% of outfluxes). The mass balances for the lanthanides appear to be very unbalanced, with higher outfluxes than influxes. Confidence in the estimates of inflow and outflow via water is relatively high, whereas data on atmospheric deposition is lacking for many elements and the estimate of sediment accumulation is rather uncertain (further discussed in section 7.6).

7.3.3 Detailed description of phosphorus pools and mass balances

Pools

The distribution of phosphorus between different ecosystem components is similar in the five lakes Bolundsfjärden, Eckarfjärden, Gällsboträsket, Puttan and Norra Bassängen (Table 7-2). The sediment contains by far the largest phosphorus pool, containing between 95 and 99.8% of total phosphorus in the lakes. The second largest pool is consumers followed by producers. Phosphorus deviates from most other elements in that primary producers usually contain most of the biotic pool of an element (Figure 7-8). However, this result is expected and in accordance with the literature since the phosphorus content of bacteria is high /Wetzel 2001/.

The distribution of phosphorus between the particulate and dissolved components is similar in the five lakes. In contrast to most other elements, a relatively large share of the abiotic phosphorus in water is present in the particulate component (Figure 7-4). The main reason for this is that inorganic phosphorus is often limiting for primary production and bacterial secondary production. Therefore, phosphorus available in the dissolved component is rapidly taken up by biota, and the concentrations of dissolved phosphorus remain low.

Table 7-1. Elements which show the largest and smallest mass fluxes (g y^{-1}) for each of the major in- and outfluxes in lakes in the Forsmark area. For example, the element with the highest sediment accumulation is carbon, followed by calcium and silicon, and the element least accumulated in the sediments is mercury. The sizes of the different fluxes are found in Appendix 12.

Flux	Ranking of elements with highest mass flux	Ranking of elements with lowest mass flux
Accumulation in sediment	C > Ca > Si > N > S > Fe	Tb > Ta > Lu > Tm > Hg
Atmospheric deposition	C > Cl > N > Na > S > Ca > K	Sr > I > U > Al > Th
Inflow via water	C > Ca > Cl > Na > S > Mg	Ho > Tm, Eu > Sm > Hg
Outflow via water	C > Cl > Ca > Na > S > Mg	Ho, Tm, Eu, Sm > Hg

Table 7-2. Absolute and relative sizes of phosphorus pools and fluxes in five lakes in the catchment Forsmark 2. (g P and % of total mass in the lake i.e. in all components of the system) (% of total in- or outflux). The last three rows show the net balance for each lake (as g P y^{-1} and %, respectively).

	Bolundsfjärden	**Eckarfjärden**	**Gällsboträsket**	**Norra Bassängen**	**Puttan**	**Mean values, Forsmark Lake**
Pools, g P (% of total P in the lake components)						
Producers	2×10^4 (0.1)	1×10^4 (0.01)	4×10^2 (0.01)	2×10^3 (0.9)	1×10^3 (0.2)	7×10^3 (0.04)
Consumers	1×10^5 (0.5)	5×10^4 (0.01)	2×10^3 (0.1)	7×10^3 (3.7)	6×10^3 (0.8)	3×10^4 (0.2)
Particulate phase of water	2×10^3 (0.01)	1×10^3 (0.001)	1×10^2 (0.004)	2×10^2 (0.1)	2×10^2 (0.02)	9×10^2 (0.003)
Dissolved phase of water	3×10^3 (0.01)	1×10^3 (0.002)	3×10^2 (0.01)	2×10^2 (0.1)	2×10^2 (0.03)	9×10^2 (0.004)
Upper sediment layer*	–	–	5×10^3 (0.1)	–	–	–
Deeper sediment layer	2×10^7 (99.4)	8×10^7 (99.9)	4×10^6 (99.8)	2×10^5 (95.3)	8×10^5 (98.96)	2×10^7 (99.8)
Fluxes, g P year^{-1} (% of total influx/outflux)						
Inflow via water	1×10^4 (69)	3×10^3 (57)	5×10^3 (98)	1×10^4 (97)	4×10^2 (55)	6×10^3 (70)
Influx from air	5×10^3 (31)	2×10^3 (43)	1×10^2 (2)	4×10^2 (3)	3×10^2 (45)	2×10^3 (30)
Outflow via water	1×10^4 (48)	3×10^3 (32)	5×10^3 (94)	1×10^4 (93)	4×10^2 (31)	7×10^3 (60)
Net sediment accumulation	1×10^4 (52)	7×10^3 (68)	3×10^2 (6)	1×10^3 (7)	9×10^2 (69)	5×10^3 (40)
Net balance (*g P year^{-1}*)	-1×10^4	-4×10^3	-2×10^2	-8×10^2	-6×10^2	-2×10^3
Net balance (% of total influx)	–71	–80	–5	–6	–85	–23
Net balance (% of total outflux)	–44	–44	–5	–5	–46	–19

*An upper 1 cm sediment layer is only differentiated for Gällsboträsket, which lacks a microbial mat. This layer represents the oxygenated upper layer. In the other lakes, this layer is part of the microbial mat (layer consisting of microphytobenthos and benthic bacteria), which is part of the "producers" component.

Although the distribution of phosphorus in the lake ecosystem shows a strong concentration in the sediments in all five lakes, the phosphorus amount per unit area in the sediments differs among the lakes. This is a direct result of the sediment thickness: Gällsboträsket and Eckarfjärden are among the oldest lakes in the Forsmark area with thick sediment layers and high amounts of phosphorus bound in the sediments, whereas Norra Bassängen is one of the youngest lakes with a thin sediment layer and lower amount of phosphorus. Moreover, Norra Bassängen has been situated in an exposed wind direction before isolation from the Baltic Sea, resulting in very low sediment accumulation during the marine stage (see Chapter 8).

The upper centimetre of the sediment is recognized as a separate component in Gällsboträsket (which lacks microphytobenthos) in order to differentiate a biologically active upper sediment layer. The deeper sediment component consists of the rest of the sediment. For the lakes with microphytobenthos, deeper sediment is the only sediment layer as the microphytobenthos belongs to the biotic component.

Mass balances

The most important flux differs among the lakes (Table 7-2). Inflow via water dominated in all lakes. However, for Bolundsfjärden, Eckarfjärden and Puttan, the influx via atmospheric deposition comprise a relatively large part of the total influx (31–45% of total influxes). In Gällsboträsket and Norra Bassängen, on the other hand, inflow via water totally dominates, comprising 95–96% of total phosphorus influx to the lakes. This is an effect of lake size and position in the catchment. In terms of quantity, inflow via water is largest in Bolundsfjärden and Norra Bassängen, which are situated the furthest downstream in the catchment. The amounts of phosphorus reaching the two lakes are of the same magnitude, but the proportion of this influx to the total influx is smaller for Bolundsfjärden because of the larger lake size and thereby larger amounts added via atmospheric deposition.

Outflux of phosphorus via accumulation in sediment is of the same magnitude as outflow via water for Bolundsfjärden, Eckarfjärden and Puttan. For Gällsboträsket and Norra Bassängen, outflow via water dominates. Although accumulation in sediment is the largest outflux from Puttan, the total accumulated amount is small compared to the amounts accumulated in the two larger lakes. The largest sediment accumulation is found in the larger lakes Bolundsfjärden and Eckarfjärden. Lakes of this type (oligotrophic hardwater lakes) are expected to function as phosphorus sinks, as co-precipitation of phosphorus and calcium from the water phase to the sediment is assumed to take place /Brunberg and Blomqvist 2000/. The large pool of phosphorus in lake sediments also indicates that this is the case.

In Bolundsfjärden, Eckarfjärden and Puttan, the annual influx of phosphorus is lower than the estimated size of the total biotic phosphorus pools in the lakes, whereas in Gällsboträsket and Norra Bassängen the biotic pools are smaller than the annual influx of phosphorus. The estimated pools and flows of phosphorus in Bolundsfjärden and Gällsboträsket are presented in Figure 7-10. Bolundsfjärden is one of the larger lakes in the area, whereas Gällsboträsket is one of the smaller.

The total phosphorus pool in the lakes is relatively large compared to annual influxes and outfluxes. Accordingly, the phosphorus dynamics in these lakes might be dependent on internal circulation to a large degree. However, as no ecosystem budget for phosphorus has been calculated, we cannot determine the internal circulation, and the influx may be crucial for the functioning of the lake ecosystem. Sediment accumulation appears to be an important process in the phosphorus dynamics, and sediment is by far the largest phosphorus pool in the lakes.

The mass balances are somewhat unbalanced, with higher outfluxes than influxes for all lakes. The largest deficit is seen for Puttan (85% of total influx and 46% of total influx), Bolundsfjärden (71% of total influx and 44% of total outflux) and Eckarfjärden (80% of total influx and 44% of total outflux), whereas the mass balances for Gällsboträsket and Norra Bassängen show good agreement (only c. 5% deficit). The flux associated with largest uncertainties is sediment accumulation. Calculating sediment accumulation as the difference between the other in- and outfluxes in the mass balance indicates a rate about half of our estimates using phosphorus data from lake sediments. This is a realistic result as sediment accumulation can be expected to vary over time, and the estimates from lake sediments are long-term estimates.

7.3.4 Detailed description of pools and mass balances of iodine, uranium and thorium

As described in section 7.1.1, iodine, uranium and thorium are elements with different sorption properties. Iodine is very mobile, thorium almost immobile, and uranium possess properties somewhere in between iodine and thorium. A description of the pools and mass balances for these elements in the five lakes Bolundsfjärden, Eckarfjärden, Gällsboträsket, Norra Bassängen and Puttan follows below in order to describe how the different sorption properties influence the flow pattern of elements in lake ecosystems.

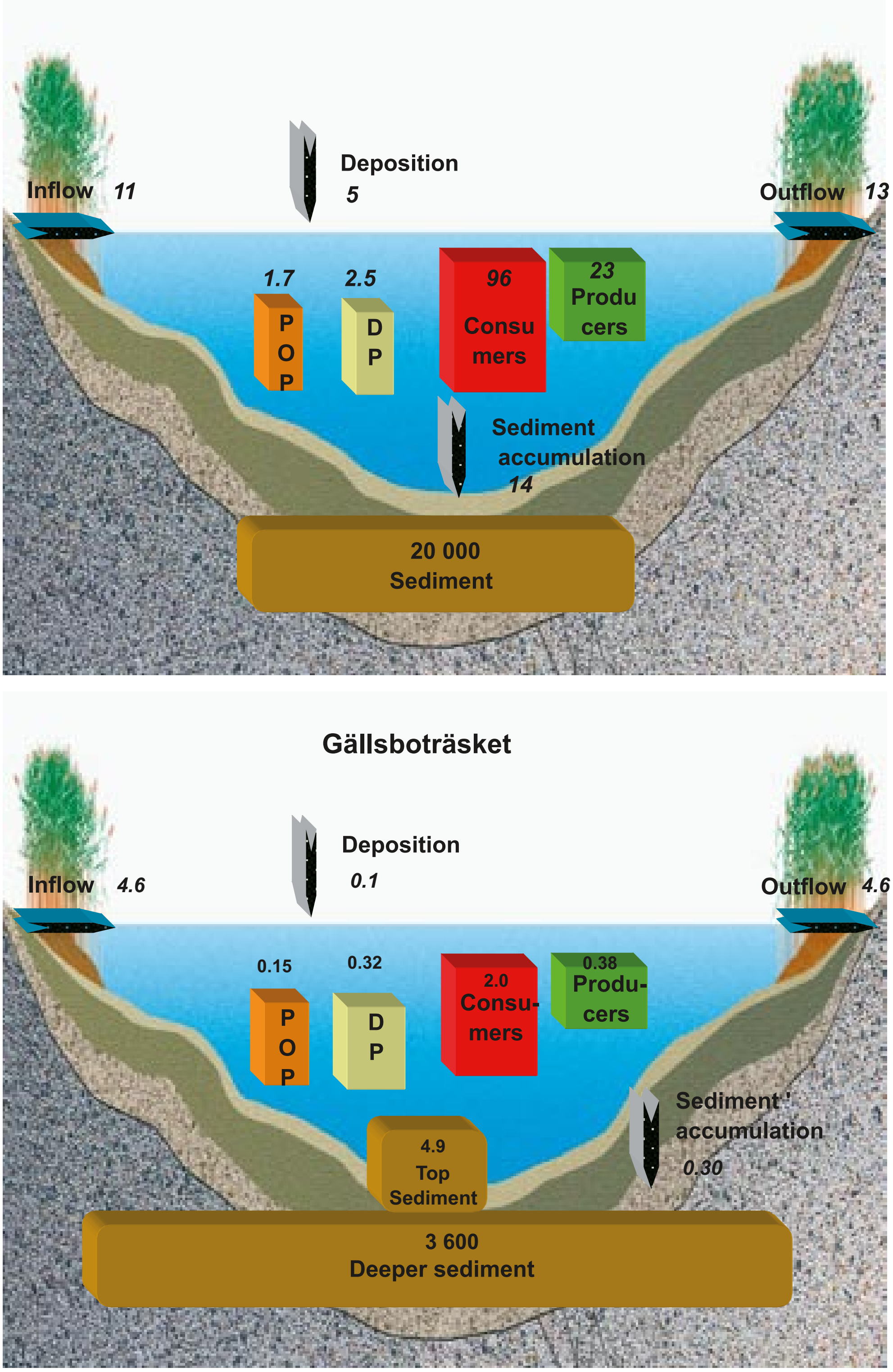


Figure 7-10. *Phosphorus pools (kg P) and fluxes (kg P per year) in Bolundsfjärden (above) and Gällsboträsket (below). Note that the sediment pools are scaled differently than the other pools in order to fit all pools in the same picture.*

Pools

Iodine, thorium and uranium are all strongly concentrated in the abiotic pool, and particularly in the sediments (Tables 7-3, 7-4 and 7-5). This is a direct result of the large amounts of sediments in the lakes. As expected, thorium is the element with highest Kd value and the strongest concentration in the sediment, which contains between 99.998 and 99.9994% of total thorium in the 5 lakes. Iodine, the element with lowest Kd, is strongly concentrated in the sediments, but the relative amount (95.9 to 99.2% of total iodine in the lakes) is somewhat lower than for thorium. Uranium, with an intermediate Kd value, is concentrated in the sediments with relative amounts in between those of iodine and thorium (99.6–99.97% of total uranium in the five lakes). As in the case of phosphorus, Eckarfjärden and Gällsboträsket have a larger share of total iodine, uranium and thorium in the sediment component than Puttan, Bolundsfjärden and Norra Bassängen. This is a direct result of sediment thickness: Gällsboträsket and Eckarfjärden are among the oldest lakes in the Forsmark area with thick sediment layers leading to higher amounts of iodine, uranium and thorium than in the younger lakes with shallower sediment depths. The second largest pool of iodine and uranium is the pool dissolved in lake water, while for thorium the second largest pool is contained in the biota.

Between 0.7% and 3.5% of total iodine is dissolved in the lake water, whereas the amounts of iodine in the biota are low. The high solubility of iodine leads to only minor amounts of iodine in particulate matter in lake water in all five lakes (below the detection limit in three of the lakes). Data on the iodine content of bacteria are lacking, making it difficult to compare iodine content in producers and consumers. However, the available data indicate that iodine is concentrated in primary producers, as concentrations in these are high, whereas concentrations in consumers are low. This is in agreement with a study by /Kumblad and Bradshaw 2008/

Table 7-3. Iodine amounts (g) and fluxes (g y^{-1}) in five lakes in the catchment Forsmark 2. The last three rows show the net balance for each lake (as g y^{-1} and %, respectively). The particulate pool of iodine is below the detection limit in some lakes, noted as <d.l, and in the calculation of a mean value for iodine the concentrations in these lakes were set at 0.

	Bolunds-fjärden	Eckar-fjärden	Gällsbo-träsket	Norra Bassängen	Puttan	Average Lake
Pools, g iodine (% of total iodine pool in the lakes)						
Producers	266	124	5	21	17	87
Consumers	8	4	0.1	1	1	3
Particulate phase of water	< d.l.	41	0.4	< d.l.	< d.l.	
Dissolved phase of water	2,165	1,305	52	127	170	764
Upper sediment layer*	–	–	56	–	–	11
Deeper sediment layer	165,012	164,285	7,129	3,454	14,241	70,824
Fluxes (g year^{-1})						
Inflow via water	6,987	2,023	2,364	9,009	309	4,138
Influx from air	56	26	2	4	4	18
Outflow via water	8,270	2,023	2,364	9,066	309	4,406
Net sediment accumulation	258	120	6	20	17	84
Net balance (g year^{-1})	**–1,486**	**–94**	**–4**	**–73**	**–13**	**–334**
Net balance (% of total influx)	**–21**	**–5**	**–0.2**	**–1**	**–4**	**–7**
Net balance (% of total outflux)	**–17**	**–4**	**–0.2**	**–1**	**–4**	**–8**

* An upper 1 cm sediment layer is only differentiated for Gällsboträsket, which lacks a microphytobenthos. This layer represents the oxygenated upper layer. In the other lakes, this layer is part of the microbial mat (layer consisting of microphytobenthos), which is part of the "producers" component.

Table 7-4. Uranium amounts (g) and fluxes (g y^{-1}) in five lakes in the catchment Forsmark 2. The last three rows show the net balance for each lake (as g y^{-1} and %, respectively).

	Bolunds-fjärden	Eckar-fjärden	Gällsbo-träsket	Norra Bassängen	Puttan	Average lakes
Pools (g U)						
Producers	174	81	1	14	11	56
Consumers	0.2	0.1	0.003	0.01	0.01	0.1
Particulate phase of water	0.6	0.5	0.01	0.03	0.04	0.2
Dissolved phase of water	668	264	18	33	44	205
Upper regolith layer*	–	–	92	–	–	18
Deeper regolith layer	668,840	1,250,267	49,953	12,639	54,469	407,234
Fluxes (g U y^{-1})						
Inflow via water	2,645	977	1,012	2,822	99	1,511
Influx from air	7	3	0.2	1	0.5	2
Outflow via water	2,606	687	959	2,820	68	1,428
Net sediment accumulation	1,017	474	22	80	67	332
Net balance (*g U year^{-1}*)	**–971**	**–180**	**32**	**–77**	**–35**	**–240**
Net balance (% of total influx)	**–37**	**–18**	**3**	**–3**	**–35**	**–16**
Net balance (% of total outflux)	**–27**	**–15**	**3**	**–3**	**–26**	**–14**

* An upper 1 cm sediment layer is only differentiated for Gällsboträsket, which lacksa microphytobenthos. This layer represents the oxygenated upper layer. In the other lakes, this layer is part of the microbial mat (layer consisting of microphytobenthos), which is part of the "producers" component.

Table 7-5. Thorium amounts (g) and fluxes (g y^{-1}) in five lakes in catchment Forsmark 2. The last three rows show the net balance for each lake (as g y^{-1} and %, respectively).

	Bolunds-fjärden	Eckar-fjärden	Gällsbo-träsket	Norra Bassängen	Puttan	Average lake
Pools (g Th)						
Producers	12	6	0,03	1	1	4
Consumers	0.2	0.1	0.003	0.02	0.01	0.01
Particulate phase of water	1	0.5	0.01	0.05	0.07	0.4
Dissolved phase of water	3	2	0.1	0.2	0.2	1.2
Upper sediment layer*	–	–	6	–	–	1
Deeper sediment layer	297,387	1,435,612	68,483	1,682	6,736	361,980
Fluxes (g Th year^{-1})						
Inflow via water	19	6	7	25	1	11
Influx from air	2	1	0.1	0.2	0.2	1
Outflow via water	23	6	7	25	1	12
Net sediment accumulation	120	56	3	9	8	39
Net balance (*g Th year^{-1}*)	**–121**	**–55**	**–3**	**–9**	**–8**	**–39**
Net balance (% of total influx)	**–556**	**–812**	**–38**	**–37**	**–757**	**–320**
Net balance (% of total outflux)	**–89**	**–85**	**–28**	**–27**	**–88**	**–76**

* An upper 1 cm sediment layer is only differentiated for Gällsboträsket, which lacks microphytobenthos. This layer represents the oxygenated upper layer. In the other lakes, this layer is part of the microbial mat (layer consisting of microphytobenthos), which is part of the "producers" component.

showing that iodine was abundant in the plant species. Furthermore, /Kumblad and Bradshaw 2008/ state that marine macroalgae have a high ability to fix halide ions, which may be true also for the macroalgae in lakes as the iodine content in these are high. Fish contain very little iodine and all measurements on fish were below the detection limit.

Although the dissolved component of uranium is the second largest pool of uranium, this component contains small amounts of total uranium in the lakes, between 0.02% and 0.26%. The biotic pool is even smaller (0.001–0.1% of total uranium) and the particulate pool is negligible (0.00004–0.0001% of total uranium). Data on uranium in phytoplankton, bacterioplankton and benthic bacteria are lacking and it is therefore difficult to make any comparison between uranium content in producers and consumers. Available data indicate that uranium in the biotic pool is concentrated in benthic primary producers and the amounts in benthic fauna and fish are negligible (Figure 7-8). Sorption properties of uranium are dependent on salinity, especially at high pH, which could hypothetically have an influence on the uranium concentrations in water in lakes with salt water intrusion. However, comparison between uranium concentrations in Bolundsfjärden that have occasional saltwater intrusions and the more upstream Eckarfjärden show no differences in uranium concentrations in water, suggesting that there are no differences in the distribution of uranium between different compartments in the lakes in the area.

In the case of thorium, the second largest pool (next to sediment) is contained in biota, with 0.004–0.06% of total thorium in the lakes. The dissolved component contains somewhat smaller amounts of thorium than the biotic component (0.0001–0.01% of total thorium), but approximately 3 times more thorium than the particulate component. As in the case of iodine and uranium, data are not available on the thorium content of bacteria, making it difficult to compare thorium content in producers and consumers. The thorium in the biota (excluding bacteria) is almost exclusively found in benthic primary producers, while the thorium content of the consumers is low. In the study by /Kumblad and Bradshaw 2008/, thorium concentrations were highest in benthic microalgae followed by phytoplankton and plants.

Mass balances

The mass balances of iodine, uranium and thorium show that the most important fluxes differ among the elements due to their sorption properties and mobility in the ecosystem. The distribution of fluxes for iodine (very mobile), uranium (intermediate) and thorium (almost immobile) is shown in Figure 7-11 and Tables 7-3, 7-4 and 7-5. As expected, the outflow via water is much more important for mobile iodine than for uranium (intermediate) and thorium (lowest fluxes). For uranium, outflow via water is the largest outflux, but accumulation in sediments is also an important process. Thorium accumulation in sediments is c. 3 times larger than outflow via water. A detailed description of the mass balances for iodine, thorium and uranium follows below.

Iodine

The influx and outflux of iodine to the lakes are dominated by water in- and outflow. Water inflow constituted between 99 and 100% of the total iodine influx to the five investigated lakes. Likewise, the accumulation of iodine in sediment has little impact on outfluxes and between 94 and 100% of the iodine outflux is composed of outflow through water.

The mass balances for iodine are well balanced. The outfluxes were higher than the influxes, but the differences were small: for Gällsboträsket the iodine deficit was only 0.2% of total influx and outflux, and for Bolundsfjärden with the largest differences the net balance was 17% and 21% of total outfluxes and influxes, respectively. The atmospheric deposition can be considered uncertain as it is estimated as half the detection limit based on a few measurements below detection limit. However, although in the lower range, it is within the reported range of iodine concentrations in rainwater from a study in United Kingdom (range 0.4–5.9 $\mu g\ L^{-1}$) /Sheppard et al. 2002/.

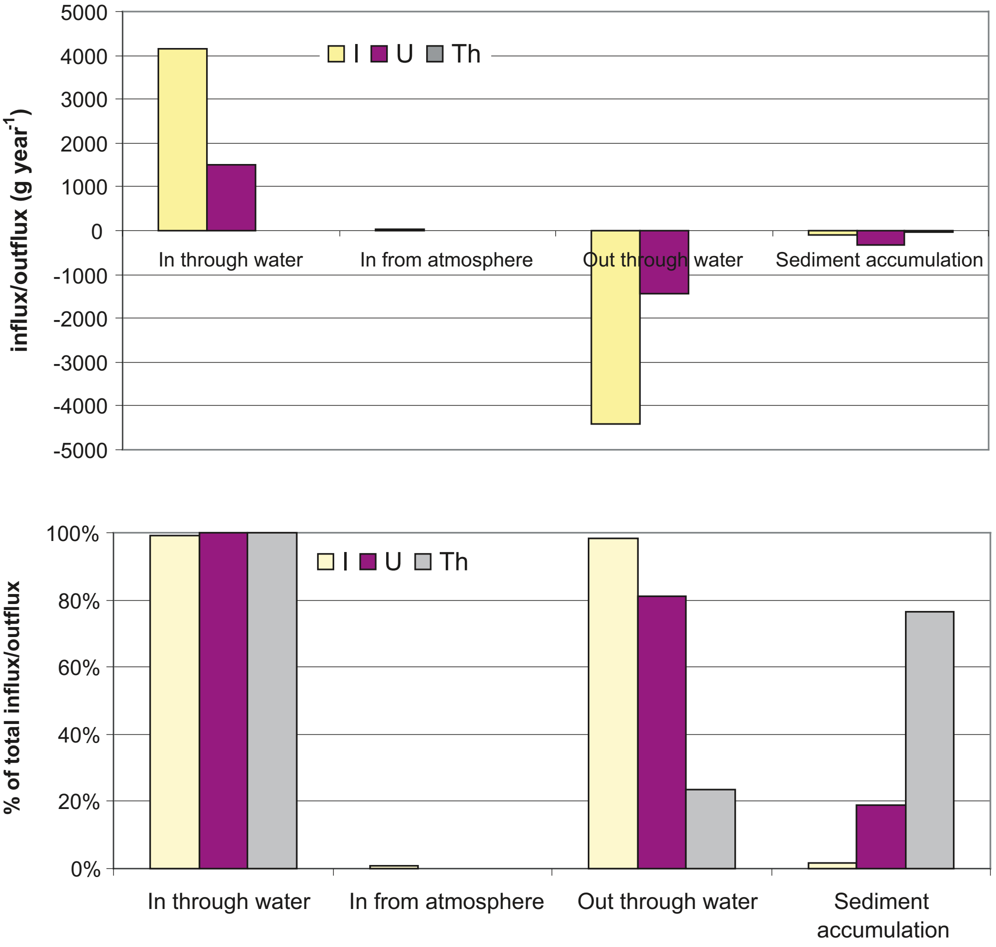


Figure 7-11. *Distribution of fluxes of iodine, uranium and thorium in the average Forsmark lake in weight and in % of influx and % of outflux, respectively.*

With the exception of the sediments, which to a large degree can be assumed not to be utilized by the biotic pool, the pools in the lakes are of the same size or smaller than the fluxes into and out of the five lakes. The largest amounts of iodine in the biotic pool were found in benthic primary producers. As the pools and fluxes are of the same size, it is possible that much of the incoming iodine will be incorporated into the food web.

Uranium

The influx of uranium is strongly dominated by inflow via water and atmospheric deposition comprises at most 0.3% of total influxes in the investigated lakes (Table 7-5). The outflux of uranium is dominated by outflow via water in all lakes (between 50% and 98% of total outflux in the five investigated lakes). Again, uranium fluxes in Norra Bassängen and Gällsboträsket were more dominated by outflow via water compared with the lakes Bolundsfjärden, Eckarfjärden and Puttan, where a relatively large portion of the outflux was through sediment accumulation: 28%, 41% and 50% of total outflux, respectively.

The mass balances for uranium for Gällsboträsket and Norra Bassängen are well balanced, and the net balance differs only by ±3% from the total in- and outfluxes in these lakes. For Bolundsfjärden, Eckarfjärden, Norra Bassängen and Puttan, the mass balances are not as well balanced, and there is a deficit of uranium in the mass balance, equivalent to 18–35% of total influx.

The influx and outflux of uranium are small compared with the total pool of uranium in the lake when the sediment is included. However, large amounts of the sediment can be considered to be unavailable to the biota. The influx is almost 27 times higher than the biotic pool in the average Forsmark lake, and unless there is a rapid recycling of uranium in the biotic pool, much of the uranium influx should pass through the lake without being incorporated in the food web. However, according to the model there is a relatively large sediment accumulation in some of the lakes that could be a uranium sink.

Thorium

The influx of thorium is dominated by the inflow via water. Atmospheric deposition is as low as 1% of the total influx in Gällsboträsket and Norra Bassängen. Atmospheric deposition is relatively low in Bolundsfjärden, Eckarfjärden and Puttan as well, constituting between 11% and 17% of the total influx.

The outflux differs between the lakes. In the smaller lakes Gällsboträsket and Norra Bassängen the outflow via water dominates and comprises 72–73% of the total outflux. In the larger lakes Bolundsfjärden and Eckarfjärden and in Puttan, on the other hand, sediment accumulation is the dominant outflux, constituting 84–91% of the total outflux.

The mass balances for thorium are heavily unbalanced and the outflux exceeds the influx for all five lakes. Norra Bassängen and Gällsboträsket are the best balanced, but still the thorium deficits are 37% and 38% of the total influx for these lakes. The deficit is much higher for the other lakes, varying between 556% and 812% of the total influx. The most uncertain flow in the mass balance is sediment accumulation. The fact that Eckarfjärden, Bolundsfjärden and Puttan, the lakes with high sediment accumulation, have the most unbalanced mass balances indicates that sediment accumulation may be somewhat overestimated. Confidence and uncertainties in the mass balances will be further discussed in section 7.6.

The influx and outflux of thorium are about 4 times larger than the biotic pool, while the flow is small compared to all pools in the lake. Some of the thorium influx could be incorporated in the food web, and according to the model large amounts are incorporated in the sediment through sediment accumulation.

7.4 Evaluation of elemental pools and fluxes for a number of elements in Laxemar-Simpevarp

The main results of the mass balances for a number of elements in Frisksjön are presented in section 7.4.1, while more detailed results for phosphorus, iodine, uranium and thorium are presented in sections 7.4.2 and 7.4.3. Detailed results for separate elements are found in Appendices 11 and 12.

7.4.1 Chemical composition of different ecosystem components

The most common elements in Frisksjön (all components: dissolved, particulate, biotic and sediment) are silicon (38% of total mass of investigated elements) and carbon (37% of total) (Figure 7-12). Other elements that make a substantial contribution to the total mass are sulphur (5%), nitrogen (5%), aluminium (4%), iron (4%), and calcium (2%), while all other elements comprise 1% or less of the total mass of investigated elements in the lake (hydrogen and oxygen, the elements of which water is composed, are not included in the analysis).

The abiotic component (sediment, dissolved, and particulate) comprises 99.998% of the total mass of investigated elements, and this component accordingly has the same distribution of elements as the total lake ecosystem. All elements are strongly concentrated in the sediment

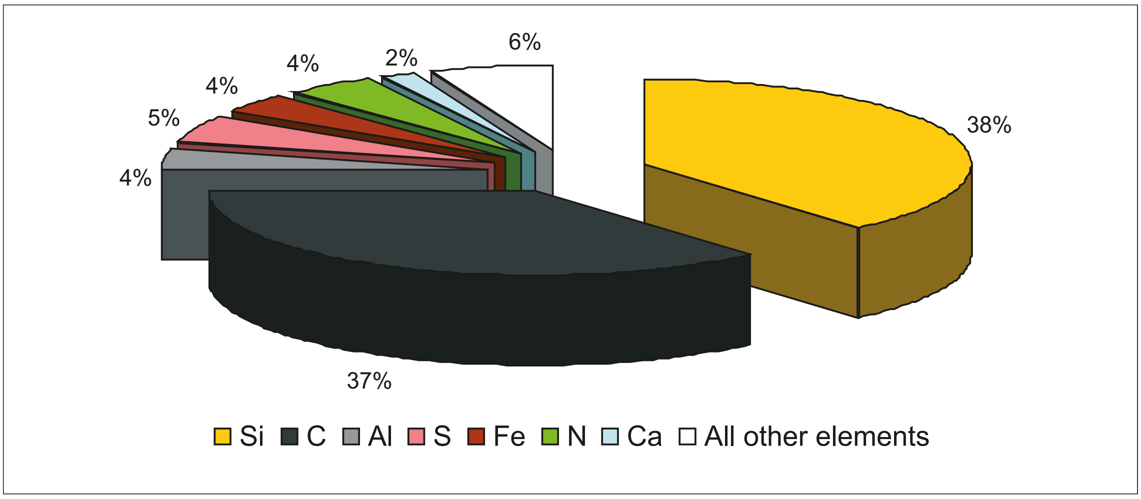


***Figure 7-12.** Distribution of elements (% of total investigated elements, based on mass) in Frisksjön (in all ecosystem components: dissolved, particulate, biotic and sediment). Note that not all elements are analyzed and that the elements of which water is composed, oxygen and hydrogen, are not included.*

component (Figure 7-13). The sediment constitutes between 97% and 100% of the total abiotic component and has the same distribution and share of major elements as the total distribution of the lake ecosystem. A large portion of the deeper sediment can be assumed to be unavailable for the biotic processes in the lake, and it is therefore of interest to evaluate the distribution of elements in the ecosystem when excluding the deeper sediments. After excluding the deeper sediment, many elements are still concentrated in the top sediment, but there are also some elements (Sb, Ca, Na, Mg, I, Cl, Br, F) that occur mainly in the dissolved phase (Figure 7-14). There are also considerable amounts of some elements in the biotic component, i.e. zinc, phosphorus and nitrogen. These elements are utilized by the biota, and the low concentrations of these elements in the dissolved component are probably a result of rapid biotic uptake when the element is available in the water phase. Data on the chemical composition of bacteria are lacking for all elements except carbon, phosphorus, nitrogen and sulphur, so the biotic pool of many elements may be underestimated. Overall, the distribution of all elements is strongly concentrated in the abiotic components (mainly the sediments), and only a minor fraction of the elements is present in the biotic component.

In the abiotic component in lake water, most elements are mainly present in the dissolved component, and amounts in the particulate component are considerably smaller (Figure 7-15). The only exceptions are Si, Ga, Nb, Sn, Ti, Sm and Th, which are more abundant in the particulate than in the dissolved component. The elemental composition of both the dissolved and the particulate components differs from that in the sediments. The dissolved component is dominated by carbon and major ions such as chlorine, sodium and calcium (Figure 7-16), whereas the particulate component is strongly dominated by silicon, which comprises 79% of the total mass (Figure 7-17). The second and third most common elements in the particulate component are carbon and iron. The elemental composition of the particulate component is based on a single sampling occasion in April 2008, and it seems reasonable to assume that the sampling coincided with a diatom bloom. Diatoms are a phytoplankton group that incorporate silicon in their cell surfaces, and diatoms often form blooms in lakes in the early spring during circulation of the water column. Thus, the high content of silicon in the particulate component is probably not representative of the entire year. The relatively high iron content in the particulate component, on the other hand, is probably representative and caused by a high concentration of humic substances in the water.

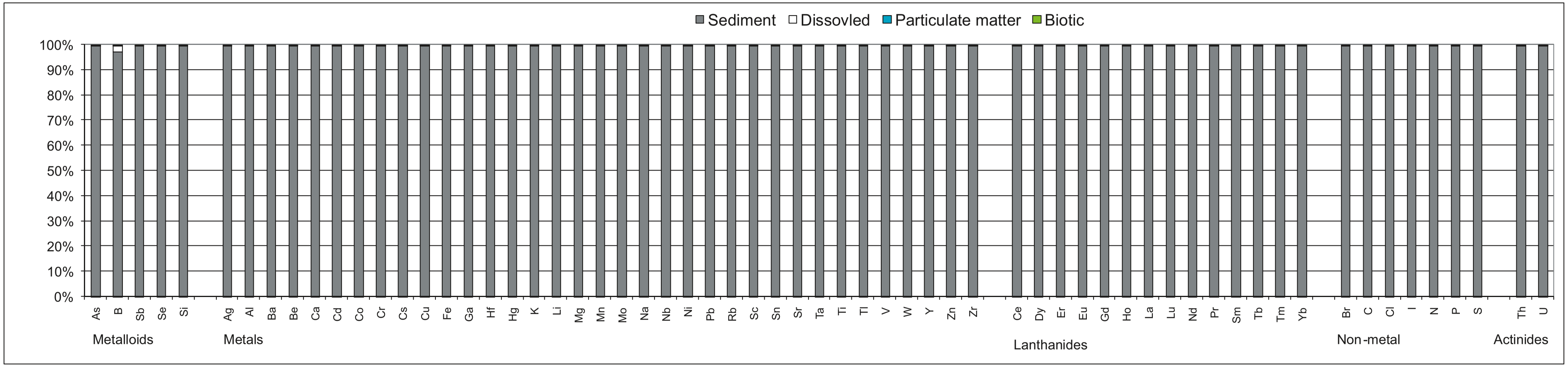


Figure 7-13. *Distribution of analyzed elements among the different components of the ecosystem in Frisksjön: sediment (black), dissolved in water (blue), particulate (white) and biotic (green). Sediment is totally dominant and is the only visible component in the figure.*

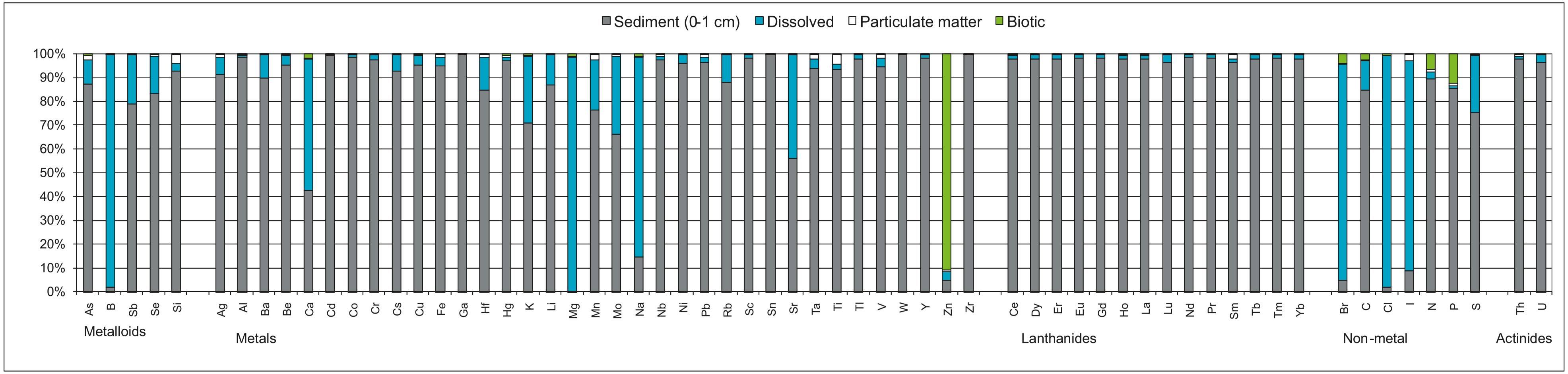


Figure 7-14. *Distribution of elements in percent between biotic, dissolved, top sediment and particulate components in Lake Frisksjön.*

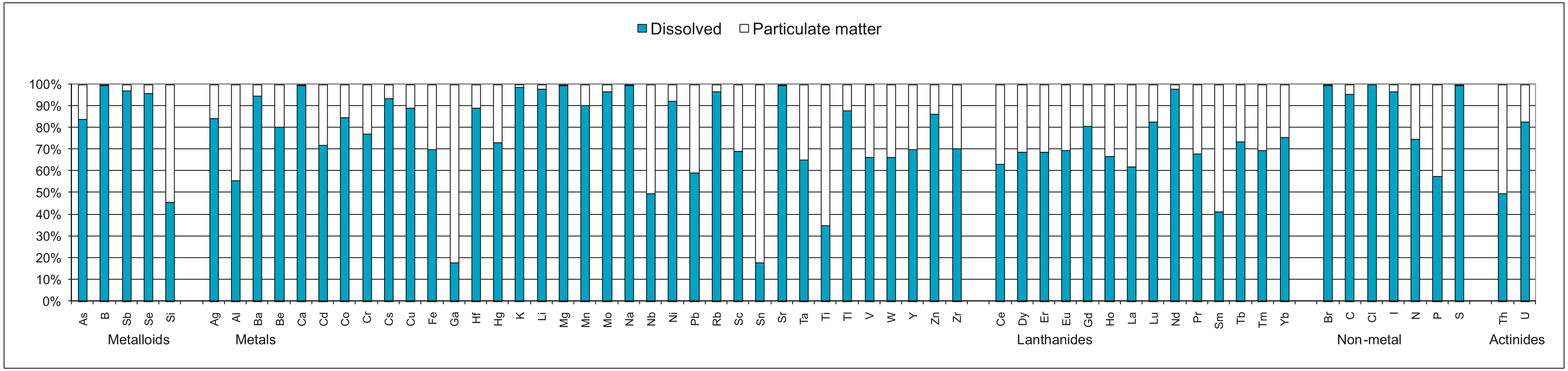


Figure 7-15. *Distribution of elements in percent between the dissolved and particulate components of the water in Frisksjön.*

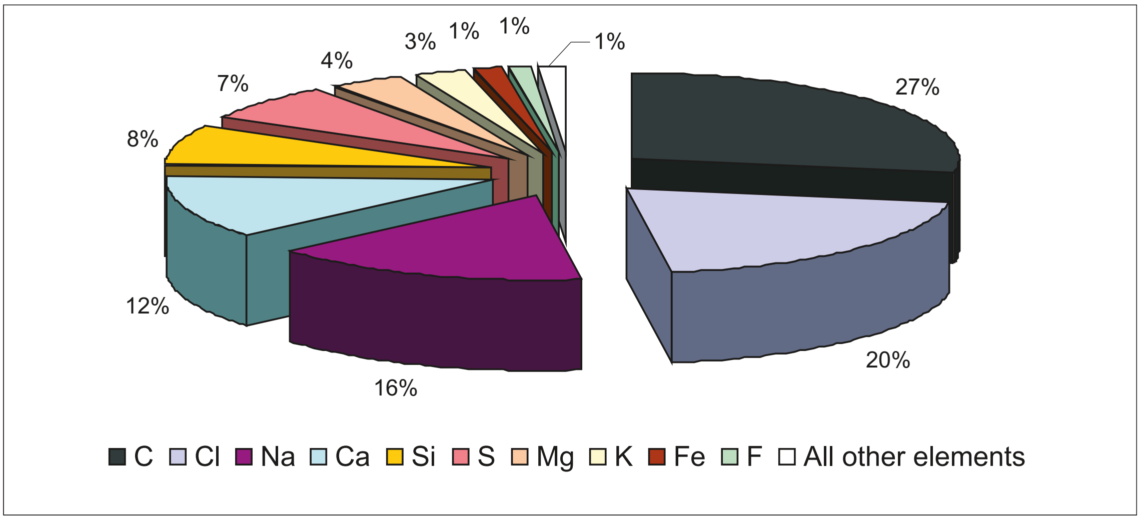


Figure 7-16. *Distribution of elements (% of total investigated elements, based on mass) in the dissolved component in Frisksjön. Note that not all elements are analyzed and the elements of which water is composed, oxygen and hydrogen, are not included.*

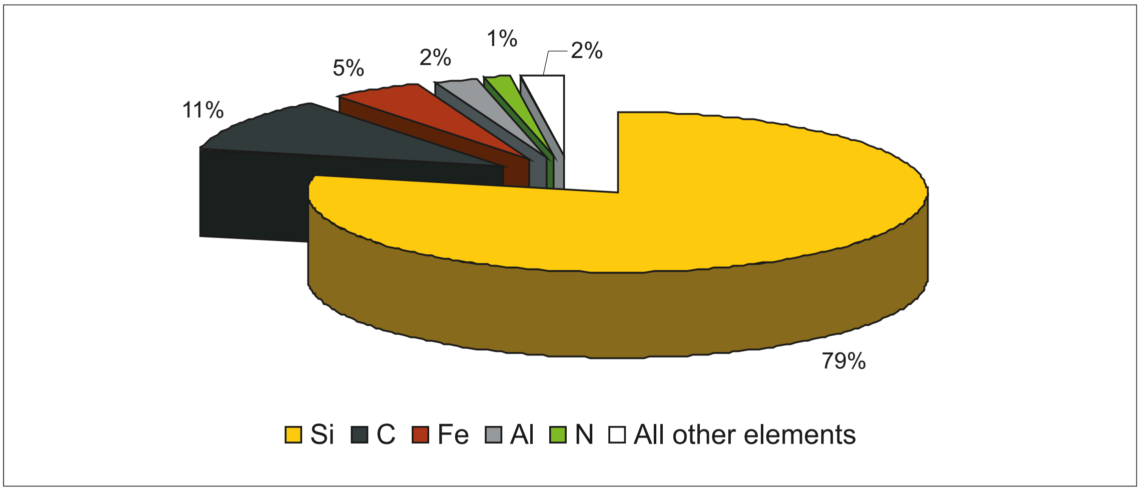


Figure 7-17. *Distribution of elements (% of total investigated elements, based on mass) in the particulate component in Frisksjön. Note that not all elements are analyzed and the elements of which water is composed, oxygen and hydrogen, are not included. Moreover, this distribution is based on one measurement in April 2008. This may explain the high abundance of silicon as diatoms often form blooms at this time of the year.*

The biotic component, which comprises only 0.002% of total mass in Frisksjön, is dominated by carbon (64% of total biotic component), followed by nitrogen (12% of total biotic component, Figure 7-18). Calcium, silicon, phosphorus, sodium, chlorine and zinc each comprise 2% or more of the total mass of investigated elements in the biotic components, while each of the other elements constitute 1% or less.

Within the biotic components, there is a clear difference in distribution of elements among different functional groups (Figure 7-19). Metals are present in higher proportions in primary producers than lanthanides, which are strongly concentrated in consumers. In all, most elements are concentrated in the consumers, and on average 66% of all elements are present in consumers. Mercury is an element known for biomagnification in nature, so one would expect to find a high share of this element in the top predator fish. This is indeed the case, and 75% of

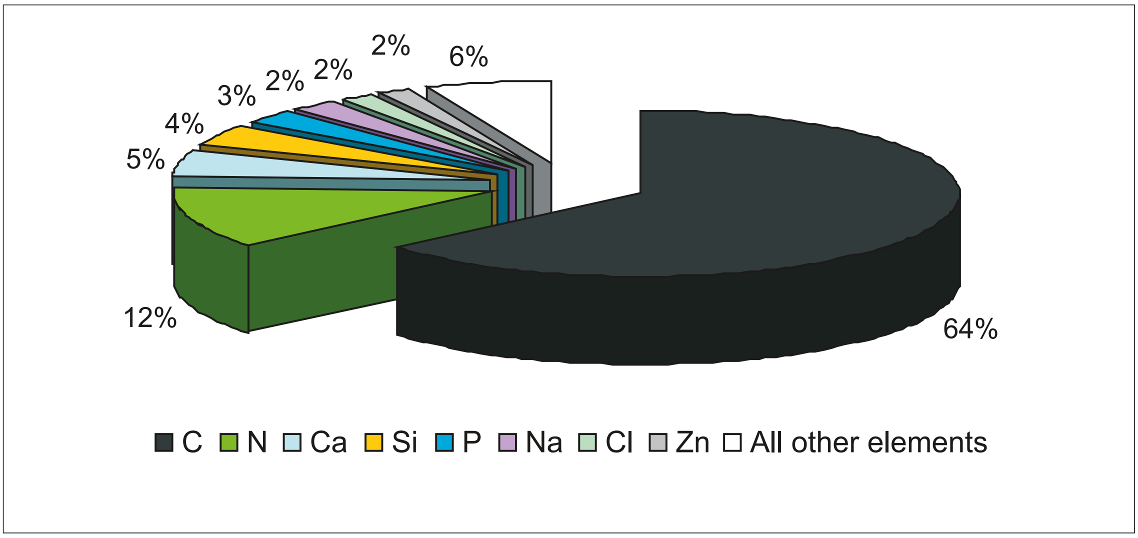


Figure 7-18. *Distribution of elements (% of total investigated elements, based on mass) in the biotic component in Frisksjön. Note that not all elements are analyzed and the elements of which water is composed, oxygen and hydrogen, are not included. Moreover, data on bacteria are lacking for all elements except carbon, nitrogen, phosphorus and sulphur.*

biotic mercury is present in fish (this percentage is probably slightly lower as data for bacteria are lacking). Likewise, zinc and rubidium are strongly concentrated in fish (99% and 60%, respectively, of the total biotic pools). Lanthanides have a strong concentration in zooplankton, while most metals tend to have a higher occurrence in benthic fauna. In addition to the lanthanides, bromine is also strongly concentrated in zooplankton. The reason for the concentration of bromine and lanthanides in zooplankton is unknown, but the concentration of bromine in zooplankton is also seen in the Forsmark lakes and in the marine areas /Wijnbladh et al. 2008/.

Data on the chemical composition of bacteria is lacking for all elements except carbon, phosphorus, nitrogen and sulphur, and this may affect the picture of the distribution of elements in the biotic components. A large portion of the biotic C, N, P and S is present in bacteria (69%, 67%, 88% and 57% of the total biotic mass of each element, respectively), and thus, the concentration of elements in the consumer part of the biotic component may be even larger than suggested by Figure 7-19.

7.4.2 Mass balances

We have data to estimate all 4 fluxes (in- and outflow through water, atmospheric deposition and accumulation in sediment) for 16 elements (Al, C, Ca, Cl, Fe, I, K, Mg, N, Na, P, S, Si, Sr, Th, U). For another 28 elements the only flux missing is deposition from atmosphere. For the 16 elements where data for all fluxes are available, deposition from the atmosphere was most often small. The mass balances for elements where data on atmospheric deposition are lacking are therefore also discussed in this section. A compilation of estimated elemental fluxes is presented in Appendix 12.

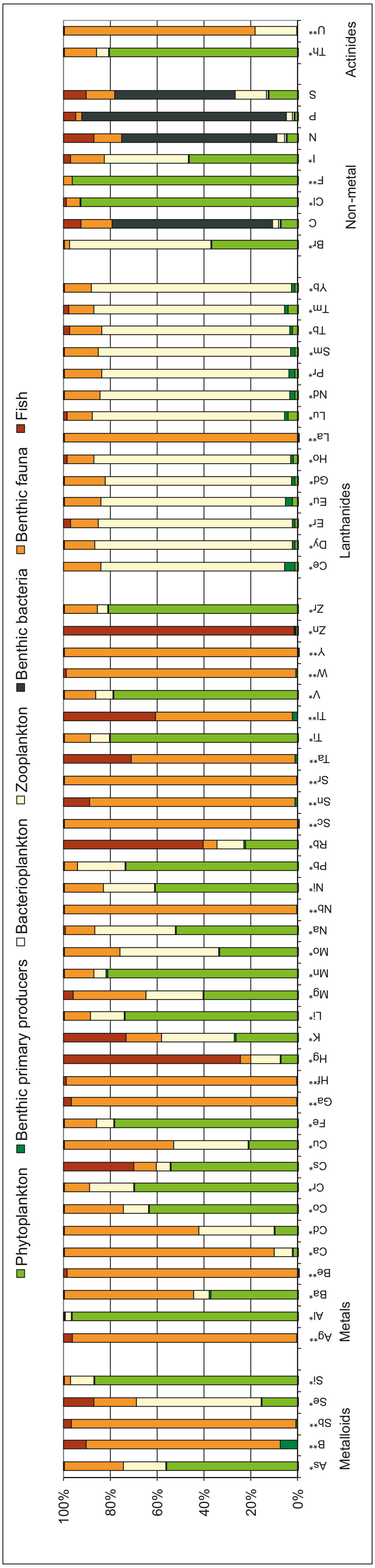


***Figure 7-19.** Distribution of a number of elements among the biotic components of the ecosystem in Frisksjön. * indicates missing data for bacterioplankton and benthic bacteria. ** indicates missing data for at least one more functional group in addition to bacterioplankton and benthic bacteria (for further information of missing data see Appendix 6).*

For the 16 elements were all fluxes are estimated, the inflow via water is the largest influx and the atmospheric deposition made up 14% or less of total influx (mean 3%, median 1.2% of total influx). It is therefore reasonable to conclude that atmospheric deposition makes a small contribution for most elements. For most elements, sediment accumulation is the dominant outflux. This is particularly true for the lanthanides, where between 75% and 99% of the total outfluxes consist of sediment accumulation (Figure 7-20). The ions Ca, Mg, Na, Cl and S, which have a relatively large share of their total pools in the dissolved component, have outflow via water as the dominant outflux. The dominant outflux is via water for C, Ba and Sr as well, but for all other elements sediment accumulation is the dominant outflux from the system.

Most of the mass balances are not balanced and the outfluxes often exceed the influxes. The mass balances are well balanced for only 7 of the elements (Ca, Cl, I, Mg, Na, S, Sr), with influxes between 81% and 108% of outfluxes. The uncertainties in the mass balances will be further discussed in section 7.6.

The most and least common elements in the fluxes (based on mass) are shown in Table 7-6. The most common elements in sediment accumulation were silicon, carbon, iron, aluminium, sulphur and nitrogen. Silicon, carbon and nitrogen are common elements in biota, whereas iron is common in humic substances. Certain metalloids and metals – silver, mercury tantalum and thallium – have the lowest accumulation rate in sediment in accordance with their uncommonness in nature. Among the 16 elements for which atmospheric deposition has been measured, certain ions (Cl, Na and Ca) dominate together with carbon. Inflow as well as outflow via water is dominated by carbon, sulphur and calcium. The fourth most common element in the inflow is silicon, but this element is found in the sixth place among the elements most common in outflow. This can be explained by high sediment accumulation of silicon, and the lakes can be considered a sink for this element. Mercury is the least common elements in inflow as well as outflow via water.

7.4.3 Detailed description of phosphorus pools and mass balances

Pool

The estimated pools and fluxes of phosphorus in Frisksjön are presented in Figure 7-21 and Table 7-7. The sediment layer is by far the largest phosphorus pool and almost 100% of the total amounts of phosphorus are allocated there. This is expected considering the large amounts of sediments. However, even when the deeper sediment is excluded and only the top centimetre of sediment is included, there is a strong allocation of phosphorus to the sediment pool (c. 90%). The second largest pool of phosphorus is found in the consumers, followed by the dissolved and particulate pools in lake water. Bacteria constitute the major part of the biotic biomass in the lake, so the concentration of biotic phosphorus in consumers is expected, considering the high phosphorus content of bacteria. The phosphorus pool in the primary producers is small.

Table 7-6. Most and least common elements in the fluxes to and from Frisksjön, based on amounts (g year^{-1}) of elements that show the highest and lowest mass fluxes (g y^{-1}) for each of the major in- and outfluxes in lakes in Frisksjön. For example, the element with the highest sediment accumulation is silicon, followed by carbon and iron, and the elements least accumulated in the sediments are silver and mercury. The sizes of the different flows are found in Appendix 12.

Flux	Ranking of elements with highes mass flux	Ranking of elements with lowest mass flux
Accumulation in sediment	Si> C > Fe > Al > S > N	Sb > Tl > TA > Hg > Ag
Atmospheric deposition	Cl > C > Na > Ca > N	I > U > Al > Th
Inflow via water	C > S > Ca > Si > Cl > Na	Lu> Tm > Ti > Hg
Outflow via water	C > S > Ca > Cl > Na > Si	Cd > Tb > Ti > Hg

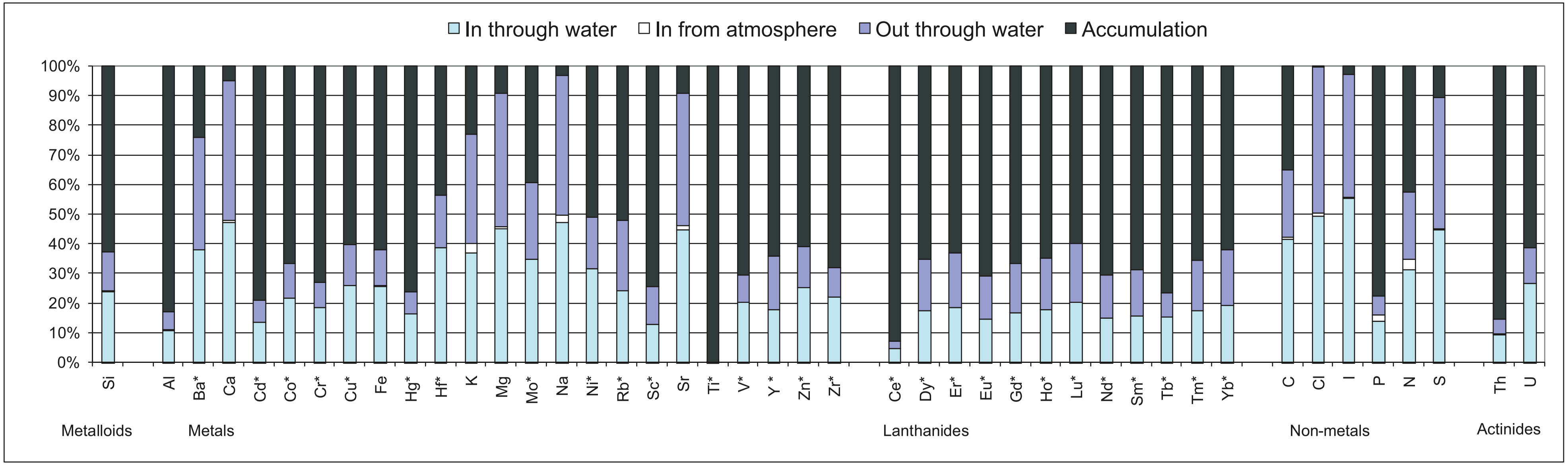


Figure 7-20. *Relative magnitude of different in- and outfluxes for a number of elements in Frisksjön. Elements included are those where all fluxes were determined or where only atmospheric deposition was lacking (indicated by *). All fluxes are estimated separately: sediment accumulation is estimated from sediment cores, in- and outflows are estimated from concentrations in inlets and outlets, and atmospheric deposition is estimated from concentrations in precipitation. The uncertainties in the estimated flows can thereby lead to imbalance in the mass balances, e.g. higher outfluxes than influxes to the lake, which is the case for most lanthanides.*

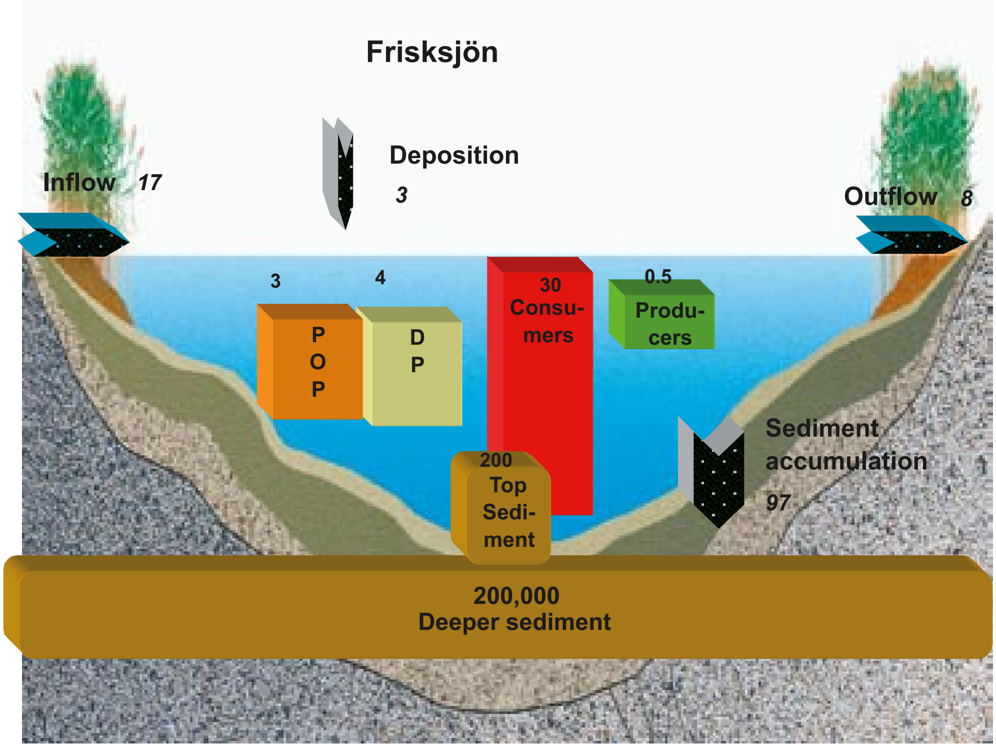


Figure 7-21. Phosphorus pools (kg P) and fluxes (kg P per year) in Frisksjön). Note that the sediment pools are scaled differently than the other pools in order to fit all pools in the same picture.

Mass balance

The influx of phosphorus into Frisksjön is dominated by the inflow via water, which is about one order of magnitude larger than the influx via air (Figure 7-21 and Table 7-7). Outfluxes of phosphorus are clearly dominated by sediment accumulation, which is one order of magnitude higher than the outflow via water. The inflow via water is somewhat higher than the outflow via water, but the difference is not enough to balance the high sediment accumulation. There is a deficit of 8.5×10^4 g P y^{-1} which corresponds to over 400% of the total influx, or 81% of the total outfluxes. Thus, there are large uncertainties in the mass balance, which will be further discussed in section 7.6.

The phosphorus pool in biota is about twice as large as the annual phosphorus influx, and the phosphorus pool in the top sediment is c. 10 times larger than the annual influxes (inflow and deposition). Thus, the lakes are probably more influenced by internal circulation of phosphorus than phosphorus entering the lake from the catchment. Phosphorus is often a limiting nutrient in lakes, and considering the fact that the biotic pool of phosphorus is larger than the amount of phosphorus entering the lake, it is reasonable to assume that much of the phosphorus influx will be incorporated in the food web.

In conclusion, sedimentation appears to be an important process in the dynamics of phosphorus, and the sediments contain by far the largest phosphorus pool in the lake.

7.4.4 Pools and mass balances for iodine, thorium and uranium

As described in section 7.1.1, iodine, uranium and thorium are elements with different sorption properties. Iodine is very mobile, thorium almost immobile, and uranium possess properties somewhere in between iodine and thorium. A description of the pools and mass balances for these elements follows below.

Table 7-7. Amounts (g) and fluxes (g y^{-1}) of phosphorus, iodine, uranium and thorium in Frisksjön. The last three rows show the net balance (as g y^{-1} and % of influx/outflux, respectively).

	Phosphorus	Iodine	Uranium	Thorium
Pools, g (% of total pools)				
Producers	5×10^{2} (0.0002)	5×10^{0} (0.0001)	5×10^{-4} (0.00000003)	4×10^{-1} (0.00005)
Consumers	3×10^{4} (0.02)	6×10^{0} (0.0001)	3×10^{-1} (0.00002)	1×10^{-1} (0.00001)
Particulate phase of water	3×10^{3} (0.001)	2×10^{2} (0.01)	1×10^{1} (0.001)	2×10^{1} (0.002)
Dissolved phase of water	4×10^{3} (0.002)	6×10^{3} (0.1)	7×10^{1} (0.003)	2×10^{1} (0.002)
Upper sediment (0–1 cm)	2×10^{5} (0.10)	6×10^{2} (0.02)	2×10^{3} (0.1)	2×10^{3} (0.2)
Deeper sediment	2×10^{8} (99.9)	4×10^{6} (99.8)	2×10^{6} (99.9)	9×10^{5} (99.8)
Fluxes, g year^{-1}, (% of total influx/outflux)				
Inflow via water	$+2\times10^{4}$ (+86)	4.5×10^{3} (+99.7)	2.5×10^{2} (99)	5×10^{1} (99)
influx from air	$+3\times10^{3}$ (+14)	1.5×10^{1} (+0.3)	2×10^{0} (1)	6×10^{-1} (1)
Outflow via water	-8×10^{3} (–8)	4.5×10^{3} (–95)	2×10^{2} (25)	3×10^{1} (6)
Net sediment accumulation	-1×10^{5} (–92)	3×10^{2} (5)	6.5×10^{2} (75)	5×10^{2} (94)
Net balance (g P year^{-1})	-9×10^{4}	-2×10^{2}	–618	–445
Net balance (% of total influx)	–427	–5	–246	–849
Net balance (% of total outflux)	–81	–5	–71	–89

Pools

As in the Forsmark lakes, iodine, uranium and thorium are all strongly concentrated in the sediment pool in Friskjön (Table 7-7). In the biotic pools, most of the elements are concentrated in benthic primary producers. A detailed description of the pools for each of the three elements follows below:

Iodine is strongly concentrated in the sediments (99.8%, Table 7-7). This is due to the very thick layers of sediment. If the deeper sediments are subtracted, the most important pool of iodine is instead the dissolved component (0.1% of total iodine in the lake). This is in accordance with the mobility of iodine in water. The third and fourth largest pools of iodine are the top sediment component followed by the particulate component. The biotic components contain little iodine in comparison with the abiotic components (only 0.0002% of total iodine).

Of the biotic pool, producers and consumers are of equal importance. However, data on iodine in bacteria are lacking, so the consumers may have a higher share of the total iodine than is shown here. In consumers, more iodine is found in zooplankton than benthic fauna. Little iodine is found in fish. In the study by /Kumblad and Bradshaw 2008/ iodine was most abundant in the plant species. They state that marine macroalgae have a high ability to fix halide ions and that many different halogenated compounds have been detected in red and brown algae. In Frisksjön, the biomass of plant species is low and thus it is reasonable that our result indicate a concentration of iodine in consumers.

The largest pool of uranium is deep sediments, where 99.9% (1,990 kg) of total uranium occurs (Table 7-7). The second most abundant pool of uranium is the top 1 centimetre of the sediment (0.1% of total uranium), illustrating the very strong concentration of uranium in the sediments. The dissolved and particulate pools contain much less uranium (0.02% each of total uranium in the lake), and the amounts in biota are almost negligible in comparison with the abiotic pools (0.00006% of total uranium). Data for uranium in bacterioplankton, benthic bacteria and phytoplankton is lacking in the biotic pool. Excluding the microbiota, available data indicate that uranium is concentrated in benthic fauna, whereas concentrations in fish are very low, which could be a sign of active avoidance.

Like uranium, thorium is strongly concentrated in the sediments, and 99.8% of the total thorium in the lake is found in the deeper sediments while another 0.2% is found in the upper sediment. The dissolved and particulate fractions contain only 0.002% each of the total thorium, and the thorium content of the biota is negligible. In contrast to iodine and uranium, biotic thorium is more abundant in producers than consumers. The thorium content in biota (excluding bacteria) is concentrated in phytoplankton, where 80% of total biotic thorium occurs. The most important consumers in terms of thorium are benthic fauna, while fish and zooplankton have very small thorium contents. In the study by /Kumblad and Bradshaw 2008/, thorium concentrations were highest in benthic microalgae followed by phytoplankton and plants. Among the animal species analyzed, *Theodoxus fluviatilis* and *Idotea spp* (both benthic grazers) had the highest concentrations. Thus the concentration of thorium in phytoplankton and benthic fauna in this study agrees very well with the study by /Kumblad and Bradshaw 2008/.

Mass balances

Similar to in Forsmark, the mass balances of iodine, uranium and thorium show that the most important flows differ among the elements due to their sorption properties and mobility in the ecosystem. The distribution of fluxes for iodine (very mobile), uranium (intermediate) and thorium (almost immobile), are shown in Figure 7-22 and Table 7-7. As expected, the outflow via water is much more important for the mobile iodine than for uranium (intermediate) and thorium (lowest flows).

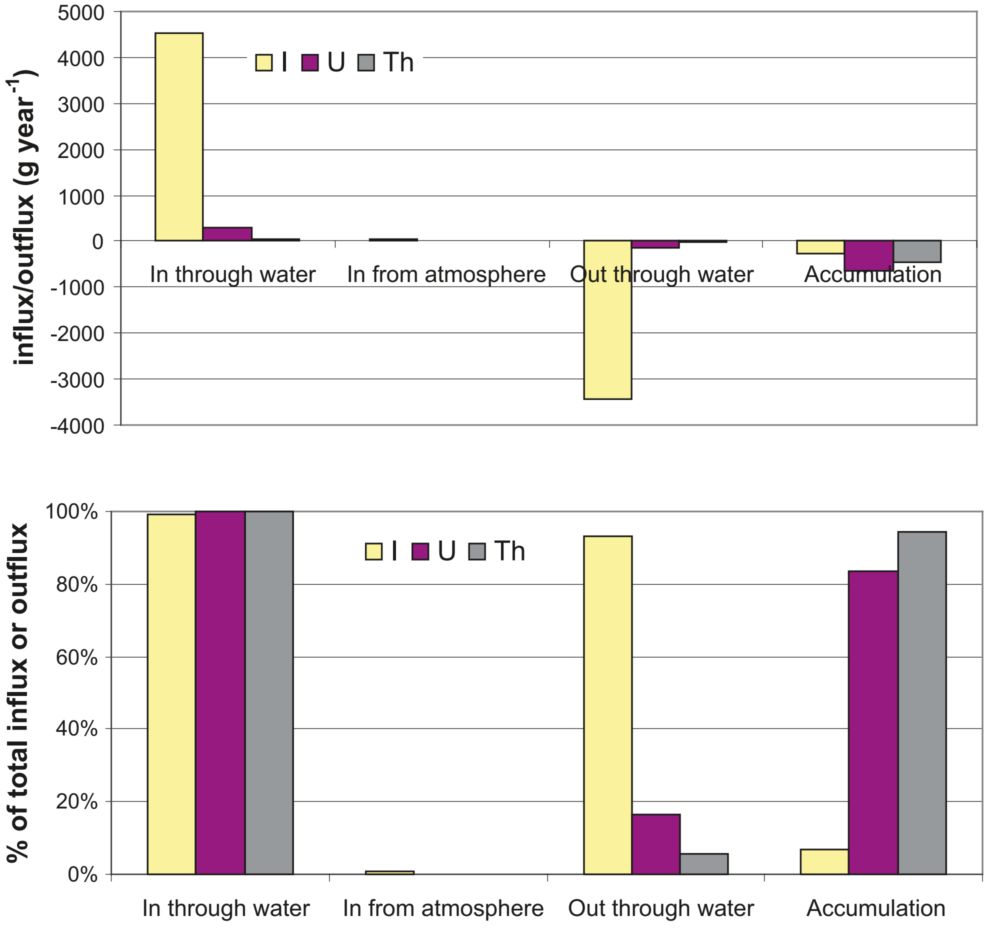


Figure 7-22. *Distribution among fluxes of iodine, uranium and thorium in Frisksjön (% of influx and % of outflux).*

Iodine

As expected, the influx of iodine is dominated by inflow via water and atmospheric deposition makes up small share (0.3%) of total influx. The influx via deposition was always below detection limit in the site measurements but the estimate of half detection limit seem reasonable as it is within (although in the lower range) of reported iodine precipitation in an English study /Sheppard et al. 2002/. The calculated sediment accumulation is the largest outflux of iodine from the system. The mass balance of iodine is relatively well balanced.

Influx of iodine is almost twice the size of the biotic pool of iodine. Since iodine plays an active role in biota it is possible that incoming iodine will be incorporated into the food web but the majority of iodine should pass through the lake with the flowing water.

Uranium

The mass balance for uranium indicates that the influx via water totally dominate the total influx of uranium. The influx of uranium via atmospheric deposition is not site specific, but literature estimates indicate that the influx via the atmosphere is negligible in comparison to the inflow via water. The outflux of uranium is dominated by sediment accumulation, which comprises 88% of the total outflux.

The mass balance for uranium is very unbalanced with 618 g lower influx than outflux, equivalent to 246% of the total influx and 71% of the total outflux. The uncertainties in the mass balance will be discussed further in section 7.6.

The influx of uranium is much larger than the biotic pool, and unless there is a rapid cycling of uranium in biota there is a small probability for uranium entering the lake to be incorporated into the food web. However, there is a large sediment accumulation and large amounts of uranium entering the lake may be bound in the sediment.

Thorium

The mass balance for thorium indicates that inflow totally dominates the total influx of thorium to Frisksjön. The influx of thorium via atmospheric deposition is not site-specific, but literature estimates indicate that the influx via the atmosphere is negligible in comparison to the inflow via water. The inflow via water is almost twice as high as the outflow via the outlet. Nevertheless, the outflux of thorium greatly exceeds the influx due to high accumulation of thorium in the sediments. The mass balance for thorium is not balanced and the outflux exceeds the influx by 445 g (equivalent to 849% of the total influx and 89% of the total outflux). The uncertainties in the mass balance will be further discussed in section 7.6.

The influx of thorium is much larger than the biotic pool, and unless there is a rapid cycling of thorium in the biota there is a small probability for thorium entering the lake to be incorporated into the food web. However, there is a large sediment accumulation and large amounts of thorium entering the lake may be bound in the sediment.

7.5 Comparison of element pools and fluxes between Forsmark and the Laxemar-Simpevarp lakes

In this section, the lakes in Forsmark and Laxemar-Simpevarp are compared with each other in terms of distribution of elements between different components in the ecosystems. In addition, the main results of the mass balances are compared between the sites. Since these kinds of thorough mass balances are very rare in the literature, the comparison between sites provides some information as to whether the results are representative of Sweden or whether they should be viewed as site-specific.

7.5.1 Pools of elements in different components of the lake ecosystems

Both in Forsmark and Laxemar-Simpevarp, the sediment is the largest component in terms of mass of elements. The sediment therefore has a large impact on the elemental composition in both areas. Due to thicker sediment depths in Frisksjön, almost all elements are more abundant (g m^{-2}) in the sediments there than in the mean Forsmark lake (Figure 7-23). However, the relative chemical composition in the Forsmark and Laxemar-Simpevarp lakes is similar, silicon being the most common element, followed by carbon. Carbon, sulphur and nitrogen comprise larger fractions of the sediments in Frisksjön than in the average Forsmark lake, while aluminium, potassium and magnesium contribute more to the total weight of elements in the average Forsmark lake than in Frisksjön.

The dissolved pool of the ions Ca Cl, K, Mg, Na, as well as carbon and nitrogen on an areal basis (g m^{-2}), is larger in Forsmark than in Laxemar-Simpevarp (Figure 7-24). The reason for this is the contribution of calcium from calcareous soils as well as a more recent emergence from the sea and thereby a stronger marine influence in Forsmark. All other elements are more abundant in Laxemar-Simpevarp than in Forsmark, which is expected due to the larger water depth in Frisksjön than in the average lake in Forsmark. The dissolved component in both areas is dominated by carbon, iron chlorine, sodium, calcium and manganese, although the order differs somewhat between the sites (Figure 7-5 and 7-13).

The pools of elements in particulate matter on an areal basis (g m^{-2}) are much larger in Frisksjön than in the average Forsmark lake for almost all elements (Figure 7-25). This is caused both by higher concentrations of particulate matter in Frisksjön but also by a larger mean depth of Frisksjön compared with all lakes in the Forsmark area. The particulate component in the water has a somewhat different elemental composition in the two areas. Particulate matter in the Forsmark lakes is strongly dominated by carbon, followed by nitrogen, calcium and silicon (Figure 7-6). In Frisksjön, on the other hand, particulate matter is totally dominated by silicon, followed by carbon and iron (Figure 7-14). The strong dominance of silicon in the particulate pool in Frisksjön is most probably caused by a diatom bloom during sampling. The estimated chemical composition of particulate matter in both areas is based on one sampling in April 2008 and may thus not be representative of the entire year. The only exceptions are carbon, nitrogen and phosphorus, for which long-term measurements are available. The particulate pool in the average Forsmark lake does not show any signs of a diatom bloom, but the elemental composition indicates biotic origin as the carbon to nitrogen ratio is close to the Redfield ratio (7:1 in weight). As discussed in earlier chapters, calcium concentrations are high in Forsmark and iron concentrations are high due to the high humic content of Frisksjön.

The pools of elements in biota are larger on an areal basis for almost all elements in the average Forsmark lake than in Frisksjön (Figure 7-26). The only exceptions are Al, As, Br, Cl, F, K, Na and P. The fact that the mass of phosphorus is higher on an areal basis in Frisksjön than in the average Forsmark lake may be an indication of the higher proportion of consumers than producers in Frisksjön, as consumers contain more phosphorus per biomass than primary producers. The larger pools of most elements in the biotic component in Forsmark than in Laxemar-Simpevarp are an effect of the very high biomass (carbon) of benthic primary producers in Forsmark. The weight of benthic primary producers on an areal basis is several orders of magnitude higher in the Forsmark lakes than the corresponding weight in Frisksjön (Figure 7-27).

Due to higher biomasses (g C m^{-3}) of phytoplankton and zooplankton in Frisksjön than in Forsmark, these functional groups show a higher weight per unit area of most elements in Frisksjön than in the average Forsmark lake (Figure 7-28 and 7-29). Although pools of major nutrients (C, N, P) in fish are somewhat larger in Forsmark than in Laxemar-Simpevarp, pools of many other elements are larger in fish in Laxemar-Simpevarp (Figure 7-30). This is caused by higher concentrations of many elements in fish in Laxemar-Simpevarp than in Forsmark. Many elements in fish in Forsmark are below the detection limit, while appreciable concentrations are found in the Laxemar-Simpevarp fish.

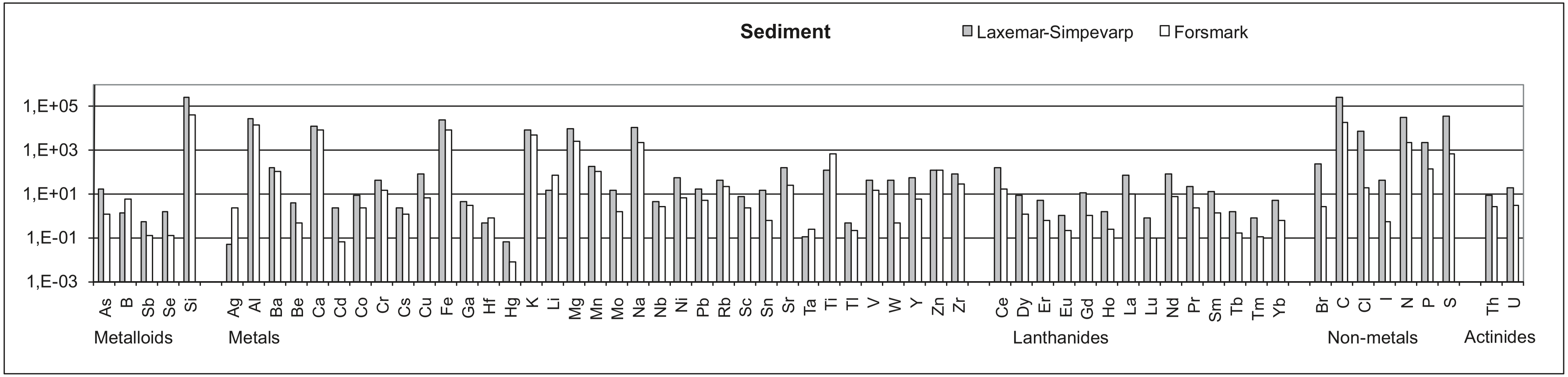


Figure 7-23. *Total amounts of different elements (g m^{-2}) in the sediments in Laxemar-Simpevarp (Frisksjön) compared with mean values for Forsmark lakes.*

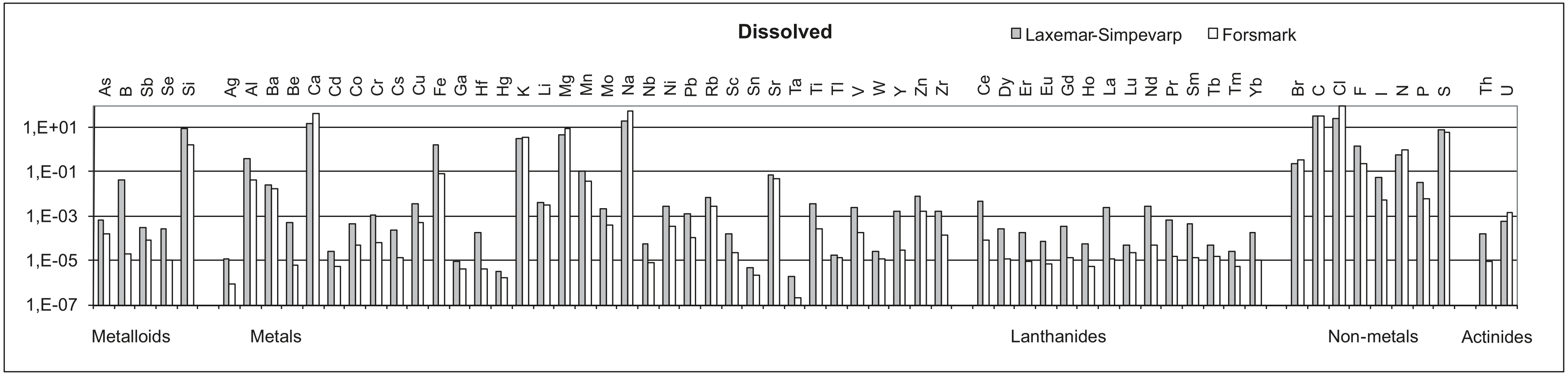


Figure 7-24. *Total amounts of different elements (g m^{-2}) dissolved in lake water in Laxemar-Simpevarp (Frisksjön) compared with mean values for Forsmark lakes.*

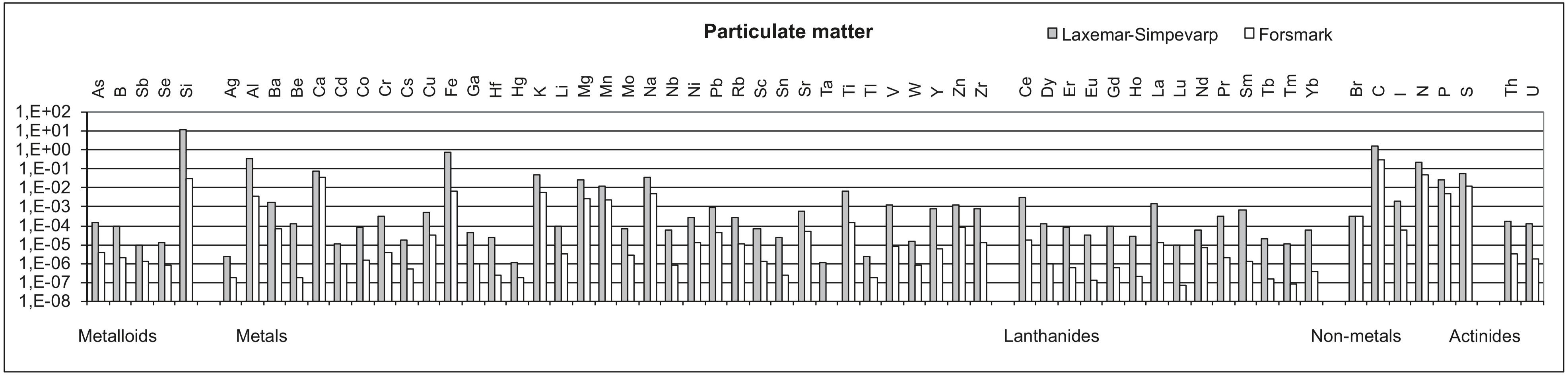


Figure 7-25. Total amounts of different elements (g m^{-2}) in particulate matter in lake water in Laxemar-Simpevarp (Frisksjön) compared with mean values for Forsmark lakes.

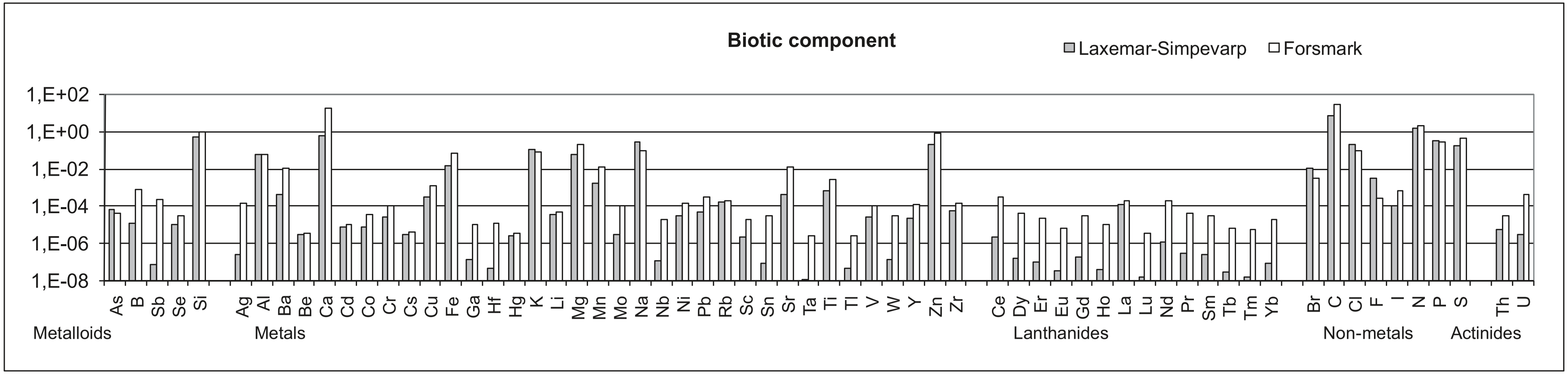


Figure 7-26. Total amounts of different elements (g m^{-2}) in the biotic components of the lake ecosystem in Laxemar-Simpevarp (Frisksjön) compared with mean values for Forsmark lakes.

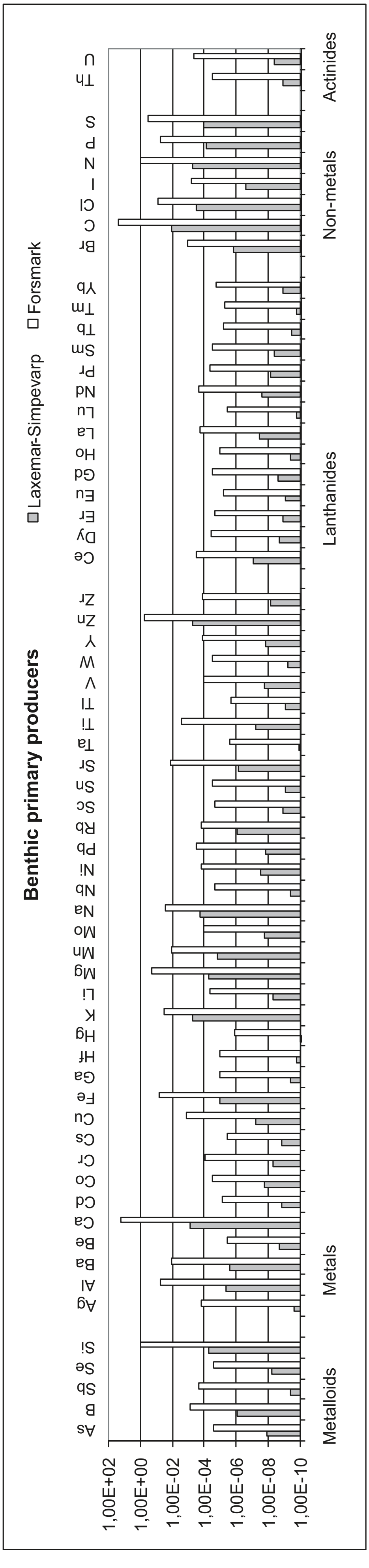


Figure 7-27. *Total amounts of different elements* $(g\ m^{-2})$ *in benthic primary producers in Laxemar-Simpevarp (Frisksjön) compared with mean values for Forsmark lakes.*

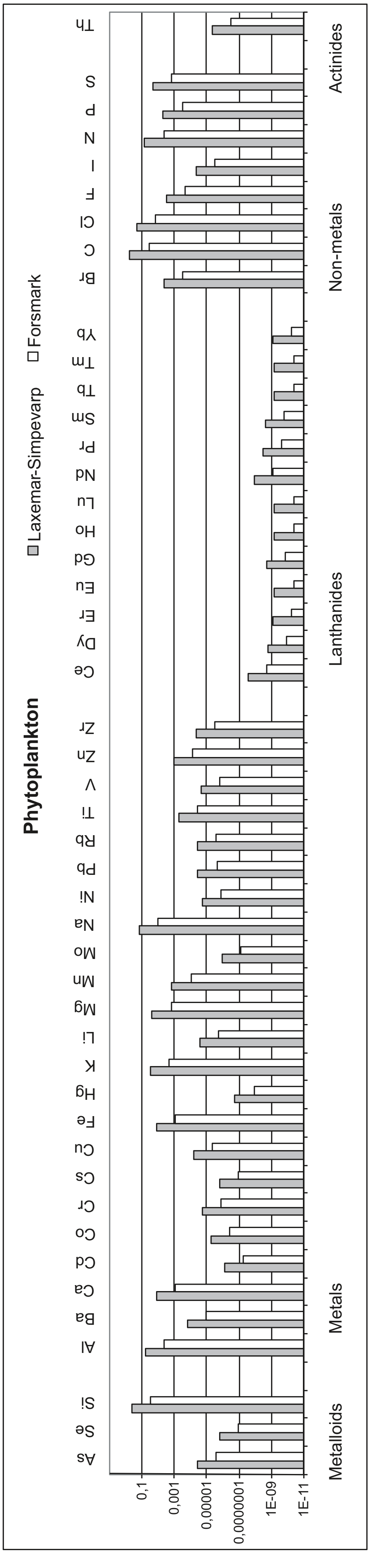


Figure 7-28. *Total amounts of different elements* $(g\ m^{-2})$ *in phytoplankton in Frisksjön compared with mean values for Forsmark lakes.*

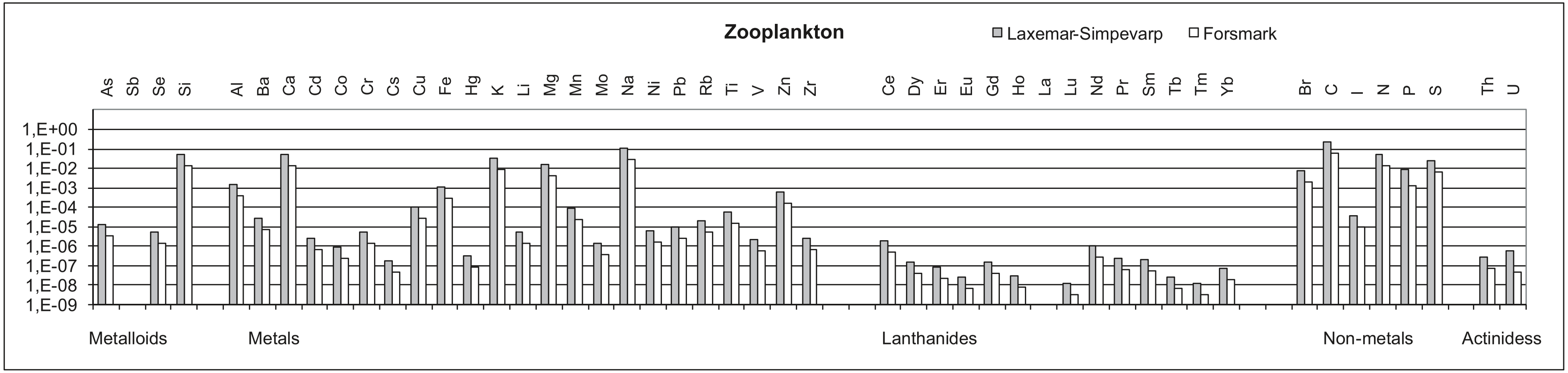


Figure 7-29. *Total amounts of different elements (g m^{-2}) in zooplankton in Frisksjön compared with mean values for Forsmark lakes.*

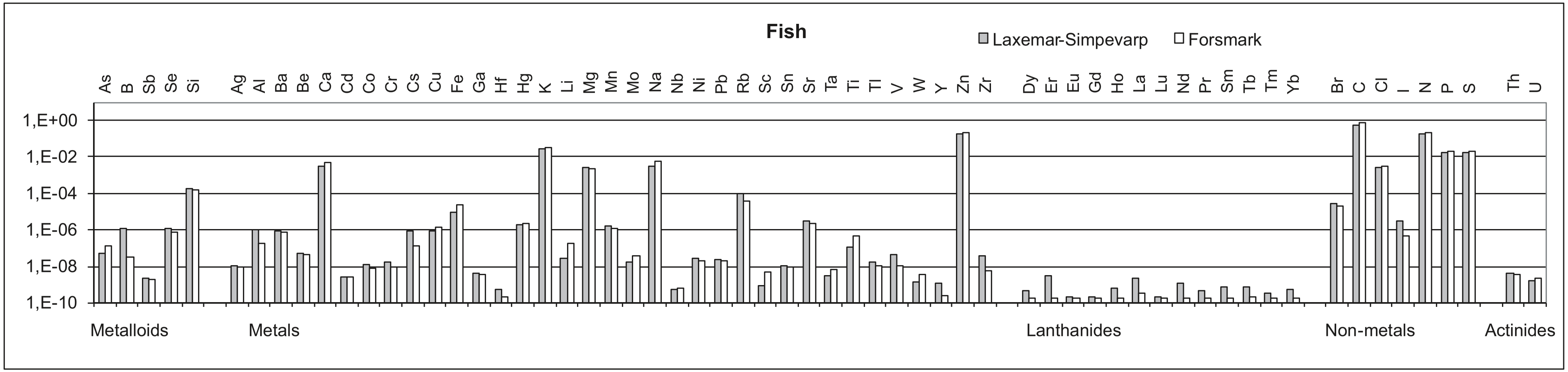


Figure 7-30. *Total amounts of different elements (g m^{-2}) in fish in Frisksjön compared with mean values for Forsmark lakes.*

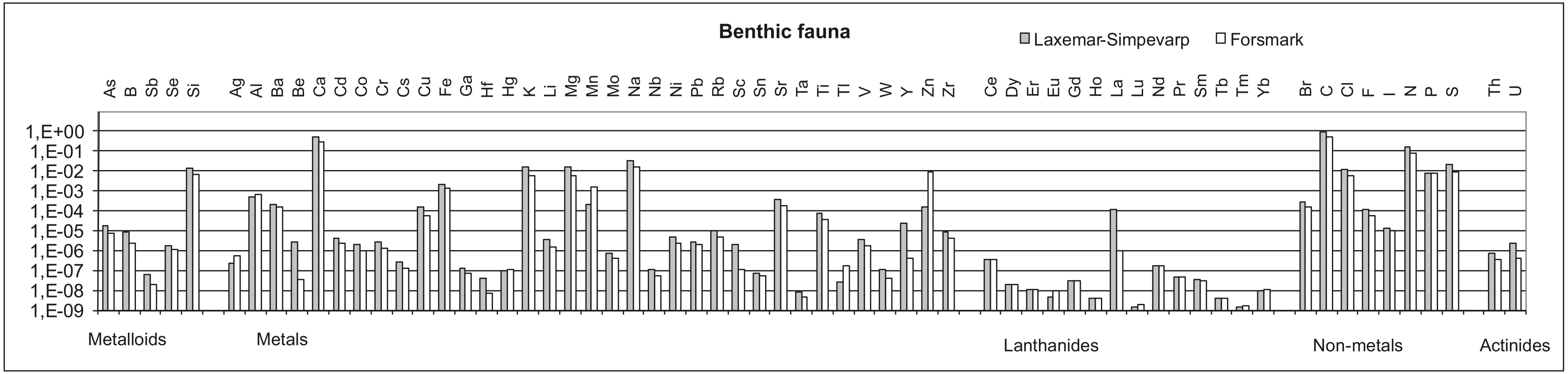


Figure 7-31. *Total amounts of different elements (g m^{-2}) in benthic fauna in Frisksjön compared with mean values for Forsmark lakes.*

In the case of benthic fauna, different groups of elements have different distributions in the two areas. The weight per unit area for lanthanides in benthic fauna is almost the same in Frisksjön as in the average Forsmark lake, while most metals and metalloids show higher mass per unit area in benthic fauna in Frisksjön than in the average Forsmark lake (Figure 7-31). The different pattern between different groups of elements indicates that there is a difference in the benthic fauna communities that is not entirely explained by abundance, but there is also some other functional difference between the benthic fauna communities.

7.5.2 Fluxes of elements

In both areas, the inflow via water is the main influx to the lakes. In Laxemar-Simpevarp the largest outflux of elements is sediment accumulation for most elements and especially the lanthanides. In Forsmark, the most important outflux differs somewhat between elements. For metalloids, metals and non-metals, outflow via water is the most important outflux, while for lanthanides, as in Laxemar-Simpevarp, the most important outflux is accumulation in sediments (Figure 7-9). However, the importance of different outfluxes differs among the lakes in Forsmark. In three of five lakes (Bolundsfjärden, Eckarfjärden and Puttan), accumulation in sediment is the dominant outflux for most elements, while in the other two (Gällsboträsket and Norra Bassängen) outflow via water dominates for almost all elements. It is evident that in Forsmark, lake size and position in the catchments greatly influence the distribution of fluxes.

In addition to lake size and position in catchments, the properties of the elements (e.g. sorption properties) also influence the flow pattern of the elements. In both Forsmark and Laxemar-Simpevarp, outflow via water is much more important for soluble iodine than for uranium (intermediate solubility) and thorium (almost immobile). When it comes to uranium, outflow via water is the largest outflux, but accumulation in sediments is also an important process. Thorium accumulation in sediments is c. 3 and 17 times larger than outflow via water in Forsmark and Laxemar-Simpevarp, respectively.

The elements that account for the largest mass fluxes are similar between the sites. The largest sediment accumulation in mass is accounted for by elements common in biota (carbon, silicon, nitrogen, calcium, iron, sulphur) in both areas but in somewhat different orders. In Forsmark, calcium accumulation in sediments is relatively greater than in Frisksjön, and in Frisksjön the relative importance of iron is greater than in Forsmark. Ions common in the marine area, Na and Cl, show the largest atmospheric deposition in both areas. Carbon, calcium and sulphur show large influxes and outfluxes via water in both areas, although the relative importance of the fluxes is different between the sites.

7.6 Confidence and uncertainties in the mass balance results

The estimates of pools and fluxes of different elements in lakes in the two investigated areas are based on data from extensive site investigations. Generally, the estimated pools and mass balances in the Forsmark lakes can be considered reliable for most elements. In the case of Frisksjön in the Laxemar-Simpevarp area, the estimated pools can be considered relatively reliable, while the estimated flows of elements in the mass balances are associated with more uncertainties. A detailed description of the confidence and uncertainties of the different types of estimates follows below.

7.6.1 Forsmark

Pools

Site-specific measurements are available for all ecosystem components in the Forsmark lakes and confidence in the pool estimates is high. The estimated pools of different elements in particulate matter in lake water, in biota, and in sediments are associated with some uncertainties with regard to absolute numbers, but the orders of magnitude of the estimates are most probably correct. The estimated pools of different elements dissolved in lake water are based on site-specific data from several lakes and several years and can be considered reliable.

Data on the pool of elements dissolved in water are available for 18 sampling sites for the period March 2002–June 2004, and for 9 of these sampling sites for the period July 2004–June 2006 as well, giving these estimates a relatively good resolution in both time and space.

The pools of **particulate** carbon, nitrogen, and phosphorus are available for the same time period and sampling stations as the elements in the dissolved component and can be regarded as reliable estimates with good resolution in time and space. The estimated pools of other elements in particulate matter are, however, based on a single sampling performed in spring 2008. Using the results from this sampling to estimate the mean annual pool of different elements in particulate matter naturally entails relatively high uncertainty in the estimates. Moreover, the particulate fraction also includes the living biota. No estimate of living biota was made at the same occasion as suspended material and the living biota has not been subtracted from the particulate component in the result and thus the particulate fraction may be somewhat overestimated. However, as the data are site-specific they provide high confidence in the order of magnitude of the pools of elements in the particulate component.

The largest uncertainty in pools of elements in the **biotic component** stems from the lack of data on the chemical composition of bacteria for all elements except phosphorus, nitrogen, sulphur and carbon. This of course leads to uncertainties in the distribution of the elements within the biotic component. A relatively large share of biotic carbon, nitrogen, phosphorus and sulphur is present in bacteria. This is particularly true of phosphorus, as phosphorus concentrations in bacteria are higher than in other organisms. The concentrations of most elements in bacteria will probably be proportionate to the concentration of carbon, sulphur and nitrogen, but the possibility cannot be excluded that some trace elements will, like phosphorus, be highly concentrated in bacteria. Either way, it is clear that most elements are probably present in consumers to a considerably greater degree than presented. In the case of other organisms, the elemental composition data for biotic pools is a reliable estimate, since it is mainly site-specific. There are relatively few replicates, which causes some uncertainties, but the available replicates show small discrepancies for most functional groups. Biomass data and chemical composition are used to estimate the pools of different elements. Although small, uncertainties are of course also associated with the biomass data (further discussed in section 5.6.1).

The pools of elements in the **sediment component** are highly dependent on the estimated sediment volume. The volumes are based on average values of layer thickness from lake-specific stratigraphical data measured in field. The representativity of these average values is dependent on the number of sampling points used and their spatial resolution. The number of sampling points in each lake was adjusted to the size of the lake basin (fewer points in smaller lakes, see /Hedenström 2004/). In the calculation of average sediment thickness, data points lacking organic sediments were excluded, probably resulting in overestimated sediment volumes. On the other hand, the sampler used in the investigations does not sample the top sediment, leading to underestimation of sediment volumes. Another way to estimate the volume of sediment layers is to use the geometrical regolith depth model (RDM) constructed for the Forsmark area /Hedenström et al. 2008/. The RDM presents sub-models for the lake sediments in eight lakes. The sub-models give the geometry of the gyttja layer and clay layer separately so the volume of each of these layers can be calculated. In general, the model predicts smaller sediment volumes than our calculations above. The largest difference is for the clay layer in Gällsboträsket, which is about 5 times larger in our calculations. This is equivalent to a difference in layer thickness of c. 0.55 m. In a few cases the RDM predicts larger sediment volumes, for example the gyttja layer in Eckarfjärden which is c. 10% larger than in our calculations. This is equivalent to a difference in layer thickness of c. 15 cm. Since the model also includes Littoral I, which in this report has been considered to be a wetland, we have used the average values. It is difficult to decide which of the two methods gives the most realistic sediment volumes. In conclusion, the absolute numbers for element concentration in lake sediments may be incorrect, and the estimate of this pool of elements is one of the most uncertain in the model. Nevertheless, regardless of which sediment depth is used, the order of magnitude of the sediment pool will be the same and the total dominance in the lake ecosystem of elemental pools contained in the sediment is most certainly accurate.

The elemental composition data for sediment is also site-specific with data from two lakes (Eckarfjärden and Stocksjön). The different sediment layers are represented by different numbers of observations, so the reliability of the estimates differs between the different layers: the clay gyttja layer is represented by only one sample from each lake, while the clay layer is represented by one sample from Stocksjön and 3 samples from Eckarfjärden. The number of samples for the gyttja layer is greater: 5 samples from Eckarfjärden and 9 samples from Stocksjön. In the model, it was assumed that the chemical composition of different sediment layers does not differ between lakes. Instead, a mean value of the different samples from the same sediment layer was calculated and used as a representative value for that sediment type in the area. A simple comparison of the chemical composition of the sediments from the two lakes (Stocksjön and Eckarfjärden) has been performed. The concentrations of different elements in a specific sediment layer are higher in Eckarfjärden for some elements and lower for others. However, differences between the lakes are always smaller or of the same order of magnitude as the in-lake variations. Thereby, it seems reasonable to use the same data on chemical composition of sediments for all the lakes in the area.

Mass balances

Mass balances for a large number of elements have been constructed for five lakes in Forsmark. Only about half of the mass balances for the average lake were well balanced. Generally, the mass balances for the smaller lakes Gällsboträsket and Norra Bassängen are well balanced, while those for Bolundsfjärden, Eckarfjärden and Puttan are less well balanced for many elements. This is most probably due to uncertainties in estimated sediment accumulation. In Gällsboträsket and Norra Bassängen, sediment accumulation is small compared to in- and outflow via water, so even if the estimate of sediment accumulation is incorrect this will not greatly affect the mass balance. In the other three lakes, sediment accumulation is larger than outflow via water for many elements. An incorrect estimate of sediment accumulation in these lakes should have a significant influence on the total mass balance. The most reliable flow estimates in the mass balance are the in- and outflow of elements via water. Atmospheric deposition is lacking for many elements, but for those elements where atmospheric deposition is available the estimated annual deposition is of little importance for the mass balance and also of good certainty.

The most reliable estimates of elemental fluxes are for flows into and out of the lakes via water, as they are based on a large quantity of measured data from different parts of the catchment and therefore have a better spatial resolution than the other fluxes (atmospheric deposition and accumulation in sediments, see below). They are also based on longer time series of data (c. 5 years), resulting in more representative values over a longer time period. There was a mismatch among the discharge and chemistry stations with respect to time periods, sampling interval and spatial coverage of the stations, similar to that described for the carbon mass balance. Accordingly, there was a need for extrapolation in time and space in order to make transport estimates possible. This transformation is further discussed in section 5.2.1.

The site-specific data on atmospheric deposition include only a few elements. This flux is therefore lacking for many elements. For most elements this flux is small and probably does not alter the mass balance in any significant way. However, in the case of the lanthanides atmospheric deposition has not been estimated for a single element. Although less likely, we cannot exclude the possibility that atmospheric deposition is high for these group of elements. For elements where site-specific measurements of atmospheric deposition are available, the estimates of this flux can be considered reliable. The estimate of annual mean chemical composition of precipitation is based on sampling during more than one year, and thus the results should be relatively representative.

The estimates of sediment accumulation of elements are dependent on lake size, since the estimates are based on the assumption of the same (constant) area-specific accumulation rate in all lakes, independent of lake size or age. Moreover, estimated sediment accumulation is dependent on the element content of the sediments, which is based on data from one sampling point each in two lakes (Eckarfjärden and Stocksjön). Accordingly, element accumulation in sediments must be considered to be the least certain part of the mass balances, although the concentrations for each sediment layer are based on more than 1 sample (gyttja layer n=14, clay gyttja n=2, clay n=4).

7.6.2 Laxemar-Simpevarp

Pools

Site-specific measurements are available for all ecosystem components in Frisksjön, and there is high confidence in the pool estimates. The estimated pools of elements in particulate matter in water, in biota, and in sediments are associated with some uncertainties regarding the absolute numbers, but the orders of magnitude of the estimates are probably correct. The estimated pools of elements in the dissolved component are based on site-specific data from several years and can be considered reliable.

Site-specific data for most elements in the dissolved component are available for the period November 2002–July 2007, giving these estimates a relatively good resolution both in time and space. For some elements (Ag, B, Be, Ga, Nb, Se, Sn, Ta, Ti, W) data are only available from a single occasion and thus the estimates of these pools are more uncertain, although the site-specific data provide confidence in the order of magnitude of element pools.

The pools of **particulate** carbon, nitrogen, and phosphorus are available for the same time period and sampling stations as the elements in the dissolved component and can be regarded as reliable estimates with good resolution in time and space. The estimated pools of other elements in the particulate component are, however, based on a single sampling performed in spring 2008. Using the results from this sampling to estimate the mean annual pool of different elements in particulate matter naturally entails relatively high uncertainty in the estimates. Moreover, the particulate fraction also includes the living biota. No estimate of living biota was made at the same occasion as suspended material and the living biota has not been subtracted from the particulate component in the result and thus the particulate fraction may be somewhat overestimated. However, as the data are site-specific they provide high confidence in the order of magnitude of the pools of element in the particulate component.

As in Forsmark, the largest uncertainty in the pools of elements in the **biotic component** in Laxemar-Simpevarp is the lack of data on the chemical composition of bacteria for all elements except phosphorus, nitrogen, sulphur and carbon (further discussed in section 7.6.1). For other organisms, the estimated pools of elements are reliable, since they are mainly based on site-specific measurements. There are relatively few replicates, which imply some uncertainty, but the available replicates show small differences for most elements. Biomass data and chemical composition are used to estimate the pools of different elements. Uncertainties in these estimates are of course also associated with the biomass data, but for most organisms these can be considered small (further discussed in section 5.6.2).

The pools of elements in the **sediment component** are highly dependent on the estimated sediment volume. The sediment depth has been measured in field, but the number of replicates is limited. However, although the number of replicates is few, there is no doubt that the sediment pool is large and that the order of magnitude of the sediment volume should be correct. In addition to sediment volume, there are uncertainties associated with the sediment component since data on the chemical composition of the sediments are available only for the upper 4.4 m. For the remaining 5.6 meters, chemical composition was assumed to be identical to the layer 1.97–4 metres. This assumption is based on the fact that sediment layers in the upper 1.97 metres had a similar chemical composition and sediment layers between 1.97 and 4.4 metres had a similar chemical composition. Although the sediment pool is the most uncertain of the pools, we conclude that regardless of which sediment depth and chemical composition are used, the order of magnitude of the sediment pool will be the same and its dominance in the lake ecosystem is most certainly accurate.

Mass balances

Mass balances for a large number of elements have been constructed for Frisksjön in Laxemar-Simpevarp. Most mass balances are not well balanced, and most often the outfluxes exceed the influxes. There are relatively large uncertainties associated with sediment accumulation as well as in- and outflow via water. The in- and outfluxes are estimated from site-specific measurements and should be of the right order of magnitude, but the absolute numbers are more uncertain. The mass balances could easily be brought into balance by making adjustments in one or several of the flows. However, it is not possible to determine which of the flows are inaccurate in the unbalanced mass balances, as all flows are associated with uncertainties. A description of the confidence and uncertainties of separate flows follows below.

As discussed in section 5.6.2, in- and outflows to/from the lake via water are extrapolated from measurements in the Laxemar-Simpevarp area and are not site-specific data for Frisksjön. This of course makes the estimates uncertain, although they should be of the right order of magnitude.

The site-specific data on atmospheric deposition include only a few elements. This flux is therefore lacking for many elements. For most elements (except phosphorus) this flux was small and probably does not alter the mass balance to any significant degree. However, in the case of the lanthanides atmospheric deposition has not been estimated for a single element. Although less likely, we cannot exclude the possibility that atmospheric deposition is high for these group of elements. For elements where site-specific measurements of atmospheric deposition are available, the estimates of this flux can be considered reliable. The estimate of the annual mean chemical composition of precipitation is based on sampling during more than one year, so the results should be relatively representative.

The estimate of sediment accumulation is high and may be somewhat overestimated. As discussed in section 5.6.2, the water-rich top of the sediments is not included, which may lead to overestimation of the sediment accumulation of carbon and other elements. On the other hand, high concentrations of inorganic nutrients, and substantial reed production in areas surrounding the lake, may contribute to large sediment accumulation. Judging from the unbalance in the models and the fact that outfluxes exceed influxes, it is reasonable to assume that sediment accumulation is overestimated. It is difficult to determine by how much, but the order of magnitude of the estimated sediment accumulation is probably correct.

8 Long-term development of lakes and streams

Lake basins may be formed in many different ways, often related to catastrophic events in the history of earth. Lakes appear wherever a threshold that obstructs the passage of runoff water is formed. /Hutchinson 1975/ defined eleven main classes and characterized 76 sub-classes of lake basins, based on the processes involved in their formation. Lake basins found in Sweden include e.g. tectonic basins, basins formed by glacial activity, by fluvial action and by meteorite impact, as well as man-made dams. The most common types of lake basins in Sweden are those that have been formed directly or indirectly by glacial activities during and after the Pleistocene glaciations. New lakes are still continuously being formed along the coast as the land rises from the depression that occurred during the last glacial period. This is the case in both the Forsmark and the Laxemar-Simpevarp areas.

The structure of the drainage network is important for ecosystem development since it determines, or at least strongly affects, groundwater levels and water content in the upper soil layers. However, processes that may affect the drainage network mainly took place prior to or during the latest glacial period. It is therefore reasonable to assume that no major topographical changes due to e.g. erosion or sedimentation have occurred after the investigated sites emerged above sea level, with the exception of sedimentation in lakes. Sediment accumulation will probably not change the catchment areas, since thresholds are generally formed in glacial till or bedrock. Peat formation may lead to damming, resulting in expanding peatlands. However, damming due to peat formation is considered to be of minor importance for drainage network evolution in the investigated areas, and it is probably only in the most elevated parts that peat formation may have caused any changes in the drainage pattern.

The aim of this chapter is to describe the historical developement of the areas from the last glaciation until today.

8.1 Succession processes

Succession is a directional change of ecosystem structure and functioning that may occur over time scales from decades to millennia. Succession may be a result of new land or lakes emerging (primary succession) or of disturbance such as after a clear-cut (secondary succession). The vegetation development and the species community at any given time is limited by the availability of dispersal propagules and the local abiotic conditions /i.e. Rydin and Borgegård 1991/. In the investigated coastal areas, shoreline displacement continuously transforms the near-shore sea bottom to new terrestrial areas or to freshwater lakes. The subsequent development of these terrestrial areas and lakes may follow different trajectories depending on factors such as fetch during the shallow marine stage, slope and surrounding topography. A schematic illustration of some of the main trajectories is shown in Figure 8-1, where the sea bottom is the starting point and the endpoint is an inland bog or a forest.

The starting conditions for ecosystem succession from the original sea bottom in a coastal area are strongly dependent on the topographical conditions, where low points in the bottoms accumulate sediments (accumulation bottoms) to a higher degree than higher located bottoms (transport bottoms). This difference becomes even more pronounced in near-coast locations, where the bottoms of sheltered bays accumulate organic and fine-grained inorganic material, while the finer fractions are washed out from more wave-exposed shorelines with a large fetch.

During the process of shoreline displacement, a sea bay may either be isolated from the sea at an early stage and thereafter gradually be transformed into a lake as the water becomes less saline, or it may remain as a bay until shoreline displacement transforms it into a wetland. The Baltic

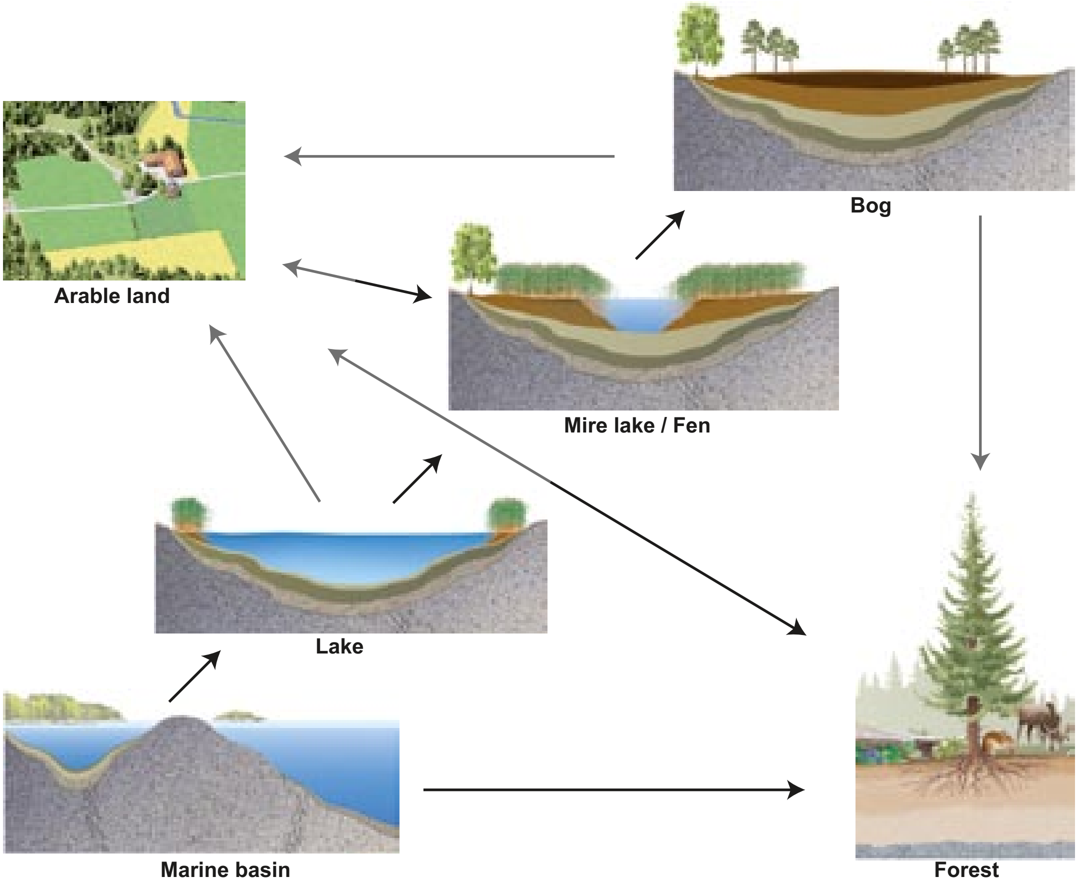


Figure 8-1. Schematic illustration of the major ecosystems that may be found at different stages of succession, where the original sea bottom slowly is transformed into land due to shoreline displacement. Black arrows indicate natural succession, whereas grey arrows indicate human-induced changes to create new agriculture land or improving the forest. Agriculture land may be abandoned and will then develop into forest or, if the hydrological conditions are suitable, into a fen. A forest may be "slashed and burned" and used as agriculture land.

Sea shore can be divided into four different types: rocky shores, shores with wave-washed till, sandy shores and shores with fine sediments. Wave-exposed shores will undergo a relocation of previously accumulated sediments, and these shores will emerge as wave-washed till, where the grain size of the remaining sediments is a function of the fetch at the specific shore.

Shores with wave-washed till are the most common kinds in the Forsmark area, but rocky shores and shores with fine sediments can also be found. In the Laxemar-Simpevarp area, rocky shores are the most common types followed by shores with wave-washed till, and shores with fine sediments. These shores later become forests (see below). In coastal basins that will later develop into lakes, there is a threshold in the mouth of the basin towards the open sea. This threshold allows fine material to accumulate in the deeper parts of the basin. Provided that the water depth is less than 2–3 m, different macrophyte species (e.g. *Chara* sp.) colonize the illuminated sediments. Along the shores, *Phragmites australis* and other aquatic vascular plants colonize the system, and a wind-sheltered littoral zone develops. In both these habitats, colonization by plants reduces the water currents, resulting in increased sedimentation and accelerated terrestrialization of the bay. When the threshold rises above sea level, inflow of fresh surface water and groundwater slowly changes the system from a brackish to a freshwater stage (Figure 8-2).

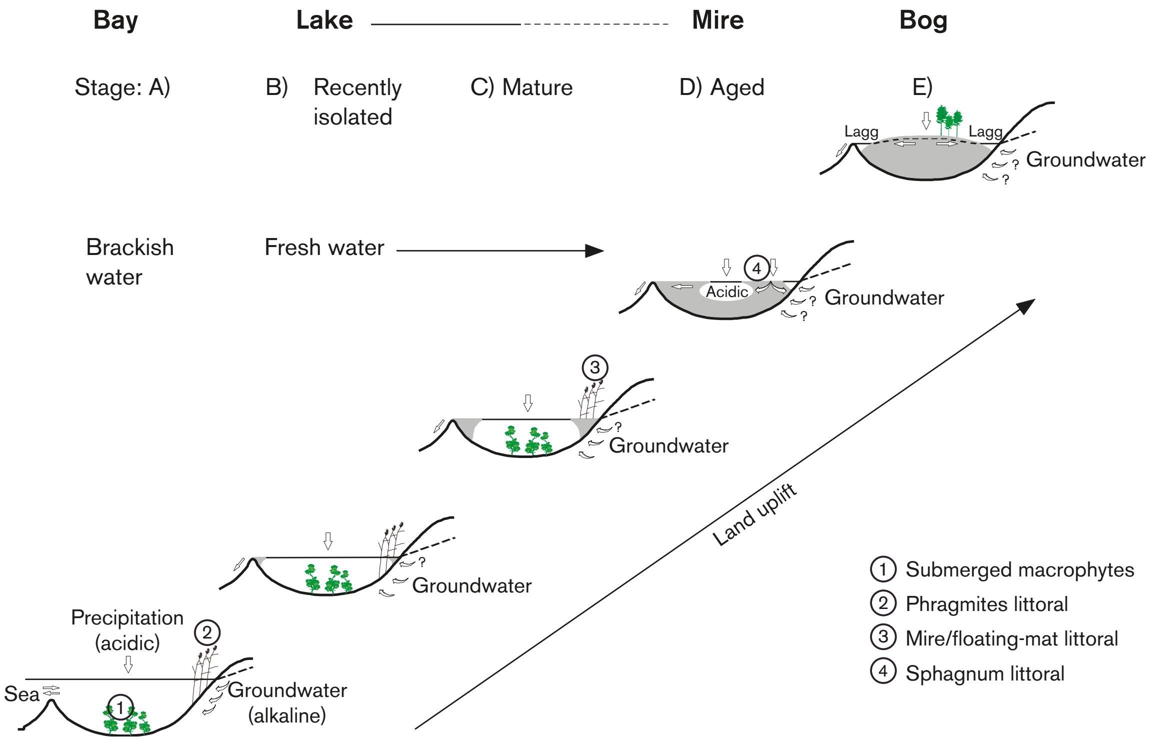


Figure 8-2. *Schematic description of the ontogeny of a closed-off bay of the sea to a mire. The figures represent different important components of the ecosystem. Modified from /Brunberg and Blomqvist 2000/.*

All present-day lakes in the investigation areas originated from depressions in the bottom of the coastal system, and where shoreline displacement is regressive new freshwater lake basins are continuously being formed along the coast of the Baltic Sea. The lake ecosystem gradually matures in an ontogenetic process, which includes subsequent sedimentation and deposition of allochthonous (transported from the surrounding catchment area) as well as autochthonous (originating from/produced within the lake) substances. Hence, the ultimate, inevitable fate of all lakes is infilling and transformation to either a wetland or a drier land area, the final result depending on local hydrological and climatic conditions. A common pattern for this ontogeny is the progressive development of more and more eutrophic (nutrient-rich) conditions as lake depth and volume decrease /Wetzel 2001/. In later stages, aquatic macrophytes speed up the process by colonizing large areas of the shallow sediments, and finally more terrestrial plant communities can colonize and grow there. Accordingly, the peat layers developed during this ontogenetic process follow a certain bottom-up order with a more limnic character at the bottom with *Phragmites* peat, followed by *Equisetum* and then sedge-fen peat, usually over-grown by bog peat /Sjörs 1983/. However, various environmental conditions may alter this general ontogenetic pattern, and there are examples of lake ontogeny that include a transition to more oligotrophic (nutrient-poor) conditions /Engstrom et al. 2000/, as well as to more dystrophic (low pH, brown-water) conditions /Brunberg et al. 2002, Brunberg and Blomqvist 2003/.

Dystrophic conditions are typical of small forest lakes in large areas of Sweden. These lakes are characterized by a high input of allochthonous carbon from the drainage area and often by a short water turnover (retention) time /Brunberg and Blomqvist 2000/. The development into dystrophic conditions starts with colonization by *Sphagnum* mosses in areas with macrophytes in the sheltered littoral. As the growth of *Sphagnum* proceeds in an outward direction and organic accumulation underneath these plants increases, a mire/floating-mat littoral zone is gradually developed. This mire-littoral is important in that it may alter the groundwater flow and/or the chemistry of the inflowing groundwater and turn the system increasingly acidic.

Thus, the invasion of the sheltered littoral by *Sphagnum* should, at least theoretically, have a profound effect on the functioning of the lake ecosystem. In a later stage of succession, the accumulation of organic detritus in the lake basin completely covers the previously illuminated benthic area. At this stage, the *Sphagnum* littoral alone dominates the metabolism of the system, as most of the previously benthic habitat has been lost through accumulation of peat. The whole ecosystem, the mire-littoral as well as the open water, is now acidic. The area of open water is continuously reduced due to expansion of the floating mats. The floating mats fill in the lake from the top, which means that bog-like peat can be deposited directly on the lake bottom (with some mud layer in between), as the weight of the growing peat pushes the lower parts downwards /Sjörs 1983/. The final stage of this ontogenetic process is the raised bog ecosystem (Figure 8-1 and 8-2).

8.2 Historical development

8.2.1 The Forsmark area

When the latest deglaciation in Forsmark took place in approximately 8800 BC, the closest shore was situated c. 80 km to the west of Forsmark. At that time, the Forsmark area was situated 150 m below the surface of the Yoldia Sea (section 4.3.4 in /Söderbäck (ed) 2008/). Since most of the Forsmark regional model area was covered by water until c. 2,500 years ago, the postglacial development of the area is determined mainly by the development of the Baltic basin and by shoreline displacement.

At around 500 BC, a few scattered islands situated in the western part of the regional model area were the first land areas to emerge from the brackish water of the Bothnian Sea (Figure 8-3). The surface of these first islands was covered by sandy till and exposed bedrock, similar to the present situation on the islands outside Forsmark. Palaeo-ecological studies from the Florarna mire complex, situated c. 30 km west of the regional model area, indicate a local humid and cold climate at approximately this time /Ingmar 1963/.

At 0 BC, the Bothnian Sea still covered the Forsmark candidate area, whereas the islands in the western part of the regional model area had expanded in size (Figure 8-3). Land areas presently covered by peat had emerged and, at that time, these newly isolated basins were small and shallow freshwater lakes/ponds, similar to the near-shore lakes which can be found in the area today. The apparent isolation of Lake Bruksdammen in the western part of the area around 0 BC is an artefact caused by the use of today's lake thresholds when constructing the map. The lake was probably created by man in the 17th century by damming the river Forsmarksån /Brunberg and Blomqvist 1998/.

At 1000 AD, the mainland had expanded further in the south-western part of the area (Figure 8-3). The isolation process of the Eckarfjärden basin was initiated, but the bay still had an open connection with the Baltic in the northern part /cf. Hedenström and Risberg 2003/. The area west of Eckarfjärden presently occupied by the Stenrösmossen mire had emerged, and a short lake phase was succeeded by invasion by reed /cf. Fredriksson 2004a/. The Börstilåsen esker and the most elevated areas at Storskäret constituted some small islands in the east, exposed to waves and erosion.

At 1500 AD, a considerable part of the regional model area had emerged from the Baltic and several freshwater lakes were isolated, e.g. Eckarfjärden and Gällsboträsket (Figure 8-3). A shallow strait connected the bays that today are Bolundsfjärden and Fiskarfjärden. The northern part of this archipelago was heavily exposed to wave action, whereas the southern part was relatively protected. The area covered by clayey till at Storskäret formed a large island, partly protected from wave exposure by the Börstilåsen esker. A hundred years later, the strait between Bolundsfjärden and Fiskarfjärden had been cut off, and there were two bays with different conditions. At about 1650 AD, most of the candidate area was situated above sea level.

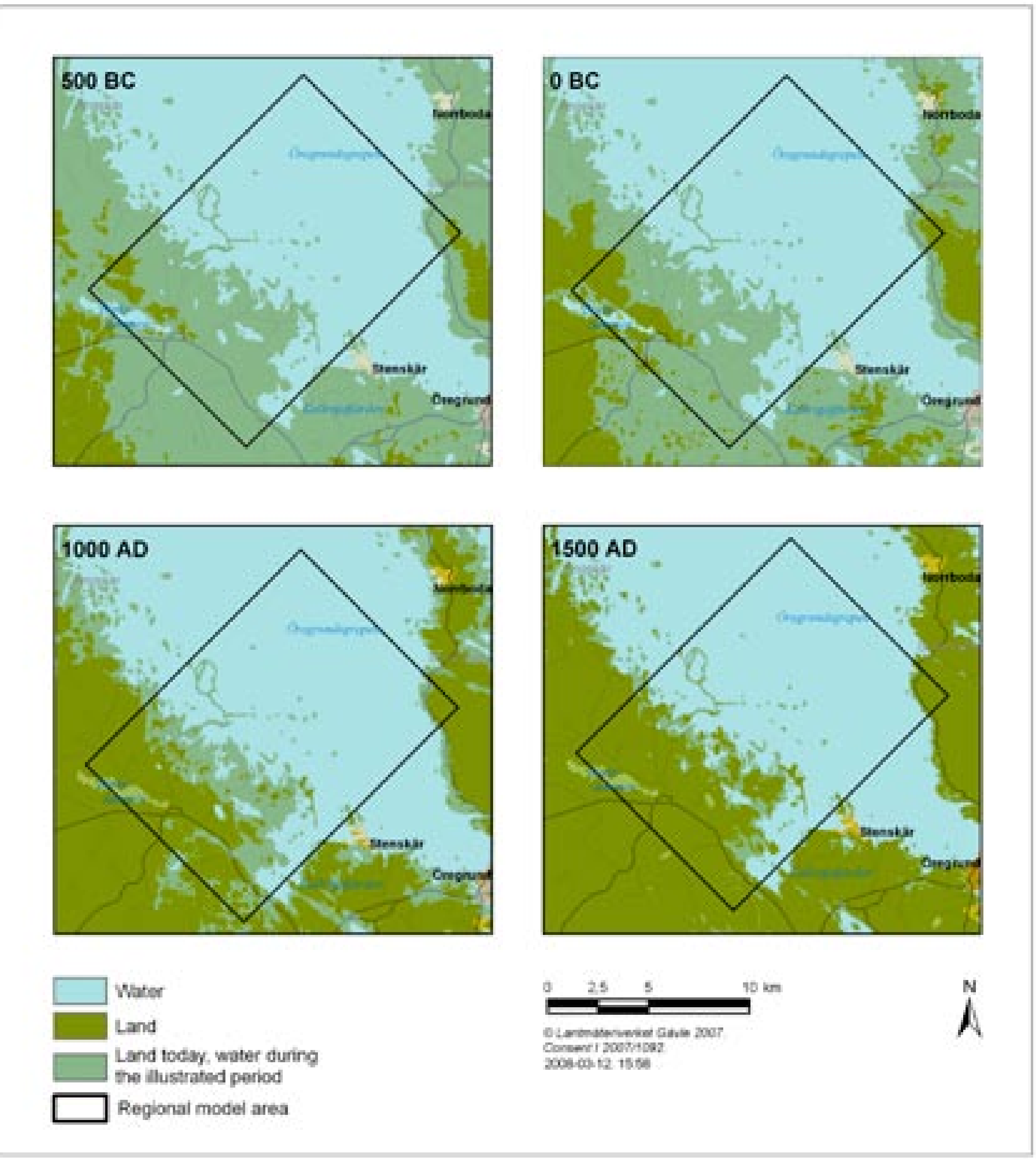


Figure 8-3. The distribution of land and sea in the Forsmark area at 500 BC, 0 BC, 1000 AD and 1500 AD.

Long-term development of lakes in the Forsmark area

Ontogeny of oligotrophic hardwater lakes

All lakes existing in the Forsmark investigation area today (see Figure 3-1), as well as a number of previously small and shallow lakes which over time have been converted to wetlands due to the ontogenetic process, can be classified as oligotrophic hardwater lakes. Accordingly, they are characterized by high pH (pH 7–8), low phosphorus concentration (total-P often lower than 0.015 mg L^{-1}), high concentrations of major ions and high electrical conductivity (section 3.9). This is a combined effect of the calcium-rich Quaternary deposits, recent emergence from the Baltic Sea and the shallow lake depths, resulting in high primary production at the light-illuminated sediment surface and very low production in the water mass /Brunberg et al. 2002/. The high primary production at the sediment surface results in a high benthic pH, which in turn causes benthic precipitation of $CaCO_3$ and co-precipitation of phosphorus. Much of the precipitated phosphorus is more or less permanently locked in the sediments by high pH and high O_2 concentration /Brunberg et al. 2002/.

/Brydsten 2006/ used the lake elevation today, together with the shoreline equation model by /Påsse 2001/, and estimated the sedimentation rate to model the isolation time and the duration of the lake phase for the lakes in the Forsmark area. The oldest of the present-day lakes in the area emerged from the Baltic Sea around 1100 AD (Table 8-1), whereas the largest lake in the area, Lake Bolundsfjärden, and several of the small near-shore lakes in the area, are still affected by occasional intrusions of sea water (cf. section 4.1.1 in /Tröjbom et al. 2007/). Due to both chemical and biological processes in the lake water, the amount of nutrients available in the lakes is effectively reduced by co-precipitation together with calcium-rich particulate matter. Because of this, the phosphorus concentration in lakes and streams is generally low. The nitrogen concentration, on the other hand, tends to be high, or even very high, due to a combination of high input and low biotic utilization /Brunberg and Blomqvist 1999, 2000/. These conditions, together with shallow lake depths, give rise to the unique type of lake found in the Forsmark area, the oligotrophic hardwater lake.

As described above, all lakes can in the long-term be regarded as temporary since they will eventually be filled up and converted to either a wetland or drier land area. However, provided that the lake is deep enough, the oligotrophic hardwater stage may also be of a temporary nature. /Brunberg et al. 2002/ proposed that light conditions at the sediment surface may have a major influence on nutrient conditions in this type of lake. If the lake water during the ontogenetic process turns more brownish, reduced benthic photosynthesis may contribute to a change from an oligotrophic hardwater stage into a more eutrophic stage. Additionally, it is only the minerogenic Quaternary deposits, such as glacial till and glacial clay, and not the bedrock, that contain carbonates and coupled anions, and these sources will therefore be depleted with time. The system will reach a point when precipitation of $CaCO_3$ from the lake water will no longer take place. At that point, there will be no co-precipitation of important plant micronutrients (e.g. phosphorus) or essential trace elements (e.g. iron, manganese). Instead, these elements, and especially phosphorus, will contribute to the production of organisms in the lake system and there will be a rapid change towards more eutrophic conditions. This change will in turn lead

Table 8-1. Time of isolation from the Baltic Sea and estimated time of conversion to wetland for existing lakes in the Forsmark area (modified from Table 3-1 in /Brydsten 2006/). For identification of catchments and sub-catchments, see /Brunberg et al. 2004/.

Catchment	Sub-catchment	Lake	Lake isolation time (Year AD)	Time at conversion to wetland (Year AD)
Forsmark 1	1:3-4	Labboträsket	1400	2200
	1:1-4	Gunnarsbo-Lillfjärden	1700	2900
Forsmark 2	2:8	Gunnarsboträsket	1100	2900
	2:10	Eckarfjärden	1200	7100
	2:9-10	Stocksjön	1500	2400
	2:7	Kungsträsket	1600	2200
	2:8	Gällsboträsket	1700	2500
	2:5	Fräkengropen	1800	2200
	2:6	Vambördsfjärden	1800	3000
	2:4-5	Graven	1900	2500
	2:11	Puttan	1900	3200
	2:1-10	Norra Bassängen	1900	3400
	2:3-10	Bolundsfjärden	1900	7600
Forsmark 3	3:1	Tallsundet	2000	2600
Forsmark 4	4:2	Lillfjärden	2000	3700
Forsmark 5	5:1	Bredviken	2000	5900
Forsmark 6	6:1	Simpviken	2000	2200
Forsmark 7	7:2-4	Märrbadet	2000	2300
Forsmark 8	8:1	Fiskarfjärden	1900	7600

to increased amounts of sedimenting organic matter (i.e. increased infilling), increased decomposition rates, at least until anoxic conditions are reached, and enhanced nutrient recycling /Brunberg and Blomqvist 2000/.

However, due to the shallow depths of both previous and present-day lakes in the Forsmark area, it is unlikely that they reached or will reach a stage of increasing eutrophication before they are completely filled with material. Instead, a likely ontogeny of the shallow hardwater lakes in Forsmark is growth of reed around the lakes and a succession towards a reed swamp, a fen and finally a bog ecosystem. This idea is supported by the fact that mires (fens) constitute a large part of the Forsmark area today (10–20% of the area in the three major catchments). It is also supported by the fact that the riparian zone of most existing oligotrophic hardwater lakes in the area is dominated by mires. Interestingly, this was also supported by a vascular plant inventory of different mire types /Göthberg and Wahlman 2006/, where the number of indicator species for bog increased with the height above sea level (section 4.1.1 in /Löfgren 2008/).

Ontogeny of brown-water lakes in the region

Today there are no brown-water lakes in the Forsmark area. However, investigations of lakes in the nearby catchment Forsmarksån /Brunberg and Blomqvist 2000, 2003/ showed that lakes in the vicinity of the Forsmark area may develop to brown-water lakes after passing through an oligotrophic hardwater stage, but may also form brown-water lakes directly after isolation. From an ontogenetic point of view, the catchment of the Forsmarksån River, and thereby also its lakes, may be divided into two parts with differing ontogeny: the areas upstream and downstream of the 13 m high waterfalls at Lövstabruk /Brunberg and Blomqvist 2000/.

Palaeoecological studies by Tord Ingemar et al. (referenced in /Brunberg and Blomqvist 1998/) show that the upstream Lake Vikasjön passed through an oligotrophic hardwater stage after its isolation from the Baltic Sea, a period when "cyanophycée-gyttja" was formed. This corresponds to the present situation in the oligotrophic hardwater lakes along the coast, e.g. Lake Eckarfjärden and Lake Bolundsfjärden in the regional model area. In Lake Vikasjön, this stage lasted for about 1,000 years, and was followed by a period of 1,000–2,000 years when the lake sub-basins were gradually isolated from each other and partly transformed into mires. The sediments in the remaining lake basins then switched to "dy" sediments, i.e. lake sediments mainly consisting of humic compounds, transported to the lake from the terrestrial surroundings.

The lakes situated below the 13 m fall in Lövstabruk have a different history. Due to the substantial difference in the topography, they were isolated from the Baltic Sea at least 2,000–2,500 years later than the upstream lakes. At that time, the upstream lakes had passed the oligotrophic hardwater stage, and were already more or less brown-water systems. The inflowing water from the upstream areas to the newly formed lakes was thus brownish and less alkaline. This water from the main river constituted a major component of the inflowing water to the newly formed lake basins. The large flow of water dominated, and still dominates, the hydrology of the systems, thus diluting and washing out the contributions from the land areas in the close vicinity of the newly formed lakes. Consequently, no oligotrophic hardwater stage occurred in the chain of lakes situated along the main river below Lövstabruk. Instead, they developed into brown-water flow-through lakes more or less directly after isolation /Brunberg and Blomqvist 2000/. Brown water lakes in the region today are further described in section 3.12.1.

Ontogeny of deep eutrophic lakes in the region

There are no deep eutrophic lakes in the Forsmark area today, but the deepest parts of Öresundsgrepen will in the future develop into a number of deep lakes which will differ consi2bly from the present-day lakes in the Forsmark area (cf. Table 5-1 in /Kautsky (ed) 2001/). There are a few deep lakes in the region, and the ontogeny of two deep lakes in the vicinity of the Forsmark area, Lake Erken and Lake Limmaren, was assessed by /Brunberg and Blomqvist 2000/. Both of these lakes are relatively eutrophic today. In investigations of sediments from Lake Limmaren, /Brunberg et al. 2002/ found no signs of changing trophic status after isolation from the Baltic Sea, despite the fact that the lake surroundings, like the Forsmark lakes, have calcareous soils. It seems likely that neither Lake Erken nor Lake Limmaren have passed an oligotrophic hardwater stage, and the main reason is probably that, due to their larger depths, dark conditions prevail at the sediment surface. Thus, benthic photosynthesis is limited and instead pelagic photosynthesis dominates /Brunberg et al. 2002/.

For Lake Erken, the accumulation of sediments in the deepest parts of the basin is at most 1 m over the 2,500 years that have passed since the lake was isolated from the Baltic Sea. Assuming the same rate of sediment deposition, the accumulation of sediments during the next 10,000 years would be 4 m. The accumulation of sediments in other parts of the lake would be considerably less. Thus, even 10,000 years from now, Lake Erken will be a large and, for the region, relatively deep lake (maximum depth c. 16 m).

The situation in Lake Limmaren is different. First, the sedimentation rate over the last 1,000 years has been considerably higher than that in Lake Erken, with an accumulation of some 1.4 m of sediment in the deepest part of the lake /Bergström 2001/. Secondly, Lake Limmaren is much shallower than Lake Erken. Taken together, it seems reasonable to conclude that the Lake Limmaren basin will be completely filled with sediments 5,000 to 10,000 years from now. An initial transition to reed-marsh seems very likely, but whether this state will be a mire or a wetland forest (dominated by alders) is highly uncertain.

8.2.2 The Laxemar-Simpevarp area

The latest deglaciation in the Laxemar-Simpevarp area took place c. 16,000 BC, and the highest shoreline in the region is located c. 100 m above the present sea level. Thus, the whole Simpevarp regional model area is situated below the highest shoreline, since the highest point in the area is situated c. 50 m above the present sea level. The sea level dropped fast during the end of the Baltic Ice Lake, from c. 66 meters above present sea level (m.a.s.l.) around 10,000 BC to less than 20 m.a.s.l. just over 1,000 years later (Figure 4-28 in /Söderbäck (ed) 2008/). Accordingly, the first islands in the area emerged from the sea around 9400 BC.

The Yoldia Sea stage (9500–8800 BC) was characterized by regressive shoreline displacement, whereas the onset of the Ancylus Lake stage around 8700 BC was characterized by a transgression with total amplitude of c. 11 m. Figure 8-4 shows the former shoreline in the Simpevarp regional model area at four different occasions during Holocene. At around 8000 BC, i.e. in the middle of the lacustrine Ancylus Lake stage, the shoreline was situated just over 20 m.a.s.l., which means that the western part of the Simpevarp regional model area was dry. Between 8000 BC and 5000 BC, i.e. the first part of the Littorina Sea stage, shoreline displacement was mostly regressive, although there are indications of several minor transgressions during that period (section 4.4 in /Söderbäck (ed) 2008/). At 5000 BC, when the shoreline was situated c. 15 m.a.s.l., the central parts of the regional model area were dry, but the fissure valleys still constituted long and narrow coastal bays which intersected the area. At 2000 BC, most of today's terrestrial areas had emerged from the sea and the coastal bays were considerably reduced in size. From 0 BC and onwards, the sea level has dropped c. 3 m, but this has resulted in only minor changes in the distribution of land and sea in the regional model area.

Long term development of lakes in the Laxemar-Simpevarp area

Only five lakes are situated completely within the Simpevarp regional model area today. All of these lakes are relatively small, shallow, and characterised by more or less dystrophic conditions /cf. Tröjbom and Söderbäck 2006a/. The ontogeny of these lakes has not been examined explicitly, but there are no reasons to suggest any major differences from the general ontogeny of dystrophic lakes outlined in section 8.1 above. The higher situated lakes, e.g. Jämsen and Plittorpsgöl, were isolated from the Baltic Sea early during the Holocene (both these lakes were isolated around 8200 BC). The near-shore Frisksjön is today situated at 1.3 m.a.s.l., indicating that the lake was isolated from the Baltic Sea at 1200 AD. However, the lake threshold has been lowered by man in recent centuries, and the lowering is probably larger than 1 m. This means that Frisksjön was isolated from the Baltic Sea much earlier, possibly before 0 BC/AD.

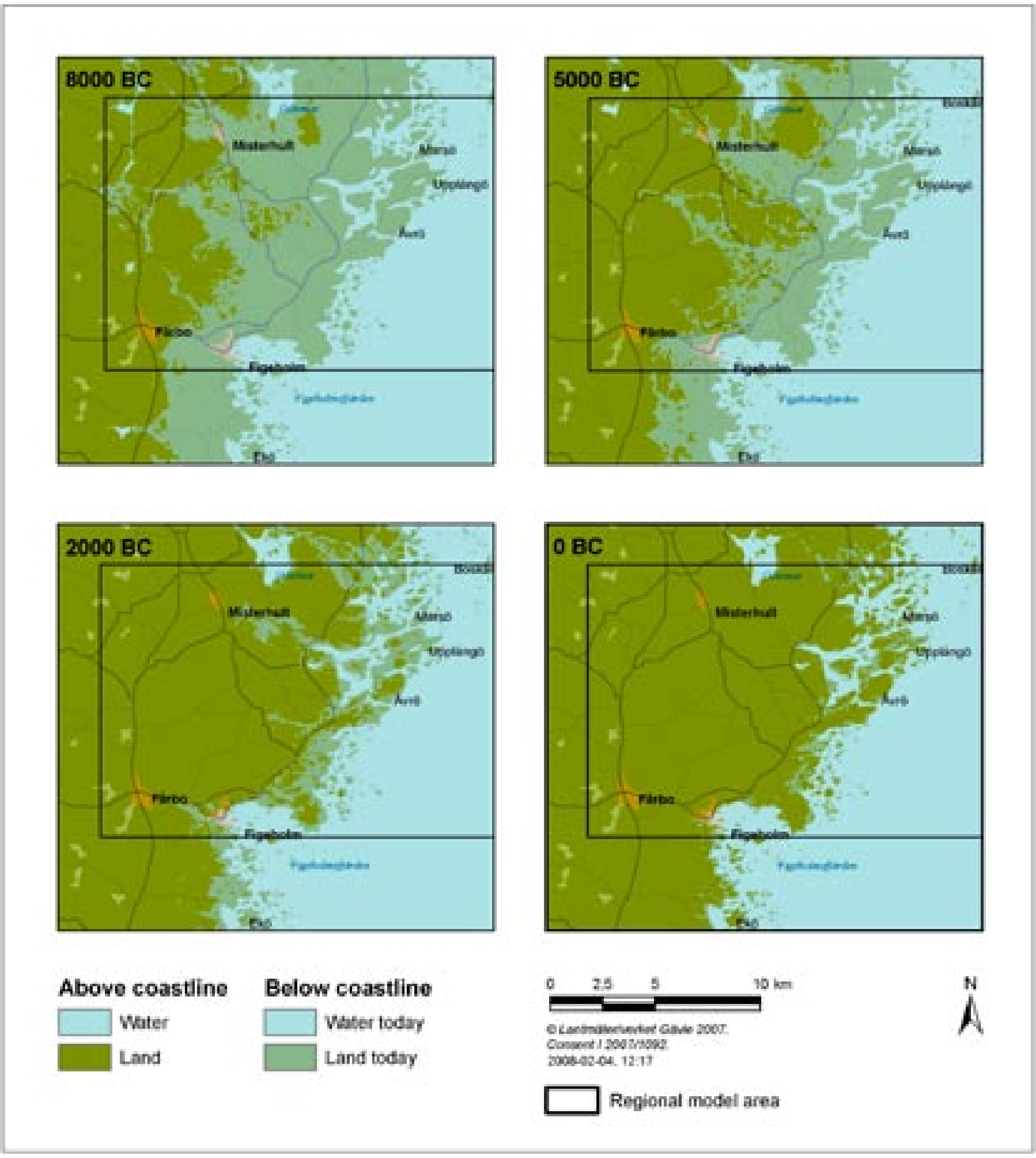


Figure 8-4. The distribution of land and sea in the Laxemar-Simpevarp area at 8000 BC, 5000 BC, 2000 BC and 0 BC.

Moreover, there is at least one previously shallow lake in the area (Gäster) which has been totally drained in recent centuries in order to gain new agriculture land (Appendix 1 in /Nyborg et al. 2004/), further discussed in section 4.11.1.

The considerably larger and deeper Götemar (surface area 3.0 km^2, max. depth 18 m) is situated just north of, and partly within, the regional model area, at an altitude of 1 m above the present sea level. According to the shoreline displacement model /Påsse 2001/ it was isolated from the Baltic Sea around 1200 AD. Götemar is characterized by oligotrophic, clear-water conditions /Tröjbom and Söderbäck 2006a/. There are no investigations of sediment accumulation from Götemar, but considering the relative nutrient-poor conditions and large depth it seems reasonable to suggest that the lake will remain large and deep for many millennia to come (cf. Erken in the Forsmark region, section 8.2.1). The currently relatively deep coastal basins north of Äspö (Granholmsfjärden and Kalvholmsfjärden) are expected to be isolated from the sea around 4000 AD (section 4.1.6 in /SKB 2006b/). When they eventually develop into freshwater lakes, they will probably be more similar to the oligotrophic clear-water Götemar than to the small dystrophic lakes in the area.

9 Couplings to the interaction matrix

9.1 Introduction

The overall objective of this report is to provide a thorough description of the limnic ecosystem that may be further used in the Safety Assessment. With the aid of an interaction matrix this chapter illustrates how important processes for the Safety Assessment are considered in the report. All processes in the ecosystem are identified but the work describing the processes are still ongoing and therefore this chapter should be viewed as a first draft that will be replaced later on. The general principles of an interaction matrix are illustrated in Figure 9-1. The system of interest is decomposed into various components that are listed along the lead diagonal of the matrix. These components can be spatially or conceptually distinct. Thus, for example, two components might be water in regolith and surface water (physically distinct) or herbivores and carnivores (conceptually distinct). Components may also be abstract concepts such as temperature.

Processes that relate the components are entered into the off-diagonal elements, as shown in Figure 9-1. Note that the matrix is read in a clockwise sense, so that processes by which component 1 affects component 3 are found in the top right element, whereas processes by which component 3 affects component 1 are found in the bottom left element.

It is important to ensure that the effects of processes are direct and are not mediated by interactions via a third component listed on the lead diagonal.

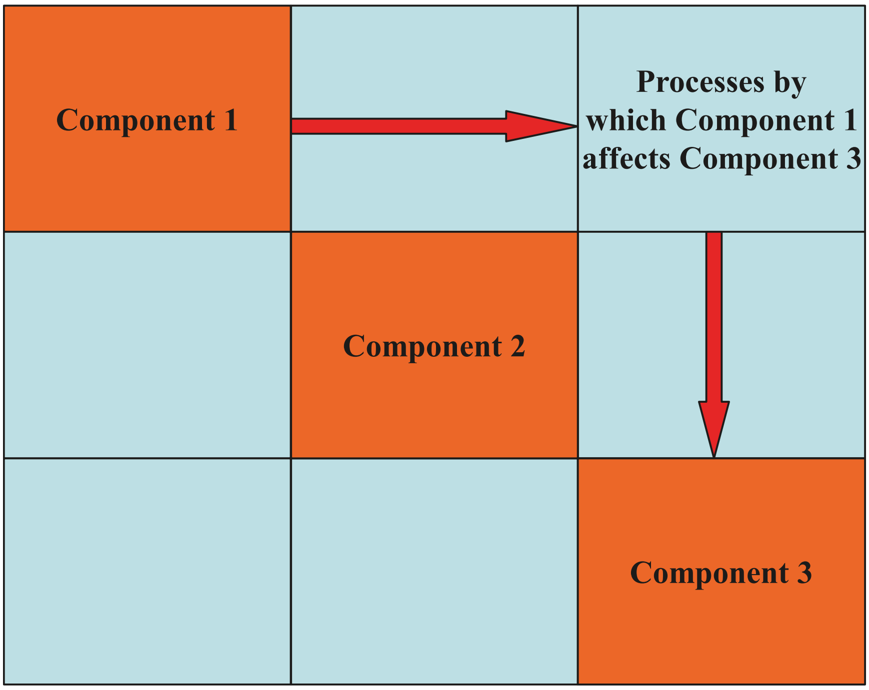


Figure 9-1. *Illustrative interaction matrix.*

9.2 Elements in the interaction matrix

From previous studies, 15 diagonal elements of the interaction matrix have been identified and the interaction matrix for the limnic ecosystem is presented in Figure 9-2. The diagonal components of the limnic ecosystem are further described in Table 9-1. The number of elements is a compromise between the need to keep the matrix to a manageable size and the requirement to be specific as to the processes relating the various diagonal elements. Note that these elements are of different kinds, e.g. environmental media such as surface waters and properties of those media such as water composition. Also, the definitions of these elements are often more wide reaching than might be inferred from the short names given in Table 9-1.

9.3 Processes in the interaction matrix

All processes in the limnic ecosystem are listed in the interaction matrix. The period considered in the assessment of processes is 10,000 years, and it is assumed that both the climate and the human behaviour are similar to today's conditions during the whole period. The aim of this chapter is to demonstrate that processes important for the safety assessment are described and considered in the construction of models of the limnic ecosystems in this report.

Table 9-1. Components (diagonal elements) of the limnic interaction matrix.

Element	Definition
Geosphere	The geosphere is the solid Earth that includes continental and oceanic crust as well as the various layers of the Earth's interior.
Regolith	The unconsolidated material that covers almost the Earth's entire land surface and is composed of soil, sediment and fragments from the bedrock beneath it.
Primary producers	Autotroph organism, able to utilize inorganic sources of carbon as starting material for biosynthesis, using sunlight as energy source.
Decomposers	Organism that feed on dead plant and animal matter, breaking it down physically and chemically and recycling elements and organic and inorganic compounds to the environment.
Filter feeders	Organisms that feed on small organisms and organic matter in water or air, straining them out of surrounding medium by various means.
Herbivores	Animals that feed extensively on plants.
Carnivores	Animals that feed on other animals.
Humans	Tend to be omnivores, although some individuals are strict herbivores.
Water in Quaternary Deposits	The water component in regolith.
Surface Waters	Water collecting on the ground or in a stream, river, lake, wetland, or ocean is called surface water, as opposed to groundwater or atmospheric water.
Water Composition	Chemical composition of elements and compounds in water.
Gases and Atmosphere	In physics, a **gas** is a state of matter, consisting of a collection of particles (molecules, atoms, ions, electrons, etc) without a definite shape or volume that are in more or less random motion. Here, the **atmosphere** is a layer of gases above the lakes.
Temperature	On the macroscopic scale, temperature is the unique physical property that determines the direction of heat flow between two objects placed in thermal contact. If no heat flow occurs, the two objects have the same temperature; otherwise heat flows from the hotter object to the colder object.
Radionuclides and Toxicants	A radionuclide is an atom with an unstable nucleus. The radionuclide undergoes radioactive decay, and emits a gamma rays and/or subatomic particles. Radionuclides may occur naturally, but can also be artificially produced. A toxicant is a chemical compound that has an adverse effect on organisms.
External Conditions	In this case the external conditions is the environment outside the limnic ecoystem.

The processes in the interaction matrix (Table 9-2 and Figure 9-2) are ranked according to importance for the safety assessment; 0 = irrelevant, 1 = insignificant, 2 = indefinable influence, and 3 = important. Most processes in the interaction matrix have been considered in the description and modelling in this report. In the interaction matrix in Figure 9-2, processes that are not considered in the description or model are shaded. To give an account of how processes are included in the report, processes are grouped together and presented in Table 9-2. In total, 57 grouped processes were identified and how these are considered in the report is described in the section below.

Table 9-2. Processes in the interaction matrix for the limnic system. The processes are ranked according to importance for the safety assessment as follows: 0=not relevant, 1=insignificant, 2= indefinable influence, 3=important.

Process	Ranking	Considered
Biological processes		
Bioturbation	3	yes
Consumption, Feeding	3	yes
Decomposition, Degradation	3	yes
Food supply	3	yes
Human activities, Resource, Filtering, Living and building	3	yes
Settlement	3	yes
Uptake/Excretion, Sorption, Water uptake	3	yes
Growth, Root growth, Root penetration (biological), Root penetration (Rock)	1	yes
Dispersal/Extermination	0	no
Emigration, Immigration	0	no
Intrusion	0	no
Movement	0	no
Pollution, Anthropogenic effects, Fertilizing	0	yes
Stimulation/Inhibation	0	yes
Chemical processes		
Mixing	3	yes
Reaction	3	yes
Sorption/desorption, ion exchange	3	yes
Phase transition	0	yes
External processes		
Gravitation	3	yes
Processes on geosphere level		
Export/import	3	yes
Mass flux	3	yes
Export/import of heat and energy	0	no
Export/Import of primary producers	0	no
Hydrological/Meteorological processes		
Advection	3	yes
Light absorbtion, light attenuation, insolation	3	yes
Precipitation/dissolution	3	yes
Sea level changes	3	yes
Covering	2	yes
Water pumping, Water use, Water extraction	2	yes
Wind stress	2	yes
Air pressure	1	yes
Change in water content	1	yes
Interception	1	no
Dehydration	0	no
Light reflection, Scattering, Radiation	0	yes
Retardation, Acceleration, Wind retardation, Wind field changes	0	yes
Mechanical processes		
Deposition, sedimentation, Surface deposition/uptake	3	yes

Process	Ranking	Considered
Geometric extension	3	yes
Landrise	3	yes
Resuspension, Deposition/Removal, Spray/Snowdrift, Saltation	3	yes
Consolidation	2	no
Material supply	2	yes
Changes in rock surface location	1	no
Relocation; Relocation in water, Disturbance	1	yes
Weathering, Erosion	1	no
Density effect, Property changes	0	yes
Iceload, Mechanical load	0	no
Particle production and trapping	0	yes
Volume expansion/contraction, Pingo formation, Adiabatic compression, Adiabatic temperature change, Pressure change	0	no
Radiological processes		
Decay and Formation of stabile isotopes	3	no
External exposure and External load of contaminants	3	yes
Internal exposure	3	yes
Irradiation	0	no
Radiolysis	0	no
Thermal processes		
Heat from decay	0	no
Heat storage	0	no
Heat transport	0	no

9.3.1 Biological processes

Important processes and processes of indefinable influence (rank 3-2)

Bioturbation is the displacement and mixing of sediment particles by benthic fauna (e.g. annelid worms, bivalves, gastropods) or flora. Faunal activities, such as burrowing, ingestion of sediment grains, construction and maintenance of galleries, and infilling of abandoned dwellings, displace sediment grains and mixing of the sediment. The sediment-water interface increases in area as a result of bioturbation, affecting chemical fluxes and thus exchange between the sediment and water column. Some organisms may further enhance chemical exchange by flushing their burrows with the overlying waters. Benthic flora can affect sediments in a manner analogous to burrow construction and flushing by establishing root structures. Bioturbation is included in the descriptive chapters of this book (Chapters 3 and 4) as biomass of benthic fauna and root biomass of reed. In addition, sediment chemistry and oxygenated sediment layer is also discussed. The former is influenced by the depth of the bioturbation and the latter is a measure of how deep the bioturbation reaches.

Consumption/Feeding is the consumption of solid material and organisms, accidentally or on purpose. This process affects both the prey and the consumer. The process is considered in the ecosystem carbon models in Chapter 5. The estimates of consumption and feeding rely on a large amount of site specific data on biomass of consumers and literature data on feeding rates of different consumers.

Decomposition/Degradation is the breakdown of organic matter by organisms. The type and efficiency of decomposers affects the content of non-degraded organic material in the regolith. Decomposition can also influence the water content in the regolith as decomposers release water from pores and cells. Degradation of toxicants by organisms affects the type and concentration of toxicants in the different parts of the biosphere system. The biomass of decomposers is included in the descriptive Chapters 3 and 4, and consumption of decomposers is considered in the ecosystem carbon models (Chapter 5). In addition, the chemical composition of the sediments (affected by decomposition) is included in both descriptive Chapters 3 and 4 and also in the calculations of mass balances in Chapter 7.

Food supply is the available energy for the next trophic level. If food is limited it will limit consumption. The food supply is accounted for in the ecosystem carbon models (Chapter 5).

Modification of the environment by humans includes resource utilization, filtering of water, living and building in the area. Human activities can affect the concentration of radionuclides and toxicants in the biosphere system, e.g. by pollution and by industrial establishments. Human impact may affect the composition of surface waters and in turn human settlement and use of water (e.g. bathing) are influenced by mineral resources and supply of water. Human impact is described in Chapter 3 and 4.

Settlement is the active choice by organisms of select a place for living. Settlement in lakes is influenced by properties of the regolith (e.g. grain size, porosity and chemical composition), of rock surfaces (roughness and structure) and of the water bodies (geometry and water composition). Habitat distribution is investigated in the lakes and thereby settlement is included in the descriptive chapters and included in the input data to the models.

Uptake and Excretion of water and chemical elements by biota affect water composition in lakes. Uptake of radionuclides and other toxicants by primary producers affects the concentration of radionuclides and other toxicants in primary producers, as well as in other components of the biosphere (i.e. in consumers and in the regolith). Accumulation in organisms is the net effect of uptake and excretion. Accumulation of different elements in biota, together with chemical composition of water and sediments, is accounted for in the description of chemical composition of biota, water and sediments (Chapters 3, 4, and 7).

Insignificant and irrelevant processes (rank 0–1)

Growth is increase in biomass by organisms, and the rate of growth affects the concentration of radionuclides and other toxicants in the organisms. Growth is considered insignificant in that the process has low impact on radionuclides in the ecosystem. Nevertheless, it has been given great consideration in the report. Growth of primary producers is assessed as net primary production in both descriptive chapters and in the ecosystem models (Chapters 3, 4 and 5). Growth of consumers is not directly assessed in the report, but it is included in the calculations of consumption and respiration by organisms. Root growth is influenced by type and way of growing. Root growth influences the depth of root penetration and thereby the physical properties of the sediments, e.g. porosity. The porosity of sediments is described in the descriptive chapters and used in the calculations of mass balances (Chapters 3, 4, and 7). Potentially, the penetration of roots via fractures in the rock and via the plugged and backfilled tunnels could affect the biological mass in the geosphere. However, the sediments in the lakes are often thick and it is unlikely that roots from lake vegetation will reach the bedrock. Accordingly, this process is not further assessed in the report.

Dispersal and **Extermination.** Dispersal is the process where organisms settle in new habitats with seeds, fragmentation or migration, and extermination is the process where organisms are not able to maintain their territory.

Migration is when humans colonize the area (immmigration) or leave the area (emmigration) for a period longer than one year. The rate of immigration influences e.g. living conditions and human behaviour. However, human migration rates as well as population sizes in both Forsmark and Laxemar-Simpevarp are small today and should have a small impact on the lake ecosystems. Therefore the migrations are considered irrelevant.

Intrusion is when organisms enter the geosphere by locomotion or growth (e.g. roots). However, considering the large depths of lake sediments and anoxic conditions in deeper layers of sediment, this is most probably an insignificant process in the lakes and is considered irrelevant.

Movement is the influence on surface waters by animal movement. Considering the small size and biomass of the animals in the lakes, this process is considered insignificant and irrelevant.

Pollution, Anthropogenic effects and **Fertilizing** are different examples of how humans may affect the lake ecosystems. Lakes in the Forsmark area are generally relatively unaffected by human activities, whereas most of the lakes in the Laxemar-Simpevarp area in a historical perspective are more or less affected by lowering of the water table. However, current human impact on the lake ecosystems in Forsmark and Laxemar is small and, thus, this process is considered to be irrelevant for the safety assessment. Nevertheless, the human impact is accounted for in the descriptive Chapters 3 and 4.

Stimulation/Inhibation. Stimulation is when an organism positively influences another organism, e.g. by providing substrate. Inhibition is when an organism negatively influences another, e.g. by resource competition for substrate. This process inevitably affects the species composition and may also influence the biomass of different species. However, it probably does not alter the overall ecosystem productivity. The process is assumed to be included already in the input data for the descriptive chapters (Chapters 3 and 4), e.g. as biomass and occurrence of different species.

9.3.2 Chemical processes

Important processes and processes of indefinable influence (rank 3-2)

Mixing concerns water, the solvent and main carrier of elements in the ecosystem. The magnitude, direction and distribution of the water flow in lakes and streams will affect the mixing of water from different sources, and thereby also the composition of the water. In addition, the temperature influences the diffusion. Both in Forsmark and Laxemar-Simpevarp, water chemistry and temperature measurements are available both for the surface and bottom water. Thus, this process is considered in the report.

Reactions include chemical reactions, exotherm/endotherm reactions, oxidation, photochemical reactions, non-biological decomposition, kinetics and chemical equilibria. Chemical reactions, e.g. decomposition of organic toxicants, and all other reactions involving radionuclides and toxicants in dissolved and particulate form may affect the composition of the water in the different components of the biosphere system. Abiotic processes influence the temperature in the biosphere. The humidity of the atmosphere and the content of oxidants, e.g. O_2, will affect the oxidation of minerals in Quaternary deposits and thereby the composition. Photochemical reactions can produce toxicants, and photochemical reactions close to the surface will affect the composition of the atmosphere, e.g. ozone formation, smog formation and reactions in exhaust gases. Reactions are not addressed explicitly in the report, but the effect of the reactions, as well as temperature and chemical composition of water, is measured at the sites and thus this process is to a large extent included already in the input data.

Sorption/desorption and **ion exchange.** The distribution of radionuclides and toxicants between the solid phase and the aqueous phase is influenced by the water composition, by the composition and grain size distribution (available surfaces for sorption) of sediments, and by the mineralogy and porosity of the surface rock. The amount of elements in the particulate and dissolved phases is accounted for in the mass balances in Chapter 7.

Phase transition is the change of elements from one state to another, e.g. from liquid to gaseous form. The phase transition between water and ice is affected by temperature and this has been considered in the model as both temperature and period of ice cover is included (Chapters 3, 4, and 5). In addition, the dissolution of gaseous carbon dioxide into water in the interface between atmosphere and surface waters is included in the mass balances of carbon (Chapter 5). Phase transitions for other elements are not considered in the report.

9.3.3 External processes

Important processes and processes of indefinable influence (rank 3-2)

Gravitation influences the habitat distribution of biota and the flow of water. The influence of gravitation is not explicitly considered in the report, but is included in the input data as distribution of biota and in the form of flow measurements in streams (considered in Chapters 3, 4, 5, and 7).

9.3.4 Processes on the geosphere level

Important and indefinable processes (rank 3-2)

Import/Export includes export and import of most diagonal elements (primary producers, fauna, humans, water, and elements in water, gases, radionuclides and toxicants) out of and into the system. The export and import of water, elements in the water, and radionuclides and toxicants, and the gas flux of CO_2 are considered in mass balance models (Chapters 5 and 7). The influence of migrating fish (import of consumers) is considered in the descriptive chapters (Chapters 3 and 4).

Mass flux. Transport of groundwater components into the limnic ecosystem will affect the composition of surface waters and water in sediments. Groundwater inflow is included in the calculations of mass balances and, accordingly, this process is accounted for in the report (Chapters 5 and 7).

Insignificant and irrelevant processes (rank 0-1)

Import and export of heat from the system is considered of minor importance and is not treated in the report. **Export of primary producers** occurs as phytoplankton export in the outlet streams, but this process is considered to be of minor importance and is not considered.

9.3.5 Hydrological and meteorological processes

Important processes and processes of indefinable influence (rank 3-2)

Advection refers to the transport of water, contaminants and gases in and between the sediments, groundwater and surface water. There are many factors influencing the advection; the hydraulic conductivity and storage capacity (porosity) of Quaternary deposits, the topography, the atmospheric pressure, the pressure of existing gas , temperature and temperature changes, air intrusion and infiltration of water in sediments by human activities, bottom topography, the fetch (the distance where the blowing wind is not disturbed). The water flow and CO_2 gas transport have been estimated in calculations of the mass balances and thus advection is considered in the report (Chapters 5 and 7).

Precipitation/dissolution. The amount of precipitation, such as rainfall, snow fall and hail, will influence the amounts of surface waters and of ice/snow on surfaces, as well as the amount of different substances transported to the lake. This has been considered in the mass balances where precipitation of different elements, as well as transport of different elements to the lake, has been calculated (Chapter 7).

Sea level changes will affect the amount and movement of surface waters. Sea level changes can be caused by e.g. earth quakes (tsunamis), global heating, land slides, earth tides, weather and climatic changes. This has been addressed in the historical description as development of the area and formation of lakes (Chapter 8). Future development of lakes and sea level changes are not considered in this report.

Covering. Ice coverage and the amount of primary producers covering the contact area between surface waters and the atmosphere determine evaporation and thereby affect the amount of surface waters. The length of the period with ice coverage is described in Chapters 3 and 4, and is further used in carbon ecosystem modelling (Chapter 5).

Water pumping, water use and water extraction. The amount of accessible water in the Quaternary deposits affects how and how much of the water is used by humans living in the area, e.g. how much of the water that is used as drinking water and for bathing, washing etc. In the same time, the extraction by humans e.g. from wells may affect the flow and water content in the sediments. This has been considered in the section "Land use and human impact" (Chapters 3 and 4).

Wind stress. The strength and direction of the wind will affect the movement of surface waters, e.g. wave formation. In addition, it will influence CO_2 gas transport between the water surface and the atmosphere and the amount of water droplets and snow particulates that are released to the atmosphere, and thus the amounts of surface waters and amounts of snow/ice on surfaces. Wind has been considered in the calculations of CO_2 transport in the mass balances and is also included in the time period of ice coverage (Chapter 5).

Insignificant and irrelevant processes (rank 0-1)

Air pressure affects the exchange of gases between surface waters and the atmosphere. This is considered in the calculation of carbon exchange between lakes and the atmosphere in the mass balance models (Chapter 5)

Change in water content. The magnitude and direction of the water flow influences the water content in the Quaternary deposits. In an aquatic environment the water content in sediments is relatively constant and is not expected to change over time but varies with the properties of the sediment, so this process is considered insignificant. Nevertheless, recharge/discharge areas, as well as the water content of the Quaternary deposits, have been identified in the report and thus the water content is considered although changes are not (Chapters 3 and 4).

Interception can be technically defined as the capture of precipitation by the plant canopy. The amount of precipitation intercepted by plants varies with leaf type, canopy architecture, wind speed, available radiation, temperature, and the humidity of the atmosphere. The surface area of primary producers influences the amount of water from precipitation and irrigation that is retained in the primary producers, and influences thereby the amount of surface waters as the droplets on primary producers are included in the definition of surface waters. In the limnic environment, the amount of above-surface vegetation is limited and this process has not been considered.

Dehydration is the transformation of crystal water in minerals in Quaternary deposits (equivalent to the sediments of lakes) to "free" water. Potentially, this process affects the water content of the quaternary deposits. However, the water content in lake sediments is high and this process is considered irrelevant.

Light absorption, light attenuation, insolation. Light absorption and light attenuation determines the settlement of primary producers and insolation determines the primary production. This has been considered in the models. Habitat definition is based on light attenuation; the Littoral includes areas where more than 1% of the incoming light reaches the bottom (sections 3.7 and 4.7). Moreover, the insolation is considered in the ecosystem models (Chapter 5), directly as measured insolation and indirectly as primary production.

Light reflection, scattering and radiation in surface water influence the adsorption and distribution of light and thereby the type and productivity of primary producers. The actual reflection is not measured at the sites, but the resulting productivity of primary producers and type of primary producers are included in the descriptive chapters as well as in the ecosystem models.

Retardation, acceleration, wind retardation, and wind field changes include the influences of primary producers, humans and topography on water movement and wind. The type, amount and location of primary producers determine the degree of sheltering and will thereby influence wind directions and velocities. In addition, man made structures such as buildings can redistribute wind velocities. The topography of the catchments results in increases and decreases in the wind flow and thereby influences the distribution of the wind velocities and directions. Wind speed is included in the calculation of the mass balances for carbon, and the amount of primary producers is included both in descriptions and carbon models of the lake ecosystems.

9.3.6 Mechanical processes

Important processes and processes of indefinable influence (rank 3-2)

Deposition, sedimentation, surface deposition/uptake are important for the mass balances of the lake ecosystems. These processes have been included in the report in the description, in the ecosystem carbon models, as well as in the mass balances (Chapters 3, 4, 5 and 7).

Land rise is the recovery of the earth crust from the compression caused by the load of the latest glacial ice cover. Today, interglacial conditions prevail and there is a land rise that influences the topography. The isostatic land rise in combination with eustatic sea level changes result in the shoreline displacement, which is accounted for in the description of long term development of lakes (Chapter 8).

Resuspension, Deposition/Removal, Spray/Snowdrift. These processes alter the position of elements in the ecosystem. Resuspension is the processes of stirring up settled fine particles into the water. The size distribution of the particles in the sediments influences the amount of material resuspended into the water, and thereby the particulate content of the water. The magnitude of wind velocities and the distribution of the wind field determine the deposition and removal of particulates, but also the removal of parts of primary producers and thus the living conditions. The composition of surface waters and snow will affect the composition of water droplets and snow particles that are part of the atmosphere. Wind velocities and the composition of particles in water is included in the report. The effect of resuspension is considered in the discussion of possible sinks of elements (in Chapters 5 and 7) and although resuspension is not measured, the sediment accumulation (net effect of sedimentation and resuspension) is included.

Consolidation is the transformation of sediments to solid rock. The time is an important factor for the extent of consolidation. This process has not been considered in the report.

Material supply is matter used for construction, e.g. stones or wood. This process may be important for land ecosystems, but there is no matter originating from lakes that is traditionally used for these kind of purposes and the process is considered irrelevant.

Geometric extension is the process delimiting water bodies in height, e.g. sills or thresholds. This process is accounted for in the report and the thresholds of the lakes are measured at the sites.

Insignificant and irrelevant processes (rank 0-1)

Changes in rock surface location may be induced by neotectonic movements or by events induced by the repository itself (e.g. collapse of caverns). This process is considered unlikely and is considered not significant in the report.

Relocation and Disturbance Relocation is the movement of solid matter and sessile organism dependent on gravitation and other forces e.g. wind. Movement of solid matter can also be caused by disturbance e.g. humans digging and dumping. The degree of relocation is influenced by the grain size and water content of the Quaternary deposits and influences the height distribution of the topography. The magnitude of the wind velocities and the distribution of the wind field affect the extent of relocation. The relocation is accounted for in the report as the extent of accumulation bottoms is used in the calculation of mass balances (Chapter 7), i.e. from all other lake bottom relocation occurs. Disturbance is considered to be small and is not further treated.

Weathering, Erosion are the processes where solid matter disintegrates into smaller pieces. This is considered irrelevant for the lake ecosystems and is not included in the report.

Density effect, Property changes is the effect of water pressure on the density of the water and thereby on the water composition. However, the difference in density is too small to have any significant impact on the water composition, and the process is considered irrelevant. The result of the process is considered in the report already in the input data as water chemistry is measured in situ at naturally occurring water pressures.

Ice load, Mechanical load is the total weight that e.g. an ice sheet has on the underlying regolith or rock. Changes in thickness of the ice sheet during periods of glaciation and deglaciation will affect the mechanical stress in the rock. This process is considered irrelevant for the functioning of the present lake ecosystem, and the process is not included in the report.

Particle production and trapping are the processes whereby particles are released (e.g. fragmentation, spawning) or trapped by organisms (e.g. filtration) and thereby altering the chemical composition of surface waters. Particle production is accounted for in the ecosystem models as the net result of primary production/consumption minus respiration, and particle trapping is accounted for as the consumption of filter feeders.

Volume expansion/contraction, Pingo formation, Adiabatic compression, Adiabatic temperature change, Pressure change includes e.g. the change in geometry due to temperature and phase transitions (water freezing). This is considered irrelevant for the lake ecosystem and is not included in the report.

9.3.7 Radiological processes

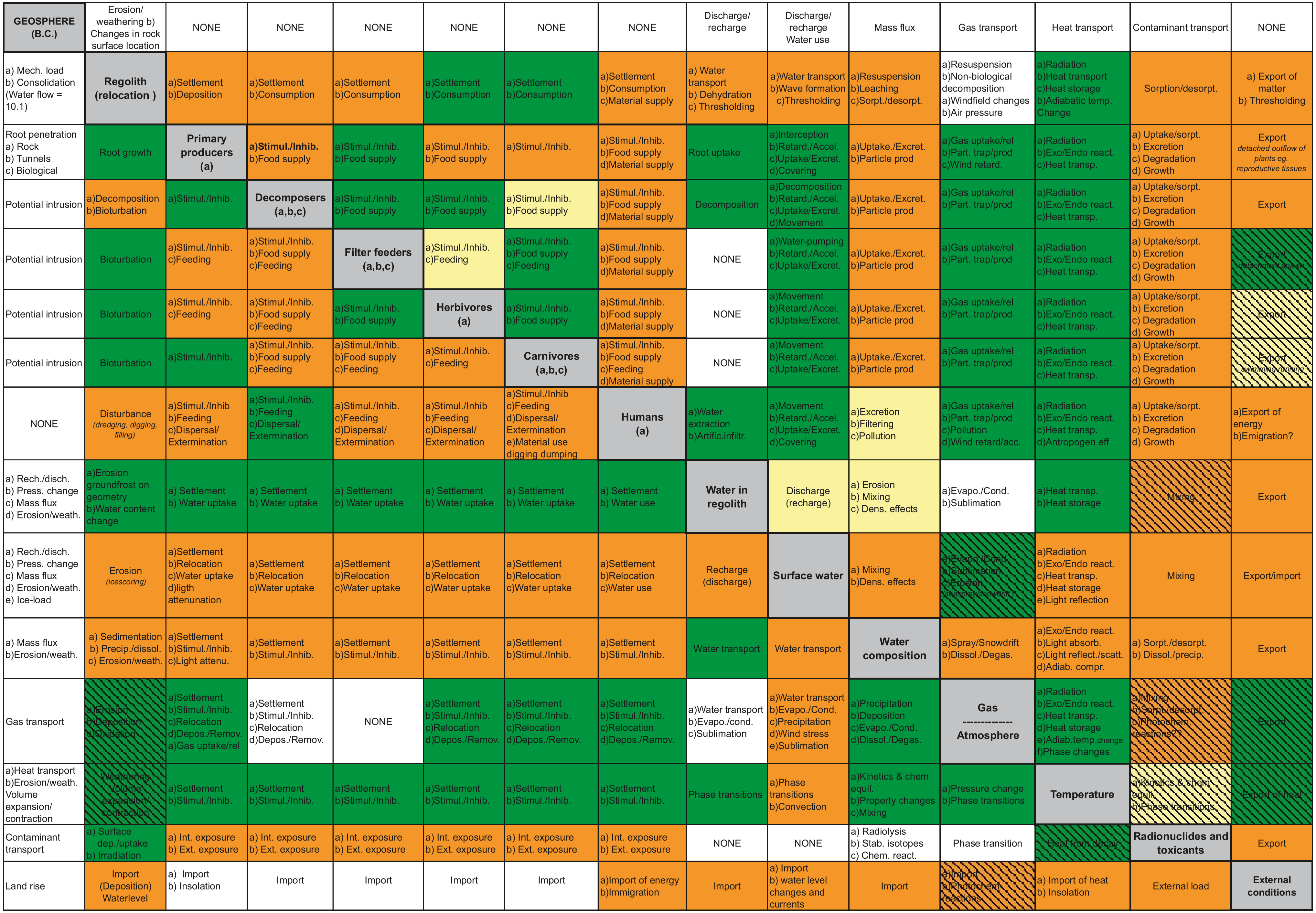
Important processes and processes of indefinable influence (rank 3-2)

Decay, Formation of stabile isotopes. The decay of radionuclides to stable isotopes affects the water composition in the different component of the biosphere (surface water, groundwater, water in regolith). The decay is not considered in this version of the report.

External exposure. Concentration, location and type of radionuclides in surface waters, Quaternary deposits and in the atmosphere, i.e. in all parts of the biosphere system, affect the external exposure and the radiologic and toxic effects on humans as well as on flora and fauna. In most cases it is not possible to study the actual radionuclides themselves, so the distribution pattern of naturally occurring radionuclides and their stable isotopes has often been used to study long-term behaviour of the radionuclides that may originate from nuclear waste. The concentrations of radionuclides and stable isotopes in the water, quaternary deposits and biota are considered in the mass balances (Chapter 7).

Internal exposure: Concentration, location and type of radionuclides and other toxicants incorporated into organisms will affect the exposure and the radiologic and toxic effects on the organism. This is considered as concentrations of radionuclides and stable isotopes in biota (Chapter 7).

Figure 9-2. *Interaction matrix with ecosystem component on the diagonal axis. Processes are coloured as; red = important processes, yellow = indefinable importance, green = insignificant processes and white = irrelevant processes in aquatic environment. Hatched cells indicate processes that have not been considered in this resport. Note that no effort has been made to evaluate whether processes coloured white are considered in the report as these processes are considered irrelelvant for the Safety assessment.*



GEOSPHERE (B.C.)	Erosion/ weathering b) Changes in rock surface location	NONE	NONE	NONE	NONE	NONE	NONE	Discharge/ recharge	Discharge/ recharge Water use	Mass flux	Gas transport	Heat transport	Contaminant transport	NONE
a) Mech. load b) Consolidation (Water flow = 10.1)	**Regolith (relocation)**	a)Settlement b)Deposition	a)Settlement b)Consumption	a)Settlement b)Consumption	a)Settlement b)Consumption	a)Settlement b)Consumption	a)Settlement b)Consumption c)Material supply	a) Water transport b) Dehydration c) Thresholding	a)Water transport b)Wave formation c)Thresholding	a)Resuspension b)Leaching c)Sorpt./desorpt.	a)Resuspension b)Non-biological decomposition a)Windfield changes b)Air pressure	a)Radiation b)Heat transport c)Heat storage b)Adiabatic temp. Change	Sorption/desorpt.	a) Export of matter b) Thresholding
Root penetration a) Rock b) Tunnels c) Biological	Root growth	**Primary producers (a)**	**a)Stimul./Inhib.** b)Food supply	a)Stimul./Inhib. b)Food supply	a)Stimul./Inhib. b)Food supply	a)Stimul./Inhib.	a)Stimul./Inhib. b)Food supply d)Material supply	Root uptake	a)Interception b)Retard./Accel. c)Uptake/Excret. d)Covering	a)Uptake./Excret. b)Particle prod	a)Gas uptake/rel b)Part. trap/prod c)Wind retard.	a)Radiation b)Exo/Endo react. c)Heat transp.	a) Uptake/sorpt. b) Excretion c) Degradation d) Growth	Export *detached outflow of plants eg. reproductive tissues*
Potential intrusion	a)Decomposition b)Bioturbation	a)Stimul./Inhib.	**Decomposers (a,b,c)**	a)Stimul./Inhib. b)Food supply	a)Stimul./Inhib. b)Food supply	a)Stimul./Inhib. b)Food supply	a)Stimul./Inhib. b)Food supply d)Material supply	Decomposition	a)Decomposition b)Retard./Accel. c)Uptake/Excret. d)Movement	a)Uptake./Excret. b)Particle prod	a)Gas uptake/rel b)Part. trap/prod	a)Radiation b)Exo/Endo react. c)Heat transp.	a) Uptake/sorpt. b) Excretion c) Degradation d) Growth	Export
Potential intrusion	Bioturbation	a)Stimul./Inhib. c)Feeding	a)Stimul./Inhib. b)Food supply c)Feeding	**Filter feeders (a,b,c)**	a)Stimul./Inhib. c)Feeding	a)Stimul./Inhib. b)Food supply c)Feeding	a)Stimul./Inhib. b)Food supply d)Material supply	NONE	a)Water-pumping b)Retard./Accel. c)Uptake/Excret.	a)Uptake./Excret. b)Particle prod	a)Gas uptake/rel b)Part. trap/prod	a)Radiation b)Exo/Endo react. c)Heat transp.	a) Uptake/sorpt. b) Excretion c) Degradation d) Growth	Export *detachment spawn*
Potential intrusion	Bioturbation	a)Stimul./Inhib. c)Feeding	a)Stimul./Inhib. b)Food supply c)Feeding	a)Stimul./Inhib. b)Food supply	**Herbivores (a)**	a)Stimul./Inhib. b)Food supply	a)Stimul./Inhib. b)Food supply d)Material supply	NONE	a)Movement b)Retard./Accel. c)Uptake/Excret.	a)Uptake./Excret. b)Particle prod	a)Gas uptake/rel b)Part. trap/prod	a)Radiation b)Exo/Endo react. c)Heat transp.	a) Uptake/sorpt. b) Excretion c) Degradation d) Growth	Export
Potential intrusion	Bioturbation	a)Stimul./Inhib.	a)Stimul./Inhib. b)Food supply c)Feeding	a)Stimul./Inhib. b)Food supply c)Feeding	a)Stimul./Inhib. c)Feeding	**Carnivores (a,b,c)**	a)Stimul./Inhib. b)Food supply c)Feeding d)Material supply	NONE	a)Movement b)Retard./Accel. c)Uptake/Excret.	a)Uptake./Excret. b)Particle prod	a)Gas uptake/rel b)Part. trap/prod	a)Radiation b)Exo/Endo react. c)Heat transp.	a) Uptake/sorpt. b) Excretion c) Degradation d) Growth	Export *swimming running*
NONE	Disturbance *(dredging, digging, filling)*	a)Stimul./Inhib b)Feeding c)Dispersal/ Extermination	a)Stimul./Inhib. b)Feeding c)Dispersal/ Extermination	a)Stimul./Inhib. c)Feeding d)Dispersal/ Extermination	a)Stimul./Inhib b)Feeding c)Dispersal/ Extermination	a)Stimul./Inhib c)Feeding d)Dispersal/ Extermination e)Material use digging dumping	**Humans (a)**	a)Water extraction b)Artific.infiltr.	a)Movement b)Retard./Accel. c)Uptake/Excret. d)Covering	a)Excretion b)Filtering c)Pollution	a)Gas uptake/rel b)Part. trap/prod c)Pollution d)Wind retard/acc.	a)Radiation b)Exo/Endo react. c)Heat transp. d)Antropogen eff	a) Uptake/sorpt. b) Excretion c) Degradation d) Growth	a)Export of energy b)Emigration?
a) Rech./disch. b) Press. change c) Mass flux d) Erosion/weath.	a)Erosion groundfrost on geometry b)Water content change	a) Settlement b) Water uptake	a) Settlement b) Water uptake	a) Settlement b) Water uptake	a) Settlement b) Water uptake	a) Settlement b) Water uptake	a) Settlement b) Water use	**Water in regolith**	Discharge (recharge)	a) Erosion b) Mixing c) Dens. effects	a)Evapo./Cond. b)Sublimation	a)Heat transp. b)Heat storage	Mixing	Export
a) Rech./disch. b) Press. change c) Mass flux d) Erosion/weath. e) Ice-load	Erosion *(icescoring)*	a)Settlement b)Relocation c)Water uptake d)ligth attenuation	a)Settlement b)Relocation c)Water uptake	a)Settlement b)Relocation c)Water uptake	a)Settlement b)Relocation c)Water uptake	a)Settlement b)Relocation c)Water uptake	a)Settlement b)Relocation c)Water use	Recharge (discharge)	**Surface water**	a) Mixing b)Dens. effects	a)Evapo./Cond b)Sublimation c)Erosion *(seaspray/snowdrift.)*	a)Radiation b)Exo/Endo react. c)Heat transp. d)Heat storage e)Light reflection	Mixing	Export/import
a) Mass flux b)Erosion/weath.	a) Sedimentation b) Precip./dissol. c) Erosion/weath.	a)Settlement b)Stimul./Inhib. c)Light attenu.	a)Settlement b)Stimul./Inhib.	a)Settlement b)Stimul./Inhib.	a)Settlement b)Stimul./Inhib.	a)Settlement b)Stimul./Inhib.	a)Settlement b)Stimul./Inhib.	Water transport	Water transport	**Water composition**	a)Spray/Snowdrift b)Dissol./Degas.	a)Exo/Endo react. b)Light absorb. c)Light reflect./scatt. d)Adiab. compr.	a) Sorpt./desorpt. b) Dissol./precip.	Export
Gas transport	a)Erosion b)Deposition c)Oxidation	a)Settlement b)Stimul./Inhib. c)Relocation d)Depos./Remov. a)Gas uptake/rel	a)Settlement b)Stimul./Inhib. c)Relocation d)Depos./Remov.	NONE	a)Settlement b)Stimul./Inhib. c)Relocation d)Depos./Remov.	a)Settlement b)Stimul./Inhib. c)Relocation d)Depos./Remov.	a)Settlement b)Stimul./Inhib. c)Relocation d)Depos./Remov.	a)Water transport b)Evapo./cond. c)Sublimation	a)Water transport b)Evapo./Cond. c)Precipitation d)Wind stress e)Sublimation	a)Precipitation b)Deposition c)Evapo./Cond. d)Dissol./Degas.	**Gas -------------- Atmosphere**	a)Radiation b)Exo/Endo react. c)Heat transp. d)Heat storage e)Adiab.temp.change f)Phase changes	a)Mixing b)Sorpt./desorpt. c)Photochem. reactions??	Export
a)Heat transport b)Erosion/weath. Volume expansion/ contraction	Weathering Volume expansion/ contraction	a)Settlement b)Stimul./Inhib.	a)Settlement b)Stimul./Inhib.	a)Settlement b)Stimul./Inhib.	a)Settlement b)Stimul./Inhib.	a)Settlement b)Stimul./Inhib.	a)Settlement b)Stimul./Inhib.	Phase transitions	a)Phase transitions b)Convection	a)Kinetics & chem equil. b)Property changes c)Mixing	a)Pressure change b)Phase transitions	**Temperature**	a)Kinetics & chem equil. b)Phase transitions	Export of heat
Contaminant transport	a) Surface dep./uptake b) Irradiation	a) Int. exposure b) Ext. exposure	a) Int. exposure b) Ext. exposure	a) Int. exposure b) Ext. exposure	a) Int. exposure b) Ext. exposure	a) Int. exposure b) Ext. exposure	a) Int. exposure b) Ext. exposure	NONE	NONE	a) Radiolysis b) Stab. isotopes c) Chem. react.	Phase transition	Heat from decay	**Radionuclides and toxicants**	Export
Land rise	Import (Deposition) Waterlevel	a) Import b) Insolation	Import	Import	Import	Import	a)Import of energy b)Immigration	Import	a) Import b) water level changes and currents	Import	a)Import b)Photochem-reactions	a) Import of heat b) Insolation	External load	**External conditions**

Insignificant and irrelevant processes (rank 0-1)

Irradiation, Radiolysis. Irradiation of the materials in Quaternary deposits by radionuclides may affect the mineralogic structure of the materials in Quaternary deposits. Radiolysis is radiation from decaying radionuclides causing radiolytic decomposition of the water, which thereby affect the water composition in the different components of the biosphere system. Both irradiation and radiolysis are considered to be of minor importance for the lake ecosystem and are not treated in the report.

9.3.8 Thermal processes

Insignificant and irrelevant processes (rank 0-1)

Heat from decaying radionuclides, heat storage capacity in the quaternary deposits and **heat transport** in the biosphere are considered to be of minor importance for the lake ecosystem and are thus not treated in the report.

10 Concluding descriptions of the limnic ecosystems in Forsmark and Laxemar-Simpevarp and comparison between the two areas

This report has three primary aims: 1) to characterize and describe the limnic ecosystems today and in the past in the Forsmark and Laxemar-Simpevarp areas and compare these ecosystems with limnic ecosystems in other areas, 2) to evaluate and visualize major pools, fluxes and sinks of elements in the limnic ecosystems, and finally 3) to describe the human impact on the limnic ecosystems. Large quantities of data from site investigations and models have been presented in the previous chapters in order to thoroughly describe the limnic ecosystems, human impact, pools, fluxes and sinks of elements in the ecosystems. In this chapter, we summarize this knowledge in an attempt to address the special characteristics of the limnic ecosystems at each site and to identify differences between the sites. The focus is to produce a description of a typical lake in each of the two areas, including identification of the major pathways of carbon and other elements, thereby identify the functioning of the lakes at the two sites in the biogeochemical cycling of matter.

10.1 Characterization of the limnic ecosytems in Forsmark and Laxemar-Simpevarp

The lakes in the Forsmark and Laxemar-Simpevarp areas resemble each other in the sense that they are relatively small and shallow, but they also differ in a number of aspects. The lakes in the Forsmark area are clear-water lakes, strongly influenced by calcium-rich water and low phosphorus concentrations. These lakes are dominated by primary producers, especially benthic macroalgae and microphytobenthos. The lakes in Laxemar-Simpevarp, on the other hand, are strongly influenced by humic substances transported to the lake from the surrounding catchment. This leads to a brown water colour and a dominance of consumers, especially benthic bacteria.

10.1.1 Lake size and influence of the catchment

The lakes in both Forsmark and Laxemar-Simpevarp can be considered small, but the lakes in Laxemar-Simpevarp are somewhat larger than the lakes in Forsmark (Table 10-1). The mean lake area is similar in the two areas, while the mean depth of the Forsmark lakes is considerably shallower than the mean depth of the Laxemar-Simpevarp lakes, leading to smaller lake volumes in Forsmark.

The catchments in both Forsmark and Laxemar-Simpevarp are dominated by forest, but the influence of wetlands is higher in the Forsmark area. Lakes in the Laxemar-Simpevarp area are strongly influenced by humic substances produced in the terrestrial parts of the catchment, leading to brown-water systems. The Forsmark lakes are, on the other hand, strongly influenced by the calcareous soils transported into the area during the last glaciation.

Catchment size influences the water retention time in lakes, and retention time is generally longer in the Laxemar-Simpevarp lakes than in the Forsmark lakes. A long retention time increases the chance that elements entering the lake will be incorporated into the food web. However, there is a wide range in retention times for the Forsmark lakes, which makes it difficult to draw any general conclusions for the area concerning the influence of lake retention time.

Table 10-1. Median and mean values for morphometry parameters in lakes in the Forsmark and Laxemar-Simpevarp areas. Data for Forsmark is based on 25 lakes (Table 3-8) and data for Laxemar-Simpevarp is based on 5 lakes (Table 4-6).

Parameter	Median lake		Mean lake		Range	
	Forsmark	Laxemar-Simpevarp	Forsmark	Laxemar-Simpevarp	Forsmark	Laxemar-Simpevarp
Area (km^2)	0.05	0.10	0.12	0.11	0.01–0.75	0.03–0.24
Max depth (m)	1.0	4.9	1.2	5.6	0.4–2.2	2.0–10.9
Mean depth (m)	0.3	2.0	0.4	2.4	0.1–0.9	1.1–3.7
Volume (Mm^3)	0.01	0.199	0.053	0.290	0.002–0.374	0.029–0.877
Retention time (days)	44	275	76	397	5–328	218–829

10.1.2 Water chemistry

Lakes in Forsmark and Laxemar-Simpevarp differ considerably in their chemical characteristics (Table 10-2). The water chemistry of the lakes in Forsmark is very uncommon compared with lakes in the rest of Sweden, while the water chemistry in the Laxemar-Simpevarp lakes is typical of boreal forest lakes. The water chemistry in the streams at both sites resembles the water chemistry in the lakes and, accordingly, the stream water chemistry differs between the two sites.

The water chemistry of the Forsmark lakes is strongly influenced by the calcareous soils, leading to high pH and high conductivity. The ions are strongly dominated by calcium and carbonate (HCO_3). The high calcium concentration leads to precipitation of $CaCO_3$ and co-precipitation of phosphorus. This, in turn, leads to low phosphorus concentration in the lakes. The concentration of nitrogen and dissolved organic carbon (DOC) is high, even higher than in the brown-water lakes in Laxemar-Simpevarp. The high DOC concentration in combination with the moderate water colour in the Forsmark lakes is especially unusual, and is an indication that much of the DOC is produced within the lakes.

The Laxemar-Simpevarp lakes also have relatively high pH values, and, although lower than in the Forsmark lakes, the pH values in the Laxemar-Simpevarp lakes are somewhat higher than the mean regional pH value for Kalmar County /Wilander et al. 2003/. Cations in the Laxemar-Simpevarp lakes are dominated by sodium followed by calcium, while anions are dominated by carbonate and chlorine. Concentrations of nitrogen and DOC are high. The lakes are brown-water systems influenced by humic substances, which explains the high DOC concentrations. The rich occurrence of humic substances also leads to high concentrations of iron and manganese, and, accordingly, these elements are more abundant in the Laxemar-Simpevarp lakes than in the Forsmark lakes.

Lakes in both the Forsmark and Laxemar-Simpevarp areas develop low oxygen concentrations in the bottom water during stagnant conditions, i.e. winter in the Forsmark lakes and winter and summer in Frisksjön in Laxemar-Simpevarp.

10.1.3 Biota

The composition of the biota in lakes differs considerably between the two areas, as the lakes in Forsmark are strongly dominated by primary producers, whereas Frisksjön in Laxemar-Simpevarp is strongly dominated by consumers (Table 10-3). The microbiota in the Forsmark lakes is, although common in the coastal areas in Upland, unique for the rest of Sweden and worldwide, whereas the lake biota in the Laxemar-Simpevarp area is typical of boreal forest lakes in Sweden.

Table 10-2. Water chemistry for the average Forsmark and Laxemar-Simpevarp lakes. Data from Table 3-16 and 4-16 (originally from /Tröjbom and Söderbäck 2006ab/).

	Mean	Mean	Range	
	Forsmark	Laxemar-Simpevarp	Forsmark	Laxemar-Simpevarp
Element				
pH (unit)	7.94	7.01	6.31–9.52	6.22–8.01
Conductivity (mS m^{-1})	45	13	17–450	9.4–18
Tot-P (mg/l)	0.012	0.019	0.0044–0.039	0.0054–0.043
Tot-N (mg/l)	1.1	0.92	0.33–3.7	0.52–1.3
TOC (mg/l)	17	15	5.5–35	8.6–25
Fe (mg/l)	0.094	0.86	0.0069–0.67	0.031–2.0
Mn (mg/l)	0.034	0.051	<0.003–0.64	<0.003–0.22
Cations				
Ca (mg/l)	49	8.8	13–130	6.3–13
Mg (mg/l)	5.4	2.6	0.70–26	1.9–4.3
Na (mg/l)	23	10	1.4–210	2.7–17
K (mg/l)	2.8	1.7	0.73–9.6	0.86–2.9
Anions				
Cl (mg/l)	38	14	0.90–430	7.6–24
HCO_3 (mg/l)	160	18	46–370	11–48
F (mg/l)	0.27	0.69	<0.2–3.1	<0.2–1.5
Br (mg/l)	<0.2	<0.2	<0.2–12	<0.2–0.50
I (mg/l)	0.0073	0.019	<0.001–0.026	0.0040–0.033

The biota in the Forsmark lakes is strongly dominated by the macroalgae *Chara sp.* and in many lakes the benthic habitat is also covered by a thick microbial mat consisting of microphytobenthos and benthic bacteria. A large biomass of *Chara sp.* is found also in other hardwater lakes, both in Sweden and worldwide, and the *Chara* biomasses in the Forsmark lakes are within the values reported in the literature /e.g. Pereyra-Ramos 1981, Blindow 1992, Kufel and Kufel 2002/. The thickness of the microbial mat in the Forsmark lakes, reaching several centimetres up to decimetres, is on the other hand unique, as most investigations of microbial mats in other lakes show values of a few mm /e.g. Hargrave 1969, Wiltshire 2000/. The biomass of the biota in the Forsmark lakes is strongly concentrated in the benthic habitat, and the biomasses of plankton (phytoplankton, zooplankton, bacterioplankton) are low.

The biomass of biota in Laxemar-Simpevarp is also strongly concentrated in the benthic habitat and consists there mainly of benthic bacteria. The total biomass of benthic bacteria and benthic fauna is similar in the Laxemar-Simpevarp and Forsmark lakes, whereas the biomass of the pelagic biota is much larger in Laxemar-Simpevarp than in Forsmark. In both areas, the phytoplankton communities are to a large extent composed of mixotrophic species that are able to consume bacteria as an alternative energy source. This is often the case in brown-water lakes where light is a limiting factor, as well as in very nutrient-poor lakes where there is strong competition for nutrients between phytoplankton and bacteria. Thus, although the magnitude of the phytoplankton biomass differs between the Forsmark and Laxemar-Simpevarp lakes, different mechanisms lead to a similar composition of the phytoplankton community.

The fish biomass is larger in the Forsmark lakes than in the Laxemar-Simpevarp lakes, and there is also a difference in species composition. The Forsmark lakes are strongly influenced by the low oxygen concentrations during winter. As an effect of this, Crucian carp, a species resistant to low oxygen concentrations, is common in the Forsmark lakes but not in Laxemar-Simpevarp.

Table10-3. Biomasses of biota in habitats where they are present, i.e. in the case of phytoplankton bacterioplankton, zooplankton and fish in the pelagic habitat, and in the case of macroalgae and microphytobenthos in Littoral II and III and in the case of benthic bacteria in Littoral II, III, and profundal habitats. All data for Laxemar-Simpevarp are from Frisksjön. As regards Forsmark, all data except for benthic fauna and fish are from one lake (Eckarfjärden or Bolundsfjärden). Values for benthic fauna are means of data from two lakes (Fiskarfjärden and Bolundsfjärden), while values for fish are means of data from four lakes (Eckarfjärden, Bolundsfjärden, Fiskarfjärden and Gunnarsbo-Lillfjärden). Reed belts are treated as part of the terrestrial area in the site description and are thus not included in this compilaiton.

	Biomass		**Primary production**		**Respiration**	
	Forsmark	**Laxemar-Simpevarp**	**Forsmark**	**Laxemar-Simpevarp**	**Forsmark**	**Laxemar-Simpevarp**
Primary producers						
Phytoplankton (gC m^{-3})	0.04	0.28	15	20	8.4	14.5
Macroalgae (gC m^{-2})	22	–	87	–		–
Microphytobenthos (gC m^{-2})	3.8	–	56	–	–	–
Consumers						
Bacterioplankton (gC m^{-3})	0.054	0.026	–	–	39	16
Zooplankton (gC m^{-3})						
Ciliates	0.007	–	–	–	0.20	–
Heterotrophic flagellates	0.002	–	–	–	0.05	–
Metazooplankton	0.06	0.11	–	–	0.81	2.93
Fish (zooplanktivore) (gC m^{-2})	0.013	0.014		–	0.062	0.083
Fish (benthivore) (gC m^{-2})	0.84	0.29		–	5.1	1.7
Fish (carnivore) (gC m^{-2})	0.20	0.27		–	1.2	1.56
Benthic bacteria (gC m^{-2})	3.6	5.3	–	–	45	64
Benthic fauna (gC m^{-2})	0.43	0.39			2.4	2.2

The limnic fish community in Forsmark is also composed of species feeding on benthic fauna to a greater extent than in Laxemar-Simpevarp. This functional group is common in Laxemar-Simpevarp as well, but the fish community is also composed of piscivorous species to a high degree.

In both areas, reed belts surrounding the lakes are extensive and the biomasses of the reed belts are high. However, to ensure a similar treatment of all areas covered by reed in the site description, the entire reed belt has been regarded as wetland in this report and is further described in /Löfgren 2008/.

Primary production in Forsmark is concentrated in the benthic habitat, whereas phytoplankton dominates primary production in the Laxemar-Simpevarp. Due to the higher phytoplankton biomasses in Laxemar-Simpevarp, pelagic primary production is larger there than in Forsmark lakes. However, due to the high benthic primary production in the Forsmark lakes, primary production is considerably larger in these lakes.

In the Forsmark lakes containing a microbial mat, primary production is larger than respiration and the lakes have a positive net ecosystem production (NEP). Primary production and respiration are of equal size in the Forsmark lakes lacking a distinct microbial mat, and it is more uncertain whether the lakes have a positive or negative NEP. Mass balances for lakes in the Forsmark area indicate that the NEP depends on lake size rather than the occurrence of a microbial mat, and in the mass balances the smaller lakes have a negative NEP. In Frisksjön in Laxemar-Simpevarp, respiration is much larger than the primary production and the lake has a negative NEP. The question of positive or negative NEP is of importance for the functioning of the lake ecosystem. A positive NEP indicates that the lake is dependent on in-lake primary production and that there is a net inflow of inorganic carbon to the lakes. A negative NEP indicates that the lake is dependent on allochtonous organic carbon entering the lake ecosystem from the surrounding catchment and that there is a net outflux of inorganic carbon to the atmosphere.

10.2 Major pools, fluxes and sinks of elements in the lake ecosystems

10.2.1 Pools of elements

In both Frisksjön in Laxemar-Simpevarp and in the average Forsmark lake, the sediment contains by far the largest amount of matter in the lake ecosystem, comprising c. 99% of total weight of all elements. The elemental composition of the limnic system is similar in the two areas: aside from the components of water (hydrogen and oxygen), silicon is the most common element in the sediment (and thus also totally), followed by carbon. Due to a thicker sediment layer in Frisksjön, almost all elements are more abundant per unit area in the Frisksjön sediments than in the average Forsmark lake.

Lake water in Frisksjön contains more suspended matter, and the lake has a greater mean depth than the average Forsmark lake, which means that the particulate component of the water is much larger in Laxemar-Simpevarp than in Forsmark. The particulate components in the two areas reflect the special characteristics of the lakes. In Forsmark, carbon and nitrogen are the most abundant particulate elements, but calcium is also very abundant, illustrating the high concentration of calcium in the area. In Frisksjön, silicon is the dominant element. This is probably due to a diatom bloom during sampling and is most probably not representative of the entire year. Relatively high amounts of iron in the particulate component in Frisksjön, on the other hand, are probably representative of the entire year (iron concentrations are high in humic substances and large quantities of humic substances reach brown-water lakes such as Frisksjön).

The larger mean depth in Frisksjön than in the average Forsmark lake also leads to a larger dissolved compartments in Laxemar-Simpevarp than in Forsmark. Accordingly, the pool of elements dissolved in lake water is, for most elements, larger in Laxemar-Simpevarp than in Forsmark. Exceptions are the major ions Ca, Cl, K, Mg and Na, illustrating the high conductivity and high concentration of ions in the Forsmark lakes. This difference between Forsmark and Laxemar-Simpevarp is due mainly to two factors: 1) the calcareous soils in Forsmark, leading to high calcium levels, and 2) the younger age of the Forsmark lakes and thereby the stronger influence of marine ions.

The pool of elements in biota in both areas is dominated by carbon, but the second most common element differs between the two areas: calcium in Forsmark and nitrogen in Laxemar-Simpevarp. Calcium precipitates on the surface of the benthic macroalgae *Chara sp.*, which explains the very high content of this element in Forsmark. In Forsmark, all elements are strongly concentrated in the primary producers, while in Laxemar-Simpevarp most elements are found in consumers. Mercury, an element known for biomagnification, shows high concentration in fish in both areas. Other similarities between the areas are that rubidium and zinc are common in fish, and bromine is strongly concentrated in zooplankton.

Due to the very high biomass of benthic primary producers in Forsmark lakes, the biotic pool of elements is generally larger in Forsmark than in Laxemar-Simpevarp. There are some notable differences between functional groups in the two areas. The pool of elements in plankton is, for most elements, larger in Laxemar-Simpevarp than in Forsmark, due both to higher concentrations of most elements in the biota and to larger mean depth in Laxemar-Simpevarp. Fish in particular exhibit lower concentrations of most elements in Forsmark lakes than in the Laxemar-Simpevarp lakes. Many elements are below the detection limit in fish in Forsmark, while there are appreciable concentrations in fish in Laxemar-Simpevarp (cf. Appendix 10).

Elemental pools contained in benthic fauna differ between the two areas. Pools of lanthanides and non-metals in benthic fauna are of similar sizes in the two areas, while most metals and metalloids are more abundant in benthic fauna in Frisksjön than in the average Forsmark lake. The different patterns between different groups of elements indicate that there is a difference between the two areas in the benthic fauna communities that is not entirely explained by abundance, but that there is also some other functional difference between the benthic fauna communities.

10.2.2 Fluxes within the lake ecosystems

In both Forsmark and Laxemar-Simpevarp, the main pathway for food consumed by the top predator fish goes from benthic fauna via benthivorous fish to piscivorous fish. Thus, in both areas, the pelagic part of the food web plays a minor role in the processing and transfer of matter compared with the benthic part. However, there is a difference in the base of the food web between the two areas. In Forsmark, the benthic fauna derives most of its food from benthic primary producers, whereas in Frisksjön the benthic fauna feeds mainly on benthic bacteria.

In the Forsmark lakes, only a minor portion (7–10%) of the carbon incorporated into primary producers is directly consumed by organisms and transported upwards in the food chain. This indicates that any pollutant incorporated into primary producers would to a great extent circulate within the microbial food web. In Frisksjön, on the other hand, as much as 34% of the carbon incorporated into primary producers is consumed by higher organisms, mainly zooplankton. Thus, any pollutant incorporated into primary producers in Frisksjön has a high probability of being transported upwards in the food chain.

As the food web in both areas has its largest base in the benthic habitat (benthic primary producers and/or benthic bacteria), elements settling on the sediments have a relatively large chance of being re-incorporated into the food web.

10.2.3 Fluxes to and from the lake ecosystems

In both areas, inflow via water is the most important influx to the ecosystem for almost all elements. The relative importance of atmospheric deposition is a function of lake size and area of the catchment. Accordingly, in Forsmark, atmospheric deposition plays a more important role in the larger lakes than in the smaller ones. Nevertheless, the atmospheric deposition makes a small contribution to total influx in all Forsmark lakes as well as in Frisksjön in Laxemar-Simpevarp. In Laxemar-Simpevarp, the most important outflux from the lake ecosystem for most elements, and particularly for the lanthanides, is via sediment accumulation. In the average Forsmark lake as well, the most important outflux for lanthanides is via sediment accumulation, but for metalloids, metals and non-metals, outflow via water is the largest outflux. In Forsmark there is a difference between smaller and larger lakes in that outflow via water dominates in the smaller lakes, whereas sediment accumulation dominates for many elements in the larger lakes. Moreover, the results from the relatively small Lake Puttan indicate that, in addition to lake size, position within the catchment also influences which outflux that is the most important. Puttan has a very small inflow and outflow of water and elements, which means that although sediment accumulation is low, the relative contribution of sediment accumulation to the total outflux is larger in Puttan than in other small lakes with larger inflows from the catchment.

Different sorption properties of elements may also influence the flow pattern. In both Forsmark and Laxemar-Simpevarp, this is clearly illustrated by the flows patterns of iodine, thorium and uranium. The inflow and outflow of the highly soluble iodine is totally dominated by in- and outflow via water. The largest outflux of thorium, which is almost immobile, is via sediment accumulation. The outflow of uranium, which has sorption properties between those of iodine and thorium, has a lower share of sediment accumulation than thorium but a higher share of sediment accumulation than iodine.

10.2.4 Sinks of elements

The ecosystem models indicate that in both Frisksjön and in larger lakes in Forsmark, the fluxes of carbon involved in the in-lake processes (primary production and respiration) are larger than the fluxes of carbon entering the lake from the catchment. This implies that there is a high probability that carbon entering the lake will be incorporated into the food web. Primary production dominates the in-lake processes in Forsmark, while bacterial processing of organic carbon dominates in Laxemar-Simpevarp. In Laxemar-Simpevarp, carbon consumption by bacteria is larger than inflowing organic carbon, which means that the models are not balanced. However, although the absolute numbers may be incorrect, the models strongly indicate that the in-lake processes are of great importance in the Laxemar-Simpevarp area. Moreover, sediment accumulation is the dominant outflux for many elements in both the larger lakes in Forsmark and in Frisksjön. The lakes in both areas are thus important sites of biogeochemical processing and may act as sinks of elements in the landscape. Some of the smaller lakes in Forsmark differ from both Frisksjön and the larger lakes in Forsmark in the sense that in-lake processes are small compared to the influx of carbon from the surroundings. For many of the smaller lakes, outflux of carbon is totally dominated by outflow via water, and these lakes probably do not functions as sinks of elements, but rather as flow-through systems. However, some of the smaller lakes, e.g. Puttan, also exhibit relatively high sediment accumulation compared with outflow. Thus, elements may be permanently bound in the sediments in the smaller lakes as well, but the amounts are most probably greater in the larger lakes.

10.3 Human impact on the limnic ecosystem

The limnic ecosystems in both Forsmark and Laxemar-Simpevarp are affected to a great degree by human activities. This is especially true for the streams at both sites, since only small portions flow in natural and unaffected channels. Most parts of the streams are highly affected by excavation and straightening, and these stretches can often be categorized as man-made ditches. Moreover, many of the lakes in the Laxemar-Simpevarp area are affected by lowering of the lake level for the purpose of creating new farmland. As an example, Frisksjön has been artificially lowered over the past few centuries by 1 m, or even more. The names of some wetlands and fields in the area indicate that a number of former lakes have disappeared. Lowering of lakes has been considerably less extensive in Forsmark; the only lake known to have been affected by lowering activities is Eckarfjärden.

A major human influence on lakes in Laxemar-Simpevarp is the construction of the Söråmagasinet reservoir. This reservoir was previously a sea bay, which was dammed during the 1970s to ensure a freshwater supply to the nuclear power plant. Occasional pumping of water from the stream Laxemarån to Söråmagasinet takes place a few days each year or every second year in order to maintain the water volume in Söråmagasinet. There are also other pumping activities that influence the limnic systems in the Laxemar-Simepvarp area: 1) since 1983, drinking and process water for the nuclear power plant (OKG) is pumped from Lake Götemar (situated north of the Laxemar subarea) in a pipeline to a water supply plant operated by OKG, 2) historically (up to 1987), water was pumped from Lake Trästen (situated west of the Laxemar subarea, upstream of Lake Fårbosjön) into Lake Jämsen, which discharges into the stream Laxemarån, in order to compensate for the pumping from Laxemarån. Historical and present-day pumping activities in the Laxemar-Simpevarp area are further described in /Werner et al. 2008b/.

The largest human impact on lakes in Forsmark is the construction of a road in Lake Gunnarsbo-Lillfjärden, which divides the lake into a northern and a southern basin. The basins are connected to each other and to the outlet by pipes, which probably restrict migration possibilities for aquatic animals between the Baltic Sea and the basins.

Another technical encroachment in streams, beside the examples of excavation and straightening mentioned above, is conducting stream water via pipes under roads, which may introduce barriers for migration of fish and other organisms between lakes. Man-made technical encroachments in streams at the two sites, such as installation of pipes (of the necessary diameter, length and height for water to descend to the substrate), construction of dams and filling of channels are described in detail in /Carlsson et al. 2005ab/.

Today, the areas have few inhabitants and the lakes and streams are most probably not used for fishing or bathing to any great extent. Moreover, farmland, which may affect lakes via high nutrient inputs, comprises a relatively small portion of the catchments. Accordingly, the influence of agricultural activities on the limnic ecosystems at the sites is limited.

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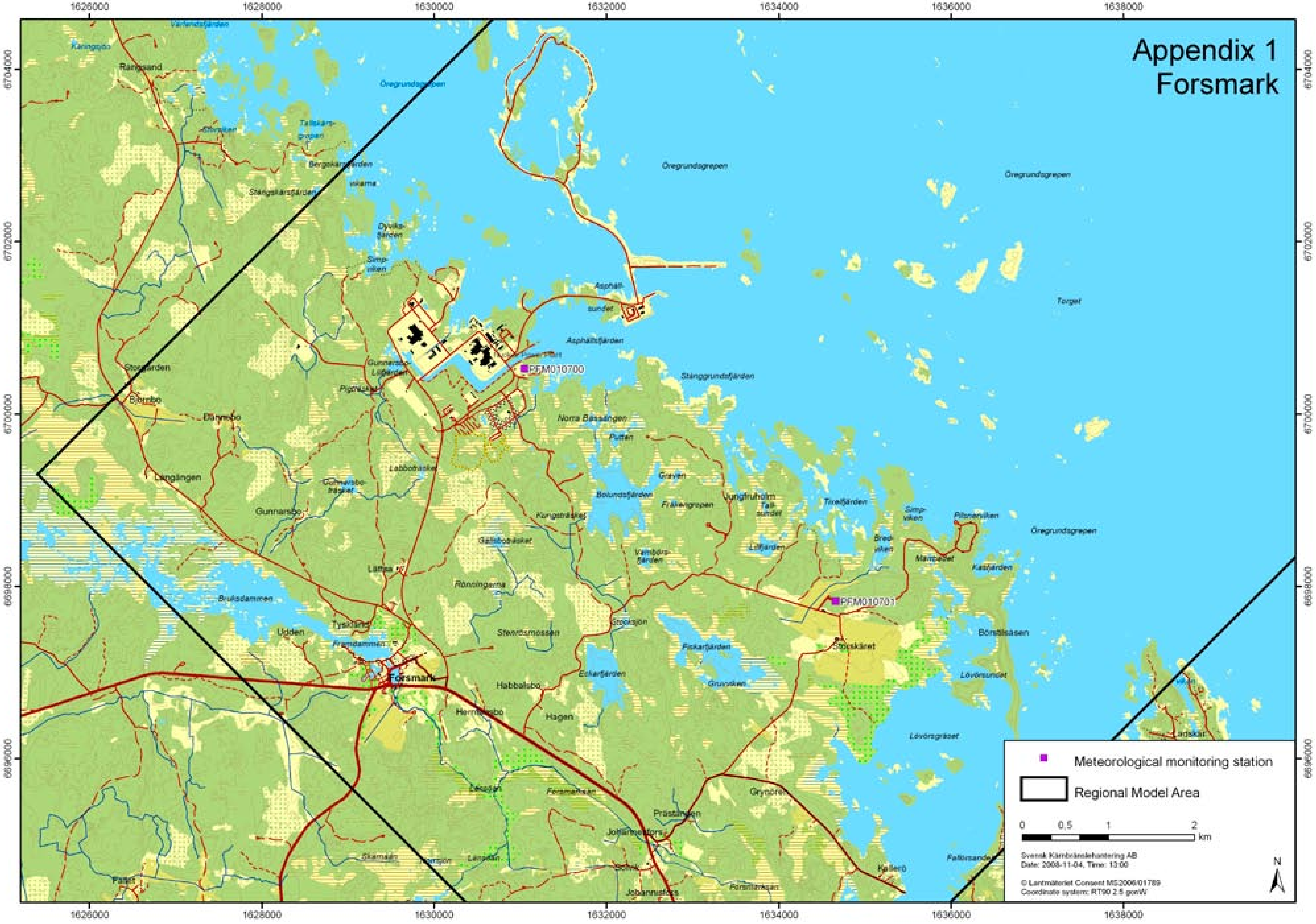
Appendix 1

Map Forsmark



Appendix 2

Map Laxemar-Simpevarp

Appendix 3

Input data table

In this table, SKB-reports used in the description and modelling of the lakes and streams are listed. In addition, site data from the database SICADA and limnic data in literature have been used in some of the models in Chapter 5 and 7. For these references, see method descriptions in the chapters.

Available data	Reference	Usage in the report	Section
Hydrology			
Discharge	P-07-135	Description	3.3
	P-07-172	Description	4.3
	R-06-49	Description	3.3
	R-08-08	Description	3.3
	R-07-55	Description and modelling	Chapter 7
	R-08-71	Description	4.3
Stream characteristics			
Flooded areas, bottom substrate, morphmetry	P-05-150	Description	3.3, 3.8
	P-04-141	Description	3.3, 3.8
	P-05-40	Description	4.8
	P-06-05	Description	4.3
Meteorologic data			
Global radiation	R-08-10	Description, modelling	3.4
	P-07-172	Description, modelling	4.4
Temperature	R-08-10	Description	3.4
	R-08-71	Description	4.4
	R-02-03	Description	4.4
Precipitation	R-08-10	Description and mass balance models	Chapter 3, 5, and 7
	R-08-73	Description and mass balance models	Chapter 4, 5 and 7
Snow and ice cover	P-03-117	Description, modelling	3.4, 4.4
	P-04-137	Description, modelling	3.4, 4.4
	P-05-134	Description, modelling	3.4, 4.4
	P-06-97	Description, modelling	3.4, 4.4
	P-07-81	Description, modelling	3.4, 4.4
Lake bathymetry and habitat distribution			
Habitat borders	P-04-25 and P-04-141	Description, Ecosystem models, mass balance models	3.5
	P-04-242	Description, Ecosystem models, mass balance models	4.5
Chemistry in water			
Water chemistry	R-05-41	Understanding, description and models	Chapter 3, 45, and 7
	R-06-19		
	R-06-18		
Chemistry in sediment			

Available data	Reference	Usage in the report	Section
Sediment stratigraphy	TR-03-17	Understanding, Description and modelling	3.6, Chapter 5 and 7
	P-04-86		
	R-01-12		
	P-03-24		
	R-08-04		
	R-08-05		
Sediment chemistry	P-04-17	Description and mass balance models	3.6, 4.6, Chapter 5 and 7
	P-04-05		
	P-04-273		
	P-06-220		
	R-06-96		
	P-06-301		
	P-06-320		
	p-07-196		
Marine sediments	P-06-301	Understanding	3.6 and 4.6
Primary producers in the Forsmark lakes			
Phytoplankton, Microphytobenthos	R-02-41	Description, modelling	3.10
	R-03-27	Description, modelling	3.10
	P-04-253	Description, modelling	4.10
Microphytobenthos	R-02-41	Description, modelling	3.10
	R-03-27	Description, modelling	3.10
	P-04-05	Description	3.10
Emergent macrophytes	R-03-27	Description, modelling	3.10
	P-06-232	Description, modelling	4.10
Submerged vegetation	P-05-136	Description	3.10
	P-06-221	Description, modelling	3.10
	P-05-173	Description, modelling	4.10
Consumers in the Forsmark lakes			
Bacteria	R-02-41	Description, modelling	3.10
	R-03-27	Description, modelling	3.10
	P-06-232	Description, modelling	4.10
	R-02-41	Description, modelling	3.10
	R-03-27	Description, modelling	3.10
Zooplankton	R-03-27	Description, modelling	3.10
	P-04-253	Description, modelling	4.10
Benthic fauna	P-05-136	Description, modelling	3.10
	R-03-27	Description	3.10
	P-04-252	Description, modelling	4.10
Fish	P-04-06	Description, modelling	3.10
	P-04-251	Description, modelling	4.10
Biota in streams			
Vegetation	P-05-40	Description	4.10
	P-05-150	Description	3.10
Fish migration	P-06-251	Description, understanding in modelling	4.10
Benthic fauna	P-04-252	Description	4.10
Chemical composition of biota	P-06-220	Description, modelling	Chapter 3, 4, 7
	P-06-320	Description, modelling	

Appendix 4

Species list

In the following table, species found in the site investigations in Forsmark (Fm) and Laxemar-Simpevarp (L-S) are listed. Data are gathered from SKB-reports (Appendix 3) and in some cases from the database SICADA (microphytobenthos and phytoplankton in Forsmark). For fish, species in the Forsmark region (section 3.12) are also listed.

Latin name	English namne	Swedish namne	Fm/L-S
Phytoplankton			
Bacillariophyceae	Diatoms	Kiselalger	
Aulacoseira alpigena-typ			L-S
Aulacoseira sp.			L-S
Centriska kiselalger			L-S
Cyclotella			Fm
Pennate diatoms			Fm
Rhizosolenia longiseta			L-S
Chlorophyceae	Green algae	Grönalger	
Botryococcus sp.			Fm
Crucigenia sp.			L-S
Elakotrix sp.			Fm
Elakatothrix genevensis			L-S
Monoraphidium sp.			Fm
Monoraphidium dybowskii			L-S
Monosigales			Fm
Nephrocytium			Fm
Oocystis			Fm, L-S
Pediastrum privum			L-S
Pediastrum tetras			L-S
Quadrigula sp.			L-S
Scenedesmus sp.			Fm, L-S
Scourfieldia			Fm
Tetraedon sp.			Fm
Tetraedron caudatum			L-S
Chrysophyceae	Golden algae	Guldalger	
Bikosoeca			Fm
Bitrichachodati			Fm
Bitrichia			Fm
Chrysochromulina			Fm
Chrysoikos skujai			Fm
Chrysomonadales			Fm
Dinobryon spp.			Fm
Dinobryon bavaricum			L-S
Dinobryon crenulatum			L-S
Dinobryon divergens			L-S
Kephyrion			Fm
Mallomonas akrokomos			L-S
Mallomonas tonsurata			L-S
Mallomonas caudate			L-S
Synura sp.			L-S
Uroglena sp.			L-S
Conjugatophyceae	”Jewelry algae”	Smyckesalger	
Closterium acutum var. variabile			L-S
Cryptophyceae	Cryptophytes	Rekylalger	
Chroomonas sp.			L-S
Cryptomonas spp.			Fm, L-S
Rhodomonas			Fm
Cyanophyceae	Cyanobacteria	Cyanobakterier, blågröna alger	
Anabaena			Fm
Anabaena lemmermannii			L-S
Aphanothece sp.			L-S
Chroococcus			Fm
Komvophoron			Fm
Merismopedia sp.			Fm

Latin name	English namne	Swedish namne	Fm/L-S
Merismopedia warmingiana			L-S
Microcystis aeruginosa			Fm
Oscillatoria			Fm
Dinophyceae	“Dinoflagellates”	Dinoflagellater/ Pansaralger	
Ceratium hirundinella			Fm, L-S
Gymnodinium			Fm
Peridinium sp.			Fm
Peridinium umbonatum			L-S
Peridinium willei			L-S
Woloszynskia			Fm
Euglenophyceae		Ögondjur	
Euglena			Fm
Trachelomonas sp.			L-S
Microphytobenthos			
Bacillariophyceae	Diatoms	Kiselalger	
Pennate diatoms			
Chlorophyceae	Green algae	Grönalger	
Botryococcus			Fm
Scenedesmus			Fm
Tetraedron			Fm
Cyanophyceae	Cyanobacteria	Cyanobakterier, blågröna alger	
Chrococcus			Fm
Komvophoron			Fm
Lyngbya			Fm
Merismopedia			Fm
Oscillatoria			Fm
Konjugatophyceae			
Staurastrum			Fm
Macrophytes-Macroalgae			
Alchemilla sp.	Lady’s mantle	Daggkåpa	Fm
Alisma plantago-aquatica	Water-plantain	Svalting	Fm, L-S
Aldus glutinosa	Alder	Klibbal	Fm, L-S
Batrachospermaceae	Red algae	Rödalger	Fm
Callitriche sp.	Water-starwort	Lånke	Fm, L-S
Cardamine pratensis	Cuckooflower	Kärrbräsma	Fm
Carex sp.	Sedge	Starr	Fm, L-S
Carex acuta	Slender tufted sedge	Vasstarr	Fm
C. elata	Tufted sedge	Bunkestarr	Fm
C. nigra	Common sedge	Hundstarr	L-S
C. rostrata	Bottle Sedge	Flaskstarr	Fm, L-S
C. vesicaria	Bladder-sedge	Blåsstarr	Fm, L-S
Chara spp.	Stoneworths	Kransalger	Fm
C. baltica	Baltic Stonewort	Grönsträfse	Fm
C. tomentosa	Coral stonewoth	Rödsträfse	Fm
C. intermedia.	Intermediate stonewort	Mellansträfse	Fm
C. virgata	Delicate stonewoth	Kransalg	Fm
Equisetum fluviatile	Water horsetail	Sjöfräken	Fm, L-S
Equisetum palustre	Marsh Horsetail	Kärrfräken	L-S
Eriophorum angustifolium	Common cottongrass	Ängsull	Fm
Filipendula ulmaria	Meadowsweet	Älggräs	Fm, L-S
Fontinalis sp.	Water moss	Näckmossa	Fm
F. antipyretica	Common water moss	Stor näckmossa	Fm, L-S
F. dalecarlica	Water moss	Smal näckmossa	Fm
Galium palustre	Marsh-bedstraw	Vattenmåra	Fm, L-S
Glyceria fluitans	Floating Sweetgrass	Mannagräs	Fm, L-S
G. maxima	Reed Sweetgrass	Jättegröe	Fm, L-S
Hippuris vulgaris	Mare´s-tail	Hästsvans	Fm
Hottonia palustris	Water-violet	Vattenblink	Fm, L-S
Hydrocharis morsus-ranae	Frogbit	Dyblad	Fm
Iris Pseudocouros	Yellow Iris	Svärdslilja	Fm, L-S
Juncus sp.	Rush	Tåg	Fm, L-S
Juncus bulbosus	Bulbous Rush	Löktåg	L-S
Juncus effusus	Soft-Rush	Veketåg	L-S
Lemna minor	Common Duckweed	Vanlig andmat	Fm, L-S
Lycopus europaeus	Gypsywort	Topplösa	Fm, L-S
Lysimachia thyrsiflora	Tufted Loosestrife	Strandklo	Fm, L-S

Latin name	English namne	Swedish namne	Fm/L-S
L. vulgaris	Yellow Loosestrife	Videört (strandlysing)	Fm, L-S
Lythrum salicaria	Purple-loosestrife	Fackelblomster	L-S
Mentha arvensis	Corn mint	Åkermynta	Fm, L-S
Menyanthes trifoliata	Bogbean	Vattenklöver	Fm, L-S
Myosotis laxa	Tufted Forget-me-not	Sumpförgätmigej	Fm, L-S
Myriophyllum alterniflorum	Alternate water-milfoil	Hårlsinga	L-S
M. spicatum	Spiked Water-milfoil	Axslinga	Fm, L-S
Najas marina	Spiny Naiad	Havsnajas	Fm
Nuphar lutea	Yellow Water-lily	Gul näckros	Fm
Nymphaeaceae	Water lily	Näckros	Fm, L-S
Nymphea alba	White Water-lily	Vit näckros	L-S
Oenanthe aquatica	Fine-leaved Water dropwort	Vattenstäkra	L-S
Peusedanum palustre	Milk-parsley	Kärrsilja	Fm
Phalaris arundinacea	Reed Canary-grass	Rörflen	Fm, L-S
Phragmites australis	Common reed	Vass	Fm, L-S
Potamogeton berchtoldii	Small Pondweed	Gropnate	L-S
P. filiformis	Slender-leaved Pondweed	Trådnate	Fm
P.natan	Floating-leaved Pondweed	Gäddnate	Fm, L-S
P.pectinatus	Sago Pondweed	Borstnate	Fm
P.polygonifilus	Bog Pondweed	Bäcknate	Fm, L-S
Potentilla palustris	Marsh Cinquefoil	Kråkklöver	L-S
Ranunculus flammula	Lesser Spearwort	Ältranunkel	L-S
Rumex hydrolapathum	Water Dock	Vattenskräppa	L-S
Salix sp.	Willow	Vide	L-S
Salix caprea	Goat Willow	Sälg	L-S
Schoenoplectus lacustris	Common club-rush	Säv	Fm, L-S
Sparganium sp.	Unbranched Bur-reed	Igelknopp	L-S
S. angustifolium Michx.	Floating Bur-reed	Plattbladig igelknopp	L-S
S.emersum	Unbranched Bur-reed	Vanlig igelknopp	Fm
Typha sp.	Bulrush	Kaveldun	L-S
T. latifolia	Bulrush	Bredkaveldun	L-S
Utricularia sp.	Bladderwort	Bläddra	L-S
Purple Sulphur bacteria			
Zooplankton			
Heterotrophic flagellates			
Chrysophycae	Golden algae	Guldalger	
Monosigales			Fm
Cryptophycae			
Kateblepharis			Fm
Ciliphora	Ciliates	Ciliater	Fm
Metazooplankton			
Cladocera	Water fleas	Hinnkräftor	
Acroperus			Fm
Alonella nana			L-S
Bosmina sp			Fm
Bosmina longispina			L-S
Ceriodapnia sp.			Fm , L-S
Chydorus			Fm
Daphnia			Fm
Daphnia cucullata			L-S
Diaphanosoma sp.			Fm
Diaphanosoma brachyurum			L-S
Leptodora kindti			L-S
Copepoda	Copepods	Hoppkräftor	
Cyclopoida			Fm
Calanoida			Fm, L-S
Eudiaptomus			L-S
Mesocyclops			L-S
Thermocyclops sp			L-S
Rotifera	Rotifers	Hjuldjur	
Ascomorpha			Fm
Asplanchna sp.			Fm L-S
Collotheca			Fm
Conochilus sp.			Fm, L-S
Euchlanis			Fm

Latin name	English namne	Swedish namne	Fm/L-S
Kellicottia longispina			Fm, L-S
Keratella cochlearis			Fm, L-S
Keratella quadrata			L-S
Lecane			Fm
Ploesoma			Fm
Polyarthra			Fm
Pompholyx sp			Fm, L-S
Synchaeta sp.			Fm , L-S
Trichocerca sp.			Fm, L-S
Trichotria			Fm
Benthic fauna			
Hydrozoa		Hydror	
Hydridae			Fm
Nematoda			
Nematoda			Fm, L-S
Hirudinea	Leeches	Iglar	
Erpobdella octoculata			Fm, L-S
Erpobdella sp.			Fm, L-S
Glossosiphonia heteroclita			Fm
Glossosiphonia sp.			L-S
Helobdella stagnalis			Fm
Piscicola geometra			Fm
Turbellaria	Flatworms	Virvelmaskar	
Dendrocoelum lacteum			L-S
Planaridae			L-S
Polycelis sp.			L-S
Oligochaeta	Earthworms	Fåborstmaskar	
Limnodrilus sp.			L-S
Naididae			Fm
Oligochaeta sp.			L-S
Potamotrix hammoniensis			L-S
Ripistes parasita			L-S
Stylaria lacustris			Fm
Tubifex tubifex			L-S
Tubificidae			L-S
Isopoda	Water slater	Gråsuggor	
Asellus aquaticus			Fm, L-S
Hydrocarina	Water mites	Sötvattenskvalster	
Hydracarina sp.			Fm, L-S
Aranea	Water spiders	Spindlar	
Argyroneta aquatica			L-S
Odonata	Damselflies and dragonflies	Trollsländor	
Aeshnidae			Fm
Aeshna grandis			L-S
Anisoptera			L-S
Coenagrionidae			Fm, L-S
Coenagrion sp.			L-S
Cordulidae			L-S
Cordulia aenae			Fm, L-S
Erythromma najas			L-S
Libellulidae			Fm
Platycnemidae			Fm
Platycnemis pennipes			Fm, L-S
Somatochlora metallica			L-S
Zygoptera			L-S
Ephemeroptera	Mayflies	Dagsländor	
Caenis horaria			Fm, L-S
Caenis lactea			Fm
Caenis robusta			Fm
Caenis sp.			Fm
Centroptilum luteolum			L-S
Cloeon sp.			Fm, L-S
Heptagenia fuscogrisea			L-S
Leptophlebia marginata			L-S
Leptophlebia vespertina			L-S

Latin name	English namne	Swedish namne	Fm/L-S
Leptophlebia sp.			L-S
Leptophlebia sp.			L-S
Plecoptera	Stoneflies	Bäcksländor	
Amphinemura sulcicollis			L-S
Amphinemura sp.			L-S
Nemoura cinerea			L-S
Nemoura sp.			L-S
Megaloptera	Alderflies, Dobsonflies and Fishflies	Sävsländor	
Sialis lutaria			Fm, L-S
Sialis sp.			L-S
Trichoptera	Caddisflies	Nattsländor	
Anabolia sp.			L-S
Athripsoides sp.			Fm
Cyrnus flavidus			L-S
Cyrnus sp.			Fm, L-S
Ecnomus tenellus			L-S
Glyphotaelius pellucidus			L-S
Halesus			L-S
Trichoptera			
Holocentropus			Fm
Hydropsyche angustipennis			L-S
Leptoceridae			Fm
Limnephilidae			L-S
Limnephilus sp.			L-S
Lype phaeopa			L-S
Mystacides azurea			L-S
Mystacides longicornia			Fm
Mystacides sp.			Fm, L-S
Oecetis ochracea			L-S
Oecetis sp.			Fm
Oxyethira sp.			L-S
Phryganeidae			Fm
Phryganea bipunctata			L-S
Phryganea sp.			Fm
Polycentropodidae			L-S
Polycentropus flavomaculatus			L-S
Polycentropus irroratus			L-S
Potamophylax cingulatus			L-S
Trianodes sp.			L-S
Ylodes sp.			L-S
Lepidoptera	Butterflies	Fjärilar	Fm
Coleoptera	Beetles	Skalbaggar	
Donacia sp.			Fm
Dyticidae			Fm
Gyrinus sp.			L-S
Haliplus sp.			Fm
Oulimnius tuberculatus			L-S
Oulimnius sp.			L-S
Hemiptera	True bugs	Skinnbaggar	
Gerris lacustris			L-S
Nepa cinerea			L-S
Notonecta glauca			L-S
Sigara fossarum			L-S
Diptera	True flies	Tvåvingar	
Ceratopogonidae			Fm, L-S
Chaoborus flavicans			L-S
Chaoborus sp.			L-S
Chironomidae			Fm, L-S
Chironomus anthtracinus			Fm
Cladopelma sp.			L-S
Cladotanytarsus sp.			L-S
Culicidae			L-S
Ephydridae			Fm
Heterotanytarsus apicalis			L-S
Limoniidae			L-S
Orthocladinae			Fm

Latin name	English namne	Swedish namne	Fm/L-S
Muscidae			Fm
Parachironomus sp.			L-S
Parakiefferiella sp.			L-S
Pediciidae			L-S
Pentaneurini			L-S
Phaenopsectra sp.			L-S
Polypedilum sp.			L-S
Procladius sp.			L-S
Sergentia sp.			L-S
Simuliidae			L-S
Tanypodinae			Fm
Tanytarsinae			Fm
Tanytarsus sp.			L-S
Diptera			
Tipulidae			L-S
Gastropoda	Snails	Snäckor	
Acroloxus lacustris			L-S
Bithynia tentaculata			L-S
Gyraulus albus			Fm
Gyraulus sp.			L-S
Hippeutis complanatus			L-S
Lymnea stagnalis			Fm
Lymnea peregra			Fm
Lymnea spp			Fm
Marstoniopsis scholtzi			L-S
Planorbidae			Fm
Planorbis cavinatus			Fm
Physa fontinalis			Fm
Valvata cristata			Fm
Valvata sp.			Fm
Bivalvia	Bivalves	Musslor	
Anodonta anatina			L-S
Anodonta sp.			Fm
Pisidium sp.			Fm, L-S
Sphaerium spp			Fm
Copepoda	Copepods	Hoppkräftor	
Cyclopoida			
Cladocera	Water fleas	Hinnkräftor	
Chydoridae			Fm
Diaphansosoma brachyurum			Fm
Eurycercus lamellatus			Fm
Sida crystallina			Fm
Ophryoxus gracilis			Fm
Ostracoda	Seed shrimp	Musselkräftor	Fm
Crustacea			
Astacus astacus	Noble crayfish	Flodkräfta	L-S
Pacifastacus leniusculus	Signal crayfish	Signalkräfta	L-S
Fish			
Abramis brama	Bream	Braxen	Fm region, L-S
Alburnus alburnus	Bleak	Löja	L-S
Blicca bjoerkna	White bream	Björkna	Fm
Carassius carassius	Crucian carp	Ruda	Fm
Cottus gobio	Bullhead	Stensimpa	Fm region
Esox lucius	Pike	Gädda	Fm, L-S
Gymnocephalus cernua	Ruffe	Gärs	Fm, L-S
Lampetra planeri	European brook lamprey	Bäcknejonöga	Fm region
Leuciscus idus	Ide	Id	Fm region, L-S
Lota lota	Burbot	Lake	Fm region
Perca fluviatilis	Perch	Aborre	Fm, L-S
Rutilus rutilus	Roach	Mört	Fm, L-S
Salmo trutta	Brown trout	Öring	Fm region
Scardinius erythrophthalmus	Rudd	Sarv	Fm, L-S
Tinca tinca	Tench	Sutare	Fm
Vimba vimba	Wimba	Vimma	Fm region

Fish histograms

This appendix contains histograms showing length or weight distribution data for each species in the 8 lakes which has been fished during the site investigations /Borgiel 2004b, Engdahl and Ericson 2004/. Data is presented for Bolundsfjärden, Eckarfjärden, Fiskarfjärden and Gunnarsbo-Lillfjärden in the Forsmark area, and for Frisksjön, Söråmagasinet, Plittorpsgöl and Jämsen in the Laxemar-Simpevarp area.

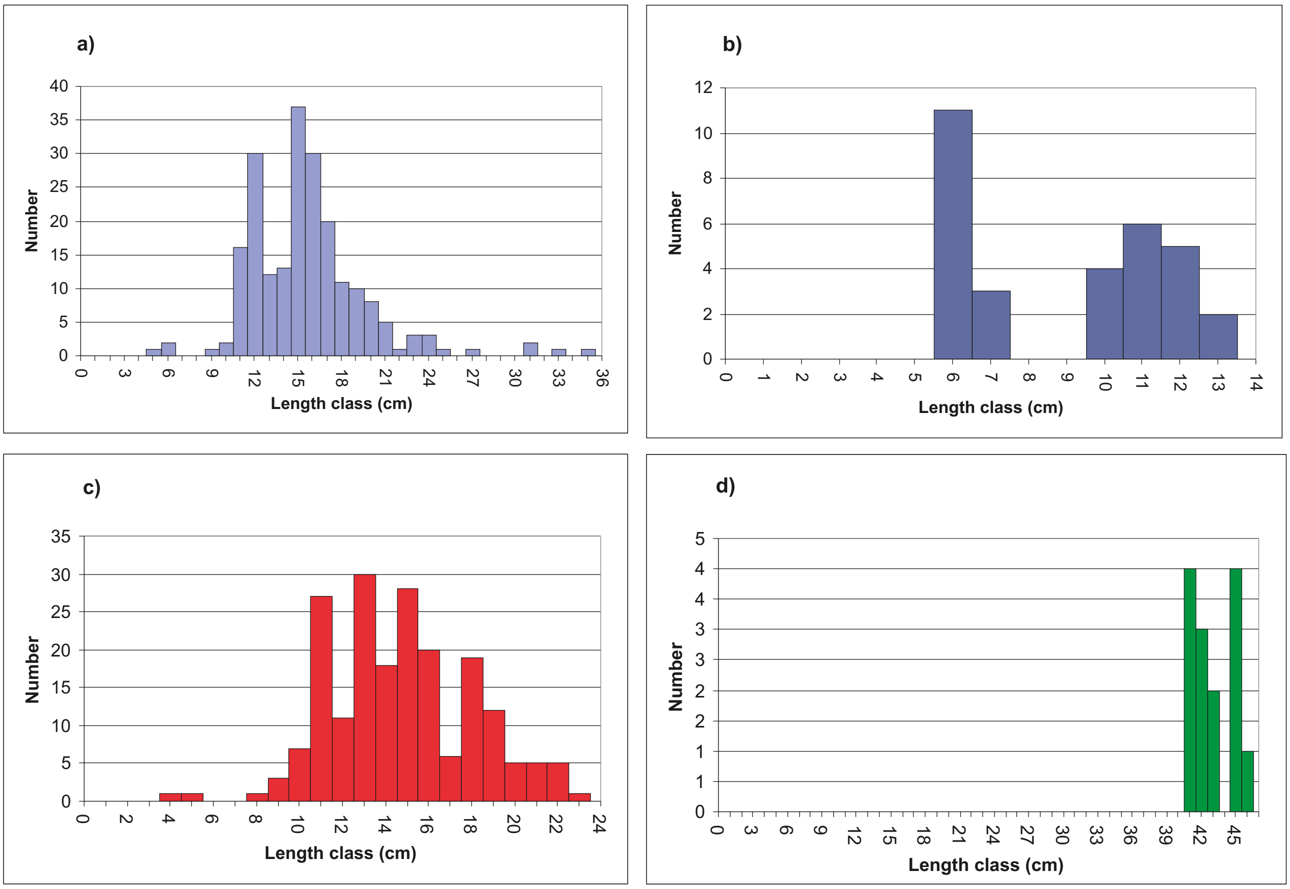


***Figure A5-1.** Length frequency distribution for the most common species in Bolundsfjärden a) perch, b) ruffe, c) roach and d) tench. Species with too few replicates (not shown) were white bream (n=1), pike (n=3), crucian carp (n=4) and rudd (n=4).*

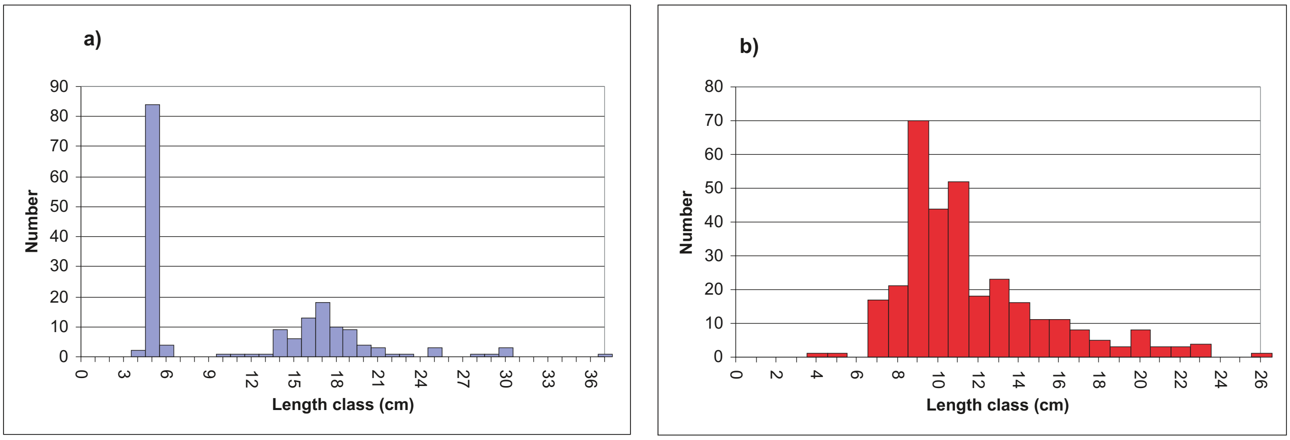


Figure A5-2. Length frequency distribution for the most common species in Eckarfjärden, a) perch and b) roach. Species with too few replicates (not shown) were pike (n=2), ruffe (n=1) and tench (n=5) /data from Borgiel 2004b/.

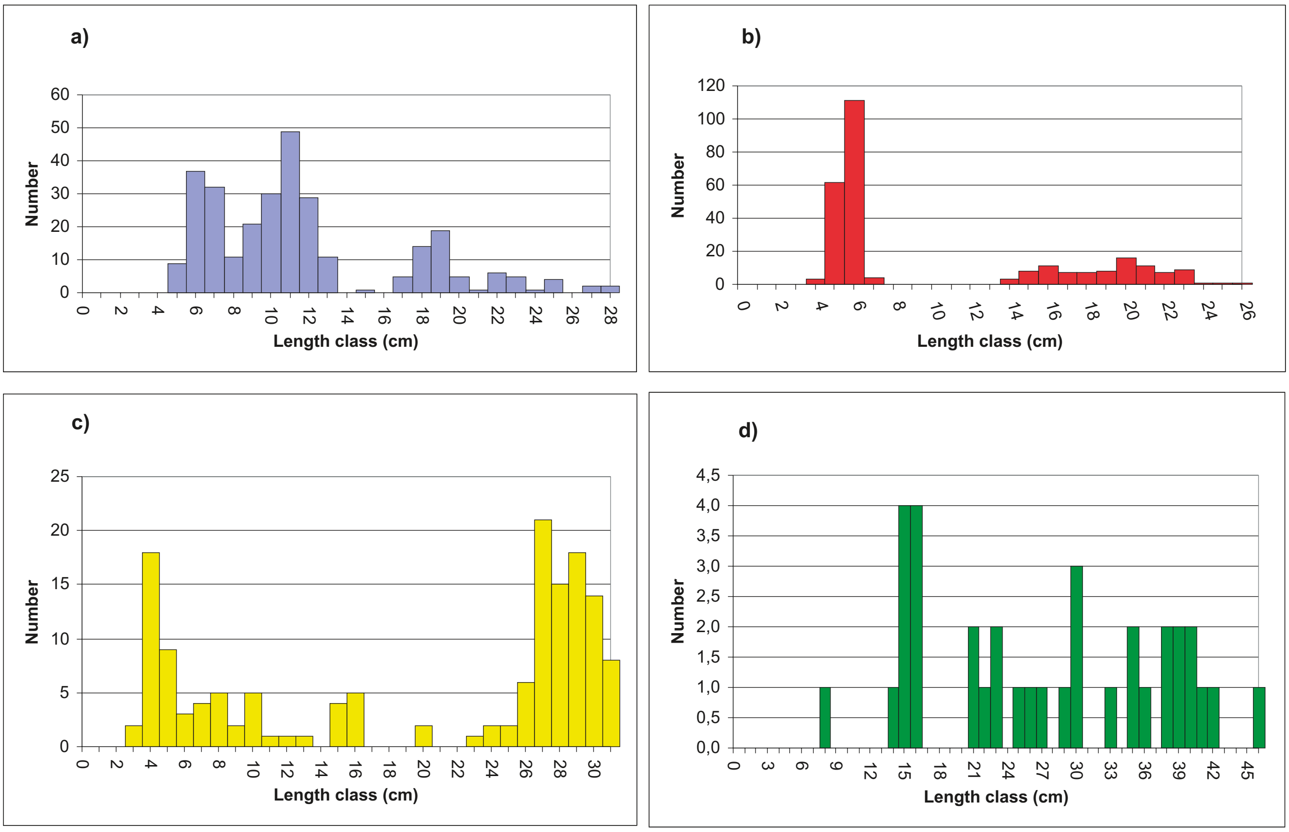


Figure A5-3. Length frequency distribution for the most common species in Fiskarfjärden a) perch, b) roach, c) tench and d) crucian carp. Species with too few replicates (not shown) were pike (n=5) and ruffe (n=1) /data from Borgiel 2004b/.

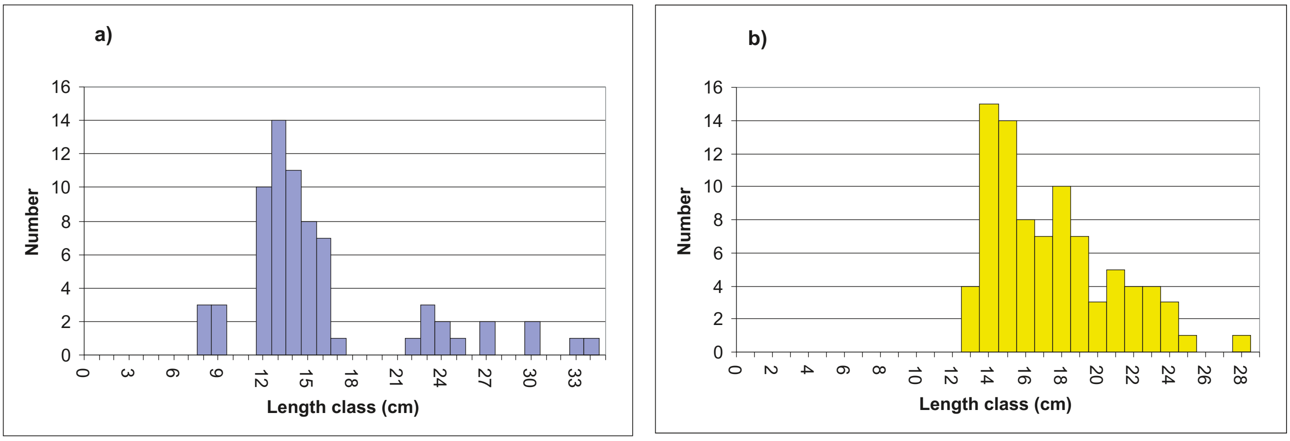


Figure A5-4. *Length frequency distribution for the most common species in Gunnarsbo-Lillfjärden a) perch and b) crucian carp. Species with too few replicates (not shown) was roach (n=2) /data from Borgiel 2004b/.*

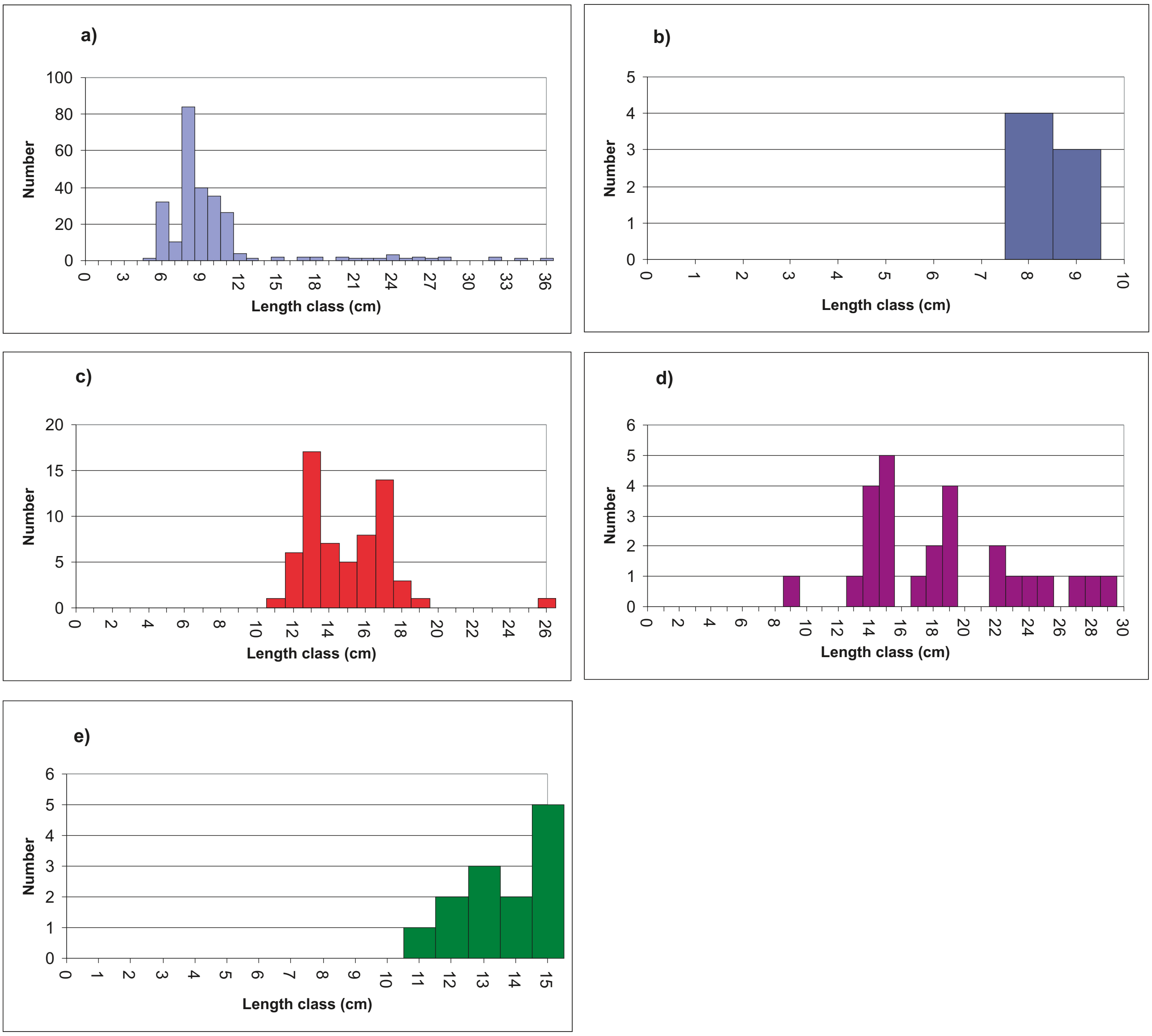


Figure A5-5. *Length frequency distribution for the most common species in Frisksjön a) perch, b) ruffe, c) roach, d) bream and e) rudd. Species with too few replicates (not shown) was pike (n=2) /data from Engdahl and Ericsson 2004/.*

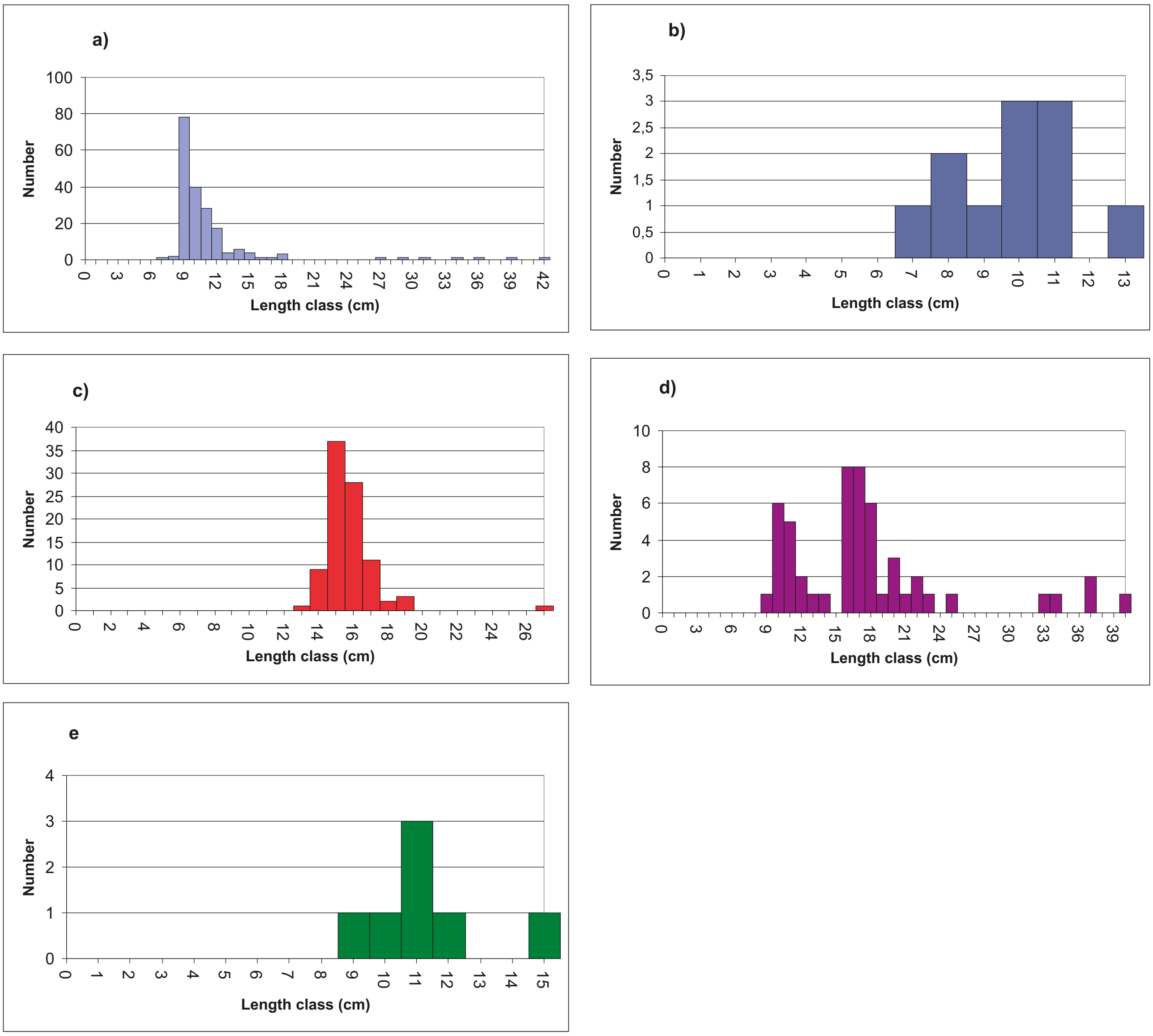


Figure A5-6. *Length frequency distribution for the most common species in Söråmagasinet a) perch, b) ruffe, c) roach, d) bream and e) rudd /data from Engdahl and Ericsson 2004/.*

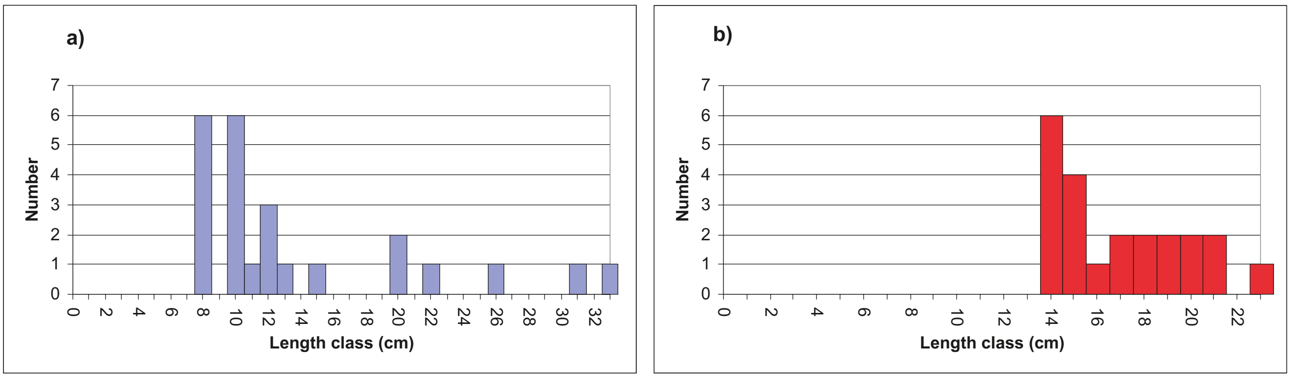


Figure A5-7. *Length frequency distribution for the most common species in Plittorpsgöl a) perch and b) roach. Species with too few replicates (not shown) was pike (n=1) /data from Engdahl and Ericsson 2004/.*

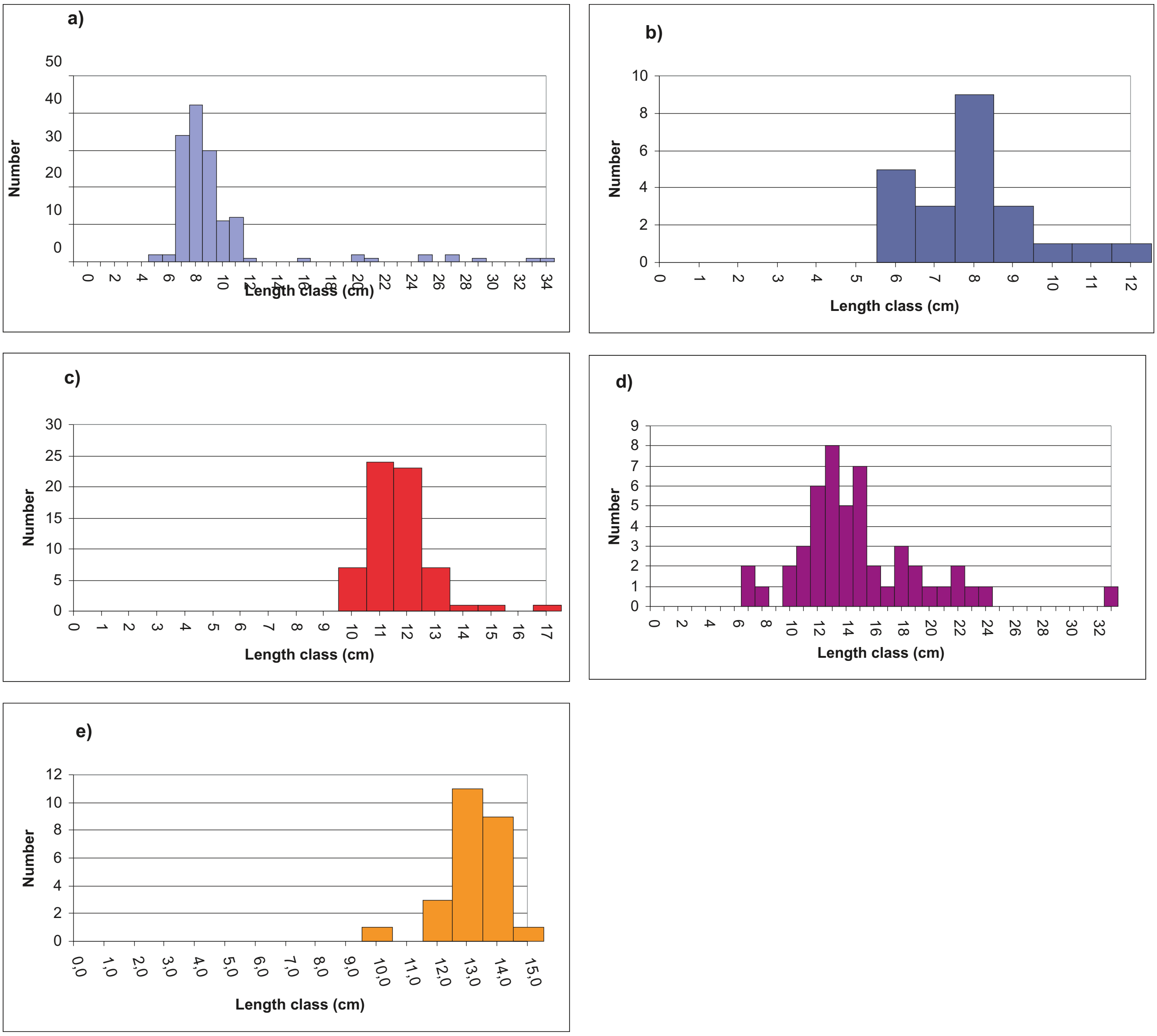


Figure A5-8. *Length frequency distribution for the most common species in Jämsen a) perch, b) ruff, c) roach, d)bream and e) bleak. Species with too few replicates (not shown) were pike (n=2) and rudd (n=1) /data from Engdahl and Ericsson 2004/.*

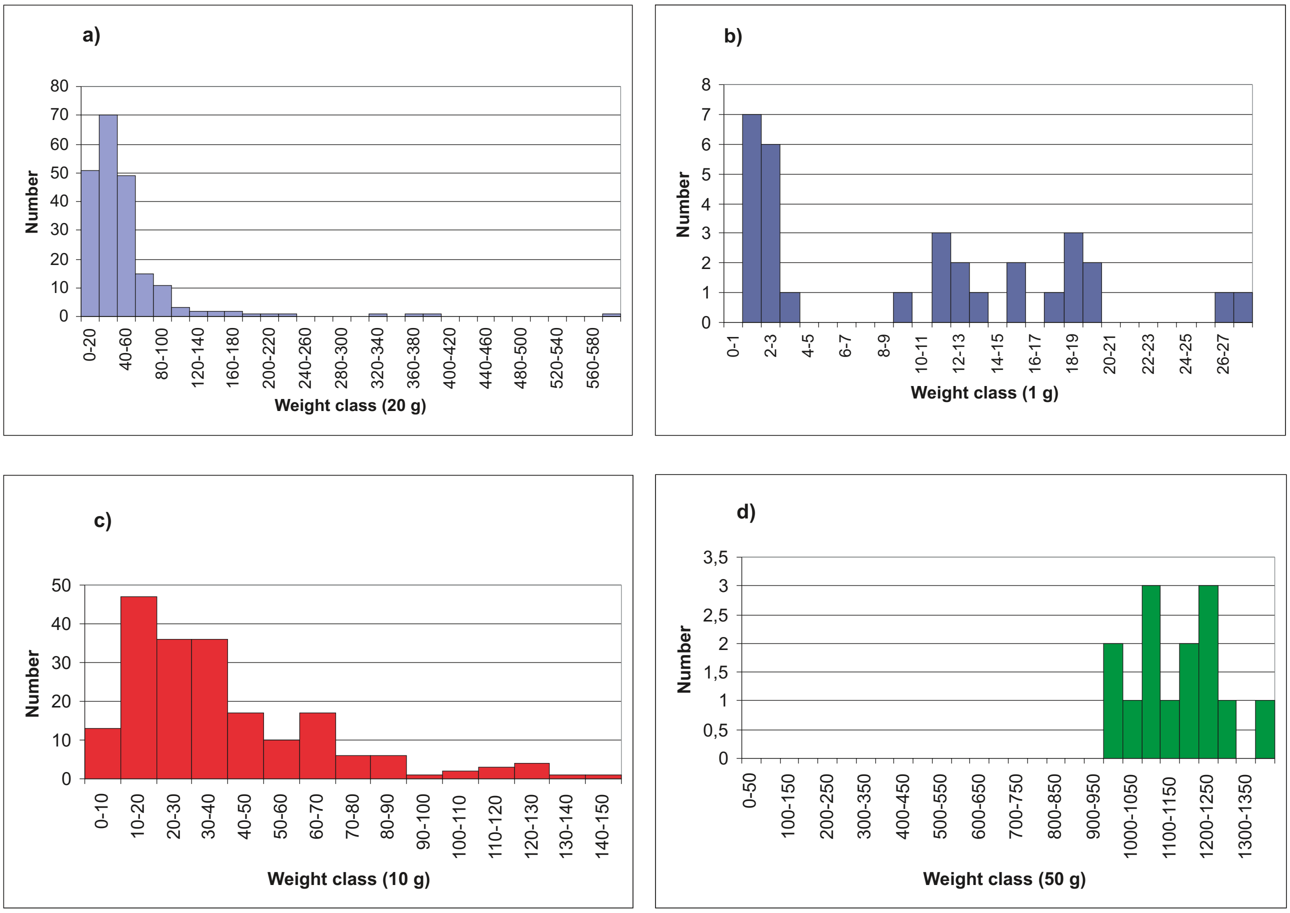


Figure A5-9. *Weight frequency distribution for the most common species in Bolundsfjärden a) perch, b) ruffe, c) roach and d) tench. Species with too few replicates (not shown) were white bream (n=1), pike (n=3), crucian carp (n=4) and rudd (n=4) /data from Borgiel 2004b/.*

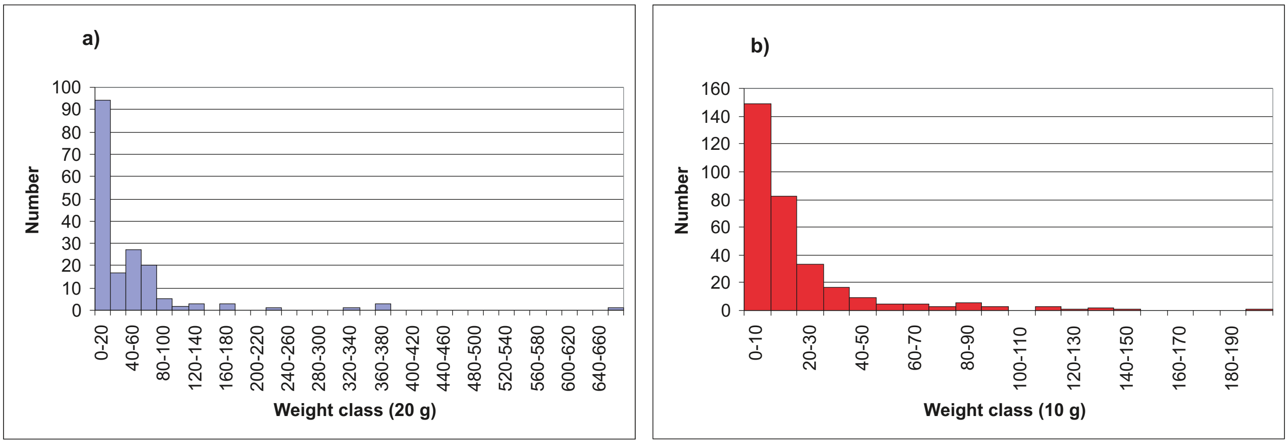


Figure A5-10. *Weight frequency distribution for the most common species in Eckarfjärden a) perch and b) roach. Species with too few replicates (not shown) were pike (n=2), ruffe (n=1) and tench (n=5) /data from Borgiel 2004b/.*

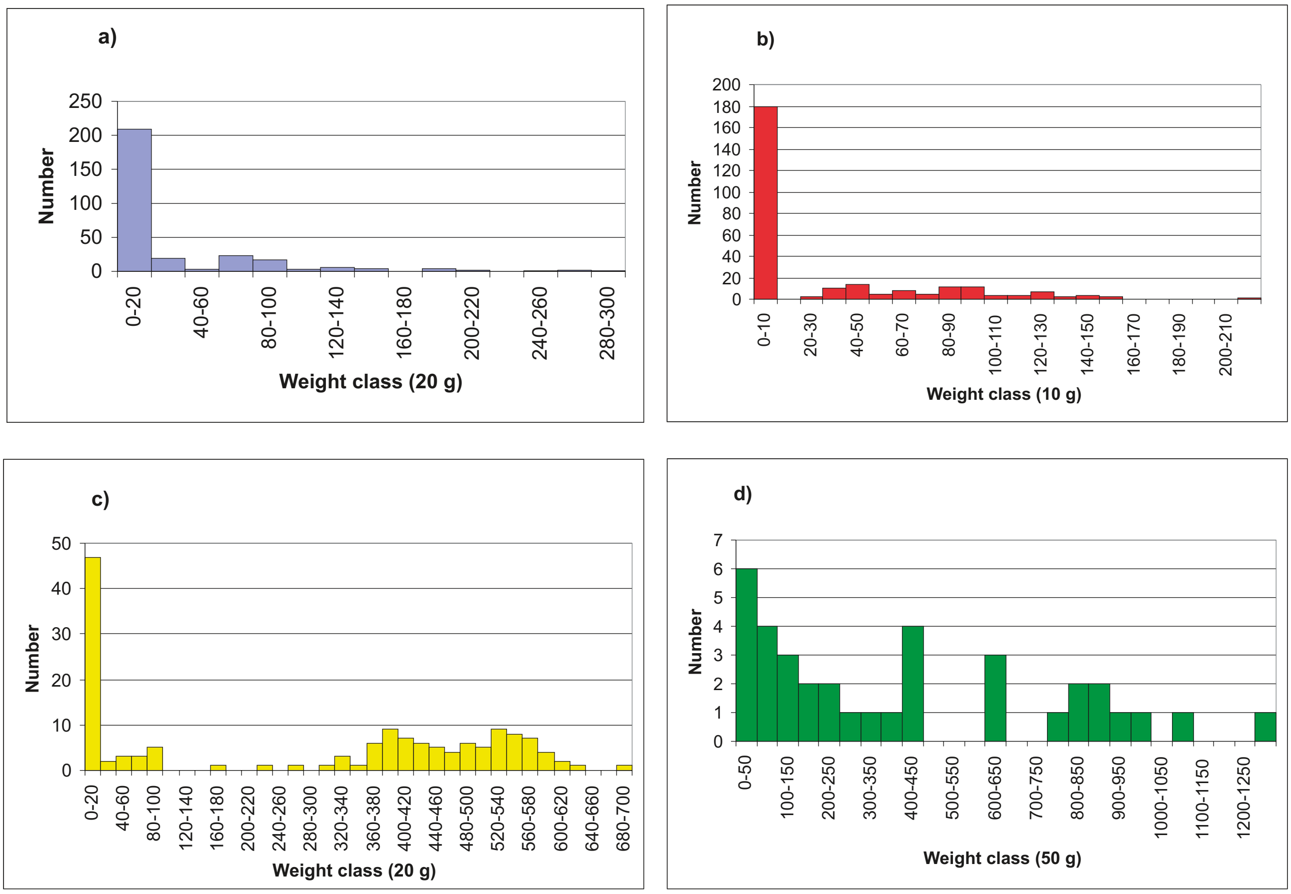


Figure A5-11. *Weight frequency distribution for the most common species in Fiskarfjärden a) perch, b) roach, c) rudd and d) tench. Species with too few replicates (not shown) were pike (n=5) and ruffe (n=1) /data from Borgiel 2004b/.*

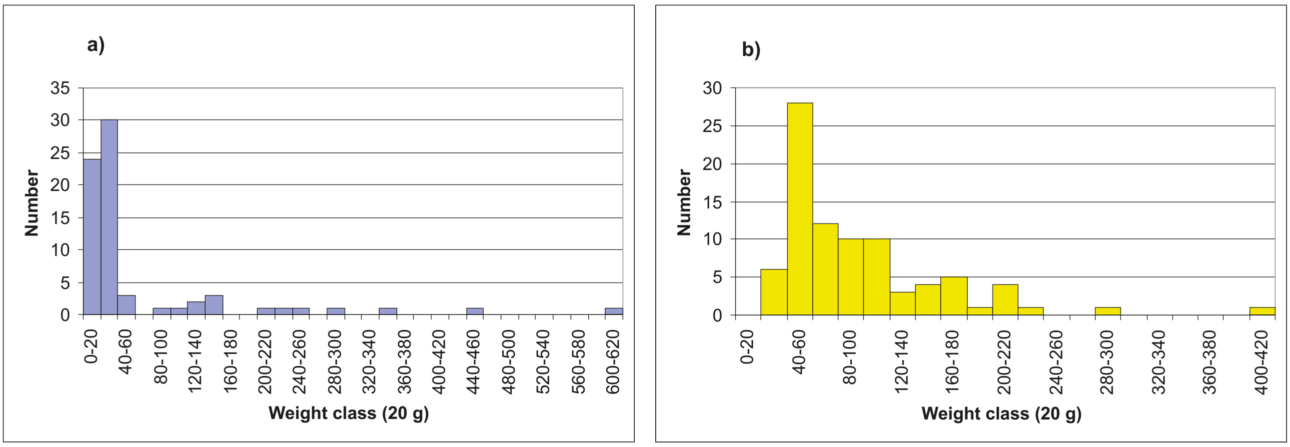


Figure A5-12. *Weight frequency distribution for the most common species in Gunnarsbo-Lillfjärden a) perch and b) rudd. Species with too few replicates (not shown) was roach (n=2) /data from Borgiel 2004b/.*

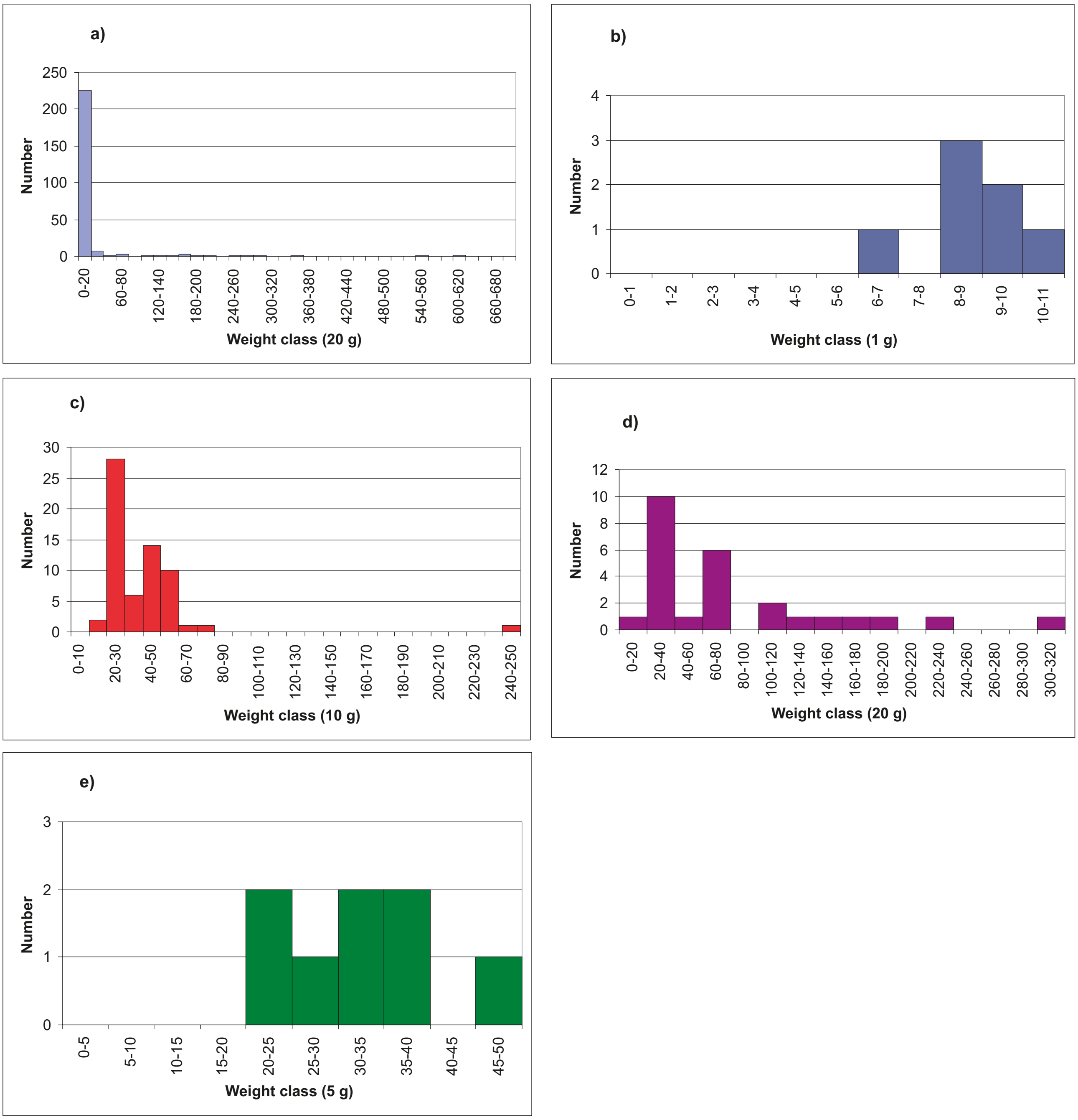


Figure A5-13. *Weight frequency distribution for the most common species in Frisksjön a) perch, b) ruffe, c) roach, d) bream and e)rudd. Species with too few replicates (not shown) was pike (n=2) /data from Engdahl and Ericsson 2004/.*

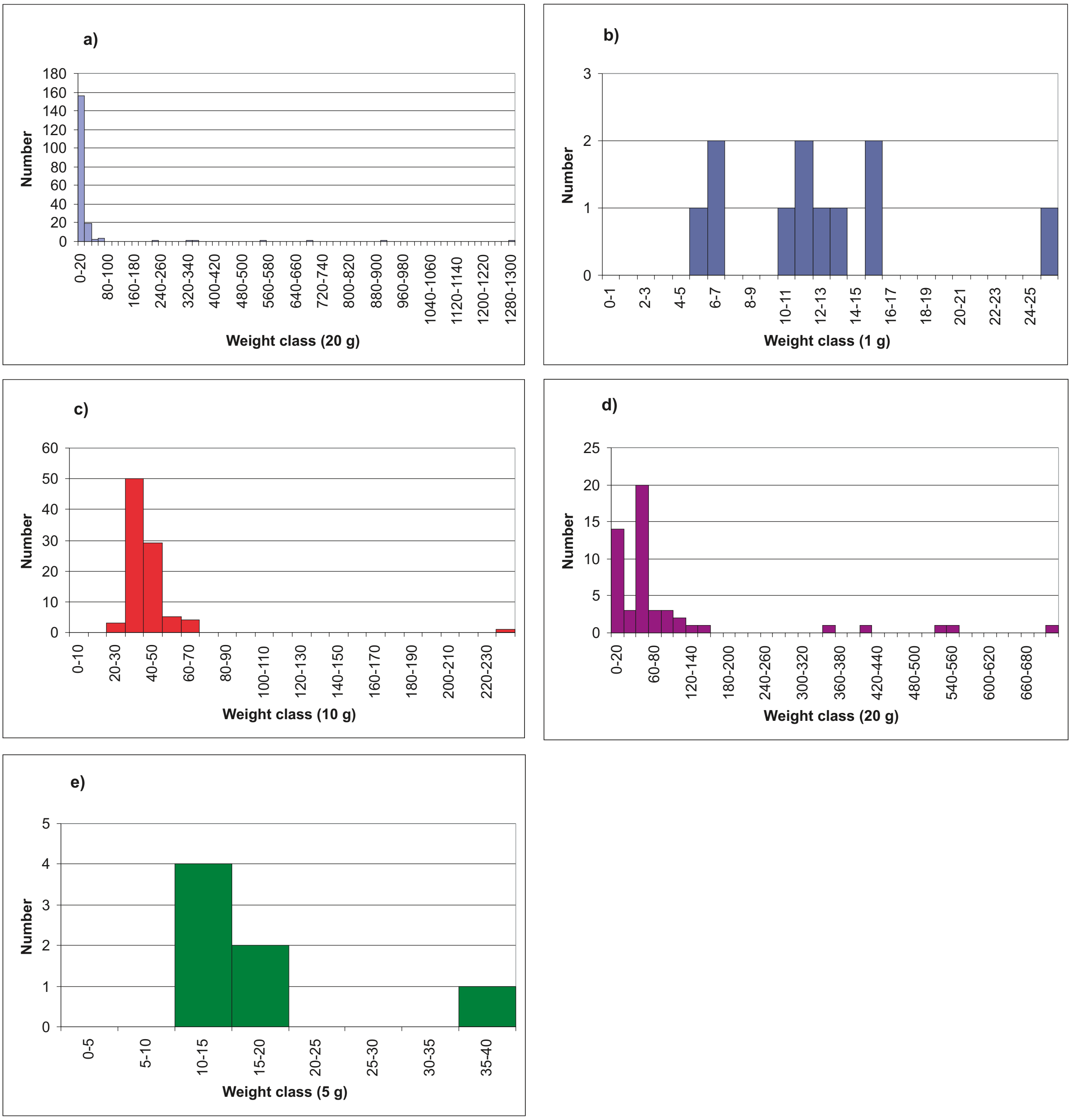


Figure A5-14. *Weight frequency distribution for the most common species in Söråmagasinet a) perch, b) ruffe, c) roach, d) bream and e)rudd /data from Engdahl and Ericsson 2004/.*

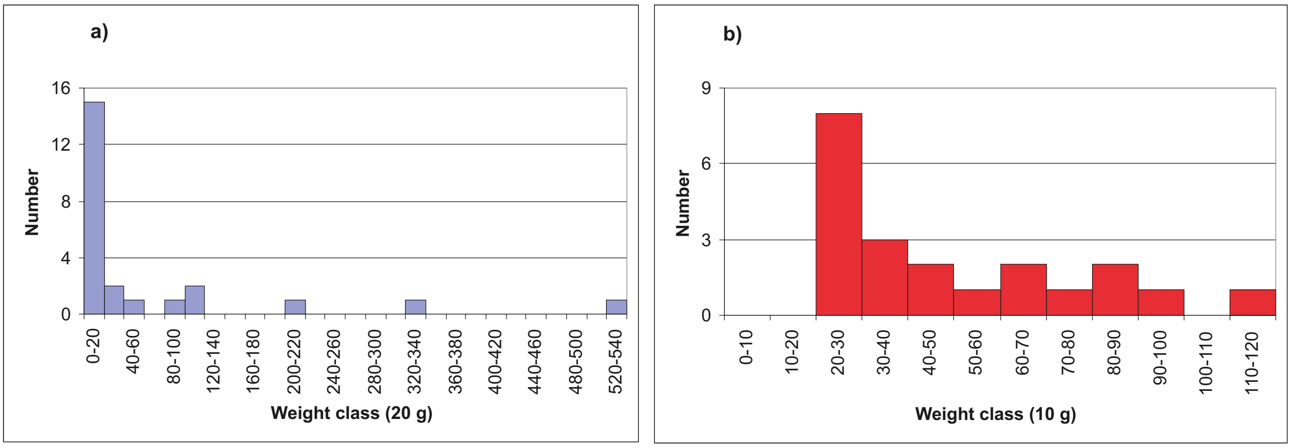


Figure A5-15. *Weight frequency distribution for the most common species in Plittorpsgöl a) perch and b) roach. Species with too few replicates (not shown) was pike (n=1) /data from Engdahl and Ericsson 2004/.*

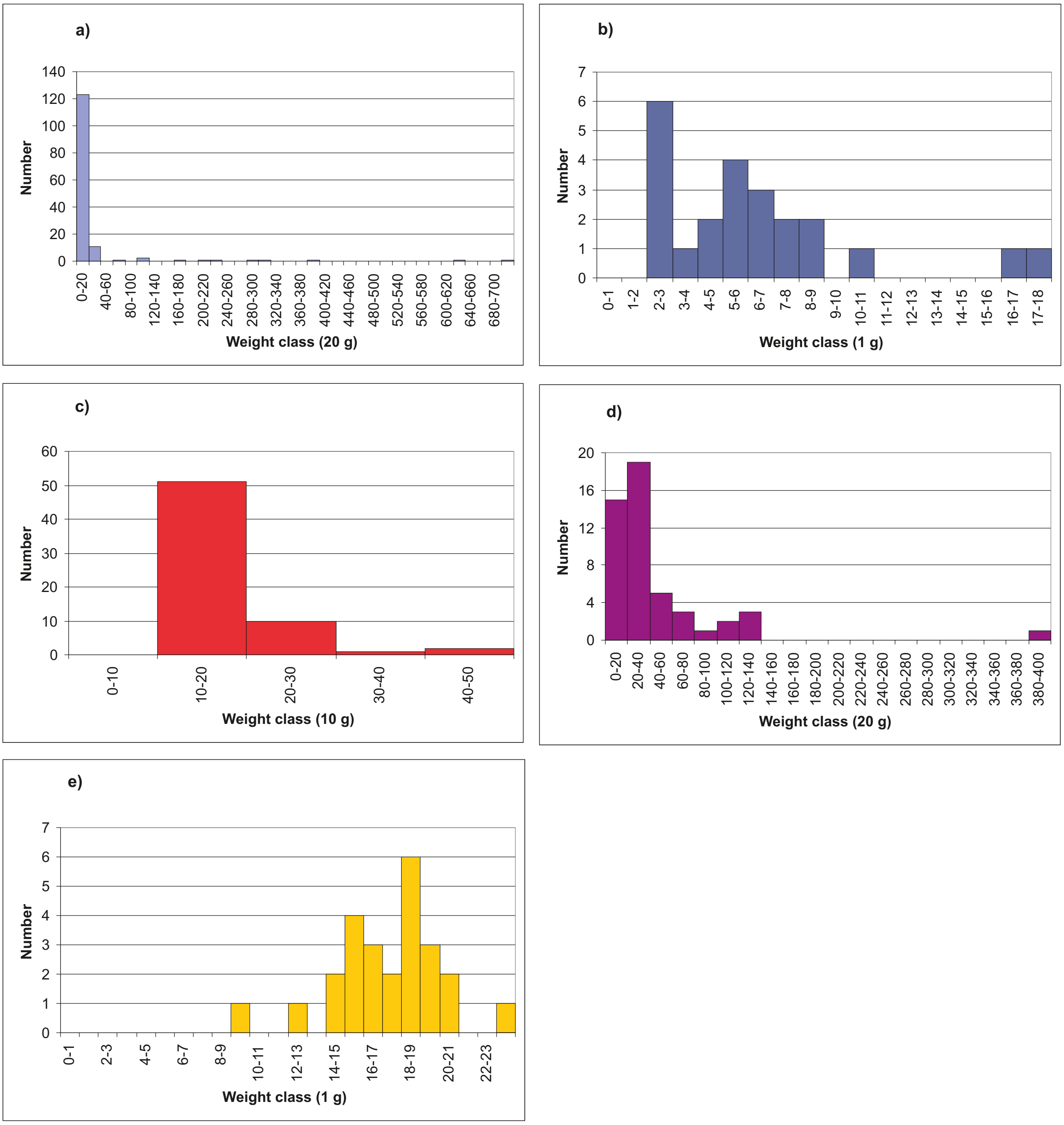


Figure A5-16. *Weight frequency distribution for the most common species in Jämsen a) perch, b) ruffe, c) roach, d) bream and e) bleak. Species with too few replicates (not shown) were pike (n=2) and rudd (n=1) /data from Engdahl and Ericsson 2004/.*

Appendix 6

Available data for models

Data on chemical composition is not available for all functional groups and for all components in the ecosystem. In Table A6-1 and A6-2 follows a description of for which pools data are available in Forsmark and Laxemar-Simpevarp, respectively

Table A6-1. Available data in modelling of lake ecosystems in Forsmark are marked with 1 and data lacking is marked with 0. The major part of data is site-specific, but also some generic data are used. For information of the data, see separate appendices and main report.

	Phyto-plankton	Micrphyto-benthos	Macro-algae	Bacterio-plankton	Zoo-plankton	Benthic bacteria	Benthic herbivores	Benthic filter-feeders	Benthic detrivores	Benthic carnivores	Benthic omnivores	B-fish	Z-fish	P-fish	Dissolved	Particular	Sediment
C	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
N	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
P	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Ag	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1
Al	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1
As	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1
B	0	1	1	0	0	0	1	1	1	1	1	1	1	1	0	1	1
Ba	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1
Be	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1
Br	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1
Ca	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1
Cd	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1
Ce	1	1	1	0	1	0	1	1	1	1	1	0	0	0	1	1	1
Cl	1	1	1	0	0	0	1	1	1	1	1	1	1	1	0	1	1
Co	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1
Cr	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1
Cs	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1
Cu	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1
Dy	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1

	Phyto-plankton	Micrphyto-benthos	Macro-algae	Bacterio-plankton	Zoo-plankton	Benthic bacteria	Benthic herbivores	Benthic filter-feeders	Benthic detrivores	Benthic carnivores	Benthic omnivores	B-fish	Z-fish	P-fish	Dissolved	Particular	Sediment
Er	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1
Eu	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1
F	1	0	0	0	0	0	1	0	1	1	1	0	0	0	0	1	0
Fe	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1
Ga	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1
Gd	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1
Hf	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1
Hg	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1
Ho	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1
I	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1
K	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1
La	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1
Li	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1
Lu	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1
Mg	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1
Mn	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1
Mo	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1
Na	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1
Nb	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1
Nd	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1
Ni	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1
P	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1
Pb	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1
Pr	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1
Rb	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1
S	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Sb	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1
Sc	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1
Se	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1
Si	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1
Sm	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1

	Phyto-plankton	Micrphyto-benthos	Macro-algae	Bacterio-plankton	Zoo-plankton	Benthic bacteria	Benthic herbivores	Benthic filter-feeders	Benthic detrivores	Benthic carnivores	Benthic omnivores	B-fish	Z-fish	P-fish	Dissolved	Particular	Sediment
Sn	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1
Sr	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1
Ta	0	1	1	0	0	0	1	1	1	1	1	1	1	1	0	1	1
Tb	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1
Th	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1
Ti	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1
Tl	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1
Tm	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1
U	0	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1
V	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1
W	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1
Y	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1
Yb	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1
Zn	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1
Zr	1	1	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1

Table A6-2. Available data in modelling of Lake Ecosystem in Laxemar-Simpevarp are marked with 1 and data lacking is marked with 0. The major part of data is site-specific, but also some generic data are used. For information of the data, see separate appendices and main report.

	Phyto-plankton	Microphyto-benthos	Macro-algae	Bacterio-plankton	Zoo-plankton	Benthic bacteria	Benthic herbivores	Benthic filter-feeders	Benthic detrivores	Benthic carnivores	Benthic omnivores	B-fish	Z-fish	P-fish	Dissolved	Particular	Upper sediment (top 1 cm)	Deeper sediment
C	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
N	1	0	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1
P	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Ag	0	0	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
Al	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
As	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
B	0	0	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
Ba	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
Be	0	0	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
Br	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
Ca	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
Cd	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
Ce	1	0	1	0	1	0	1	1	1	1	1	0	0	0	1	1	1	1
Cl	1	0	1	0	0	0	1	1	1	1	1	1	1	1	0	1	1	1
Co	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
Cr	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
Cs	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
Cu	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
Dy	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
Er	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
Eu	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
F	1	0	0	0	0	0	1	0	1	1	1	0	0	0	0	1	0	0
Fe	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
Ga	0	0	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
Gd	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
Hf	0	0	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
Hg	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
Ho	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
I	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
K	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
La	0	0	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1

	Phyto-plankton	Microphyto-benthos	Macro-algae	Bacterio-plankton	Zoo-plankton	Benthic bacteria	Benthic herbivores	Benthic filter-feeders	Benthic detrivores	Benthic carnivores	Benthic omnivores	B-fish	Z-fish	P-fish	Dissolved	Particular	Upper sediment (top 1 cm)	Deeper sediment
Li	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
Lu	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
Mg	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
Mn	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
Mo	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
Na	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
Nb	0	0	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
Nd	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
Ni	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
P	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
Pb	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
Pr	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
Rb	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
S	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Sb	0	0	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
Sc	0	0	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
Se	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
Si	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
Sm	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
Sn	0	0	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
Sr	0	0	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
Ta	0	0	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
Tb	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
Th	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
Ti	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
Tl	0	0	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
Tm	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
U	0	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
V	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
W	0	0	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
Y	0	0	1	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
Yb	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
Zn	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1
Zr	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1

Appendix 7

Chemical composition of the dissolved fractions of water

Concentrations of a large number of elements have been performed in site investigations for several years and the concentrations of the dissolved phase used in Chapter 6 are presented in Table A7-1. In addition, concentrations of elements dissolved in water (dissolved pool) has been analysed for a large number of elements at one occasion in April 2008. When available, the long-term measurements of elements have been used in Chapter 7 but for elements were long-term data are missing, data from Table A7-2 have been used. When concentrations were below detection limit, half the detection limit has been used in calculations in Chapter 7. In the tables below, the values used in the calculation are presented and the detection limits are given in footnotes.

Table A7-1. Concentrations of elements and macronutrients dissolved in water in lakes in the Forsmark (Labboträsket, Norra bassängen, Bolundsfjärden, Bolundsskogen and Eckarfjärden) and Laxemar-Simpevarp (Frisksjön) during time period 2004-06-01 to 2006-05-31 for Forsmark and 2002-11-20 to 2007-07-24 for Laxemar-Simpevarp. Values represent the mean from the whole sampling periods. When values were below detection limit, half the detection limit was used in the calculation of the mean.

Element	Unit	Labbo-träsket	Norra bassängen	Bolundsfjärden		Eckarfjärden		Bolunds-skogen	Frisksjön	
		Surface	Surface	Bottom	Surface	Bottom	Surface	Surface	Surface	Bottom
Al	µg L⁻¹	74.9		30.71	65.9	66.4	44.3	22.2	213.0	208.2
As	µg L⁻¹	0.509		0.37	1.03	0.33	0.306		0.614	0.618
Ba	µg L⁻¹	25.0		27.6	20.5	21.4	13.2	23.6	14.7	13.8
Br	mg L⁻¹	0.073	0.22	0.929	0.392	0.109	0.047	0.146	0.12	0.121
Ca	mg L⁻¹	69.5	34.9	59.6	47.4	56.0	39.7	65.0	8.08	7.51
Cd	µg L⁻¹	0.004		0.003	0.014	0.001	0.006	0.004	0.014	0.014
Ce	µg L⁻¹	0.059			0.153		0.019	0.117	2.74	2.496
Cl	mg L⁻¹	13.7	78.4	261.3	87.4	6.6	5.8	30.5	13.5	12.8
Co	µg L⁻¹	0.049		0.071	0.073	0.052	0.036	0.079	0.234	0.219
Cr	µg L⁻¹	0.139		0.138	0.143	0.136	0.098	0.138	0.546	0.591
Cs	µg L⁻¹	0.015			0.015		0.015	0.015	0.071	0.173
Cu	µg L⁻¹	0.84		0.535	0.733	0.715	0.479	1.44	2.013	2.062
Dy	µg L⁻¹	0.012			0.019		0.004	0.026	0.144	0.135
Er	µg L⁻¹	0.009			0.015		0.003	0.02	0.094	0.088
Eu	µg L⁻¹	0.006			0.011		0.003	0.01	0.041	0.037
F	mg L⁻¹	0.214	0.23	0.319	0.234	0.184	0.158	0.288	0.779	0.77
Fe	mg L⁻¹	0.05		0.146	0.109	0.06	0.023	0.226	0.847	0.875
Gd	µg L⁻¹	0.012			0.022		0.003	0.028	0.199	0.184
HCO3	mg L⁻¹	213.8	81.9	162.5	133.7	172.4	122.7	193.4	13.9	13.5
Hf	µg L⁻¹	0.005			0.006		0.004	0.01	0.106	0.095
Hg	µg L⁻¹	0.002		0.002	0.002	0.002	0.001	0.001	0.002	0.002
Ho	µg L⁻¹	0.003			0.009		0.003	0.006	0.029	0.028
I	mg L⁻¹	0.008	0.008	0.006	0.007	0.006	0.006	0.009	0.031	0.031
In	µg L⁻¹	0.025			0.043		0.025		0.025	0.025
K	mg L⁻¹	2.11	2.98	8.72	3.76	2.24	1.91	2.05	1.63	1.63
La	µg L⁻¹	0.040			0.101		0.014	0.117	1.33	1.22
Li	mg L⁻¹	0.003	0.002	0.006	0.003	0.004	0.003	0.003	0.002	0.002

Element	Unit	Labbo-träsket	Norra bassängen	Bolundsfjärden		Eckarfjärden		Bolunds-skogen	Frisksjön	
		Surface	Surface	Bottom	Surface	Bottom	Surface	Surface	Surface	Bottom
Lu	µg L^{-1}	0.004			0.041		0.008	0.003	0.021	0.028
Mg	mg L^{-1}	4.00	6.90	23.0	8.76	3.18	2.92	5.67	2.45	2.42
Mn	mg L^{-1}	0.018		0.05	0.024	0.101	0.016	0.033	0.049	0.058
Mo	µg L^{-1}	0.410		0.482	0.649	0.223	0.247	0.354	1.11	1.08
Na	mg L^{-1}	10.1	37.6	178.4	51.2	6.69	6.49	18.0	10.2	10.1
Nd	µg L^{-1}	0.043			0.08		0.014	0.12	1.48	1.385
Ni	µg L^{-1}	0.424		0.385	0.489	0.315	0.288	0.595	1.566	1.526
Pb	µg L^{-1}	0.085		0.104	0.219	0.051	0.064	0.073	0.736	0.67
Pr	µg L^{-1}	0.011			0.027		0.004	0.032	0.373	0.343
Rb	µg L^{-1}	1.79			3.80		2.17	1.78	3.81	3.89
S	mg L^{-1}								4.55	4.29
Sb	µg L^{-1}	0.051			0.126		0.096	0.066	0.157	0.147
Sc	µg L^{-1}	0.025			0.025		0.025	0.025	0.076	0.09
Si	mg/L	5.52	0.033	1.80	1.69	3.01	1.48	6.00	5.06	4.97
Sm	µg L^{-1}	0.009			0.022		0.004	0.025	0.247	0.228
SO4	mg L^{-1}	7.67	17.0	47.6	19.7	6.94	6.02	12.3	13.6	12.8
Sr	mg L^{-1}	0.082	0.107	0.197	0.104	0.06	0.05	0.101	0.039	0.038
Tb	µg L^{-1}	0.018			0.018		0.018	0.006	0.028	0.028
Th	µg L^{-1}	0.01			0.01		0.01	0.01	0.088	0.087
Tl	µg L^{-1}	0.014			0.015		0.014	0.015	0.01	0.009
Tm	µg L^{-1}	0.003			0.009		0.003	0.003	0.014	0.013
U	µg L^{-1}	1.40			2.06		1.17	2.89	0.335	0.324
V	µg L^{-1}	0.223		0.178	0.293	0.196	0.232	0.213	1.30	1.22
Y	µg L^{-1}	0.096			0.109		0.036	0.194	0.933	0.884
Yb	µg L^{-1}	0.009			0.014		0.003	0.021	0.099	0.092
Zn	µg L^{-1}	1.06		4.35	1.08	0.569	1.49	2.36	4.14	3.77
Zr	µg L^{-1}	0.143			0.2		0.094	0.21	0.892	0.938
NH4N	mg L^{-1}	0.01	0.004	0.294	0.035	0.608	0.143	0.014	0.104	0.125
NO3+NO2	mg L^{-1}	0.01	0.001	0.009	0.017	0.009	0.009	0.039	0.197	0.187
N-TOT	mg L^{-1}	0.789	0.921	1.16	0.98	1.68	1.23	0.84	1.07	1.08
P-TOT	mg L^{-1}	0.008	0.014	0.011	0.012	0.008	0.008	0.015	0.024	0.025
PO4-P	mg L^{-1}	0.001	0.001	0.001	0.001	0.001	0.001	0.003	0.034	0.002
POP	mg L^{-1}	0.003	0.006	0.004	0.005	0.004	0.004	0.005	0.012	0.012
PON	mg L^{-1}	0.035	0.064	0.036	0.045	0.049	0.054	0.033	0.107	0.102
POC	mg L^{-1}	0.250	0.575	0.263	0.336	0.403	0.431	0.245	0.854	0.825
TOC	mg L^{-1}	17.0	17.2	15.8	17.2	19.2	17.7	19.2	15.6	15.7
DOC	mg L^{-1}	16.9	17.2	15.7	17.0	18.9	17.7	18.8	15.4	15.4
DIC	mg L^{-1}	35.8	13.4	28.5	22.1	29.0	20.2	35.5	2.5	2.80

Table A7-2. Concentrations of elements (mg L^{-1}) dissolved in water in Forsmark and Laxemar-Simpevarp lakes at one occasion in April 2008. When values were below detection limit, half the detection limit is presented in the table and the detection limit is presented in footnotes below.

Element	Forsmark				Laxemar-Simpevarp			
	Bolunds-fjärden	Eckar-fjärden	Labbo-träsk	**Mean Forsmark lake**	Jämsen	Götemar	Frisksjön	**Mean Laxemar lake**
Ag	$1.0\bullet10^{-6}$ a)	$1.0\bullet10^{-6}$ a)	$1.0\bullet10^{-6}$ a)	**$1.0\bullet10^{-6}$ a)**	$6.0\bullet10^{-6}$	$1.0\bullet10^{-6}$ a)	$6.0\bullet10^{-6}$	**$4.3\bullet10^{-6}$**
Al	$7.7\bullet10^{-3}$	$8.5\bullet10^{-3}$	$8.1\bullet10^{-3}$	**$8.1\bullet10^{-3}$**	$2.0\bullet10^{-1}$	$5.2\bullet10^{-2}$	$2.3\bullet10^{-1}$	**$1.6\bullet10^{-1}$**
As	$3.8\bullet10^{-4}$	$3.6\bullet10^{-4}$	$3.0\bullet10^{-4}$	**$3.5\bullet10^{-4}$**	$2.7\bullet10^{-4}$	$4.3\bullet10^{-4}$	$3.7\bullet10^{-4}$	**$3.6\bullet10^{-4}$**
Au	$5.0\bullet10^{-7}$ b)	$5.0\bullet10^{-7}$ b)	$5.0\bullet10^{-7}$ b)	**$5.0\bullet10^{-7}$ b)**	$5.0\bullet10^{-7}$ b)	$5.0\bullet10^{-7}$ b)	$2.0\bullet10^{-6}$	**$1.0\bullet10^{-6}$**
B	$3.2\bullet10^{-2}$	$1.0\bullet10^{-2}$	$8.0\bullet10^{-3}$	**$1.7\bullet10^{-2}$**	$1.2\bullet10^{-2}$	$3.3\bullet10^{-2}$	$2.2\bullet10^{-2}$	**$2.2\bullet10^{-2}$**
Ba	$2.0\bullet10^{-2}$	$1.6\bullet10^{-2}$	$2.3\bullet10^{-2}$	**$2.0\bullet10^{-2}$**	$1.7\bullet10^{-2}$	$1.1\bullet10^{-2}$	$1.4\bullet10^{-2}$	**$1.4\bullet10^{-2}$**
Be	$9.0\bullet10^{-6}$	$5.0\bullet10^{-6}$	$4.0\bullet10^{-6}$	**$6.0\bullet10^{-6}$**	$7.7\bullet10^{-5}$	$7.4\bullet10^{-5}$	$2.6\bullet10^{-4}$	**$1.4\bullet10^{-4}$**
Bi	$1.0\bullet10^{-6}$	$5.0\bullet10^{-7}$ b)	$5.0\bullet10^{-7}$ b)	**$6.7\bullet10^{-7}$**	$4.0\bullet10^{-6}$	$5.0\bullet10^{-7}$ b)	$4.0\bullet10^{-6}$	**$2.8\bullet10^{-6}$**
Br	$4.0\bullet10^{-1}$	$5.0\bullet10^{-2}$	$4.0\bullet10^{-2}$	**$1.6\bullet10^{-1}$**	$1.2\bullet10^{-1}$	$2.0\bullet10^{-1}$	$2.5\bullet10^{-1}$	**$1.9\bullet10^{-1}$**
Ca	49	47	57	**51**	8.0	10	7.8	**8.6**
Cd	$7.0\bullet10^{-6}$	$4.0\bullet10^{-6}$	$5.0\bullet10^{-6}$	**$5.3\bullet10^{-6}$**	$1.3\bullet10^{-5}$	$1.1\bullet10^{-5}$	$2.3\bullet10^{-5}$	**$1.6\bullet10^{-5}$**
Ce	$1.1\bullet10^{-4}$	$6.3\bullet10^{-5}$	$6.0\bullet10^{-5}$	**$7.8\bullet10^{-5}$**	$3.9\bullet10^{-3}$	$4.7\bullet10^{-4}$	$3.4\bullet10^{-3}$	**$2.6\bullet10^{-3}$**
Co	$3.7\bullet10^{-5}$	$3.7\bullet10^{-5}$	$3.9\bullet10^{-5}$	**$3.8\bullet10^{-5}$**	$3.1\bullet10^{-4}$	$2.7\bullet10^{-5}$	$3.7\bullet10^{-4}$	**$2.4\bullet10^{-4}$**
Cr	$1.2\bullet10^{-4}$	$1.1\bullet10^{-4}$	$1.2\bullet10^{-4}$	**$1.2\bullet10^{-4}$**	$3.8\bullet10^{-4}$	$7.2\bullet10^{-5}$	$5.7\bullet10^{-4}$	**$3.4\bullet10^{-4}$**
Cs	$6.8\bullet10^{-5}$	$8.0\bullet10^{-6}$	$3.0\bullet10^{-6}$	**$2.6\bullet10^{-5}$**	$1.8\bullet10^{-5}$	$9.0\bullet10^{-6}$	$1.7\bullet10^{-5}$	**$1.5\bullet10^{-5}$**
Cu	$8.7\bullet10^{-4}$	$8.8\bullet10^{-4}$	$1.4\bullet10^{-3}$	**$1.1\bullet10^{-3}$**	$1.4\bullet10^{-3}$	$1.1\bullet10^{-3}$	$2.6\bullet10^{-3}$	**$1.7\bullet10^{-3}$**
Dy	$4.8\bullet10^{-5}$	$2.2\bullet10^{-5}$	$2.1\bullet10^{-5}$	**$3.0\bullet10^{-5}$**	$3.2\bullet10^{-4}$	$5.4\bullet10^{-5}$	$1.9\bullet10^{-4}$	**$1.9\bullet10^{-4}$**
Er	$2.1\bullet10^{-5}$	$1.5\bullet10^{-5}$	$1.8\bullet10^{-5}$	**$1.8\bullet10^{-5}$**	$2.4\bullet10^{-4}$	$4.9\bullet10^{-5}$	$1.3\bullet10^{-4}$	**$1.4\bullet10^{-4}$**
Eu	$4.0\bullet10^{-6}$	$3.0\bullet10^{-6}$	$4.0\bullet10^{-6}$	**$3.7\bullet10^{-6}$**	$7.5\bullet10^{-5}$	$1.2\bullet10^{-5}$	$5.2\bullet10^{-5}$	**$4.6\bullet10^{-5}$**
Fe	$6.0\bullet10^{-2}$	$2.5\bullet10^{-2}$	$2.8\bullet10^{-2}$	**$3.8\bullet10^{-2}$**	$7.4\bullet10^{-1}$	$3.4\bullet10^{-2}$	$4.8\bullet10^{-1}$	**$4.2\bullet10^{-1}$**
Ga	$5.0\bullet10^{-6}$	$4.0\bullet10^{-6}$	$3.0\bullet10^{-6}$	**$4.0\bullet10^{-6}$**	$5.0\bullet10^{-6}$	$7.0\bullet10^{-6}$	$5.0\bullet10^{-6}$	**$5.7\bullet10^{-6}$**
Gd	$2.7\bullet10^{-5}$	$1.9\bullet10^{-5}$	$2.4\bullet10^{-5}$	**$2.3\bullet10^{-5}$**	$5.4\bullet10^{-4}$	$8.4\bullet10^{-5}$	$3.2\bullet10^{-4}$	**$3.1\bullet10^{-4}$**
Ge	$7.0\bullet10^{-5}$	$4.0\bullet10^{-5}$	$4.0\bullet10^{-5}$	**$5.0\bullet10^{-5}$**	$8.0\bullet10^{-5}$	$5.0\bullet10^{-5}$	$7.0\bullet10^{-5}$	**$6.7\bullet10^{-5}$**
Hf	$1.4\bullet10^{-5}$	$1.3\bullet10^{-5}$	$1.1\bullet10^{-5}$	**$1.3\bullet10^{-5}$**	$4.0\bullet10^{-5}$	$1.1\bullet10^{-5}$	$4.2\bullet10^{-5}$	**$3.1\bullet10^{-5}$**
Hg	$1.0\bullet10^{-6}$ a)	$1.0\bullet10^{-6}$ a)	$1.0\bullet10^{-6}$ a)	**$1.0\bullet10^{-6}$ a)**	$1.0\bullet10^{-6}$ a)	$1.0\bullet10^{-6}$ a)	$1.0\bullet10^{-6}$ a)	**$1.0\bullet10^{-6}$ a)**
Ho	$7.0\bullet10^{-6}$	$5.0\bullet10^{-6}$	$5.0\bullet10^{-6}$	**$5.7\bullet10^{-6}$**	$7.3\bullet10^{-5}$	$1.5\bullet10^{-5}$	$4.2\bullet10^{-5}$	**$4.3\bullet10^{-5}$**
I	$4.0\bullet10^{-3}$	$4.0\bullet10^{-3}$	$3.0\bullet10^{-3}$	**$3.7\bullet10^{-3}$**	$4.0\bullet10^{-3}$	$1.7\bullet10^{-2}$	$2.5\bullet10^{-2}$	**$1.5\bullet10^{-2}$**
In	$2.5\bullet10^{-5}$ c)	$2.5\bullet10^{-5}$ c)	$2.5\bullet10^{-5}$ c)	**$2.5\bullet10^{-5}$ c)**	$2.5\bullet10^{-5}$ c)	$2.5\bullet10^{-5}$ c)	$2.5\bullet10^{-5}$ c)	**$2.5\bullet10^{-5}$ c)**
Ir	$1.0\bullet10^{-7}$ d)	$1.0\bullet10^{-7}$ d)	$1.0\bullet10^{-7}$ d)	**$1.0\bullet10^{-7}$ d)**	$1.0\bullet10^{-7}$ d)	$1.0\bullet10^{-7}$ d)	$1.0\bullet10^{-7}$ d)	**$1.0\bullet10^{-7}$ d)**
K	3.3	1.9	2.1	**2.4**	1.3	1.5	1.5	**1.4**
La	$1.0\bullet10^{-4}$	$6.4\bullet10^{-5}$	$7.4\bullet10^{-5}$	**$7.9\bullet10^{-5}$**	$2.3\bullet10^{-3}$	$5.2\bullet10^{-4}$	$1.8\bullet10^{-3}$	**$1.5\bullet10^{-3}$**
Li	$3.0\bullet10^{-3}$	$1.3\bullet10^{-3}$	$1.5\bullet10^{-3}$	**$1.9\bullet10^{-3}$**	$2.1\bullet10^{-3}$	$3.0\bullet10^{-3}$	$2.5\bullet10^{-3}$	**$2.5\bullet10^{-3}$**
Lu	$3.0\bullet10^{-6}$	$3.0\bullet10^{-6}$	$3.0\bullet10^{-6}$	**$3.0\bullet10^{-6}$**	$4.7\bullet10^{-5}$	$1.2\bullet10^{-5}$	$2.4\bullet10^{-5}$	**$2.8\bullet10^{-5}$**
Mg	8.3	2.7	2.9	**4.6**	2.2	3.0	2.7	**2.6**
Mn	$3.9\bullet10^{-3}$	$9.9\bullet10^{-3}$	$5.6\bullet10^{-3}$	**$6.5\bullet10^{-3}$**	$7.6\bullet10^{-2}$	$2.9\bullet10^{-3}$	$4.4\bullet10^{-2}$	**$4.1\bullet10^{-2}$**
Mo	$6.2\bullet10^{-4}$	$2.5\bullet10^{-4}$	$6.5\bullet10^{-4}$	**$5.1\bullet10^{-4}$**	$1.1\bullet10^{-4}$	$5.0\bullet10^{-4}$	$9.2\bullet10^{-4}$	**$5.1\bullet10^{-4}$**
Na	50	6.3	6.9	**21**	8.3	11	12	**10**
Nb	$1.0\bullet10^{-5}$	$9.0\bullet10^{-6}$	$9.0\bullet10^{-6}$	**$9.3\bullet10^{-6}$**	$3.0\bullet10^{-5}$	$8.0\bullet10^{-6}$	$3.1\bullet10^{-5}$	**$2.3\bullet10^{-5}$**
Nd	$1.1\bullet10^{-4}$	$8.3\bullet10^{-5}$	$8.5\bullet10^{-5}$	**$9.3\bullet10^{-5}$**	$2.6\bullet10^{-3}$	$4.6\bullet10^{-4}$	$1.9\bullet10^{-3}$	**$1.7\bullet10^{-3}$**
Ni	$5.1\bullet10^{-4}$	$5.0\bullet10^{-4}$	$6.2\bullet10^{-4}$	**$5.4\bullet10^{-4}$**	$1.0\bullet10^{-3}$	$1.2\bullet10^{-3}$	$2.2\bullet10^{-3}$	**$1.5\bullet10^{-3}$**
Os	$1.0\bullet10^{-7}$ d)	$1.0\bullet10^{-7}$ d)	$1.0\bullet10^{-7}$ d)	**$1.0\bullet10^{-7}$ d)**	$1.0\bullet10^{-7}$ d)	$1.0\bullet10^{-7}$ d)	$1.0\bullet10^{-7}$ d)	**$1.0\bullet10^{-7}$ d)**
P	$4.1\bullet10^{-3}$	$3.5\bullet10^{-3}$	$4.0\bullet10^{-3}$	**$3.9\bullet10^{-3}$**	$8.9\bullet10^{-3}$	$5.2\bullet10^{-3}$	$9.4\bullet10^{-3}$	**$7.8\bullet10^{-3}$**

Element	Forsmark				Laxemar-Simpevarp			
	Bolunds-fjärden	**Eckar-fjärden**	**Labbo-träsk**	**Mean Forsmark lake**	**Jämsen**	**Götemar**	**Frisksjön**	**Mean Laxemar lake**
Pb	$9.4\bullet10^{-5}$	$1.2\bullet10^{-4}$	$1.0\bullet10^{-4}$	**$1.0\bullet10^{-4}$**	$3.7\bullet10^{-4}$	$5.2\bullet10^{-5}$	$5.8\bullet10^{-4}$	**$3.3\bullet10^{-4}$**
Pd	$5.0\bullet10^{-6}$ e)	$5.0\bullet10^{-6}$ e)	$5.0\bullet10^{-6}$ e)	**$5.0\bullet10^{-6}$ e)**	$5.0\bullet10^{-6}$ e)	$5.0\bullet10^{-6}$ e)	$5.0\bullet10^{-6}$ e)	**$5.0\bullet10^{-6}$ e)**
Pr	$2.7\bullet10^{-5}$	$2.0\bullet10^{-5}$	$2.0\bullet10^{-5}$	**$2.2\bullet10^{-5}$**	$6.5\bullet10^{-4}$	$1.2\bullet10^{-4}$	$4.9\bullet10^{-4}$	**$4.2\bullet10^{-4}$**
Pt	$5.0\bullet10^{-7}$ b)	$5.0\bullet10^{-7}$ b)	$5.0\bullet10^{-7}$ b)	**$5.0\bullet10^{-7}$ b)**	$1.0\bullet10^{-6}$ b)	$1.0\bullet10^{-6}$ b)	$2.0\bullet10^{-6}$ b)	**$1.3\bullet10^{-6}$ b)**
Rb	$3.1\bullet10^{-3}$	$2.0\bullet10^{-3}$	$2.0\bullet10^{-3}$	**$2.4\bullet10^{-3}$**	$2.7\bullet10^{-3}$	$3.1\bullet10^{-3}$	$3.2\bullet10^{-3}$	**$3.0\bullet10^{-3}$**
Re	$2.0\bullet10^{-6}$	$1.0\bullet10^{-6}$	$1.0\bullet10^{-6}$	**$1.3\bullet10^{-6}$**	$1.0\bullet10^{-6}$	$3.0\bullet10^{-6}$	$2.0\bullet10^{-6}$	**$2.0\bullet10^{-6}$**
Rh	$5.0\bullet10^{-5}$ f)	$5.0\bullet10^{-5}$ f)	$5.0\bullet10^{-5}$ f)	**$5.0\bullet10^{-5}$ f)**	$5.0\bullet10^{-5}$ f)	$5.0\bullet10^{-5}$ f)	$5.0\bullet10^{-5}$ f)	**$5.0\bullet10^{-5}$ f)**
Ru	$2.5\bullet10^{-6}$ g)	$2.5\bullet10^{-6}$ g)	$2.5\bullet10^{-6}$ g)	**$2.5\bullet10^{-6}$ g)**	$2.5\bullet10^{-6}$ g)	$2.5\bullet10^{-6}$ g)	$2.5\bullet10^{-6}$ g)	**$2.5\bullet10^{-6}$ g)**
S	8.4	3.5	4.4	**5.4**	3.4	8.0	5.5	**5.6**
Sb	$7.1\bullet10^{-5}$	$7.0\bullet10^{-5}$	$6.0\bullet10^{-5}$	**$6.7\bullet10^{-5}$**	$6.9\bullet10^{-5}$	$9.5\bullet10^{-5}$	$1.3\bullet10^{-4}$	**$9.8\bullet10^{-5}$**
Sc	$3.0\bullet10^{-5}$	$2.7\bullet10^{-5}$	$2.0\bullet10^{-5}$	**$2.6\bullet10^{-5}$**	$1.3\bullet10^{-4}$	$3.2\bullet10^{-5}$	$1.2\bullet10^{-4}$	**$9.4\bullet10^{-5}$**
Se	$1.2\bullet10^{-4}$	$1.2\bullet10^{-4}$	$1.2\bullet10^{-4}$	**$1.2\bullet10^{-4}$**	$1.1\bullet10^{-4}$	$1.1\bullet10^{-4}$	$1.4\bullet10^{-4}$	**$1.2\bullet10^{-4}$**
Si	1.2	2.2	3.4	**2.3**	4.1	1.5	6.0	**3.9**
Sm	$2.5\bullet10^{-5}$	$2.0\bullet10^{-5}$	$2.2\bullet10^{-5}$	**$2.2\bullet10^{-5}$**	$5.0\bullet10^{-4}$	$8.4\bullet10^{-5}$	$3.4\bullet10^{-4}$	**$3.1\bullet10^{-4}$**
Sn	$2.5\bullet10^{-6}$ g)	$2.5\bullet10^{-6}$ g)	$2.5\bullet10^{-6}$ g)	**$2.5\bullet10^{-6}$ g)**	$2.5\bullet10^{-6}$ g)	$2.5\bullet10^{-6}$ g)	$2.5\bullet10^{-6}$ g)	**$2.5\bullet10^{-6}$ g)**
Sr	$1.4\bullet10^{-1}$	$5.2\bullet10^{-2}$	$7.0\bullet10^{-2}$	**$8.7\bullet10^{-2}$**	$4.7\bullet10^{-2}$	$6.7\bullet10^{-2}$	$4.4\bullet10^{-2}$	**$5.3\bullet10^{-2}$**
Ta	$2.5\bullet10^{-7}$ h)	$2.5\bullet10^{-7}$ h)	$2.5\bullet10^{-7}$ h)	**$2.5\bullet10^{-7}$ h)**	$1.0\bullet10^{-6}$	$2.5\bullet10^{-7}$ h)	$1.0\bullet10^{-6}$	**$7.5\bullet10^{-7}$**
Tb	$7.0\bullet10^{-6}$	$4.0\bullet10^{-6}$	$4.0\bullet10^{-6}$	**$5.0\bullet10^{-6}$**	$6.5\bullet10^{-5}$	$1.1\bullet10^{-5}$	$4.1\bullet10^{-5}$	**$3.9\bullet10^{-5}$**
Te	$2.0\bullet10^{-6}$	$1.0\bullet10^{-6}$ a)	$1.0\bullet10^{-6}$ a)	**$1.3\bullet10^{-6}$**	$1.0\bullet10^{-6}$ a)	$1.0\bullet10^{-6}$ a)	$1.0\bullet10^{-6}$ a)	**$1.0\bullet10^{-6}$ a)**
Th	$3.1\bullet10^{-5}$	$2.6\bullet10^{-5}$	$2.2\bullet10^{-5}$	**$2.6\bullet10^{-5}$**	$8.4\bullet10^{-5}$	$5.2\bullet10^{-5}$	$1.2\bullet10^{-4}$	**$8.5\bullet10^{-5}$**
Ti	$3.2\bullet10^{-4}$	$3.1\bullet10^{-4}$	$4.1\bullet10^{-4}$	**$3.5\bullet10^{-4}$**	$2.0\bullet10^{-3}$	$4.0\bullet10^{-4}$	$1.9\bullet10^{-3}$	**$1.4\bullet10^{-3}$**
Tl	$6.0\bullet10^{-6}$	$4.0\bullet10^{-6}$	$5.0\bullet10^{-6}$	**$5.0\bullet10^{-6}$**	$8.0\bullet10^{-6}$	$8.0\bullet10^{-6}$	$1.0\bullet10^{-5}$	**$8.7\bullet10^{-6}$**
Tm	$3.0\bullet10^{-6}$	$2.0\bullet10^{-6}$	$2.0\bullet10^{-6}$	**$2.3\bullet10^{-6}$**	$3.2\bullet10^{-5}$	$8.0\bullet10^{-6}$	$1.7\bullet10^{-5}$	**$1.9\bullet10^{-5}$**
U	$3.7\bullet10^{-3}$	$1.4\bullet10^{-3}$	$2.8\bullet10^{-3}$	**$2.6\bullet10^{-3}$**	$2.5\bullet10^{-4}$	$3.8\bullet10^{-4}$	$3.7\bullet10^{-4}$	**$3.3\bullet10^{-4}$**
V	$1.7\bullet10^{-4}$	$1.7\bullet10^{-4}$	$1.5\bullet10^{-4}$	**$1.6\bullet10^{-4}$**	$6.3\bullet10^{-4}$	$1.3\bullet10^{-4}$	$9.0\bullet10^{-4}$	**$5.5\bullet10^{-4}$**
W	$2.2\bullet10^{-5}$	$3.0\bullet10^{-6}$	$3.0\bullet10^{-6}$	**$9.3\bullet10^{-6}$**	$6.0\bullet10^{-6}$	$5.0\bullet10^{-6}$	$1.4\bullet10^{-5}$	**$8.3\bullet10^{-6}$**
Y	$2.0\bullet10^{-4}$	$1.7\bullet10^{-4}$	$1.6\bullet10^{-4}$	**$1.8\bullet10^{-4}$**	$2.7\bullet10^{-3}$	$5.3\bullet10^{-4}$	$1.4\bullet10^{-3}$	**$1.5\bullet10^{-3}$**
Yb	$2.0\bullet10^{-5}$	$1.8\bullet10^{-5}$	$1.8\bullet10^{-5}$	**$1.9\bullet10^{-5}$**	$2.5\bullet10^{-4}$	$5.7\bullet10^{-5}$	$1.3\bullet10^{-4}$	**$1.5\bullet10^{-4}$**
Zn	$9.2\bullet10^{-4}$	$1.3\bullet10^{-3}$	$1.9\bullet10^{-3}$	**$1.4\bullet10^{-3}$**	$4.4\bullet10^{-3}$	$1.3\bullet10^{-3}$	$4.6\bullet10^{-3}$	**$3.4\bullet10^{-3}$**
Zr	$3.9\bullet10^{-4}$	$3.8\bullet10^{-4}$	$3.9\bullet10^{-4}$	**$3.9\bullet10^{-4}$**	$9.3\bullet10^{-4}$	$2.8\bullet10^{-4}$	$1.1\bullet10^{-3}$	**$7.7\bullet10^{-4}$**

Detection limits (mg L^{-1}):

a) $< 2\bullet10^{-6}$

b) $< 1\bullet10^{-6}$

c) $< 5\bullet10^{-5}$

d) $< 2\bullet10^{-7}$

e) $< 1\bullet10^{-5}$

f) $< 1\bullet10^{-4}$

g) $< 5\bullet10^{-6}$

h) $< 5\bullet10^{-7}$

Appendix 8

Chemical composition of the particulate component of water

Concentrations of elements in suspended material (particulate pool) has been analysed for a large number of elements at one occasion in April 2008. The results are presented below. In Chapter 7, values in Table A7-1 have been used to describe the particulate pool of water for all elements except carbon nitrogen and phosphorus. For these three elements long-term analysis are available from the site description in the areas. When concentrations were below detection limit, half the detection limit has been used in calculations in Chapter 7. In the tables below, the values used in the calculation are presented and the detection limit is given in footnotes. When analysing particulate matter, the analysis is dependent on the total amount of an element in the sample and therefore the concentration differs between lakes also when half the detection limit are used as a result of different volumes of filtered water. For some elements, the detection limit was not specified and this sometimes resulted in negative concentration when the filters were subtracted in the analyses, so in those cases the concentration was set to 0.

Table A8-1. Chemical composition of suspended material in Forsmark and Laxemar-Simpevarp lakes from one occasion in April 2008. All values are in g m^{-3}. Values below detection limit are presented as half the detection limit and the detection limit for these elements are given in footnotes below.

	Forsmark				Laxemar-Simpevarp			
	Bolundsfjärden	Eckarfjärden	Labboträsk	Mean Forsmark lake	Jämsen	Götemar	Frisksjön	Mean Laxemar lake
Ag	$1.8\bullet10^{-7}$	$2.2\bullet10^{-7}$	$2.0\bullet10^{-7}$	**$2.0\bullet10^{-7}$**	$6.5\bullet10^{-7}$	$1.9\bullet10^{-7}$	$1.1\bullet10^{-6}$	**$6.5\bullet10^{-7}$**
Al	$4.3\bullet10^{-3}$	$3.2\bullet10^{-3}$	$4.1\bullet10^{-3}$	**$3.9\bullet10^{-3}$**	$9.7\bullet10^{-2}$	$6.5\bullet10^{-2}$	$1.7\bullet10^{-1}$	**$1.1\bullet10^{-1}$**
As	$4.1\bullet10^{-6}$	$4.0\bullet10^{-6}$	$2.5\bullet10^{-6}$	**$3.5\bullet10^{-6}$**	$4.7\bullet10^{-5}$	$1.3\bullet10^{-5}$	$7.2\bullet10^{-5}$	**$4.4\bullet10^{-5}$**
Au	$8.2\bullet10^{-8}$ e)	$8.8\bullet10^{-8}$ e)	$4.6\bullet10^{-8}$ e)	**$7.2\bullet10^{-8}$ e)**	$2.2\bullet10^{-7}$ e)	$4.9\bullet10^{-8}$ e)	$2.7\bullet10^{-7}$ e)	**$1.8\bullet10^{-7}$ e)**
B	$3.3\bullet10^{-6}$	0	$5.7\bullet10^{-5}$	**$1.7\bullet10^{-5}$**	$1.9\bullet10^{-5}$	$3.1\bullet10^{-5}$	$4.4\bullet10^{-5}$	**$3.1\bullet10^{-5}$**
Ba	$6.9\bullet10^{-5}$	$9.7\bullet10^{-5}$	$5.9\bullet10^{-5}$	**$7.5\bullet10^{-5}$**	$1.1\bullet10^{-3}$	$5.4\bullet10^{-4}$	$8.4\bullet10^{-4}$	**$8.2\bullet10^{-4}$**
Be	$2.1\bullet10^{-7}$	$1.7\bullet10^{-7}$	$1.7\bullet10^{-7}$	**$1.8\bullet10^{-7}$**	$1.5\bullet10^{-5}$	$1.2\bullet10^{-5}$	$6.3\bullet10^{-5}$	**$3.0\bullet10^{-5}$**
Bi	$4.1\bullet10^{-7}$	$2.5\bullet10^{-7}$	$1.9\bullet10^{-7}$	**$2.8\bullet10^{-7}$**	$2.3\bullet10^{-6}$	$7.8\bullet10^{-7}$	$3.3\bullet10^{-6}$	**$2.1\bullet10^{-6}$**
Br	$4.0\bullet10^{-4}$	$3.2\bullet10^{-4}$	$3.0\bullet10^{-4}$	**$3.4\bullet10^{-4}$**	$8.9\bullet10^{-4}$	$5.4\bullet10^{-4}$	$1.6\bullet10^{-4}$	**$5.3\bullet10^{-4}$**
Ca	$2.1\bullet10^{-2}$	$6.7\bullet10^{-2}$	$1.1\bullet10^{-2}$	**$3.3\bullet10^{-2}$**	$6.2\bullet10^{-2}$	$1.3\bullet10^{-2}$	$4.0\bullet10^{-2}$	**$3.9\bullet10^{-2}$**
Cd	$7.9\bullet10^{-7}$	$1.6\bullet10^{-6}$	$8.8\bullet10^{-7}$	**$1.1\bullet10^{-6}$**	$2.0\bullet10^{-5}$	0	$5.5\bullet10^{-6}$	**$5.8\bullet10^{-6}$**
Ce	$2.3\bullet10^{-5}$	$1.4\bullet10^{-5}$	$8.3\bullet10^{-6}$	**$1.5\bullet10^{-5}$**	$1.6\bullet10^{-3}$	$5.4\bullet10^{-4}$	$1.5\bullet10^{-3}$	**$1.2\bullet10^{-3}$**
Co	$1.7\bullet10^{-6}$	$1.5\bullet10^{-6}$	$1.3\bullet10^{-6}$	**$1.5\bullet10^{-6}$**	$5.2\bullet10^{-5}$	$4.1\bullet10^{-5}$	$4.0\bullet10^{-5}$	**$4.5\bullet10^{-5}$**
Cr	0	$1.1\bullet10^{-5}$	$7.3\bullet10^{-6}$	**$4.8\bullet10^{-6}$**	$8.0\bullet10^{-5}$	$5.1\bullet10^{-5}$	$1.7\bullet10^{-4}$	**$1.0\bullet10^{-4}$**
Cs	$6.6\bullet10^{-7}$	$3.7\bullet10^{-7}$	$5.3\bullet10^{-7}$	**$5.2\bullet10^{-7}$**	$4.6\bullet10^{-6}$	$4.9\bullet10^{-6}$	$8.7\bullet10^{-6}$	**$6.0\bullet10^{-6}$**
Cu	$4.0\bullet10^{-5}$	$3.0\bullet10^{-5}$	$4.6\bullet10^{-5}$	**$3.9\bullet10^{-5}$**	$1.1\bullet10^{-4}$	$6.2\bullet10^{-5}$	$2.5\bullet10^{-4}$	**$1.4\bullet10^{-4}$**
Dy	$1.2\bullet10^{-6}$	$7.9\bullet10^{-7}$	$4.6\bullet10^{-7}$	**$8.2\bullet10^{-7}$**	$8.9\bullet10^{-5}$	$1.9\bullet10^{-5}$	$6.3\bullet10^{-5}$	**$5.7\bullet10^{-5}$**
Er	$7.4\bullet10^{-7}$	$5.3\bullet10^{-7}$	$2.9\bullet10^{-7}$	**$5.2\bullet10^{-7}$**	$6.2\bullet10^{-5}$	$1.4\bullet10^{-5}$	$4.2\bullet10^{-5}$	**$3.9\bullet10^{-5}$**
Eu	$1.8\bullet10^{-7}$	$1.1\bullet10^{-7}$	$6.9\bullet10^{-8}$	**$1.2\bullet10^{-7}$**	$2.0\bullet10^{-5}$	$3.3\bullet10^{-6}$	$1.7\bullet10^{-5}$	**$1.4\bullet10^{-5}$**
Fe	$1.1\bullet10^{-2}$	$3.8\bullet10^{-3}$	$3.8\bullet10^{-3}$	**$6.0\bullet10^{-3}$**	$6.2\bullet10^{-1}$	$6.0\bullet10^{-2}$	$3.7\bullet10^{-1}$	**$3.5\bullet10^{-1}$**
Ga	$1.3\bullet10^{-6}$	$8.1\bullet10^{-7}$	$1.4\bullet10^{-6}$	**$1.2\bullet10^{-6}$**	$1.9\bullet10^{-5}$	$1.4\bullet10^{-5}$	$2.3\bullet10^{-5}$	**$1.8\bullet10^{-5}$**
Gd	$7.4\bullet10^{-7}$	$5.5\bullet10^{-7}$	$3.2\bullet10^{-7}$	**$5.4\bullet10^{-7}$**	$6.6\bullet10^{-5}$	$1.2\bullet10^{-5}$	$4.6\bullet10^{-5}$	**$4.1\bullet10^{-5}$**
Ge	$1.2\bullet10^{-7}$	$3.3\bullet10^{-7}$	$-8.2\bullet10^{-8}$	**$1.2\bullet10^{-7}$**	$2.2\bullet10^{-6}$	$1.4\bullet10^{-6}$	$2.2\bullet10^{-6}$	**$1.9\bullet10^{-6}$**
Hf	$3.3\bullet10^{-7}$	$2.1\bullet10^{-7}$	$3.6\bullet10^{-7}$	**$3.0\bullet10^{-7}$**	$7.0\bullet10^{-6}$	$4.0\bullet10^{-6}$	$1.2\bullet10^{-5}$	**$7.7\bullet10^{-6}$**

	Forsmark				**Laxemar-Simpevarp**			
	Bolunds-fjärden	**Eckar-fjärden**	**Labbo-träsk**	**Mean Forsmark lake**	**Jämsen**	**Götemar**	**Frisksjön**	**Mean Laxemar lake**
Hg	$2.3 \cdot 10^{-7}$	$1.2 \cdot 10^{-7}$	$3.6 \cdot 10^{-7}$	**$2.4 \cdot 10^{-7}$**	$8.9 \cdot 10^{-7}$	$2.2 \cdot 10^{-7}$	$5.9 \cdot 10^{-7}$	**$5.7 \cdot 10^{-7}$**
Ho	$2.5 \cdot 10^{-7}$	$1.9 \cdot 10^{-7}$	$1.1 \cdot 10^{-7}$	**$1.8 \cdot 10^{-7}$**	$2.0 \cdot 10^{-5}$	$4.2 \cdot 10^{-6}$	$1.4 \cdot 10^{-5}$	**$1.3 \cdot 10^{-5}$**
I	$-8.2 \cdot 10^{-6}$	$1.8 \cdot 10^{-4}$	$2.9 \cdot 10^{-5}$	**$6.7 \cdot 10^{-5}$**	$3.5 \cdot 10^{-4}$	$1.5 \cdot 10^{-4}$	$1.1 \cdot 10^{-3}$	**$5.2 \cdot 10^{-4}$**
In	$8.2 \cdot 10^{-8}$ e)	$8.8 \cdot 10^{-8}$ e)	$4.6 \cdot 10^{-8}$ e)	**$7.2 \cdot 10^{-8}$ e)**	$2.2 \cdot 10^{-7}$ e)	$4.9 \cdot 10^{-8}$ e)	$2.7 \cdot 10^{-7}$ e)	**$1.8 \cdot 10^{-7}$ e)**
Ir	4.1^{-10} a)	4.4^{-10} a)	2.3^{-10} a)	**3.6^{-10} a)**	$1.1 \cdot 10^{-9}$ a)	2.5^{-10} a)	$1.3 \cdot 10^{-9}$ a)	**9.0^{-10} a)**
K	$4.1 \cdot 10^{-3}$	$8.8 \cdot 10^{-3}$	$5.6 \cdot 10^{-2}$	**$2.3 \cdot 10^{-2}$**	$1.6 \cdot 10^{-2}$	$1.9 \cdot 10^{-2}$	$2.5 \cdot 10^{-2}$	**$2.0 \cdot 10^{-2}$**
La	$1.6 \cdot 10^{-5}$	$9.1 \cdot 10^{-6}$	$7.2 \cdot 10^{-6}$	**$1.1 \cdot 10^{-5}$**	$8.9 \cdot 10^{-4}$	$2.1 \cdot 10^{-4}$	$7.9 \cdot 10^{-4}$	**$6.3 \cdot 10^{-4}$**
Li	$2.5 \cdot 10^{-6}$	$5.9 \cdot 10^{-6}$	$2.7 \cdot 10^{-6}$	**$3.7 \cdot 10^{-6}$**	$2.7 \cdot 10^{-5}$	$4.5 \cdot 10^{-5}$	$4.5 \cdot 10^{-5}$	**$3.9 \cdot 10^{-5}$**
Lu	$8.4 \cdot 10^{-8}$	$6.9 \cdot 10^{-8}$	$3.4 \cdot 10^{-8}$	**$6.2 \cdot 10^{-8}$**	$7.5 \cdot 10^{-6}$	$2.1 \cdot 10^{-6}$	$5.1 \cdot 10^{-6}$	**$4.9 \cdot 10^{-6}$**
Mg	$2.5 \cdot 10^{-3}$	$4.2 \cdot 10^{-3}$	$1.5 \cdot 10^{-3}$	**$2.7 \cdot 10^{-3}$**	$1.3 \cdot 10^{-2}$	$7.2 \cdot 10^{-3}$	$1.3 \cdot 10^{-2}$	**$1.1 \cdot 10^{-2}$**
Mn	$8.7 \cdot 10^{-4}$	$4.9 \cdot 10^{-3}$	$2.0 \cdot 10^{-4}$	**$2.0 \cdot 10^{-3}$**	$1.3 \cdot 10^{-2}$	$1.1 \cdot 10^{-2}$	$5.7 \cdot 10^{-3}$	**$9.9 \cdot 10^{-3}$**
Mo	$3.3 \cdot 10^{-6}$	$2.7 \cdot 10^{-6}$	$3.4 \cdot 10^{-6}$	**$3.1 \cdot 10^{-6}$**	$9.3 \cdot 10^{-6}$	$6.5 \cdot 10^{-6}$	$3.6 \cdot 10^{-5}$	**$1.7 \cdot 10^{-5}$**
Na	$4.9 \cdot 10^{-3}$	$7.6 \cdot 10^{-3}$	$1.6 \cdot 10^{-3}$	**$4.7 \cdot 10^{-3}$**	$7.6 \cdot 10^{-3}$	$8.9 \cdot 10^{-3}$	$1.7 \cdot 10^{-2}$	**$1.1 \cdot 10^{-2}$**
Nb	$9.7 \cdot 10^{-7}$	$8.1 \cdot 10^{-7}$	$9.1 \cdot 10^{-7}$	**$9.0 \cdot 10^{-7}$**	$3.6 \cdot 10^{-5}$	$1.3 \cdot 10^{-5}$	$3.2 \cdot 10^{-5}$	**$2.7 \cdot 10^{-5}$**
Nd	$8.7 \cdot 10^{-6}$	$5.3 \cdot 10^{-6}$	$3.3 \cdot 10^{-6}$	**$5.8 \cdot 10^{-6}$**	$7.5 \cdot 10^{-4}$	$1.4 \cdot 10^{-4}$	$6.3 \cdot 10^{-4}$	**$5.1 \cdot 10^{-4}$**
Ni	$1.6 \cdot 10^{-5}$	$1.4 \cdot 10^{-5}$	$1.0 \cdot 10^{-5}$	**$1.4 \cdot 10^{-5}$**	$6.0 \cdot 10^{-5}$	$4.6 \cdot 10^{-5}$	$1.3 \cdot 10^{-4}$	**$7.8 \cdot 10^{-5}$**
Os	$1.6 \cdot 10^{-9}$ b)	$1.8 \cdot 10^{-9}$ b)	9.1^{-10} b)	**$1.4 \cdot 10^{-9}$ b)**	$4.5 \cdot 10^{-9}$ b)	9.9^{-10} b)	$5.3 \cdot 10^{-9}$ b)	**$3.6 \cdot 10^{-9}$ b)**
P	$5.5 \cdot 10^{-3}$	$5.7 \cdot 10^{-3}$	$3.4 \cdot 10^{-3}$	**$4.9 \cdot 10^{-3}$**	$1.0 \cdot 10^{-2}$	$4.9 \cdot 10^{-3}$	$1.3 \cdot 10^{-2}$	**$9.4 \cdot 10^{-3}$**
Pb	$4.8 \cdot 10^{-5}$	$5.8 \cdot 10^{-5}$	$2.1 \cdot 10^{-5}$	**$4.2 \cdot 10^{-5}$**	$3.8 \cdot 10^{-4}$	$1.2 \cdot 10^{-4}$	$4.8 \cdot 10^{-4}$	**$3.3 \cdot 10^{-4}$**
Pd	$1.6 \cdot 10^{-6}$ f)	$1.8 \cdot 10^{-6}$ f)	$9.1 \cdot 10^{-7}$ f)	**$1.4 \cdot 10^{-6}$ f)**	$4.5 \cdot 10^{-6}$ f)	$9.9 \cdot 10^{-7}$ f)	$5.3 \cdot 10^{-6}$ f)	**$3.6 \cdot 10^{-6}$ f)**
Pr	$2.6 \cdot 10^{-6}$	$1.5 \cdot 10^{-6}$	$9.0 \cdot 10^{-7}$	**$1.7 \cdot 10^{-6}$**	$2.0 \cdot 10^{-4}$	$3.8 \cdot 10^{-5}$	$1.7 \cdot 10^{-4}$	**$1.4 \cdot 10^{-4}$**
Pt	$4.1 \cdot 10^{-8}$ d)	$4.4 \cdot 10^{-8}$ d)	$2.3 \cdot 10^{-8}$ d)	**$3.6 \cdot 10^{-8}$ d)**	$1.1 \cdot 10^{-7}$ d)	$2.5 \cdot 10^{-8}$ d)	$1.3 \cdot 10^{-7}$ d)	**$9.0 \cdot 10^{-8}$ d)**
Rb	$1.1 \cdot 10^{-5}$	$1.8 \cdot 10^{-5}$	$1.2 \cdot 10^{-5}$	**$1.3 \cdot 10^{-5}$**	$7.5 \cdot 10^{-5}$	$1.0 \cdot 10^{-4}$	$1.4 \cdot 10^{-4}$	**$1.0 \cdot 10^{-4}$**
Re	1.6^{-10}	$2.1 \cdot 10^{-9}$	3.6^{-10}	**8.8^{-10}**	$2.2 \cdot 10^{-9}$	3.9^{-10}	0	**1.7^{-10}**
Rh	8.2^{-10} c)	8.8^{-10} c)	4.6^{-10} c)	**7.2^{-10} c)**	$2.2 \cdot 10^{-8}$ c)	$4.9 \cdot 10^{-9}$ c)	$2.7 \cdot 10^{-8}$ c)	**$1.8 \cdot 10^{-8}$ c)**
Ru	$4.1 \cdot 10^{-8}$ d)	$4.4 \cdot 10^{-8}$ d)	$2.3 \cdot 10^{-8}$ d)	**$3.6 \cdot 10^{-8}$ d)**	$1.1 \cdot 10^{-7}$ d)	$2.5 \cdot 10^{-8}$ d)	$1.3 \cdot 10^{-7}$ d)	**$9.0 \cdot 10^{-8}$ d)**
S	$9.9 \cdot 10^{-3}$	$2.0 \cdot 10^{-2}$	$5.1 \cdot 10^{-3}$	**$1.1 \cdot 10^{-2}$**	$1.9 \cdot 10^{-2}$	$8.0 \cdot 10^{-3}$	$3.0 \cdot 10^{-2}$	**$1.9 \cdot 10^{-2}$**
Sb	$9.6 \cdot 10^{-7}$	$2.3 \cdot 10^{-6}$	$2.7 \cdot 10^{-6}$	**$2.0 \cdot 10^{-6}$**	$5.0 \cdot 10^{-6}$	$1.5 \cdot 10^{-6}$	$4.8 \cdot 10^{-6}$	**$3.7 \cdot 10^{-6}$**
Sc	$1.4 \cdot 10^{-6}$	$1.5 \cdot 10^{-6}$	$1.2 \cdot 10^{-6}$	**$1.4 \cdot 10^{-6}$**	$2.3 \cdot 10^{-5}$	$1.1 \cdot 10^{-5}$	$3.7 \cdot 10^{-5}$	**$2.4 \cdot 10^{-5}$**
Se	$8.4 \cdot 10^{-7}$	$9.5 \cdot 10^{-7}$	$5.1 \cdot 10^{-7}$	**$7.7 \cdot 10^{-7}$**	$3.8 \cdot 10^{-6}$	$3.2 \cdot 10^{-6}$	$6.4 \cdot 10^{-6}$	**$4.5 \cdot 10^{-6}$**
Si	$3.4 \cdot 10^{-2}$	$3.3 \cdot 10^{-2}$	$2.4 \cdot 10^{-2}$	**$3.0 \cdot 10^{-2}$**	$2.6 \cdot 10^{-1}$	$2.2 \cdot 10^{-1}$	$5.1 \cdot 10^{-1}$	**$3.3 \cdot 10^{-1}$**
Sm	$1.6 \cdot 10^{-6}$	$1.1 \cdot 10^{-6}$	$6.2 \cdot 10^{-7}$	**$1.1 \cdot 10^{-6}$**	$1.4 \cdot 10^{-4}$	$2.5 \cdot 10^{-5}$	$1.1 \cdot 10^{-4}$	**$8.9 \cdot 10^{-5}$**
Sn	0	$6.5 \cdot 10^{-7}$	$2.8 \cdot 10^{-6}$	**$1.0 \cdot 10^{-6}$**	$1.2 \cdot 10^{-5}$	$4.0 \cdot 10^{-6}$	$1.2 \cdot 10^{-5}$	**$9.1 \cdot 10^{-6}$**
Sr	$4.9 \cdot 10^{-5}$	$6.9 \cdot 10^{-5}$	$2.1 \cdot 10^{-5}$	**$4.6 \cdot 10^{-5}$**	$4.2 \cdot 10^{-4}$	$1.4 \cdot 10^{-4}$	$3.0 \cdot 10^{-4}$	**$2.9 \cdot 10^{-4}$**
Ta	0	0	0	**0**	$8.9 \cdot 10^{-7}$	$4.9 \cdot 10^{-7}$	$5.3 \cdot 10^{-7}$	**$6.4 \cdot 10^{-7}$**
Tb	$1.9 \cdot 10^{-7}$	$1.3 \cdot 10^{-7}$	$7.2 \cdot 10^{-8}$	**$1.3 \cdot 10^{-7}$**	$1.4 \cdot 10^{-5}$	$2.8 \cdot 10^{-6}$	$1.0 \cdot 10^{-5}$	**$9.0 \cdot 10^{-6}$**
Te	$9.6 \cdot 10^{-8}$	$6.5 \cdot 10^{-8}$	$3.2 \cdot 10^{-8}$	**$6.4 \cdot 10^{-8}$**	$3.9 \cdot 10^{-7}$	$1.7 \cdot 10^{-7}$	$6.7 \cdot 10^{-7}$	**$4.1 \cdot 10^{-7}$**
Th	$3.3 \cdot 10^{-6}$	$2.2 \cdot 10^{-6}$	$1.6 \cdot 10^{-6}$	**$2.4 \cdot 10^{-6}$**	$6.2 \cdot 10^{-5}$	$2.7 \cdot 10^{-5}$	$8.9 \cdot 10^{-5}$	**$6.0 \cdot 10^{-5}$**
Ti	$1.6 \cdot 10^{-4}$	$1.7 \cdot 10^{-4}$	$1.6 \cdot 10^{-4}$	**$1.6 \cdot 10^{-4}$**	$4.1 \cdot 10^{-3}$	$1.5 \cdot 10^{-3}$	$3.5 \cdot 10^{-3}$	**$3.0 \cdot 10^{-3}$**
Tl	$2.4 \cdot 10^{-7}$	$1.8 \cdot 10^{-7}$	$1.4 \cdot 10^{-7}$	**$1.9 \cdot 10^{-7}$**	$1.0 \cdot 10^{-6}$	$7.9 \cdot 10^{-7}$	$1.3 \cdot 10^{-6}$	**$1.0 \cdot 10^{-6}$**
Tm	$1.0 \cdot 10^{-7}$	$7.6 \cdot 10^{-8}$	$3.8 \cdot 10^{-8}$	**$7.2 \cdot 10^{-8}$**	$8.4 \cdot 10^{-6}$	$2.1 \cdot 10^{-6}$	$5.8 \cdot 10^{-6}$	**$5.4 \cdot 10^{-6}$**
U	$1.8 \cdot 10^{-6}$	$2.0 \cdot 10^{-6}$	$2.8 \cdot 10^{-6}$	**$2.2 \cdot 10^{-6}$**	$3.1 \cdot 10^{-5}$	$3.5 \cdot 10^{-5}$	$6.8 \cdot 10^{-5}$	**$4.5 \cdot 10^{-5}$**
V	$1.0 \cdot 10^{-5}$	$5.6 \cdot 10^{-6}$	$7.4 \cdot 10^{-6}$	**$7.7 \cdot 10^{-6}$**	$6.2 \cdot 10^{-4}$	$9.6 \cdot 10^{-5}$	$6.3 \cdot 10^{-4}$	**$4.5 \cdot 10^{-4}$**
W	$9.6 \cdot 10^{-7}$	$1.0 \cdot 10^{-6}$	$9.8 \cdot 10^{-7}$	**$9.8 \cdot 10^{-7}$**	$4.7 \cdot 10^{-6}$	$2.0 \cdot 10^{-6}$	$7.1 \cdot 10^{-6}$	**$4.6 \cdot 10^{-6}$**

	Forsmark				**Laxemar-Simpevarp**			
	Bolundsfjärden	**Eckarfjärden**	**Labboträsk**	**Mean Forsmark lake**	**Jämsen**	**Götemar**	**Frisksjön**	**Mean Laxemar lake**
Y	7.0•10^{-6}	5.1•10^{-6}	2.8•10^{-6}	**5.0•10^{-6}**	5.8•10^{-4}	1.3•10^{-4}	3.9•10^{-4}	**3.6•10^{-4}**
Yb	5.1•10^{-7}	3.9•10^{-7}	2.0•10^{-7}	**3.7•10^{-7}**	4.4•10^{-5}	1.5•10^{-5}	3.1•10^{-5}	**3.0•10^{-5}**
Zn	6.6•10^{-5}	1.2•10^{-4}	5.5•10^{-5}	**8.1•10^{-5}**	7.1•10^{-4}	3.6•10^{-4}	6.4•10^{-4}	**5.7•10^{-4}**
Zr	1.4•10^{-5}	1.4•10^{-5}	1.3•10^{-5}	**1.4•10^{-5}**	2.1•10^{-4}	1.3•10^{-4}	3.9•10^{-4}	**2.4•10^{-4}**

Detection limits:

[a] < 0.005 ng

[b] < 0.02 ng

[c] < 0.1 ng

[d] < 0.5 ng

[e] < 1 ng

[f] < 20 ng

Appendix 9

Chemical composition in the sediment component

The chemical composition of lake sediments has been investigated (in Forsmark: /Hannu and Karlsson 2006, Strömgren and Brunberg 2006/ and in Laxemar: /Engdahl et al. 2006/). In this appendix the mean concentrations of each element are presented. For the Forsmark lakes data is shown according to the three different sediment layers; gyttja, gyttja clay and clay (Table A9-1). For Laxemar lake (Frisksjön) data is shown for the upper two centimetres and for the rest of the gyttja layer (0.02–4.40 m) (Table A9-2). Data in the tables below are sorted in alphabetical order.

Table A9-1. Chemistry in different sediment layers in lakes in the Forsmark area. The number of analytical results used for calculating the mean values are presented in columns denoted "n". Analytical results reported as below the detection limit has been changed to half the detection limit. The number of values below detection limit is presented in separate columns with detection limits in parenthesis.

	Gyttja			Clay gyttja			Clay		
	Conc (mg/kg dw)	n	Values below detection limit	Conc (mg/kg dw)	n	Values below detection limit	Conc (mg/kg dw)	n	Values below detection limit
Ag	18.8	5		23.5	1		8.2	3	
Al	6,563.3	5		49,224.9	1		88,922.4	3	
As	3.5	14		7.4	2		7.1	4	
B	41.4	14		33.6	2	1 (20 mg/kg dw)	25.9	4	
Ba	112.1	14		364.5	2		679.3	4	
Be	0.4	14	5 (3–4 mg/kg dw)	2.6	2		2.9	4	
Br	27.7	5		93.8	1		1.7	3	
C*	356,000.0	5		88,000.0	1		10,000.0	5	
Ca	64,751.8	5		12,650.2	1		34,710.6	3	
Cd	0.6	14		0.5	2		0.3	4	
Ce	46.8	14		84.5	2		98.6	4	
Cl	781.0	5		334.0	1		76.6	3	
Co	2.5	16		11.1	3		13.3	5	
Cr	13.7	23	3 (5–8 mg/kg dw)	43.9	3		88.0	5	
Cs	0.8	14		5.9	2		7.7	4	
Cu	26.6	23		30.5	3		35.2	5	
Dy	3.7	14		5.9	2		6.7	4	
Er	2.4	14	1 (1 mg/kg dw)	3.6	2		3.3	4	
Eu	0.5	14	1 (0.05 mg/kg dw)	1.0	2		1.3	4	
Fe	9,100.9	14		30,489.5	2		53,793.7	4	
Ga	0.6	14	13 (1 mg/kg dw)	8.9	2	1 (1 mg/kg dw)	18.1	4	1 (1 mg/kg dw)
Gd	2.0	14	3 (0.04 mg/kg dw)	5.1	2		6.2	4	
Hf	1.5	14		4.1	2		5.2	4	
Hg	0.1	14	2 (0.04–0.1 mg/kg dw)	0.0	2	1 (0.04 mg/kg dw)	0.0	4	3 (0.04 mg/kg dw)
Ho	0.8	14		1.3	2		1.3	4	
I	8.8	5		7.9	1		0.3	3	3 (0.5 mg/kg dw)
K	3,842.6	14		16,396.5	2		31,153.3	4	
La	22.2	14		48.7	2		58.6	4	
Li	11.6	14		141.7	2		438.3	4	

	Gyttja			Clay gyttja			Clay		
	Conc (mg/kg dw)	n	Values below detection limit	Conc (mg/kg dw)	n	Values below detection limit	Conc (mg/kg dw)	n	Values below detection limit
Lu	0.3	14		0.5	2		0.5	4	
Mg	2,511.9	14		7,871.8	2		16,120.5	4	
Mn	246.4	23		303.2	3		556.5	5	
Mo	15.1	14		17.0	2		5.8	4	3 (2 mg/kg dw)
N	28,766.7	3		5,980.0	1			0	
Na	2,242.5	14		7,942.0	2		12,890.5	4	
Nb	3.9	14	1 (0.2 mg/kg dw)	11.0	2		17.0	4	
Nd	22.3	14		41.1	2		45.1	4	
Ni	13.6	23	5 (5–8 mg/kg dw)	28.3	3		36.9	5	
P	477.9	14		637.1	2		792.1	4	
Pb	27.8	14		28.1	2		25.5	4	
Pr	7.9	14		12.8	2		12.8	4	
Rb	32.0	14	5 (2 mg/kg dw)	111.1	2		137.0	4	
S	8,496.4	14		8,489.0	2		1,637.5	4	
Sb	0.5	14		0.7	2		0.6	4	1 (0.02 mg/kg dw)
Sc	2.5	14	2 (0.5–0.8 mg/kg dw)	8.6	2		15.3	4	
Se	1.1	5	3 (1–2 mg/kg dw)	0.5	1	1 (1 mg/kg dw)	0.5	3	3 (1 mg/kg dw)
Si	80,343.2	14		200,791.3	2		244,619.4	4	
Sm	3.7	14	1 (0.4 mg/kg dw)	7.1	2		7.8	4	
Sn	1.6	14	6 (1 mg/kg dw)	2.9	2	1 (1 mg/kg dw)	3.4	4	
Sr	63.8	14		86.5	2		144.2	4	
Ta	0.5	14	2 (0.06 mg/kg dw)	1.0	2		1.5	4	
Tb	0.3	14	6 (0.1 mg/kg dw)	0.9	2		1.0	4	
Th	4.1	14		11.2	2		16.1	4	
Ti	531.4	14		2,254.1	2		4,358.4	4	
Tl	0.4	5		1.7	1		1.1	3	
Tm	0.3	14	3 (0.1 mg/kg dw)	0.4	2		0.7	4	
U	34.7	14		20.2	2		8.9	4	
V	13.9	23		41.5	3		94.7	5	
W	2.3	14	1 (0.4 mg/kg dw)	2.8	2		2.5	4	
Y	12.9	14		26.1	2		34.9	4	
Yb	1.8	14	1 (0.2 mg/kg dw)	2.9	2		3.8	4	
Zn	140.7	23		307.7	3		807.4	5	
Zr	26.6	14		114.0	2		167.8	4	

*Carbon data for clay has been taken from /Hedenström and Risberg 2003/. Data from Eckarfjärden.

Table A9-2. Chemistry in different sediment layers in Frisksjön in the Laxemar-Simpevarp area. The numbers of analytical results used for calculating the mean values are presented in columns denoted "n". Analytical results reported as below the detection limit has been changed to half the detection limit. The number of values which was below detection limit is presented in separate columns with detection limits in parenthesis.

	Sediment 0.00–0.02 m			Sediment 0.02–4.40 m		
	Conc (mg/kg dw)	n	Values below detection limit	Conc (mg/kg dw)	n	Values below detection limit
Ag	0.1	1	1 (0.20)	0.1	11	9 (0.030–0.20 mg/kg dw)
Al	30,170.1	1		23,770.4	11	
As	4.42	1		7.6	11	
B	0.5	1	1 (1.0 mg/kg dw)	0.9	11	11 (1.0–3.0 mg/kg dw)
Ba	181	1		145.3	11	
Be	8.73	1		5.6	11	
Br	8.4	1		82.1	11	
C	170,000	1		179,090.9	11	
Ca	8,147.58	1		8,758.3	11	
Cd	3.47	1		2.3	11	
Ce	222	1		185.0	11	
Cl	352	1		2,763.5	11	
Co	22.2	1		13.2	11	
Cr	36.6	1		34.1	11	
Cs	2.23	1		1.8	11	
Cu	66.4	1		58.8	11	
Dy	11.7	1		8.7	11	
Er	8.03	1		5.1	11	
Eu	3.57	1		2.7	11	
Fe	30,139.83	1		23,382.0	11	
Ga	67.6	1		8.3	11	8 (1.0 mg/kg dw)
Gd	16.6	1		12.1	11	
Hf	0.826	1		0.7	11	3 (0.10 mg/kg dw)
Hg	0.153	1		0.1	11	4 (0.040 mg/kg dw)
Ho	2.52	1		1.8	11	
I	4.25	1		15.3	11	
K	5,645.36	1		5,502.0	11	
La	116	1		87.0	11	
Li	19.6	1		14.0	11	
Lu	0.988	1		0.8	11	
Mg	3,257.28	1		4,968.2	11	
Mn	261.0402	1		200.3	11	
Mo	3	1	1 (6.0 mg/kg dw)	8.1	11	6 (6.0 mg/kg dw)
N	12,700	1		18,063.6	11	
Na	2,351.823	1		4,943.8	11	
Nb	3	1	1 (6.0 mg/kg dw)	3.0	11	11 (6.0 mg/kg dw)
Nd	119	1		95.5	11	
Ni	52	1		42.8	11	
P	1,557.948	1		1,765.8	11	
Pb	42.7	1		23.3	11	
Pr	32.4	1		24.3	11	
Rb	39.7	1		33.6	11	

	Sediment 0.00–0.02 m			**Sediment 0.02–4.40 m**		
	Conc (mg/kg dw)	**n**	**Values below detection limit**	**Conc (mg/kg dw)**	**n**	**Values below detection limit**
S	18,500	1		23,690.9	11	
Sb	0.785	1		0.5	11	
Sc	7.74	1		6.5	11	
Se	1	1	1 (2.0 mg/kg dw)	1.0	11	11 (2.0 mg/kg dw)
Si	192,610	1		186,150.0	11	
Sm	19.3	1		15.2	11	
Sn	10	1	1 (20 mg/kg dw)	10.0	11	11 (20 mg/kg dw)
Sr	66.8	1		94.5	11	
Ta	0.03	1	1 (0.060 mg/kg dw)	0.2	11	7 (0.060 mg/kg dw)
Tb	2.02	1		1.7	11	
Th	9.9	1		7.6	11	
Ti	107.91	1		93.2	11	
Tl	0.605	1		0.4	11	
Tm	1.18	1		0.8	11	
U	13	1		12.8	11	
V	42.5	1		35.3	11	
W	30	1	1 (60 mg/kg dw)	30.0	11	11 (60 mg/kg dw)
Y	83.2	1		61.3	11	
Yb	6.65	1		5.3	11	
Zn	233	1		139.6	11	
Zr	57.8	1		54.6	11	

Chemical composition of the biotic component

Table A10-1. Chemistry in lake biota in Forsmark used in calculations of pools in Chapter 7. Values are in g gC^{-1}. Data on fish, benthic filter feeders, microphytobenthos and macroalgae Chara sp. are site specific data from /Hannu and Karlsson 2006/. Data on phytoplankton, zooplankton benthic herbivores, benthic detritivores and benthic carnivores are taken from the coastal areas outside Forsmark /Kumblad and Bradshaw 2008/. Chemical composition of benthic omnivores was calculated as a mean of the other functional groups. Chemical composition for benthic herbivores, detritivores, carnivores of 15 elements (Ag, B, Be, Ga, Hf, La, Nb, Sb, Sc, Sn, Sr, Ta, Ti, W and Y) was assumed to be identical to chemical composition of benthic filter feeders. Data on bacterioplankton P, N and S content are from /Fagerbakke 1996/. For benthic bacteria P and N content are from /Kautsky 1995/ and S content are assumed to be identical to bacterioplankton /Fagerbakke 1996/. "–" denotes missing data, and * indicates were half the detection limit is reported. For further explanation of the use of data, see Chapter 7.

Element	Phyto-plankton	Microphyto-benthos	Macro-algae	Bacterio-plankton	Zoo-plankton	Benthic bacteria	Benthic herbivores	Benthic filter feeders	Benthic detrivores	Benthic carnivores	Benthic omnivores	B fish	Z fish	P fish
C	1	1	1	1	1	1	1	1	1	1	1	1	1	1
N	$1.2\bullet10^{-1}$	$9.8\bullet10^{-2}$	$2.6\bullet10^{-2}$	$1.9\bullet10^{-1}$	$2.3\bullet10^{-1}$	$1.8\bullet10^{-1}$	$1.2\bullet10^{-1}$	$2.2\bullet10^{-1}$	$7.9\bullet10^{-2}$	$1.8\bullet10^{-1}$	$1.5\bullet10^{-1}$	$2.6\bullet10^{-1}$	$4.0\bullet10^{-1}$	$3.4\bullet10^{-1}$
P	$7.5\bullet10^{-3}$	$3.0\bullet10^{-3}$	$2.0\bullet10^{-3}$	$4.6\bullet10^{-2}$	$2.2\bullet10^{-2}$	$5.6\bullet10^{-2}$	$1.1\bullet10^{-2}$	$6.9\bullet10^{-3}$	$8.7\bullet10^{-3}$	$2.1\bullet10^{-2}$	$2.7\bullet10^{-2}$	$2.5\bullet10^{-2}$	$2.3\bullet10^{-2}$	$3.1\bullet10^{-2}$
Ag	–	$3.8\bullet10^{-5}$	$2.5\bullet10^{-8}$	–	–	–	$1.2\bullet10^{-6}$	$1.2\bullet10^{-6}$	$1.2\bullet10^{-6}$	$1.2\bullet10^{-6}$	$1.2\bullet10^{-6}$	$1.1\bullet10^{-8}$*	$8.0\bullet10^{-8}$*	$1.2\bullet10^{-8}$*
Al	$1.1\bullet10^{-1}$	$8.4\bullet10^{-3}$	$1.1\bullet10^{-3}$	–	$6.8\bullet10^{-3}$	–	$2.7\bullet10^{-3}$	$5.6\bullet10^{-4}$	$3.5\bullet10^{-3}$	$2.0\bullet10^{-6}$	$1.7\bullet10^{-3}$	$2.3\bullet10^{-7}$	$2.4\bullet10^{-6}$	$1.2\bullet10^{-7}$
As	$7.0\bullet10^{-5}$	$3.5\bullet10^{-6}$	$7.0\bullet10^{-7}$	–	$5.5\bullet10^{-5}$	–	$1.5\bullet10^{-5}$	$5.8\bullet10^{-6}$	$1.1\bullet10^{-5}$	$1.8\bullet10^{-5}$	$1.3\bullet10^{-5}$	$1.8\bullet10^{-7}$	$1.0\bullet10^{-7}$	$1.8\bullet10^{-7}$
B	–	$5.7\bullet10^{-5}$	$2.8\bullet10^{-5}$	–	–	–	$5.1\bullet10^{-6}$	$5.1\bullet10^{-6}$	$5.1\bullet10^{-6}$	$5.1\bullet10^{-6}$	$5.1\bullet10^{-6}$	$3.7\bullet10^{-8}$	$2.9\bullet10^{-7}$	$3.5\bullet10^{-8}$
Ba	$2.7\bullet10^{-4}$	$2.2\bullet10^{-4}$	$4.5\bullet10^{-4}$	–	$1.2\bullet10^{-4}$	–	$1.2\bullet10^{-4}$	$1.1\bullet10^{-3}$*	$1.7\bullet10^{-4}$	$2.2\bullet10^{-4}$	$4.1\bullet10^{-4}$	$1.1\bullet10^{-6}$*	$2.0\bullet10^{-6}$*	$2.9\bullet10^{-7}$*
Be	–	$3.7\bullet10^{-7}$	$9.5\bullet10^{-8}$	–	–	–	$7.4\bullet10^{-8}$	$7.4\bullet10^{-8}$	$7.4\bullet10^{-8}$	$7.4\bullet10^{-8}$	$7.4\bullet10^{-8}$	$5.7\bullet10^{-8}$	$4.0\bullet10^{-7}$	$5.8\bullet10^{-8}$
Br	$7.6\bullet10^{-3}$	$3.3\bullet10^{-5}$	$4.5\bullet10^{-5}$	–	$3.1\bullet10^{-2}$	–	$6.7\bullet10^{-4}$	$1.3\bullet10^{-4}$	$1.8\bullet10^{-4}$	$2.8\bullet10^{-4}$	$3.2\bullet10^{-4}$	$2.8\bullet10^{-5}$	$1.9\bullet10^{-5}$	$2.0\bullet10^{-5}$
Ca	$2.2\bullet10^{-2}$	$1.4\bullet10^{-1}$	$7.7\bullet10^{-1}$	–	$2.1\bullet10^{-1}$	–	$5.7\bullet10^{-1}$	$2.4\bullet10^{-1}$	1.5	$3.4\bullet10^{-1}$	$6.7\bullet10^{-1}$	$4.8\bullet10^{-3}$	$9.0\bullet10^{-3}$	$1.1\bullet10^{-2}$
Cd	$1.4\bullet10^{-6}$	$7.2\bullet10^{-7}$	$2.1\bullet10^{-7}$	–	$1.1\bullet10^{-5}$	–	$4.7\bullet10^{-6}$	$1.0\bullet10^{-5}$	$8.6\bullet10^{-7}$	$5.1\bullet10^{-6}$	$5.3\bullet10^{-6}$	$3.4\bullet10^{-9}$*	$1.7\bullet10^{-8}$*	$3.5\bullet10^{-9}$*
Ce	$5.2\bullet10^{-8}$	$5.9\bullet10^{-5}$	$3.6\bullet10^{-6}$	–	$8.4\bullet10^{-6}$	–	$1.9\bullet10^{-7}$	$2.3\bullet10^{-6}$	$1.9\bullet10^{-6}$	$1.0\bullet10^{-7}$	$1.1\bullet10^{-6}$	–	–	–
Cl	$3.7\bullet10^{-1}$	$1.4\bullet10^{-3}$	$3.2\bullet10^{-3}$	–	–	–	$1.8\bullet10^{-2}$	$6.6\bullet10^{-3}$	$1.1\bullet10^{-2}$	$1.3\bullet10^{-2}$	$1.2\bullet10^{-2}$	$3.9\bullet10^{-3}$	$1.1\bullet10^{-2}$	$2.5\bullet10^{-3}$
Co	$9.2\bullet10^{-6}$	$2.6\bullet10^{-6}$	$1.0\bullet10^{-6}$	–	$3.9\bullet10^{-6}$	–	$1.9\bullet10^{-6}$	$2.2\bullet10^{-6}$	$1.7\bullet10^{-6}$	$2.0\bullet10^{-6}$	$2.0\bullet10^{-6}$	$1.2\bullet10^{-8}$	$3.9\bullet10^{-8}$	$5.8\bullet10^{-9}$
Cr	$3.5\bullet10^{-5}$	$1.3\bullet10^{-5}$	$2.1\bullet10^{-6}$	–	$2.4\bullet10^{-5}$	–	$2.3\bullet10^{-6}$	$2.1\bullet10^{-6}$	$3.0\bullet10^{-6}$	$3.0\bullet10^{-6}$	$2.6\bullet10^{-6}$	$1.1\bullet10^{-8}$*	$1.1\bullet10^{-7}$*	$1.2\bullet10^{-8}$*

Element	Phyto-plankton	Microphyto-benthos	Macro-algae	Bacterio-plankton	Zoo-plankton	Benthic bacteria	Benthic herbivores	Benthic filter feeders	Benthic detrivores	Benthic carnivores	Benthic omnivores	B fish	Z fish	P fish
Cs	$2.8\cdot10^{-6}$	$4.1\cdot10^{-7}$	$9.4\cdot10^{-8}$	–	$7.6\cdot10^{-7}$	–	$2.4\cdot10^{-7}$	$6.3\cdot10^{-8}$	$3.2\cdot10^{-7}$	$2.6\cdot10^{-7}$	$2.2\cdot10^{-7}$	$1.4\cdot10^{-7}$	$7.9\cdot10^{-8}$	$3.3\cdot10^{-7}$
Cu	$1.3\cdot10^{-4}$	$3.7\cdot10^{-5}$	$4.9\cdot10^{-5}$	–	$4.7\cdot10^{-4}$	–	$9.7\cdot10^{-5}$	$4.5\cdot10^{-5}$	$1.3\cdot10^{-4}$	$1.5\cdot10^{-4}$	$1.1\cdot10^{-4}$	$2.0\cdot10^{-6}$	$2.8\cdot10^{-6}$	$1.2\cdot10^{-6}$
Dy	$2.8\cdot10^{-9}$	$8.4\cdot10^{-6}$	$3.8\cdot10^{-7}$	–	$6.5\cdot10^{-7}$	–	$1.3\cdot10^{-8}$	$1.1\cdot10^{-7}$	$1.1\cdot10^{-7}$	$6.9\cdot10^{-9}$	$6.0\cdot10^{-8}$	$2.3\cdot10^{-10*}$	$1.7\cdot10^{-9*}$	$2.3\cdot10^{-10*}$
Er	$1.6\cdot10^{-9}$	$4.5\cdot10^{-6}$	$2.6\cdot10^{-7}$	–	$3.7\cdot10^{-7}$	–	$6.9\cdot10^{-9}$	$7.0\cdot10^{-8}$	$5.5\cdot10^{-8}$	$3.8\cdot10^{-9}$	$3.4\cdot10^{-8}$	$2.3\cdot10^{-10*}$	$1.7\cdot10^{-9*}$	$2.3\cdot10^{-10*}$
Eu	$1.2\cdot10^{-9}$	$8.8\cdot10^{-7}$	$1.3\cdot10^{-7}$	–	$1.1\cdot10^{-7}$	–	$2.1\cdot10^{-9}$	$1.8\cdot10^{-7}$	$2.6\cdot10^{-8}$	$1.1\cdot10^{-9}$	$5.3\cdot10^{-8}$	$2.3\cdot10^{-10*}$	$1.7\cdot10^{-9*}$	$2.3\cdot10^{-10*}$
F	$5.6\cdot10^{-3}$	–	–	–	–	–	$1.2\cdot10^{-4}$	–	$1.2\cdot10^{-4}$	$1.2\cdot10^{-4}$	$9.3\cdot10^{-5}$	–	–	–
Fe	$2.1\cdot10^{-2}$	$1.0\cdot10^{-2}$	$1.5\cdot10^{-3}$	–	$4.9\cdot10^{-3}$	–	$1.6\cdot10^{-3}$	$6.3\cdot10^{-3}$	$4.7\cdot10^{-3}$	$1.6\cdot10^{-3}$	$3.5\cdot10^{-3}$	$3.5\cdot10^{-5}$	$3.2\cdot10^{-5}$	$1.1\cdot10^{-5}$
Ga	–	$1.3\cdot10^{-6*}$	$2.3\cdot10^{-7}$	–	–	–	$1.4\cdot10^{-7}$	$1.4\cdot10^{-7}$	$1.4\cdot10^{-7}$	$1.4\cdot10^{-7}$	$1.4\cdot10^{-7}$	$4.5\cdot10^{-9*}$	$2.8\cdot10^{-8*}$	$4.6\cdot10^{-9*}$
Gd	$3.5\cdot10^{-9}$	$6.4\cdot10^{-6}$	$3.6\cdot10^{-7}$	–	$6.8\cdot10^{-7}$	–	$1.6\cdot10^{-8}$	$1.4\cdot10^{-7}$	$1.7\cdot10^{-7}$	$8.9\cdot10^{-9}$	$8.3\cdot10^{-8}$	$2.3\cdot10^{-10*}$	$1.7\cdot10^{-9*}$	$2.3\cdot10^{-10*}$
Hf	–	$2.8\cdot10^{-6}$	$3.6\cdot10^{-8}$	–	–	–	$1.5\cdot10^{-8}$	$1.5\cdot10^{-8}$	$1.5\cdot10^{-8}$	$1.5\cdot10^{-8}$	$1.5\cdot10^{-8}$	$2.3\cdot10^{-10*}$	$3.0\cdot10^{-9}$	$2.3\cdot10^{-10*}$
Hg	$3.2\cdot10^{-7}$	$1.8\cdot10^{-7}$	$2.8\cdot10^{-8}$	–	$1.4\cdot10^{-6}$	–	$1.1\cdot10^{-7}$	$9.4\cdot10^{-7}$	$2.2\cdot10^{-7}$	$8.6\cdot10^{-8}$	$3.4\cdot10^{-7}$	$2.0\cdot10^{-6}$	$6.3\cdot10^{-7}$	$5.9\cdot10^{-6}$
Ho	$1.2\cdot10^{-9}$	$2.5\cdot10^{-6}$	$8.1\cdot10^{-8}$	–	$1.4\cdot10^{-7}$	–	$2.4\cdot10^{-9}$	$2.4\cdot10^{-8}$	$2.0\cdot10^{-8}$	$1.3\cdot10^{-9}$	$1.2\cdot10^{-8}$	$2.3\cdot10^{-10*}$	$1.7\cdot10^{-9*}$	$2.3\cdot10^{-10*}$
I	$8.6\cdot10^{-5}$	$1.6\cdot10^{-5}$	$2.7\cdot10^{-5}$	–	$1.7\cdot10^{-4}$	–	$4.9\cdot10^{-5}$	$1.3\cdot10^{-5}$	$9.1\cdot10^{-6}$	$1.5\cdot10^{-5}$	$2.2\cdot10^{-5}$	$4.5\cdot10^{-7}$	$6.3\cdot10^{-7}$	$9.4\cdot10^{-7}$
K	$5.2\cdot10^{-2}$	$4.4\cdot10^{-3}$	$7.2\cdot10^{-4}$	–	$1.5\cdot10^{-1}$	–	$1.0\cdot10^{-2}$	$7.3\cdot10^{-3}$	$7.1\cdot10^{-3}$	$1.7\cdot10^{-2}$	$1.0\cdot10^{-2}$	$4.2\cdot10^{-2}$	$3.1\cdot10^{-2}$	$4.2\cdot10^{-2}$
La	–	$3.7\cdot10^{-5}$	$2.7\cdot10^{-6}$	–	–	–	$1.9\cdot10^{-6}$	$1.9\cdot10^{-6}$	$1.9\cdot10^{-6}$	$1.9\cdot10^{-6}$	$1.9\cdot10^{-6}$	$2.5\cdot10^{-10*}$	$1.7\cdot10^{-9*}$	$9.3\cdot10^{-10}$
Li	$4.8\cdot10^{-5}$	$2.2\cdot10^{-6}$	$1.7\cdot10^{-6}$	–	$2.3\cdot10^{-5}$	–	$3.2\cdot10^{-6}$	$7.2\cdot10^{-7}$	$2.8\cdot10^{-6}$	$4.2\cdot10^{-6}$	$2.7\cdot10^{-6}$	$2.5\cdot10^{-7}$	$1.7\cdot10^{-7}$	$1.7\cdot10^{-7}$
Lu	$1.2\cdot10^{-9}$	$7.8\cdot10^{-7}$	$3.8\cdot10^{-8}$	–	$5.6\cdot10^{-8}$	–	$1.0\cdot10^{-9}$	$1.4\cdot10^{-8}$	$7.3\cdot10^{-9}$	$5.8\cdot10^{-10}$	$5.7\cdot10^{-9}$	$2.3\cdot10^{-10*}$	$1.7\cdot10^{-9*}$	$2.3\cdot10^{-10*}$
Mg	$4.3\cdot10^{-2}$	$3.5\cdot10^{-3}$	$8.0\cdot10^{-3}$	–	$6.3\cdot10^{-2}$	–	$7.7\cdot10^{-3}$	$4.2\cdot10^{-3}$	$2.6\cdot10^{-3}$	$2.0\cdot10^{-2}$	$8.7\cdot10^{-3}$	$2.8\cdot10^{-3}$	$3.7\cdot10^{-3}$	$3.5\cdot10^{-3}$
Mn	$2.6\cdot10^{-3}$	$7.6\cdot10^{-4}$	$3.8\cdot10^{-4}$	–	$4.0\cdot10^{-4}$	–	$3.7\cdot10^{-4}$	$2.5\cdot10^{-2}$	$1.4\cdot10^{-4}$	$2.3\cdot10^{-4}$	$6.4\cdot10^{-3}$	$1.2\cdot10^{-6}$	$3.2\cdot10^{-6}$	$3.0\cdot10^{-6}$
Mo	$1.9\cdot10^{-6}$	$2.5\cdot10^{-5}$	$5.4\cdot10^{-7}$	–	$6.0\cdot10^{-6}$	–	$7.9\cdot10^{-7}$	$1.1\cdot10^{-6}$	$1.1\cdot10^{-6}$	$6.7\cdot10^{-7}$	$9.1\cdot10^{-7}$	$5.1\cdot10^{-8}$	$8.0\cdot10^{-8}$	$1.8\cdot10^{-8}$
Na	$2.8\cdot10^{-1}$	$2.4\cdot10^{-3}$	$9.1\cdot10^{-4}$	–	$4.5\cdot10^{-1}$	–	$3.4\cdot10^{-2}$	$3.5\cdot10^{-2}$	$2.4\cdot10^{-2}$	$3.8\cdot10^{-2}$	$3.3\cdot10^{-2}$	$7.9\cdot10^{-3}$	$5.5\cdot10^{-3}$	$5.4\cdot10^{-3}$
Nb	–	$4.2\cdot10^{-6}$	$2.0\cdot10^{-7}$	–	–	–	$1.1\cdot10^{-7}$	$1.1\cdot10^{-7}$	$1.1\cdot10^{-7}$	$1.1\cdot10^{-7}$	$1.1\cdot10^{-7}$	$8.1\cdot10^{-10}$	$1.7\cdot10^{-9}$	$7.5\cdot10^{-10}$
Nd	$2.2\cdot10^{-8}$	$4.1\cdot10^{-5}$	$2.3\cdot10^{-6}$	–	$4.4\cdot10^{-6}$	–	$9.6\cdot10^{-8}$	$9.6\cdot10^{-7}$	$9.3\cdot10^{-7}$	$5.3\cdot10^{-8}$	$5.1\cdot10^{-7}$	$2.3\cdot10^{-10*}$	$1.7\cdot10^{-9*}$	$2.3\cdot10^{-10*}$
Ni	$3.3\cdot10^{-5}$	$1.3\cdot10^{-5}$	$4.4\cdot10^{-6}$	–	$2.9\cdot10^{-5}$	–	$5.8\cdot10^{-6}$	$2.5\cdot10^{-6}$	$3.0\cdot10^{-6}$	$5.3\cdot10^{-6}$	$4.1\cdot10^{-6}$	$2.3\cdot10^{-8*}$	$1.7\cdot10^{-7*}$	$2.3\cdot10^{-8*}$
Pb	$6.3\cdot10^{-5}$	$4.3\cdot10^{-5}$	$6.4\cdot10^{-6}$	–	$4.2\cdot10^{-5}$	–	$2.5\cdot10^{-6}$	$1.1\cdot10^{-5}$	$5.1\cdot10^{-6}$	$2.5\cdot10^{-6}$	$5.3\cdot10^{-6}$	$2.3\cdot10^{-8*}$	$1.7\cdot10^{-7*}$	$2.3\cdot10^{-8*}$
Pr	$5.8\cdot10^{-9}$	$8.3\cdot10^{-6}$	$5.7\cdot10^{-7}$	–	$1.1\cdot10^{-6}$	–	$2.6\cdot10^{-8}$	$2.5\cdot10^{-7}$	$2.5\cdot10^{-7}$	$1.4\cdot10^{-8}$	$1.4\cdot10^{-7}$	$2.3\cdot10^{-10*}$	$1.7\cdot10^{-9*}$	$2.3\cdot10^{-10*}$
Rb	$7.1\cdot10^{-5}$	$2.8\cdot10^{-5}$	$2.1\cdot10^{-6}$	–	$9.3\cdot10^{-5}$	–	$9.5\cdot10^{-6}$	$7.5\cdot10^{-6}$	$9.9\cdot10^{-6}$	$9.9\cdot10^{-6}$	$9.2\cdot10^{-6}$	$4.7\cdot10^{-5}$	$3.5\cdot10^{-5}$	$5.1\cdot10^{-5}$

Element	Phyto-plankton	Microphyto-benthos	Macro-algae	Bacterio-plankton	Zoo-plankton	Benthic bacteria	Benthic herbivores	Benthic filter feeders	Benthic detrivores	Benthic carnivores	Benthic omnivores	B fish	Z fish	P fish
S	$4.1\bullet10^{-2}$	$2.7\bullet10^{-2}$	$9.5\bullet10^{-3}$	$1.8\bullet10^{-2}$	$1.1\bullet10^{-1}$	$1.8\bullet10^{-2}$	$1.3\bullet10^{-2}$	$2.4\bullet10^{-2}$	$6.9\bullet10^{-3}$	$2.4\bullet10^{-2}$	$1.7\bullet10^{-2}$	$2.4\bullet10^{-2}$	$2.8\bullet10^{-2}$	$2.8\bullet10^{-2}$
Sb	–	$8.1\bullet10^{-7}$	$1.0\bullet10^{-5}$	–	–	–	$4.2\bullet10^{-8}$	$4.2\bullet10^{-8}$	$4.2\bullet10^{-8}$	$4.2\bullet10^{-8}$	$4.2\bullet10^{-8}$	$2.3\bullet10^{-9*}$	$2.7\bullet10^{-8}$	$2.3\bullet10^{-9*}$
Sc	–	$2.2\bullet10^{-6}$	$5.5\bullet10^{-7}$	–	–	–	$2.4\bullet10^{-7}$	$2.4\bullet10^{-7}$	$2.4\bullet10^{-7}$	$2.4\bullet10^{-7}$	$2.4\bullet10^{-7}$	$5.4\bullet10^{-9}$	$1.7\bullet10^{-9}$	$7.8\bullet10^{-9}$
Se	$2.8\bullet10^{-6}$	$2.6\bullet10^{-6*}$	$8.3\bullet10^{-7}$	–	$2.4\bullet10^{-5}$	–	$2.3\bullet10^{-6}$	$5.9\bullet10^{-6}$	$2.3\bullet10^{-6}$	$1.7\bullet10^{-6}$	$3.1\bullet10^{-6}$	$1.1\bullet10^{-6}$	$2.9\bullet10^{-7}$	$7.3\bullet10^{-7}$
Si	$7.9\bullet10^{-1}$	$1.0\bullet10^{-1}$	$2.5\bullet10^{-2}$	–	$2.3\bullet10^{-1}$	–	$1.7\bullet10^{-2}$	$6.5\bullet10^{-3}$	$1.1\bullet10^{-2}$	$1.6\bullet10^{-2}$	$1.3\bullet10^{-2}$	$1.9\bullet10^{-4}$	$7.9\bullet10^{-4}$	$1.9\bullet10^{-4}$
Sm	$4.0\bullet10^{-9}$	$6.0\bullet10^{-6}$	$4.2\bullet10^{-7}$	–	$8.7\bullet10^{-7}$	–	$1.7\bullet10^{-8}$	$1.7\bullet10^{-7}$	$1.7\bullet10^{-7}$	$9.5\bullet10^{-9}$	$9.3\bullet10^{-8}$	$2.3\bullet10^{-10*}$	$1.7\bullet10^{-9*}$	$2.3\bullet10^{-10*}$
Sn	–	$7.0\bullet10^{-6}$	$2.9\bullet10^{-7}$	–	–	–	$1.1\bullet10^{-7}$	$1.1\bullet10^{-7}$	$1.1\bullet10^{-7}$	$1.1\bullet10^{-7}$	$1.1\bullet10^{-7}$	$1.1\bullet10^{-8*}$	$8.0\bullet10^{-8*}$	$1.2\bullet10^{-8*}$
Sr	–	$1.2\bullet10^{-4}$	$5.4\bullet10^{-4}$	–	–	–	$3.6\bullet10^{-4}$	$3.6\bullet10^{-4}$	$3.6\bullet10^{-4}$	$3.6\bullet10^{-4}$	$3.6\bullet10^{-4}$	$2.6\bullet10^{-6}$	$5.8\bullet10^{-6}$	$3.2\bullet10^{-6}$
Ta	–	$4.4\bullet10^{-7}$	$3.8\bullet10^{-8}$	–	–	–	$9.8\bullet10^{-9}$	$9.8\bullet10^{-9}$	$9.8\bullet10^{-9}$	$9.8\bullet10^{-9}$	$9.8\bullet10^{-9}$	$8.7\bullet10^{-9}$	$8.0\bullet10^{-9}$	$7.5\bullet10^{-9}$
Tb	$1.2\bullet10^{-9}$	$1.5\bullet10^{-6}$	$5.9\bullet10^{-8}$	–	$1.1\bullet10^{-7}$	–	$2.3\bullet10^{-9}$	$2.0\bullet10^{-8}$	$2.1\bullet10^{-8}$	$1.2\bullet10^{-9}$	$1.1\bullet10^{-8}$	$2.3\bullet10^{-10*}$	$1.7\bullet10^{-9*}$	$2.9\bullet10^{-10*}$
Th	$7.9\bullet10^{-6}$	$6.7\bullet10^{-6}$	$1.7\bullet10^{-7}$	–	$1.3\bullet10^{-6}$	–	$9.9\bullet10^{-7}$	$1.2\bullet10^{-7}$	$1.1\bullet10^{-6}$	$6.7\bullet10^{-7}$	$7.2\bullet10^{-7}$	$4.5\bullet10^{-9*}$	$2.8\bullet10^{-8*}$	$4.6\bullet10^{-9*}$
Ti	$1.0\bullet10^{-3}$	$4.7\bullet10^{-4}$	$4.1\bullet10^{-5}$	–	$2.6\bullet10^{-4}$	–	$7.9\bullet10^{-5}$	$1.4\bullet10^{-5}$	$1.0\bullet10^{-4}$	$7.4\bullet10^{-5}$	$6.8\bullet10^{-5}$	$5.8\bullet10^{-7}$	$1.3\bullet10^{-7}$	$8.5\bullet10^{-7}$
Tl	–	$2.7\bullet10^{-7}$	$5.7\bullet10^{-8}$	–	–	–	$3.3\bullet10^{-7}$	$3.3\bullet10^{-7}$	$3.3\bullet10^{-7}$	$3.3\bullet10^{-7}$	$3.3\bullet10^{-7}$	$1.1\bullet10^{-8*}$	$8.0\bullet10^{-8}$	$1.5\bullet10^{-8*}$
Tm	$1.2\bullet10^{-9}$	$1.2\bullet10^{-6}$	$3.7\bullet10^{-8}$	–	$5.6\bullet10^{-8}$	–	$1.0\bullet10^{-9}$	$1.1\bullet10^{-8}$	$7.2\bullet10^{-9}$	$5.8\bullet10^{-10}$	$4.9\bullet10^{-9}$	$2.3\bullet10^{-10*}$	$1.7\bullet10^{-9*}$	$2.3\bullet10^{-10*}$
U	–	$9.6\bullet10^{-5}$	$2.8\bullet10^{-6}$	–	$7.8\bullet10^{-7}$	–	$7.8\bullet10^{-7}$	$7.8\bullet10^{-7}$	$7.8\bullet10^{-7}$	$7.8\bullet10^{-7}$	$7.8\bullet10^{-7}$	$3.0\bullet10^{-9}$	$3.8\bullet10^{-9}$	$9.3\bullet10^{-10}$
V	$3.9\bullet10^{-5}$	$1.1\bullet10^{-5}$	$2.6\bullet10^{-6}$	–	$8.9\bullet10^{-6}$	–	$3.6\bullet10^{-6}$	$9.9\bullet10^{-7}$	$4.6\bullet10^{-6}$	$3.4\bullet10^{-6}$	$3.2\bullet10^{-6}$	$1.4\bullet10^{-8*}$	$8.0\bullet10^{-8*}$	$1.2\bullet10^{-8*}$
W	–	$7.1\bullet10^{-6}$	$8.7\bullet10^{-8}$	–	–	–	$8.5\bullet10^{-8}$	$8.5\bullet10^{-8}$	$8.5\bullet10^{-8}$	$8.5\bullet10^{-8}$	$8.5\bullet10^{-8}$	$4.5\bullet10^{-9*}$	$2.8\bullet10^{-8*}$	$4.6\bullet10^{-9*}$
Y	–	$1.7\bullet10^{-5}$	$2.9\bullet10^{-6}$	–	–	–	$8.0\bullet10^{-7}$	$8.0\bullet10^{-7}$	$8.0\bullet10^{-7}$	$8.0\bullet10^{-7}$	$8.0\bullet10^{-7}$	$2.6\bullet10^{-10*}$	$6.9\bullet10^{-9*}$	$2.3\bullet10^{-10*}$
Yb	$1.5\bullet10^{-9}$	$3.7\bullet10^{-6}$	$2.5\bullet10^{-7}$	–	$3.4\bullet10^{-7}$	–	$6.0\bullet10^{-9}$	$7.6\bullet10^{-8}$	$4.5\bullet10^{-8}$	$3.3\bullet10^{-9}$	$3.3\bullet10^{-8}$	$2.3\bullet10^{-10*}$	$1.7\bullet10^{-9*}$	$2.3\bullet10^{-10*}$
Zn	$2.0\bullet10^{-3}$	$1.2\bullet10^{-4}$	$1.1\bullet10^{-4}$	–	$2.4\bullet10^{-3}$	–	$1.2\bullet10^{-4}$	$1.4\bullet10^{-3}$	$2.1\bullet10^{-4}$	$1.6\bullet10^{-4}$	$4.7\bullet10^{-4}$	$3.3\bullet10^{-5}$	$1.4\bullet10^{-4*}$	$1.2\bullet10^{-4*}$
Zr	$8.6\bullet10^{-5}$	$2.8\bullet10^{-5}$	$1.4\bullet10^{-6}$	–	$1.1\bullet10^{-5}$	–	$9.3\bullet10^{-6}$	$6.7\bullet10^{-7}$	$1.5\bullet10^{-5}$	$7.1\bullet10^{-6}$	$8.1\bullet10^{-6}$	$5.7\bullet10^{-9}$	$1.3\bullet10^{-7}$	$5.8\bullet10^{-9}$

Table A10-2. Chemistry in lake biota in Lake Frisksjön, in the Laxemar area. Values are in g gC^{-1}. Data on fish, benthic filter feeders and macrophytes are lake specific data from /Engdalh et al. 2006/. Data on phytoplankton, zooplankton benthic herbivores, benthic detritivores and benthic carnivores are taken from the coastal areas outside Forsmark /Kumblad and Bradshaw 2008/. Chemical composition of benthic omnivores was calculated as a mean of the other functional groups. Chemical composition for benthic herbivores, detritivores, carnivores of 15 elements (Ag, B, Be, Ga, Hf, La, Nb, Sb, Sc, Sn, Sr, Ta, Ti, W and Y) was assumed to be identical to chemical composition of benthic filter feeders. Data on bacterioplankton P, N and S content are from /Fagerbakke 1996/. For benthic bacteria P and N content are from /Kautsky 1995/ and S content are assumed to be identical to bacterioplankton /Fagerbakke 1996/. "–" denotes missing data, and * indicates were half the detection limit is reported. For further explanation of use of data, see Chapter 7.

Element	Phyto-plankton	Macrophytes	Bacterio-plankton	Zoo-plankton	Benthic bacteria	Benthic herbivores	Benthic filter feeders	Benthic detrivores	Benthic carnivores	Benthic omnivores	B fish	Z fish	P fish
C	1	1	1	1	1	1	1	1	1	1	1	1	1
N	$1.2\cdot10^{-1}$	$5.0\cdot10^{-2}$	$1.9\cdot10^{-1}$	$2.3\cdot10^{-1}$	$1.8\cdot10^{-1}$	$1.2\cdot10^{-1}$	$2.1\cdot10^{-1}$	$7.9\cdot10^{-2}$	$1.8\cdot10^{-1}$	$1.5\cdot10^{-1}$	$3.3\cdot10^{-1}$	$4.0\cdot10^{-1}$	$3.0\cdot10^{-1}$
P	$9.1\cdot10^{-3}$	$6.9\cdot10^{-3}$	$4.6\cdot10^{-2}$	$3.8\cdot10^{-2}$	$5.6\cdot10^{-2}$	$1.1\cdot10^{-2}$	$7.4\cdot10^{-2}$	$9.1\cdot10^{-3}$	$8.4\cdot10^{-3}$	$2.7\cdot10^{-2}$	$3.1\cdot10^{-2}$	$2.3\cdot10^{-2}$	$2.8\cdot10^{-2}$
Ag	–	$2.4\cdot10^{-8}$	–	–	–	$2.4\cdot10^{-7}$	$2.4\cdot10^{-7}$	$2.4\cdot10^{-7}$	$2.4\cdot10^{-7}$	$2.4\cdot10^{-7}$	$1.6\cdot10^{-8}$	$8.0\cdot10^{-8}$	$1.6\cdot10^{-8}$
Al	$1.1\cdot10^{-1}$	$4.1\cdot10^{-4}$	–	$6.8\cdot10^{-3}$	–	$2.7\cdot10^{-3}$	$1.3\cdot10^{-3}$	$3.5\cdot10^{-3}$	$2.0\cdot10^{-6}$	$1.9\cdot10^{-3}$	$1.2\cdot10^{-6}$	$2.4\cdot10^{-6}$	$2.1\cdot10^{-6}$
As	$7.0\cdot10^{-5}$	$1.1\cdot10^{-6}$	–	$5.5\cdot10^{-5}$	–	$1.5\cdot10^{-5}$	$1.6\cdot10^{-5}$	$1.1\cdot10^{-5}$	$1.8\cdot10^{-5}$	$1.5\cdot10^{-5}$	$1.1\cdot10^{-7}$	$1.0\cdot10^{-7}$	$6.7\cdot10^{-8}$
B	–	$7.7\cdot10^{-5}$	–	–	–	$9.5\cdot10^{-6}$	$9.5\cdot10^{-6}$	$9.5\cdot10^{-6}$	$9.5\cdot10^{-6}$	$9.5\cdot10^{-6}$	$2.1\cdot10^{-6}$	$2.9\cdot10^{-7}$	$2.0\cdot10^{-6}$
Ba	$2.7\cdot10^{-4}$	$2.5\cdot10^{-4}$	–	$1.2\cdot10^{-4}$	–	$1.2\cdot10^{-4}$	$1.3\cdot10^{-3}$	$1.7\cdot10^{-4}$	$2.2\cdot10^{-4}$	$4.5\cdot10^{-4}$	$2.6\cdot10^{-6}$	$2.0\cdot10^{-6}$	$2.3\cdot10^{-7}$
Be	–	$2.0\cdot10^{-7}$	–	–	–	$2.9\cdot10^{-6}$	$2.9\cdot10^{-6}$	$2.9\cdot10^{-6}$	$2.9\cdot10^{-6}$	$2.9\cdot10^{-6}$	$8.6\cdot10^{-8}$	$4.0\cdot10^{-7}$	$8.3\cdot10^{-8}$
Br	$7.6\cdot10^{-3}$	$1.5\cdot10^{-4}$	–	$3.1\cdot10^{-2}$	–	$6.7\cdot10^{-4}$	$4.1\cdot10^{-4}$	$1.8\cdot10^{-4}$	$2.8\cdot10^{-4}$	$3.8\cdot10^{-4}$	$4.9\cdot10^{-5}$	$1.9\cdot10^{-5}$	$4.2\cdot10^{-5}$
Ca	$2.2\cdot10^{-2}$	$6.6\cdot10^{-2}$	–	$2.1\cdot10^{-1}$	–	$5.7\cdot10^{-1}$	$1.2\cdot10^{-1}$	1.5	$3.4\cdot10^{-1}$	$6.4\cdot10^{-1}$	$6.3\cdot10^{-3}$	$9.0\cdot10^{-3}$	$4.5\cdot10^{-3}$
Cd	$1.4\cdot10^{-6}$	$1.3\cdot10^{-7}$	–	$1.1\cdot10^{-5}$	–	$4.7\cdot10^{-6}$	$1.2\cdot10^{-5}$	$8.6\cdot10^{-7}$	$5.1\cdot10^{-6}$	$5.6\cdot10^{-6}$	$4.7\cdot10^{-9}$*	$1.7\cdot10^{-8}$*	$3.9\cdot10^{-9}$*
Ce	$5.2\cdot10^{-8}$	$8.7\cdot10^{-6}$	–	$8.4\cdot10^{-6}$	–	$1.9\cdot10^{-7}$	$1.3\cdot10^{-4}$	$1.9\cdot10^{-6}$	$1.0\cdot10^{-7}$	$3.3\cdot10^{-5}$	–	–	–
Cl	$3.7\cdot10^{-1}$	$2.8\cdot10^{-2}$	–	–	–	$1.8\cdot10^{-2}$	$3.8\cdot10^{-2}$	$1.1\cdot10^{-2}$	$1.3\cdot10^{-2}$	$2.0\cdot10^{-2}$	$3.4\cdot10^{-3}$	$1.1\cdot10^{-2}$	$5.5\cdot10^{-3}$
Co	$9.2\cdot10^{-6}$	$1.7\cdot10^{-6}$	–	$3.9\cdot10^{-6}$	–	$1.9\cdot10^{-6}$	$4.0\cdot10^{-6}$	$1.7\cdot10^{-6}$	$2.0\cdot10^{-6}$	$2.4\cdot10^{-6}$	$1.9\cdot10^{-8}$	$3.9\cdot10^{-8}$	$2.4\cdot10^{-8}$
Cr	$3.5\cdot10^{-5}$	$4.7\cdot10^{-7}$	–	$2.4\cdot10^{-5}$	–	$2.3\cdot10^{-6}$	$2.7\cdot10^{-6}$	$3.0\cdot10^{-6}$	$3.0\cdot10^{-6}$	$2.8\cdot10^{-6}$	$2.4\cdot10^{-8}$	$1.1\cdot10^{-7}$	$3.7\cdot10^{-8}$
Cs	$2.8\cdot10^{-6}$	$1.5\cdot10^{-7}$	–	$7.6\cdot10^{-7}$	–	$2.4\cdot10^{-7}$	$1.6\cdot10^{-7}$	$3.2\cdot10^{-7}$	$2.6\cdot10^{-7}$	$2.5\cdot10^{-7}$	$4.8\cdot10^{-7}$	$7.9\cdot10^{-8}$	$2.6\cdot10^{-6}$
Cu	$1.3\cdot10^{-4}$	$6.2\cdot10^{-6}$	–	$4.7\cdot10^{-4}$	–	$9.7\cdot10^{-5}$	$2.0\cdot10^{-5}$	$1.3\cdot10^{-4}$	$1.5\cdot10^{-4}$	$9.9\cdot10^{-5}$	$1.4\cdot10^{-6}$	$2.8\cdot10^{-6}$	$1.5\cdot10^{-6}$
Dy	$2.8\cdot10^{-9}$	$2.0\cdot10^{-7}$	–	$6.5\cdot10^{-7}$	–	$1.3\cdot10^{-8}$	$2.3\cdot10^{-6}$	$1.1\cdot10^{-7}$	$6.9\cdot10^{-9}$	$6.1\cdot10^{-7}$	$3.5\cdot10^{-10}$	$1.7\cdot10^{-9}$	$1.3\cdot10^{-9}$
Er	$1.6\cdot10^{-9}$	$1.2\cdot10^{-7}$	–	$3.7\cdot10^{-7}$	–	$6.9\cdot10^{-9}$	$1.0\cdot10^{-6}$	$5.5\cdot10^{-8}$	$3.8\cdot10^{-9}$	$2.7\cdot10^{-7}$	$3.5\cdot10^{-10}$	$1.7\cdot10^{-9}$	$1.0\cdot10^{-8}$

Element	Phyto-plankton	Macrophytes	Bacterio-plankton	Zoo-plankton	Benthic bacteria	Benthic herbivores	Benthic filter feeders	Benthic detrivores	Benthic carnivores	Benthic omnivores	B fish	Z fish	P fish
Eu	$1.2\bullet10^{-9}$	$8.9\bullet10^{-8}$	–	$1.1\bullet10^{-7}$	–	$2.1\bullet10^{-9}$	$1.2\bullet10^{-6}$	$2.6\bullet10^{-8}$	$1.1\bullet10^{-9}$	$3.1\bullet10^{-7}$	$3.5\bullet10^{-10}$	$1.7\bullet10^{-9}$	$3.6\bullet10^{-10}$
F	$5.6\bullet10^{-3}$	–	–	–	–	$1.2\bullet10^{-4}$	–	$1.2\bullet10^{-4}$	$1.2\bullet10^{-4}$	$1.2\bullet10^{-4}$	–	–	–
Fe	$2.1\bullet10^{-2}$	$1.1\bullet10^{-3}$	–	$4.9\bullet10^{-3}$	–	$1.6\bullet10^{-3}$	$1.5\bullet10^{-2}$	$4.7\bullet10^{-3}$	$1.6\bullet10^{-3}$	$5.8\bullet10^{-3}$	$1.6\bullet10^{-5}$	$3.2\bullet10^{-5}$	$1.6\bullet10^{-5}$
Ga	–	$4.2\bullet10^{-8}$	–	–	–	$1.3\bullet10^{-7}$	$1.3\bullet10^{-7}$	$1.3\bullet10^{-7}$	$1.3\bullet10^{-7}$	$1.3\bullet10^{-7}$	$7.4\bullet10^{-9}$	$2.8\bullet10^{-8}$	$6.7\bullet10^{-9}$
Gd	$3.5\bullet10^{-9}$	$2.5\bullet10^{-7}$	–	$6.8\bullet10^{-7}$	–	$1.6\bullet10^{-8}$	$4.5\bullet10^{-6}$	$1.7\bullet10^{-7}$	$8.9\bullet10^{-9}$	$1.2\bullet10^{-6}$	$3.5\bullet10^{-10}$	$1.7\bullet10^{-9}$	$3.6\bullet10^{-10}$
Hf	–	$1.8\bullet10^{-8}$	–	–	–	$4.2\bullet10^{-8}$	$4.2\bullet10^{-8}$	$4.2\bullet10^{-8}$	$4.2\bullet10^{-8}$	$4.2\bullet10^{-8}$	$1.5\bullet10^{-9}$	$3.0\bullet10^{-9}$	$3.6\bullet10^{-10}$
Hg	$3.2\bullet10^{-7}$	$9.7\bullet10^{-9}$	–	$1.4\bullet10^{-6}$	–	$1.1\bullet10^{-7}$	$3.9\bullet10^{-7}$	$2.2\bullet10^{-7}$	$8.6\bullet10^{-8}$	$2.0\bullet10^{-7}$	$1.1\bullet10^{-6}$	$6.3\bullet10^{-7}$	$5.4\bullet10^{-6}$
Ho	$1.2\bullet10^{-9}$	$4.0\bullet10^{-8}$	–	$1.4\bullet10^{-7}$	–	$2.4\bullet10^{-9}$	$4.0\bullet10^{-7}$	$2.0\bullet10^{-8}$	$1.3\bullet10^{-9}$	$1.1\bullet10^{-7}$	$3.5\bullet10^{-10}$	$1.7\bullet10^{-9}$	$1.7\bullet10^{-9}$
I	$8.6\bullet10^{-5}$	$2.5\bullet10^{-5}$	–	$1.7\bullet10^{-4}$	–	$4.9\bullet10^{-5}$	$1.9\bullet10^{-5}$	$9.1\bullet10^{-6}$	$1.5\bullet10^{-5}$	$2.3\bullet10^{-5}$	$3.3\bullet10^{-6}$	$6.3\bullet10^{-7}$	$8.4\bullet10^{-6}$
K	$5.2\bullet10^{-2}$	$4.8\bullet10^{-2}$	–	$1.5\bullet10^{-1}$	–	$1.0\bullet10^{-2}$	$8.7\bullet10^{-3}$	$7.1\bullet10^{-3}$	$1.7\bullet10^{-2}$	$1.1\bullet10^{-2}$	$4.8\bullet10^{-2}$	$3.1\bullet10^{-2}$	$5.0\bullet10^{-2}$
La	–	$3.2\bullet10^{-6}$	–	–	–	$1.1\bullet10^{-4}$	$1.1\bullet10^{-4}$	$1.1\bullet10^{-4}$	$1.1\bullet10^{-4}$	$1.1\bullet10^{-4}$	$2.7\bullet10^{-9}$	$1.7\bullet10^{-9}$	$5.7\bullet10^{-9}$
Li	$4.8\bullet10^{-5}$	$5.1\bullet10^{-7}$	–	$2.3\bullet10^{-5}$	–	$3.2\bullet10^{-6}$	$9.4\bullet10^{-7}$	$2.8\bullet10^{-6}$	$4.2\bullet10^{-6}$	$2.8\bullet10^{-6}$	$4.7\bullet10^{-8}$	$1.7\bullet10^{-7}$	$3.9\bullet10^{-8}$
Lu	$1.2\bullet10^{-9}$	$1.7\bullet10^{-8}$	–	$5.6\bullet10^{-8}$	–	$1.0\bullet10^{-9}$	$1.3\bullet10^{-7}$	$7.3\bullet10^{-9}$	$5.8\bullet10^{-10}$	$3.4\bullet10^{-8}$	$3.5\bullet10^{-10}$	$1.7\bullet10^{-9}$	$3.6\bullet10^{-10}$
Mg	$4.3\bullet10^{-2}$	$5.4\bullet10^{-3}$	–	$6.3\bullet10^{-2}$	–	$7.7\bullet10^{-3}$	$3.6\bullet10^{-3}$	$2.6\bullet10^{-3}$	$2.0\bullet10^{-2}$	$8.5\bullet10^{-3}$	$4.7\bullet10^{-3}$	$3.7\bullet10^{-3}$	$4.0\bullet10^{-3}$
Mn	$2.6\bullet10^{-3}$	$1.6\bullet10^{-3}$	–	$4.0\bullet10^{-4}$	–	$3.7\bullet10^{-4}$	$1.3\bullet10^{-2}$	$1.4\bullet10^{-4}$	$2.3\bullet10^{-4}$	$3.4\bullet10^{-3}$	$4.0\bullet10^{-6}$	$3.2\bullet10^{-6}$	$1.4\bullet10^{-6}$
Mo	$1.9\bullet10^{-6}$	$1.6\bullet10^{-6}$	–	$6.0\bullet10^{-6}$	–	$7.9\bullet10^{-7}$	$3.1\bullet10^{-6}$	$1.1\bullet10^{-6}$	$6.7\bullet10^{-7}$	$1.4\bullet10^{-6}$	$3.1\bullet10^{-8}$	$8.0\bullet10^{-8}$	$2.4\bullet10^{-8}$
Na	$2.8\bullet10^{-1}$	$1.7\bullet10^{-2}$	–	$4.5\bullet10^{-1}$	–	$3.4\bullet10^{-2}$	$2.4\bullet10^{-2}$	$2.4\bullet10^{-2}$	$3.8\bullet10^{-2}$	$3.0\bullet10^{-2}$	$5.4\bullet10^{-3}$	$5.5\bullet10^{-3}$	$5.5\bullet10^{-3}$
Nb	–	$4.3\bullet10^{-8}$	–	–	–	$1.1\bullet10^{-7}$	$1.1\bullet10^{-7}$	$1.1\bullet10^{-7}$	$1.1\bullet10^{-7}$	$1.1\bullet10^{-7}$	$1.4\bullet10^{-9}$	$1.7\bullet10^{-9}$	$4.8\bullet10^{-10}$
Nd	$2.2\bullet10^{-8}$	$2.5\bullet10^{-6}$	–	$4.4\bullet10^{-6}$	–	$9.6\bullet10^{-8}$	$4.8\bullet10^{-5}$	$9.3\bullet10^{-7}$	$5.3\bullet10^{-8}$	$1.2\bullet10^{-5}$	$1.5\bullet10^{-9}$	$1.7\bullet10^{-9}$	$3.0\bullet10^{-9}$
Ni	$3.3\bullet10^{-5}$	$2.9\bullet10^{-6}$	–	$2.9\bullet10^{-5}$	–	$5.8\bullet10^{-6}$	$4.5\bullet10^{-6}$	$3.0\bullet10^{-6}$	$5.3\bullet10^{-6}$	$4.6\bullet10^{-6}$	$5.3\bullet10^{-8}$	$1.7\bullet10^{-7}$	$3.6\bullet10^{-8}$
P	$1.2\bullet10^{-2}$	$6.9\bullet10^{-3}$	–	$1.3\bullet10^{-1}$	–	$1.2\bullet10^{-2}$	$7.4\bullet10^{-2}$	$9.6\bullet10^{-3}$	$1.9\bullet10^{-2}$	$2.9\bullet10^{-2}$	$3.1\bullet10^{-2}$	$2.3\bullet10^{-2}$	$2.8\bullet10^{-2}$
Pb	$6.3\bullet10^{-5}$	$1.3\bullet10^{-6}$	–	$4.2\bullet10^{-5}$	–	$2.5\bullet10^{-6}$	$6.6\bullet10^{-6}$	$5.1\bullet10^{-6}$	$2.5\bullet10^{-6}$	$4.2\bullet10^{-6}$	$3.5\bullet10^{-8}$	$1.7\bullet10^{-7}$	$3.6\bullet10^{-8}$
Pr	$5.8\bullet10^{-9}$	$6.8\bullet10^{-7}$	–	$1.1\bullet10^{-6}$	–	$2.6\bullet10^{-8}$	$1.4\bullet10^{-5}$	$2.5\bullet10^{-7}$	$1.4\bullet10^{-8}$	$3.6\bullet10^{-6}$	$3.5\bullet10^{-10}$	$1.7\bullet10^{-9}$	$1.2\bullet10^{-9}$
Rb	$7.1\bullet10^{-5}$	$8.1\bullet10^{-5}$	–	$9.3\bullet10^{-5}$	–	$9.5\bullet10^{-6}$	$2.0\bullet10^{-5}$	$9.9\bullet10^{-6}$	$9.9\bullet10^{-6}$	$1.2\bullet10^{-5}$	$1.2\bullet10^{-4}$	$3.5\bullet10^{-5}$	$2.5\bullet10^{-4}$
S	$4.1\bullet10^{-2}$	$9.5\bullet10^{-3}$	$1.8\bullet10^{-2}$	$1.1\bullet10^{-1}$	$1.8\bullet10^{-2}$	$1.3\bullet10^{-2}$	$2.4\bullet10^{-2}$	$6.9\bullet10^{-3}$	$2.4\bullet10^{-2}$	$1.7\bullet10^{-2}$	$3.0\bullet10^{-2}$	$2.8\bullet10^{-2}$	$3.0\bullet10^{-2}$
Sb	–	$4.0\bullet10^{-8}$	–	–	–	$6.4\bullet10^{-8}$	$6.4\bullet10^{-8}$	$6.4\bullet10^{-8}$	$6.4\bullet10^{-8}$	$6.4\bullet10^{-8}$	$3.5\bullet10^{-9}$	$2.7\bullet10^{-8}$	$3.6\bullet10^{-9}$
Sc	–	$1.1\bullet10^{-7}$	–	–	–	$2.0\bullet10^{-6}$	$2.0\bullet10^{-6}$	$2.0\bullet10^{-6}$	$2.0\bullet10^{-6}$	$2.0\bullet10^{-6}$	$1.5\bullet10^{-9}$	$1.7\bullet10^{-9}$	$1.7\bullet10^{-9}$

Element	Phyto-plankton	Macrophytes	Bacterio-plankton	Zoo-plankton	Benthic bacteria	Benthic herbivores	Benthic filter feeders	Benthic detrivores	Benthic carnivores	Benthic omnivores	B fish	Z fish	P fish
Se	$2.8 \bullet 10^{-6}$	$5.8 \bullet 10^{-7}$	–	$2.4 \bullet 10^{-5}$	–	$2.3 \bullet 10^{-6}$	$5.1 \bullet 10^{-6}$	$2.3 \bullet 10^{-6}$	$1.7 \bullet 10^{-6}$	$2.8 \bullet 10^{-6}$	$1.9 \bullet 10^{-6}$	$2.9 \bullet 10^{-7}$	$2.8 \bullet 10^{-6}$
Si	$7.9 \bullet 10^{-1}$	$5.4 \bullet 10^{-3}$	–	$2.3 \bullet 10^{-1}$	–	$1.7 \bullet 10^{-2}$	$7.1 \bullet 10^{-3}$	$1.1 \bullet 10^{-2}$	$1.6 \bullet 10^{-2}$	$1.3 \bullet 10^{-2}$	$4.3 \bullet 10^{-4}$	$7.9 \bullet 10^{-4}$	$2.3 \bullet 10^{-4}$
Sm	$4.0 \bullet 10^{-9}$	$4.0 \bullet 10^{-7}$	–	$8.7 \bullet 10^{-7}$	–	$1.7 \bullet 10^{-8}$	$6.9 \bullet 10^{-6}$	$1.7 \bullet 10^{-7}$	$9.5 \bullet 10^{-9}$	$1.8 \bullet 10^{-6}$	$3.5 \bullet 10^{-10}$	$1.7 \bullet 10^{-9}$	$2.3 \bullet 10^{-9}$
Sn	–	$8.1 \bullet 10^{-8}$	–	–	–	$7.9 \bullet 10^{-8}$	$7.9 \bullet 10^{-8}$	$7.9 \bullet 10^{-8}$	$7.9 \bullet 10^{-8}$	$7.9 \bullet 10^{-8}$	$1.6 \bullet 10^{-8*}$	$8.0 \bullet 10^{-8*}$	$1.6 \bullet 10^{-8*}$
Sr	–	$7.1 \bullet 10^{-5}$	–	–	–	$4.1 \bullet 10^{-4}$	$4.1 \bullet 10^{-4}$	$4.1 \bullet 10^{-4}$	$4.1 \bullet 10^{-4}$	$4.1 \bullet 10^{-4}$	$6.3 \bullet 10^{-6}$	$5.8 \bullet 10^{-6}$	$3.9 \bullet 10^{-6}$
Ta	–	$1.2 \bullet 10^{-8}$	–	–	–	$7.9 \bullet 10^{-9}$	$7.9 \bullet 10^{-9}$	$7.9 \bullet 10^{-9}$	$7.9 \bullet 10^{-9}$	$7.9 \bullet 10^{-9}$	$2.7 \bullet 10^{-9}$	$8.0 \bullet 10^{-9}$	$8.7 \bullet 10^{-9}$
Tb	$1.2 \bullet 10^{-9}$	$3.3 \bullet 10^{-8}$	–	$1.1 \bullet 10^{-7}$	–	$2.3 \bullet 10^{-9}$	$5.0 \bullet 10^{-7}$	$2.1 \bullet 10^{-8}$	$1.2 \bullet 10^{-9}$	$1.3 \bullet 10^{-7}$	$3.5 \bullet 10^{-10}$	$1.7 \bullet 10^{-9}$	$2.4 \bullet 10^{-9}$
Th	$7.9 \bullet 10^{-6}$	$1.3 \bullet 10^{-7}$	–	$1.3 \bullet 10^{-6}$	–	$9.9 \bullet 10^{-7}$	$6.6 \bullet 10^{-7}$	$1.1 \bullet 10^{-6}$	$6.7 \bullet 10^{-7}$	$8.5 \bullet 10^{-7}$	$7.4 \bullet 10^{-9}$	$2.8 \bullet 10^{-8}$	$6.7 \bullet 10^{-9}$
Ti	$1.0 \bullet 10^{-3}$	$5.5 \bullet 10^{-6}$	–	$2.6 \bullet 10^{-4}$	–	$7.9 \bullet 10^{-5}$	$1.6 \bullet 10^{-5}$	$1.0 \bullet 10^{-4}$	$7.4 \bullet 10^{-5}$	$6.8 \bullet 10^{-5}$	$3.0 \bullet 10^{-7}$	$1.3 \bullet 10^{-7}$	$1.0 \bullet 10^{-7}$
Tl	–	$8.7 \bullet 10^{-8}$	–	–	–	$2.6 \bullet 10^{-8}$	$2.6 \bullet 10^{-8}$	$2.6 \bullet 10^{-8}$	$2.6 \bullet 10^{-8}$	$2.6 \bullet 10^{-8}$	$1.6 \bullet 10^{-8}$	$8.0 \bullet 10^{-8}$	$4.4 \bullet 10^{-8}$
Tm	$1.2 \bullet 10^{-9}$	$1.7 \bullet 10^{-8}$	–	$5.6 \bullet 10^{-8}$	–	$1.0 \bullet 10^{-9}$	$1.2 \bullet 10^{-7}$	$7.2 \bullet 10^{-9}$	$5.8 \bullet 10^{-10}$	$3.3 \bullet 10^{-8}$	$3.5 \bullet 10^{-10}$	$1.7 \bullet 10^{-9}$	$8.6 \bullet 10^{-10}$
U	–	$4.4 \bullet 10^{-7}$	–	$2.4 \bullet 10^{-6}$	–	$2.4 \bullet 10^{-6}$	$2.4 \bullet 10^{-6}$	$2.4 \bullet 10^{-6}$	$2.4 \bullet 10^{-6}$	$2.4 \bullet 10^{-6}$	$5.3 \bullet 10^{-9}$	$3.8 \bullet 10^{-9}$	$2.7 \bullet 10^{-10}$
V	$3.9 \bullet 10^{-5}$	$1.7 \bullet 10^{-6}$	–	$8.9 \bullet 10^{-6}$	–	$3.6 \bullet 10^{-6}$	$3.6 \bullet 10^{-6}$	$4.6 \bullet 10^{-6}$	$3.4 \bullet 10^{-6}$	$3.8 \bullet 10^{-6}$	$1.4 \bullet 10^{-7}$	$8.0 \bullet 10^{-8}$	$1.6 \bullet 10^{-8}$
W	–	$6.2 \bullet 10^{-8}$	–	–	–	$1.2 \bullet 10^{-7}$	$1.2 \bullet 10^{-7}$	$1.2 \bullet 10^{-7}$	$1.2 \bullet 10^{-7}$	$1.2 \bullet 10^{-7}$	$3.1 \bullet 10^{-9}$	$2.8 \bullet 10^{-8}$	$7.1 \bullet 10^{-10}$
Y	–	$1.5 \bullet 10^{-6}$	–	–	–	$2.3 \bullet 10^{-5}$	$2.3 \bullet 10^{-5}$	$2.3 \bullet 10^{-5}$	$2.3 \bullet 10^{-5}$	$2.3 \bullet 10^{-5}$	$1.5 \bullet 10^{-9}$	$6.9 \bullet 10^{-9}$	$2.1 \bullet 10^{-9}$
Yb	$1.5 \bullet 10^{-9}$	$1.1 \bullet 10^{-7}$	–	$3.4 \bullet 10^{-7}$	–	$6.0 \bullet 10^{-9}$	$7.9 \bullet 10^{-7}$	$4.5 \bullet 10^{-8}$	$3.3 \bullet 10^{-9}$	$2.1 \bullet 10^{-7}$	$3.5 \bullet 10^{-10}$	$1.7 \bullet 10^{-9}$	$1.6 \bullet 10^{-9}$
Zn	$2.0 \bullet 10^{-3}$	$4.4 \bullet 10^{-5}$	–	$2.4 \bullet 10^{-3}$	–	$1.2 \bullet 10^{-4}$	$3.7 \bullet 10^{-4}$	$2.1 \bullet 10^{-4}$	$1.6 \bullet 10^{-4}$	$2.2 \bullet 10^{-4}$	$4.7 \bullet 10^{-5}$	$1.4 \bullet 10^{-4}$	$3.4 \bullet 10^{-5}$
Zr	$8.6 \bullet 10^{-5}$	$6.5 \bullet 10^{-7}$	–	$1.1 \bullet 10^{-5}$	–	$9.3 \bullet 10^{-6}$	$2.1 \bullet 10^{-6}$	$1.5 \bullet 10^{-5}$	$7.1 \bullet 10^{-6}$	$8.4 \bullet 10^{-6}$	$1.2 \bullet 10^{-7}$	$1.3 \bullet 10^{-7}$	$8.3 \bullet 10^{-9}$

Appendix 11

Pools of elements per unit area

The mass of elements per (g m^{-2}) in the average Forsmark and Laxemar-Simpevarp lake is presented in Table A11-1 and A11-2, respectively. "–" indicates missing data. References to how the pools of element in different components are calculated are presented in Chapter 7.

Table A11-1. Pools of elements (g $m^{-2)}$ in the average Forsmark Lake.

Element	Phyto-plankton	Benthic primary producers	Bacterio-plankton	Zooplankton	Benthic bacteria	Benthic fauna	Fish	Dissolved	Particulate	Sediment	Total
As	$2.7\bullet10^{-6}$	$2.9\bullet10^{-5}$	–	$3.3\bullet10^{-6}$	–	$7.6\bullet10^{-6}$	$1.5\bullet10^{-7}$	$1.7\bullet10^{-4}$	$3.6\bullet10^{-6}$	$1.3\bullet10^{0}$	$1.3\bullet10^{0}$
B	–	$8.3\bullet10^{-4}$	–	–	–	$2.7\bullet10^{-6}$	$3.2\bullet10^{-8}$	$2.1\bullet10^{-5}$	$2.0\bullet10^{-6}$	$6.0\bullet10^{0}$	$6.0\bullet10^{0}$
Sb	–	$2.4\bullet10^{-4}$	–	–	–	$2.2\bullet10^{-8}$	$2.1\bullet10^{-9}$	$8.9\bullet10^{-5}$	$1.3\bullet10^{-6}$	$1.3\bullet10^{-1}$	$1.3\bullet10^{-1}$
Se	$1.1\bullet10^{-7}$	$2.8\bullet10^{-5}$	–	$1.4\bullet10^{-6}$	–	$1.3\bullet10^{-6}$	$8.3\bullet10^{-7}$	$1.1\bullet10^{-5}$	$7.9\bullet10^{-7}$	$1.3\bullet10^{-1}$	$1.3\bullet10^{-1}$
Si	$3.1\bullet10^{-2}$	$9.4\bullet10^{-1}$	–	$1.4\bullet10^{-2}$	–	$7.3\bullet10^{-3}$	$1.6\bullet10^{-4}$	$1.7\bullet10^{0}$	$3.0\bullet10^{-2}$	$4.4\bullet10^{4}$	$4.4\bullet10^{4}$
Ag	–	$1.4\bullet10^{-4}$	–	–	–	$6.1\bullet10^{-7}$	$1.0\bullet10^{-8}$	$9.0\bullet10^{-7}$	$1.8\bullet10^{-7}$	$2.4\bullet10^{0}$	$2.4\bullet10^{0}$
Al	$4.1\bullet10^{-3}$	$5.5\bullet10^{-2}$	–	$4.0\bullet10^{-4}$	–	$7.0\bullet10^{-4}$	$1.9\bullet10^{-7}$	$4.6\bullet10^{-2}$	$3.5\bullet10^{-3}$	$1.5\bullet10^{4}$	$1.5\bullet10^{4}$
Ba	$1.0\bullet10^{-5}$	$1.1\bullet10^{-2}$	–	$7.0\bullet10^{-6}$	–	$1.6\bullet10^{-4}$	$7.7\bullet10^{-7}$	$1.9\bullet10^{-2}$	$7.2\bullet10^{-5}$	$1.1\bullet10^{2}$	$1.1\bullet10^{2}$
Be	–	$3.5\bullet10^{-6}$	–	–	–	$3.8\bullet10^{-8}$	$5.0\bullet10^{-8}$	$6.7\bullet10^{-6}$	$1.8\bullet10^{-7}$	$5.0\bullet10^{-1}$	$5.0\bullet10^{-1}$
Ca	$8.5\bullet10^{-4}$	$1.8\bullet10^{1}$	–	$1.2\bullet10^{-2}$	–	$3.3\bullet10^{-1}$	$5.0\bullet10^{-3}$	$4.6\bullet10^{1}$	$3.5\bullet10^{-2}$	$8.4\bullet10^{3}$	$8.5\bullet10^{3}$
Cd	$5.4\bullet10^{-8}$	$7.3\bullet10^{-6}$	–	$6.8\bullet10^{-7}$	–	$2.5\bullet10^{-6}$	$2.9\bullet10^{-9}$	$5.8\bullet10^{-6}$	$9.8\bullet10^{-7}$	$7.1\bullet10^{-2}$	$7.1\bullet10^{-2}$
Co	$3.5\bullet10^{-7}$	$3.3\bullet10^{-5}$	–	$2.3\bullet10^{-7}$	–	$1.0\bullet10^{-6}$	$8.8\bullet10^{-9}$	$5.5\bullet10^{-5}$	$1.5\bullet10^{-6}$	$2.3\bullet10^{0}$	$2.3\bullet10^{0}$
Cr	$1.4\bullet10^{-6}$	$9.5\bullet10^{-5}$	–	$1.4\bullet10^{-6}$	–	$1.4\bullet10^{-6}$	$1.0\bullet10^{-8}$	$6.9\bullet10^{-5}$	$3.7\bullet10^{-6}$	$1.5\bullet10^{1}$	$1.5\bullet10^{1}$
Cs	$1.1\bullet10^{-7}$	$3.6\bullet10^{-6}$	–	$4.5\bullet10^{-8}$	–	$1.3\bullet10^{-7}$	$1.4\bullet10^{-7}$	$1.3\bullet10^{-5}$	$4.9\bullet10^{-7}$	$1.3\bullet10^{0}$	$1.3\bullet10^{0}$
Cu	$4.8\bullet10^{-6}$	$1.2\bullet10^{-3}$	–	$2.8\bullet10^{-5}$	–	$6.5\bullet10^{-5}$	$1.5\bullet10^{-6}$	$5.6\bullet10^{-4}$	$3.3\bullet10^{-5}$	$6.9\bullet10^{0}$	$6.9\bullet10^{0}$
Fe	$8.2\bullet10^{-4}$	$7.2\bullet10^{-2}$	–	$2.9\bullet10^{-4}$	–	$1.5\bullet10^{-3}$	$2.5\bullet10^{-5}$	$8.6\bullet10^{-2}$	$7.1\bullet10^{-3}$	$9.0\bullet10^{3}$	$9.0\bullet10^{3}$
Ga	–	$1.0\bullet10^{-5}$	–	–	–	$7.4\bullet10^{-8}$	$4.0\bullet10^{-9}$	$4.1\bullet10^{-6}$	$1.0\bullet10^{-6}$	$2.9\bullet10^{0}$	$2.9\bullet10^{0}$
Hf	–	$1.2\bullet10^{-5}$	–	–	–	$8.1\bullet10^{-9}$	2.1^{-10}	$4.6\bullet10^{-6}$	$2.6\bullet10^{-7}$	$8.9\bullet10^{-1}$	$8.9\bullet10^{-1}$

Element	Phyto-plankton	Benthic primary producers	Bacterio-plankton	Zooplankton	Benthic bacteria	Benthic fauna	Fish	Dissolved	Particulate	Sediment	Total
Hg	$1.2\bullet10^{-8}$	$1.3\bullet10^{-6}$	–	$8.4\bullet10^{-8}$	–	$1.2\bullet10^{-7}$	$2.3\bullet10^{-6}$	$1.8\bullet10^{-6}$	$1.7\bullet10^{-7}$	$7.9\bullet10^{-3}$	$7.9\bullet10^{-3}$
K	$2.0\bullet10^{-3}$	$3.2\bullet10^{-2}$	–	$9.0\bullet10^{-3}$	–	$6.6\bullet10^{-3}$	$3.5\bullet10^{-2}$	$4.0\bullet10^{0}$	$5.5\bullet10^{-3}$	$5.1\bullet10^{3}$	$5.1\bullet10^{3}$
Li	$1.9\bullet10^{-6}$	$4.7\bullet10^{-5}$	–	$1.4\bullet10^{-6}$	–	$1.7\bullet10^{-6}$	$1.9\bullet10^{-7}$	$3.5\bullet10^{-3}$	$3.4\bullet10^{-6}$	$7.0\bullet10^{1}$	$7.0\bullet10^{1}$
Mg	$1.6\bullet10^{-3}$	$1.9\bullet10^{-1}$	–	$3.8\bullet10^{-3}$	–	$6.3\bullet10^{-3}$	$2.4\bullet10^{-3}$	$9.3\bullet10^{0}$	$2.8\bullet10^{-3}$	$2.7\bullet10^{3}$	$2.7\bullet10^{3}$
Mn	$9.8\bullet10^{-5}$	$1.1\bullet10^{-2}$	–	$2.4\bullet10^{-5}$	–	$1.7\bullet10^{-3}$	$1.3\bullet10^{-6}$	$4.1\bullet10^{-2}$	$2.2\bullet10^{-3}$	$1.1\bullet10^{2}$	$1.1\bullet10^{2}$
Mo	$7.4\bullet10^{-8}$	$1.1\bullet10^{-4}$	–	$3.6\bullet10^{-7}$	–	$4.4\bullet10^{-7}$	$3.7\bullet10^{-8}$	$3.9\bullet10^{-4}$	$2.8\bullet10^{-6}$	$1.6\bullet10^{0}$	$1.6\bullet10^{0}$
Na	$1.1\bullet10^{-2}$	$2.9\bullet10^{-2}$	–	$2.7\bullet10^{-2}$	–	$1.8\bullet10^{-2}$	$6.1\bullet10^{-3}$	$6.1\bullet10^{1}$	$5.3\bullet10^{-3}$	$2.2\bullet10^{3}$	$2.2\bullet10^{3}$
Nb	–	$2.0\bullet10^{-5}$	–	–	–	$5.6\bullet10^{-8}$	6.7^{-10}	$8.6\bullet10^{-6}$	$8.2\bullet10^{-7}$	$2.9\bullet10^{0}$	$2.9\bullet10^{0}$
Ni	$1.3\bullet10^{-6}$	$1.5\bullet10^{-4}$	–	$1.7\bullet10^{-6}$	–	$2.4\bullet10^{-6}$	$2.0\bullet10^{-8}$	$3.5\bullet10^{-4}$	$1.4\bullet10^{-5}$	$6.5\bullet10^{0}$	$6.5\bullet10^{0}$
Pb	$2.4\bullet10^{-6}$	$3.0\bullet10^{-4}$	–	$2.5\bullet10^{-6}$	–	$2.1\bullet10^{-6}$	$2.0\bullet10^{-8}$	$1.1\bullet10^{-4}$	$4.6\bullet10^{-5}$	$5.5\bullet10^{0}$	$5.5\bullet10^{0}$
Rb	$2.7\bullet10^{-6}$	$1.5\bullet10^{-4}$	–	$5.5\bullet10^{-6}$	–	$5.0\bullet10^{-6}$	$3.9\bullet10^{-5}$	$2.8\bullet10^{-3}$	$1.2\bullet10^{-5}$	$2.3\bullet10^{1}$	$2.3\bullet10^{1}$
Sc	–	$2.0\bullet10^{-5}$	–	–	–	$1.3\bullet10^{-7}$	$4.8\bullet10^{-9}$	$2.2\bullet10^{-5}$	$1.3\bullet10^{-6}$	$2.5\bullet10^{0}$	$2.5\bullet10^{0}$
Sn	–	$3.3\bullet10^{-5}$	–	–	–	$5.6\bullet10^{-8}$	$1.0\bullet10^{-8}$	$2.2\bullet10^{-6}$	$2.3\bullet10^{-7}$	$6.2\bullet10^{-1}$	$6.2\bullet10^{-1}$
Sr	–	$1.3\bullet10^{-2}$	–	–	–	$1.9\bullet10^{-4}$	$2.3\bullet10^{-6}$	$4.9\bullet10^{-2}$	$5.1\bullet10^{-5}$	$2.6\bullet10^{1}$	$2.7\bullet10^{1}$
Ta	–	$2.5\bullet10^{-6}$	–	–	–	$5.1\bullet10^{-9}$	$7.0\bullet10^{-9}$	$2.2\bullet10^{-7}$	–	$2.5\bullet10^{-1}$	$2.5\bullet10^{-1}$
Ti	$3.9\bullet10^{-5}$	$2.7\bullet10^{-3}$	–	$1.5\bullet10^{-5}$	–	$3.9\bullet10^{-5}$	$5.2\bullet10^{-7}$	$2.8\bullet10^{-4}$	$1.5\bullet10^{-4}$	$7.2\bullet10^{2}$	$7.2\bullet10^{2}$
Tl	–	$2.3\bullet10^{-6}$	–	–	–	$1.7\bullet10^{-7}$	$1.1\bullet10^{-8}$	$1.3\bullet10^{-5}$	$1.9\bullet10^{-7}$	$2.1\bullet10^{-1}$	$2.1\bullet10^{-1}$
V	$1.5\bullet10^{-6}$	$1.0\bullet10^{-4}$	–	$5.3\bullet10^{-7}$	–	$1.8\bullet10^{-6}$	$1.2\bullet10^{-8}$	$2.0\bullet10^{-4}$	$7.6\bullet10^{-6}$	$1.6\bullet10^{1}$	$1.6\bullet10^{1}$
W	–	$2.9\bullet10^{-5}$	–	–	–	$4.4\bullet10^{-8}$	$4.0\bullet10^{-9}$	$1.3\bullet10^{-5}$	$8.7\bullet10^{-7}$	$5.0\bullet10^{-1}$	$5.0\bullet10^{-1}$
Y	–	$1.3\bullet10^{-4}$	–	–	–	$4.2\bullet10^{-7}$	2.7^{-10}	$3.2\bullet10^{-5}$	$5.6\bullet10^{-6}$	$6.2\bullet10^{0}$	$6.2\bullet10^{0}$
Zn	$7.9\bullet10^{-5}$	$5.8\bullet10^{-1}$	–	$1.5\bullet10^{-4}$	–	$9.5\bullet10^{-3}$	$2.3\bullet10^{-1}$	$1.9\bullet10^{-3}$	$7.9\bullet10^{-5}$	$1.3\bullet10^{2}$	$1.4\bullet10^{2}$
Zr	$3.3\bullet10^{-6}$	$1.4\bullet10^{-4}$	–	$6.8\bullet10^{-7}$	–	$4.4\bullet10^{-6}$	$5.7\bullet10^{-9}$	$1.4\bullet10^{-4}$	$1.3\bullet10^{-5}$	$2.8\bullet10^{1}$	$2.8\bullet10^{1}$
Ce	$2.0\bullet10^{-9}$	$3.0\bullet10^{-4}$	–	$5.0\bullet10^{-7}$	–	$4.0\bullet10^{-7}$	–	$9.1\bullet10^{-5}$	$1.7\bullet10^{-5}$	$1.8\bullet10^{1}$	$1.8\bullet10^{1}$
Dy	1.1^{-10}	$4.0\bullet10^{-5}$	–	$3.9\bullet10^{-8}$	–	$2.2\bullet10^{-8}$	2.0^{-10}	$1.2\bullet10^{-5}$	$9.4\bullet10^{-7}$	$1.2\bullet10^{0}$	$1.2\bullet10^{0}$
Er	6.0^{-11}	$2.3\bullet10^{-5}$	–	$2.2\bullet10^{-8}$	–	$1.2\bullet10^{-8}$	2.0^{-10}	$9.1\bullet10^{-6}$	$5.9\bullet10^{-7}$	$6.4\bullet10^{-1}$	$6.4\bullet10^{-1}$
Eu	4.4^{-11}	$6.3\bullet10^{-6}$	–	$6.7\bullet10^{-9}$	–	$1.1\bullet10^{-8}$	2.0^{-10}	$6.9\bullet10^{-6}$	$1.4\bullet10^{-7}$	$2.3\bullet10^{-1}$	$2.3\bullet10^{-1}$
Gd	1.4^{-10}	$3.2\bullet10^{-5}$	–	$4.0\bullet10^{-8}$	–	$3.2\bullet10^{-8}$	2.0^{-10}	$1.3\bullet10^{-5}$	$6.0\bullet10^{-7}$	$1.1\bullet10^{0}$	$1.1\bullet10^{0}$

Element	Phyto-plankton	Benthic primary producers	Bacterio-plankton	Zooplankton	Benthic bacteria	Benthic fauna	Fish	Dissolved	Particulate	Sediment	Total
Ho	4.4^{-11}	$1.1\bullet10^{-5}$	–	$8.4\bullet10^{-9}$	–	$4.4\bullet10^{-9}$	2.0^{-10}	$6.0\bullet10^{-6}$	$2.0\bullet10^{-7}$	$2.5\bullet10^{-1}$	$2.5\bullet10^{-1}$
La	–	$2.0\bullet10^{-4}$	–	–	–	$1.0\bullet10^{-6}$	3.3^{-10}	$1.3\bullet10^{-5}$	$1.2\bullet10^{-5}$	$1.0\bullet10^{1}$	$1.0\bullet10^{1}$
Lu	4.4^{-11}	$3.8\bullet10^{-6}$	–	$3.4\bullet10^{-9}$	–	$1.9\bullet10^{-9}$	2.0^{-10}	$2.5\bullet10^{-5}$	$7.0\bullet10^{-8}$	$1.0\bullet10^{-1}$	$1.0\bullet10^{-1}$
Nd	8.3^{-10}	$2.0\bullet10^{-4}$	–	$2.6\bullet10^{-7}$	–	$1.9\bullet10^{-7}$	2.0^{-10}	$5.0\bullet10^{-5}$	$6.6\bullet10^{-6}$	$8.3\bullet10^{0}$	$8.3\bullet10^{0}$
Pr	2.2^{-10}	$4.4\bullet10^{-5}$	–	$6.7\bullet10^{-8}$	–	$5.0\bullet10^{-8}$	2.0^{-10}	$1.7\bullet10^{-5}$	$1.9\bullet10^{-6}$	$2.4\bullet10^{0}$	$2.4\bullet10^{0}$
Sm	1.5^{-10}	$3.2\bullet10^{-5}$	–	$5.2\bullet10^{-8}$	–	$3.4\bullet10^{-8}$	2.0^{-10}	$1.3\bullet10^{-5}$	$1.3\bullet10^{-6}$	$1.4\bullet10^{0}$	$1.4\bullet10^{0}$
Tb	4.4^{-11}	$6.8\bullet10^{-6}$	–	$6.7\bullet10^{-9}$	–	$4.1\bullet10^{-9}$	2.1^{-10}	$1.5\bullet10^{-5}$	$1.5\bullet10^{-7}$	$1.8\bullet10^{-1}$	$1.8\bullet10^{-1}$
Tm	4.4^{-11}	$5.4\bullet10^{-6}$	–	$3.4\bullet10^{-9}$	–	$1.7\bullet10^{-9}$	2.0^{-10}	$5.5\bullet10^{-6}$	$8.2\bullet10^{-8}$	$1.2\bullet10^{-1}$	$1.2\bullet10^{-1}$
Yb	5.7^{-11}	$2.0\bullet10^{-5}$	–	$2.0\bullet10^{-8}$	–	$1.1\bullet10^{-8}$	2.0^{-10}	$1.0\bullet10^{-5}$	$4.2\bullet10^{-7}$	$6.8\bullet10^{-1}$	$6.8\bullet10^{-1}$
Br	$2.9\bullet10^{-4}$	$1.1\bullet10^{-3}$	–	$1.8\bullet10^{-3}$	–	$1.7\bullet10^{-4}$	$2.2\bullet10^{-5}$	$3.6\bullet10^{-1}$	$3.3\bullet10^{-4}$	$2.8\bullet10^{0}$	$3.1\bullet10^{0}$
C	$3.9\bullet10^{-2}$	$2.6\bullet10^{1}$	$4.8\bullet10^{-2}$	$6.0\bullet10^{-2}$	$3.7\bullet10^{0}$	$5.2\bullet10^{-1}$	$8.3\bullet10^{-1}$	$3.7\bullet10^{1}$	$3.2\bullet10^{-1}$	$1.9\bullet10^{4}$	$1.9\bullet10^{4}$
Cl	$1.4\bullet10^{-2}$	$7.7\bullet10^{-2}$	–	–	–	$6.7\bullet10^{-3}$	$3.1\bullet10^{-3}$	$9.5\bullet10^{1}$	–	$1.9\bullet10^{1}$	$1.1\bullet10^{2}$
F	$2.2\bullet10^{-4}$	–	–	–	–	$5.7\bullet10^{-5}$	–	$2.5\bullet10^{-1}$	–	–	$2.5\bullet10^{-1}$
I	$3.3\bullet10^{-6}$	$6.5\bullet10^{-4}$	–	$9.9\bullet10^{-6}$	–	$1.1\bullet10^{-5}$	$4.5\bullet10^{-7}$	$5.8\bullet10^{-3}$	$6.2\bullet10^{-5}$	$5.4\bullet10^{-1}$	$5.4\bullet10^{-1}$
N	$4.7\bullet10^{-3}$	$9.5\bullet10^{-1}$	$9.0\bullet10^{-3}$	$1.4\bullet10^{-2}$	$6.6\bullet10^{-1}$	$8.0\bullet10^{-2}$	$2.3\bullet10^{-1}$	$1.0\bullet10^{0}$	$5.0\bullet10^{-2}$	$2.3\bullet10^{3}$	$2.3\bullet10^{3}$
P	$2.9\bullet10^{-4}$	$5.5\bullet10^{-2}$	$2.2\bullet10^{-3}$	$1.3\bullet10^{-3}$	$2.1\bullet10^{-1}$	$8.9\bullet10^{-3}$	$2.2\bullet10^{-2}$	$6.6\bullet10^{-3}$	$4.8\bullet10^{-3}$	$1.5\bullet10^{2}$	$1.5\bullet10^{2}$
S	$1.6\bullet10^{-3}$	$3.1\bullet10^{-1}$	$8.5\bullet10^{-4}$	$6.6\bullet10^{-3}$	$6.4\bullet10^{-2}$	$9.7\bullet10^{-3}$	$2.0\bullet10^{-2}$	$6.6\bullet10^{0}$	$1.2\bullet10^{-2}$	$7.5\bullet10^{2}$	$7.6\bullet10^{2}$
Th	$3.0\bullet10^{-7}$	$2.9\bullet10^{-5}$	–	$7.5\bullet10^{-8}$	–	$3.9\bullet10^{-7}$	$4.0\bullet10^{-9}$	$9.0\bullet10^{-6}$	$3.1\bullet10^{-6}$	$2.7\bullet10^{0}$	$2.7\bullet10^{0}$
U	–	$4.3\bullet10^{-4}$	–	$4.7\bullet10^{-8}$	–	$4.1\bullet10^{-7}$	$2.2\bullet10^{-9}$	$1.6\bullet10^{-3}$	$1.7\bullet10^{-6}$	$3.1\bullet10^{0}$	$3.1\bullet10^{0}$

Table A11-2. Pools of elements (g m^{-2}) in Frisksjön in Laxemar-Simpevarp.

Element	Phyto-plankton	Benthic primary producers	Bacterio-plankton	Zoo-plankton	Benthic bacteria	Benthic fauna	Fish	Dissolved	Particulate	Upper sediment	Lower sediment	Total Sediment	Total
As	$3.9\bullet10^{-5}$	$1.2\bullet10^{-8}$	–	$1.2\bullet10^{-5}$	–	$1.8\bullet10^{-5}$	$5.3\bullet10^{-8}$	$7.4\bullet10^{-4}$	$1.4\bullet10^{-4}$	$6.5\bullet10^{-3}$	$1.8\bullet10^{1}$	$1.8\bullet10^{1}$	$3.6\bullet10^{1}$
B	–	$8.7\bullet10^{-7}$	–	–	–	$9.8\bullet10^{-6}$	$1.2\bullet10^{-6}$	$4.4\bullet10^{-2}$	$8.7\bullet10^{-5}$	$7.4\bullet10^{-4}$	$1.5\bullet10^{0}$	$1.5\bullet10^{0}$	$3.0\bullet10^{0}$
Sb	–	4.5^{-10}	–	–	–	$6.6\bullet10^{-8}$	$2.5\bullet10^{-9}$	$3.0\bullet10^{-4}$	$9.6\bullet10^{-6}$	$1.2\bullet10^{-3}$	$5.3\bullet10^{-1}$	$5.3\bullet10^{-1}$	$1.1\bullet10^{0}$
Se	$1.6\bullet10^{-6}$	$6.5\bullet10^{-9}$	–	$5.4\bullet10^{-6}$	–	$1.8\bullet10^{-6}$	$1.4\bullet10^{-6}$	$2.8\bullet10^{-4}$	$1.3\bullet10^{-5}$	$1.5\bullet10^{-3}$	$1.5\bullet10^{0}$	$1.5\bullet10^{0}$	$3.1\bullet10^{0}$
Si	$4.4\bullet10^{-1}$	$6.1\bullet10^{-5}$	–	$5.1\bullet10^{-2}$	–	$1.6\bullet10^{-2}$	$2.1\bullet10^{-4}$	$1.0\bullet10^{1}$	$1.2\bullet10^{1}$	$2.8\bullet10^{2}$	$2.7\bullet10^{5}$	$2.7\bullet10^{5}$	$5.5\bullet10^{5}$
Ag	–	2.7^{-10}	–	–	–	$2.5\bullet10^{-7}$	$1.0\bullet10^{-8}$	$1.2\bullet10^{-5}$	$2.2\bullet10^{-6}$	$1.5\bullet10^{-4}$	$5.5\bullet10^{-2}$	$5.5\bullet10^{-2}$	$1.1\bullet10^{-1}$
Al	$5.9\bullet10^{-2}$	$4.6\bullet10^{-6}$	–	$1.5\bullet10^{-3}$	–	$5.5\bullet10^{-4}$	$1.0\bullet10^{-6}$	$4.2\bullet10^{-1}$	$3.4\bullet10^{-1}$	$4.5\bullet10^{1}$	$2.8\bullet10^{4}$	$2.8\bullet10^{4}$	$5.5\bullet10^{4}$
Ba	$1.5\bullet10^{-4}$	$2.8\bullet10^{-6}$	–	$2.6\bullet10^{-5}$	–	$2.2\bullet10^{-4}$	$8.8\bullet10^{-7}$	$2.9\bullet10^{-2}$	$1.7\bullet10^{-3}$	$2.7\bullet10^{-1}$	$1.7\bullet10^{2}$	$1.7\bullet10^{2}$	$3.5\bullet10^{2}$
Be	–	$2.3\bullet10^{-9}$	–	–	–	$3.0\bullet10^{-6}$	$5.5\bullet10^{-8}$	$5.2\bullet10^{-4}$	$1.3\bullet10^{-4}$	$1.3\bullet10^{-2}$	$4.1\bullet10^{0}$	$4.1\bullet10^{0}$	$8.2\bullet10^{0}$
Ca	$1.2\bullet10^{-2}$	$7.4\bullet10^{-4}$	–	$4.7\bullet10^{-2}$	–	$5.4\bullet10^{-1}$	$3.3\bullet10^{-3}$	$1.6\bullet10^{1}$	$8.1\bullet10^{-2}$	$1.2\bullet10^{1}$	$1.3\bullet10^{4}$	$1.3\bullet10^{4}$	$2.6\bullet10^{4}$
Cd	$7.7\bullet10^{-7}$	$1.5\bullet10^{-9}$	–	$2.6\bullet10^{-6}$	–	$4.6\bullet10^{-6}$	$2.8\bullet10^{-9}$	$2.8\bullet10^{-5}$	$1.1\bullet10^{-5}$	$5.1\bullet10^{-3}$	$2.3\bullet10^{0}$	$2.3\bullet10^{0}$	$4.7\bullet10^{0}$
Co	$5.1\bullet10^{-6}$	$1.9\bullet10^{-8}$	–	$8.8\bullet10^{-7}$	–	$2.1\bullet10^{-6}$	$1.3\bullet10^{-8}$	$4.5\bullet10^{-4}$	$8.1\bullet10^{-5}$	$3.3\bullet10^{-2}$	$9.5\bullet10^{0}$	$9.5\bullet10^{0}$	$1.9\bullet10^{1}$
Cr	$1.9\bullet10^{-5}$	$5.3\bullet10^{-9}$	–	$5.3\bullet10^{-6}$	–	$3.1\bullet10^{-6}$	$1.9\bullet10^{-8}$	$1.1\bullet10^{-3}$	$3.4\bullet10^{-4}$	$5.4\bullet10^{-2}$	$4.6\bullet10^{1}$	$4.6\bullet10^{1}$	$9.2\bullet10^{1}$
Cs	$1.6\bullet10^{-6}$	$1.7\bullet10^{-9}$	–	$1.7\bullet10^{-7}$	–	$2.8\bullet10^{-7}$	$8.7\bullet10^{-7}$	$2.4\bullet10^{-4}$	$1.7\bullet10^{-5}$	$3.3\bullet10^{-3}$	$2.3\bullet10^{0}$	$2.3\bullet10^{0}$	$4.7\bullet10^{0}$
Cu	$6.9\bullet10^{-5}$	$7.0\bullet10^{-8}$	–	$1.1\bullet10^{-4}$	–	$1.6\bullet10^{-4}$	$8.7\bullet10^{-7}$	$4.1\bullet10^{-3}$	$5.0\bullet10^{-4}$	$9.8\bullet10^{-2}$	$8.4\bullet10^{1}$	$8.4\bullet10^{1}$	$1.7\bullet10^{2}$
Fe	$1.2\bullet10^{-2}$	$1.2\bullet10^{-5}$	–	$1.1\bullet10^{-3}$	–	$2.2\bullet10^{-3}$	$9.7\bullet10^{-6}$	$1.7\bullet10^{0}$	$7.4\bullet10^{-1}$	$4.5\bullet10^{1}$	$2.6\bullet10^{4}$	$2.6\bullet10^{4}$	$5.1\bullet10^{4}$
Ga	–	4.7^{-10}	–	–	–	$1.3\bullet10^{-7}$	$4.6\bullet10^{-9}$	$1.0\bullet10^{-5}$	$4.6\bullet10^{-5}$	$1.0\bullet10^{-1}$	$4.5\bullet10^{0}$	$4.6\bullet10^{0}$	$9.3\bullet10^{0}$
Hf	–	2.0^{-10}	–	–	–	$4.3\bullet10^{-8}$	5.9^{-10}	$2.0\bullet10^{-4}$	$2.4\bullet10^{-5}$	$1.2\bullet10^{-3}$	$4.8\bullet10^{-1}$	$4.8\bullet10^{-1}$	$9.7\bullet10^{-1}$
Hg	$1.8\bullet10^{-7}$	1.1^{-10}	–	$3.2\bullet10^{-7}$	–	$1.1\bullet10^{-7}$	$1.9\bullet10^{-6}$	$3.2\bullet10^{-6}$	$1.2\bullet10^{-6}$	$2.3\bullet10^{-4}$	$6.7\bullet10^{-2}$	$6.7\bullet10^{-2}$	$1.3\bullet10^{-1}$
K	$2.9\bullet10^{-2}$	$5.4\bullet10^{-4}$	–	$3.4\bullet10^{-2}$	–	$1.6\bullet10^{-2}$	$2.9\bullet10^{-2}$	$3.3\bullet10^{0}$	$5.0\bullet10^{-2}$	$8.3\bullet10^{0}$	$8.3\bullet10^{3}$	$8.4\bullet10^{3}$	$1.7\bullet10^{4}$
Li	$2.7\bullet10^{-5}$	$5.7\bullet10^{-9}$	–	$5.2\bullet10^{-6}$	–	$4.1\bullet10^{-6}$	$2.8\bullet10^{-8}$	$4.3\bullet10^{-3}$	$9.0\bullet10^{-5}$	$2.9\bullet10^{-2}$	$1.6\bullet10^{1}$	$1.6\bullet10^{1}$	$3.2\bullet10^{1}$
Mg	$2.4\bullet10^{-2}$	$6.1\bullet10^{-5}$	–	$1.4\bullet10^{-2}$	–	$1.8\bullet10^{-2}$	$2.6\bullet10^{-3}$	$4.9\bullet10^{0}$	$2.7\bullet10^{-2}$	$1.5\bullet10^{-3}$	$9.5\bullet10^{3}$	$9.5\bullet10^{3}$	$1.9\bullet10^{4}$
Mn	$1.4\bullet10^{-3}$	$1.8\bullet10^{-5}$	–	$9.0\bullet10^{-5}$	–	$2.3\bullet10^{-4}$	$1.7\bullet10^{-6}$	$1.1\bullet10^{-1}$	$1.1\bullet10^{-2}$	$3.9\bullet10^{-1}$	$1.9\bullet10^{2}$	$1.9\bullet10^{2}$	$3.9\bullet10^{2}$
Mo	$1.1\bullet10^{-6}$	$1.8\bullet10^{-8}$	–	$1.4\bullet10^{-6}$	–	$7.6\bullet10^{-7}$	$1.7\bullet10^{-8}$	$2.2\bullet10^{-3}$	$7.3\bullet10^{-5}$	$4.4\bullet10^{-3}$	$1.6\bullet10^{1}$	$1.6\bullet10^{1}$	$3.2\bullet10^{1}$
Na	$1.5\bullet10^{-1}$	$1.9\bullet10^{-4}$	–	$1.0\bullet10^{-1}$	–	$3.7\bullet10^{-2}$	$3.3\bullet10^{-3}$	$2.0\bullet10^{1}$	$3.4\bullet10^{-2}$	$3.5\bullet10^{0}$	$1.1\bullet10^{4}$	$1.1\bullet10^{4}$	$2.2\bullet10^{4}$

Element	Phyto-plankton	Benthic primary producers	Bacterio-plankton	Zoo-plankton	Benthic bacteria	Benthic fauna	Fish	Dissolved	Particulate	Upper sediment	Lower sediment	Total Sediment	Total
Nb	–	4.9^{-10}	–	–	–	$1.2\bullet10^{-7}$	5.8^{-10}	$6.2\bullet10^{-5}$	$6.3\bullet10^{-5}$	$4.4\bullet10^{-3}$	$4.6\bullet10^{0}$	$4.6\bullet10^{0}$	$9.2\bullet10^{0}$
Ni	$1.8\bullet10^{-5}$	$3.2\bullet10^{-8}$	–	$6.4\bullet10^{-6}$	–	$5.1\bullet10^{-6}$	$2.9\bullet10^{-8}$	$3.1\bullet10^{-3}$	$2.6\bullet10^{-4}$	$7.7\bullet10^{-2}$	$5.4\bullet10^{1}$	$5.4\bullet10^{1}$	$1.1\bullet10^{2}$
Pb	$3.5\bullet10^{-5}$	$1.5\bullet10^{-8}$	–	$9.5\bullet10^{-6}$	–	$3.0\bullet10^{-6}$	$2.3\bullet10^{-8}$	$1.4\bullet10^{-3}$	$9.7\bullet10^{-4}$	$6.3\bullet10^{-2}$	$1.8\bullet10^{1}$	$1.8\bullet10^{1}$	$3.6\bullet10^{1}$
Rb	$3.9\bullet10^{-5}$	$9.1\bullet10^{-7}$	–	$2.1\bullet10^{-5}$	–	$1.0\bullet10^{-5}$	$1.1\bullet10^{-4}$	$7.7\bullet10^{-3}$	$2.7\bullet10^{-4}$	$5.9\bullet10^{-2}$	$4.4\bullet10^{1}$	$4.4\bullet10^{1}$	$8.8\bullet10^{1}$
Sc	–	$1.2\bullet10^{-9}$	–	–	–	$2.1\bullet10^{-6}$	9.4^{-10}	$1.7\bullet10^{-4}$	$7.4\bullet10^{-5}$	$1.1\bullet10^{-2}$	$7.6\bullet10^{0}$	$7.6\bullet10^{0}$	$1.5\bullet10^{1}$
Sn	–	9.1^{-10}	–	–	–	$8.2\bullet10^{-8}$	$1.0\bullet10^{-8}$	$5.0\bullet10^{-6}$	$2.3\bullet10^{-5}$	$1.5\bullet10^{-2}$	$1.5\bullet10^{1}$	$1.5\bullet10^{1}$	$3.1\bullet10^{1}$
Sr	–	$8.0\bullet10^{-7}$	–	–	–	$4.2\bullet10^{-4}$	$3.1\bullet10^{-6}$	$7.7\bullet10^{-2}$	$6.0\bullet10^{-4}$	$9.9\bullet10^{-2}$	$1.7\bullet10^{2}$	$1.7\bullet10^{2}$	$3.4\bullet10^{2}$
Ta	–	1.4^{-10}	–	–	–	$8.2\bullet10^{-9}$	$3.4\bullet10^{-9}$	$2.0\bullet10^{-6}$	$1.1\bullet10^{-6}$	$4.4\bullet10^{-5}$	$1.2\bullet10^{-1}$	$1.2\bullet10^{-1}$	$2.4\bullet10^{-1}$
Ti	$5.6\bullet10^{-4}$	$6.2\bullet10^{-8}$	–	$5.8\bullet10^{-5}$	–	$8.1\bullet10^{-5}$	$1.2\bullet10^{-7}$	$3.8\bullet10^{-3}$	$7.1\bullet10^{-3}$	$1.6\bullet10^{-1}$	$1.2\bullet10^{2}$	$1.3\bullet10^{2}$	$2.5\bullet10^{2}$
Tl	–	9.9^{-10}	–	–	–	$2.7\bullet10^{-8}$	$1.8\bullet10^{-8}$	$1.9\bullet10^{-5}$	$2.6\bullet10^{-6}$	$8.9\bullet10^{-4}$	$4.7\bullet10^{-1}$	$4.7\bullet10^{-1}$	$9.3\bullet10^{-1}$
V	$2.2\bullet10^{-5}$	$1.9\bullet10^{-8}$	–	$2.0\bullet10^{-6}$	–	$3.8\bullet10^{-6}$	$4.7\bullet10^{-8}$	$2.5\bullet10^{-3}$	$1.3\bullet10^{-3}$	$6.3\bullet10^{-2}$	$4.3\bullet10^{1}$	$4.3\bullet10^{1}$	$8.5\bullet10^{1}$
W	–	7.0^{-10}	–	–	–	$1.3\bullet10^{-7}$	$1.6\bullet10^{-9}$	$2.8\bullet10^{-5}$	$1.4\bullet10^{-5}$	$4.4\bullet10^{-2}$	$4.6\bullet10^{1}$	$4.6\bullet10^{1}$	$9.2\bullet10^{1}$
Y	–	$1.7\bullet10^{-8}$	–	–	–	$2.4\bullet10^{-5}$	$1.2\bullet10^{-9}$	$1.8\bullet10^{-3}$	$7.8\bullet10^{-4}$	$1.2\bullet10^{-1}$	$6.0\bullet10^{1}$	$6.0\bullet10^{1}$	$1.2\bullet10^{2}$
Zn	$1.1\bullet10^{-3}$	$5.6\bullet10^{-4}$	–	$5.5\bullet10^{-4}$	–	$1.7\bullet10^{-4}$	$1.9\bullet10^{-1}$	$7.9\bullet10^{-3}$	$1.3\bullet10^{-3}$	$9.8\bullet10^{-3}$	$1.2\bullet10^{2}$	$1.2\bullet10^{2}$	$2.5\bullet10^{2}$
Zr	$4.7\bullet10^{-5}$	$7.3\bullet10^{-9}$	–	$2.6\bullet10^{-6}$	–	$8.6\bullet10^{-6}$	$3.9\bullet10^{-8}$	$1.8\bullet10^{-3}$	$7.7\bullet10^{-4}$	$1.9\bullet10^{1}$	$7.2\bullet10^{1}$	$9.1\bullet10^{1}$	$1.8\bullet10^{2}$
Ce	$2.9\bullet10^{-8}$	$9.8\bullet10^{-8}$	–	$1.9\bullet10^{-6}$	–	$3.8\bullet10^{-7}$	–	$5.2\bullet10^{-3}$	$3.1\bullet10^{-3}$	$3.3\bullet10^{-1}$	$1.7\bullet10^{2}$	$1.7\bullet10^{2}$	$3.4\bullet10^{2}$
Dy	$1.6\bullet10^{-9}$	$2.3\bullet10^{-9}$	–	$1.5\bullet10^{-7}$	–	$2.2\bullet10^{-8}$	5.1^{-10}	$2.8\bullet10^{-4}$	$1.3\bullet10^{-4}$	$1.7\bullet10^{-2}$	$8.5\bullet10^{0}$	$8.5\bullet10^{0}$	$1.7\bullet10^{1}$
Er	8.6^{-10}	$1.4\bullet10^{-9}$	–	$8.2\bullet10^{-8}$	–	$1.2\bullet10^{-8}$	$3.0\bullet10^{-9}$	$1.8\bullet10^{-4}$	$8.3\bullet10^{-5}$	$1.2\bullet10^{-2}$	$5.0\bullet10^{0}$	$5.0\bullet10^{0}$	$1.0\bullet10^{1}$
Eu	6.4^{-10}	$1.0\bullet10^{-9}$	–	$2.5\bullet10^{-8}$	–	$5.0\bullet10^{-9}$	2.3^{-10}	$7.7\bullet10^{-5}$	$3.4\bullet10^{-5}$	$5.3\bullet10^{-3}$	$1.1\bullet10^{0}$	$1.1\bullet10^{0}$	$2.3\bullet10^{0}$
Gd	$1.9\bullet10^{-9}$	$2.8\bullet10^{-9}$	–	$1.5\bullet10^{-7}$	–	$3.4\bullet10^{-8}$	2.3^{-10}	$3.8\bullet10^{-4}$	$9.2\bullet10^{-5}$	$2.5\bullet10^{-2}$	$1.1\bullet10^{1}$	$1.1\bullet10^{1}$	$2.3\bullet10^{1}$
Ho	6.4^{-10}	4.5^{-10}	–	$3.2\bullet10^{-8}$	–	$4.3\bullet10^{-9}$	6.2^{-10}	$5.7\bullet10^{-5}$	$2.8\bullet10^{-5}$	$3.7\bullet10^{-3}$	$1.7\bullet10^{0}$	$1.7\bullet10^{0}$	$3.4\bullet10^{0}$
La	–	$3.6\bullet10^{-8}$	–	–	–	$1.2\bullet10^{-4}$	$2.4\bullet10^{-9}$	$2.6\bullet10^{-3}$	$1.6\bullet10^{-3}$	$1.7\bullet10^{-1}$	$7.8\bullet10^{1}$	$7.8\bullet10^{1}$	$1.6\bullet10^{2}$
Lu	6.4^{-10}	2.0^{-10}	–	$1.3\bullet10^{-8}$	–	$1.6\bullet10^{-9}$	2.3^{-10}	$4.9\bullet10^{-5}$	$1.0\bullet10^{-5}$	$1.5\bullet10^{-3}$	$8.2\bullet10^{-1}$	$8.2\bullet10^{-1}$	$1.6\bullet10^{0}$
Nd	$1.2\bullet10^{-8}$	$2.8\bullet10^{-8}$	–	$9.8\bullet10^{-7}$	–	$1.9\bullet10^{-7}$	$1.3\bullet10^{-9}$	$2.9\bullet10^{-3}$	$6.3\bullet10^{-5}$	$1.8\bullet10^{-1}$	$8.8\bullet10^{1}$	$8.8\bullet10^{1}$	$1.8\bullet10^{2}$
Pr	$3.2\bullet10^{-9}$	$7.7\bullet10^{-9}$	–	$2.5\bullet10^{-7}$	–	$5.1\bullet10^{-8}$	4.7^{-10}	$7.2\bullet10^{-4}$	$3.4\bullet10^{-4}$	$4.8\bullet10^{-2}$	$2.2\bullet10^{1}$	$2.2\bullet10^{1}$	$4.4\bullet10^{1}$
Sm	$2.2\bullet10^{-9}$	$4.5\bullet10^{-9}$	–	$2.0\bullet10^{-7}$	–	$3.5\bullet10^{-8}$	7.9^{-10}	$4.8\bullet10^{-4}$	$6.8\bullet10^{-4}$	$2.9\bullet10^{-2}$	$1.3\bullet10^{1}$	$1.3\bullet10^{1}$	$2.7\bullet10^{1}$

Element	Phyto-plankton	Benthic primary producers	Bacterio-plankton	Zoo-plankton	Benthic bacteria	Benthic fauna	Fish	Dissolved	Particulate	Upper sediment	Lower sediment	Total Sediment	Total
Tb	6.4^{-10}	3.8^{-10}	–	$2.5 \bullet 10^{-8}$	–	$4.4 \bullet 10^{-9}$	8.2^{-10}	$5.5 \bullet 10^{-5}$	$2.0 \bullet 10^{-5}$	$3.0 \bullet 10^{-3}$	$1.6 \bullet 10^{0}$	$1.6 \bullet 10^{0}$	$3.2 \bullet 10^{0}$
Tm	6.4^{-10}	1.9^{-10}	–	$1.3 \bullet 10^{-8}$	–	$1.6 \bullet 10^{-9}$	3.8^{-10}	$2.7 \bullet 10^{-5}$	$1.2 \bullet 10^{-5}$	$1.7 \bullet 10^{-3}$	$8.1 \bullet 10^{-1}$	$8.1 \bullet 10^{-1}$	$1.6 \bullet 10^{0}$
Yb	8.1^{-10}	$1.3 \bullet 10^{-9}$	–	$7.6 \bullet 10^{-8}$	–	$1.0 \bullet 10^{-8}$	6.0^{-10}	$1.9 \bullet 10^{-4}$	$6.2 \bullet 10^{-5}$	$9.8 \bullet 10^{-3}$	$5.2 \bullet 10^{0}$	$5.3 \bullet 10^{0}$	$1.1 \bullet 10^{1}$
Br	$4.2 \bullet 10^{-3}$	$1.7 \bullet 10^{-6}$	–	$6.9 \bullet 10^{-3}$	–	$2.8 \bullet 10^{-4}$	$2.7 \bullet 10^{-5}$	$2.4 \bullet 10^{-1}$	$3.2 \bullet 10^{-4}$	$1.2 \bullet 10^{-2}$	$2.3 \bullet 10^{2}$	$2.3 \bullet 10^{2}$	$4.7 \bullet 10^{2}$
C	$5.5 \bullet 10^{-1}$	$1.1 \bullet 10^{-2}$	$5.2 \bullet 10^{-2}$	$2.2 \bullet 10^{-1}$	$5.3 \bullet 10^{0}$	$1.0 \bullet 10^{0}$	$6.0 \bullet 10^{-1}$	$3.6 \bullet 10^{1}$	$1.7 \bullet 10^{0}$	$2.5 \bullet 10^{2}$	$2.6 \bullet 10^{5}$	$2.6 \bullet 10^{5}$	$5.2 \bullet 10^{5}$
Cl	$2.0 \bullet 10^{-1}$	$3.2 \bullet 10^{-4}$	–	–	–	$1.3 \bullet 10^{-2}$	$2.7 \bullet 10^{-3}$	$2.6 \bullet 10^{1}$	–	$5.2 \bullet 10^{-1}$	$7.8 \bullet 10^{3}$	$7.8 \bullet 10^{3}$	$1.6 \bullet 10^{4}$
F	$3.1 \bullet 10^{-3}$	–	–	–	–	$1.3 \bullet 10^{-4}$	–	$1.5 \bullet 10^{0}$	–	–	–	–	$1.6 \bullet 10^{0}$
I	$4.8 \bullet 10^{-5}$	$2.8 \bullet 10^{-7}$	–	$3.7 \bullet 10^{-5}$	–	$1.5 \bullet 10^{-5}$	$3.4 \bullet 10^{-6}$	$6.2 \bullet 10^{-2}$	$2.1 \bullet 10^{-3}$	$6.3 \bullet 10^{-3}$	$4.2 \bullet 10^{1}$	$4.2 \bullet 10^{1}$	$8.3 \bullet 10^{1}$
N	$6.7 \bullet 10^{-2}$	$5.6 \bullet 10^{-4}$	$9.6 \bullet 10^{-3}$	$5.1 \bullet 10^{-2}$	$9.6 \bullet 10^{-1}$	$1.7 \bullet 10^{-1}$	$1.9 \bullet 10^{-1}$	$6.1 \bullet 10^{-1}$	$2.1 \bullet 10^{-1}$	$1.9 \bullet 10^{1}$	$3.1 \bullet 10^{4}$	$3.1 \bullet 10^{4}$	$6.1 \bullet 10^{4}$
P	$5.1 \bullet 10^{-3}$	$7.8 \bullet 10^{-5}$	$2.4 \bullet 10^{-3}$	$8.5 \bullet 10^{-3}$	$3.0 \bullet 10^{-1}$	$8.8 \bullet 10^{-3}$	$1.8 \bullet 10^{-2}$	$3.6 \bullet 10^{-2}$	$2.6 \bullet 10^{-2}$	$2.3 \bullet 10^{0}$	$2.2 \bullet 10^{3}$	$2.2 \bullet 10^{3}$	$4.4 \bullet 10^{3}$
S	$2.3 \bullet 10^{-2}$	$1.1 \bullet 10^{-4}$	$9.1 \bullet 10^{-4}$	$2.5 \bullet 10^{-2}$	$9.3 \bullet 10^{-2}$	$2.3 \bullet 10^{-2}$	$1.8 \bullet 10^{-2}$	$8.8 \bullet 10^{0}$	$6.0 \bullet 10^{-2}$	$2.7 \bullet 10^{1}$	$3.7 \bullet 10^{4}$	$3.7 \bullet 10^{4}$	$7.5 \bullet 10^{4}$
Th	$4.4 \bullet 10^{-6}$	$1.4 \bullet 10^{-9}$	–	$2.8 \bullet 10^{-7}$	–	$7.6 \bullet 10^{-7}$	$4.6 \bullet 10^{-9}$	$1.8 \bullet 10^{-4}$	$1.8 \bullet 10^{-4}$	$1.5 \bullet 10^{-2}$	$8.7 \bullet 10^{0}$	$8.7 \bullet 10^{0}$	$1.7 \bullet 10^{1}$
U	–	$4.9 \bullet 10^{-9}$	–	$5.5 \bullet 10^{-7}$	–	$2.5 \bullet 10^{-6}$	$1.7 \bullet 10^{-9}$	$6.6 \bullet 10^{-4}$	$1.4 \bullet 10^{-4}$	$1.9 \bullet 10^{-2}$	$1.9 \bullet 10^{1}$	$1.9 \bullet 10^{1}$	$3.9 \bullet 10^{1}$

Appendix 12

Fluxes of elements

Fluxes of elements are described in Chapter 5 and 7. Range of carbon fluxes into and out of the 5 lakes in Chapter 5 are presented in Table A12-1. Fluxes into and out of the 5 lakes in Forsmark and one lake in Laxemar-Simpevarp (Frisksjön) for a number of elements are presented in Table A12-2 below. In Table A12-3 and A12-4, values of atmospheric deposition are presented. Details of how fluxes were calculated are presented in Chapter 7. For carbon, more detailed mass balances are described in Chapter 5 for Bolundsfjärden, Eckarfjärden and Frisksjön.

Table A12-1. Calculated carbon influxes and outfluxes (minimum, maximum and best guess) to/from Eckarfjärden, Bolundsfjärden, Gunnarsbo-Lillfjärden, and Labboträsk in Forsmark and to/from Frisksjön in Laxemar-Simpevarp. All values are in kgC lake^{-1} year $^{-1}$.

Lake	DIC inflow	TOC inflow	Atmospheric deposition	CO2 gas exchange	DIC Outflow	TOC Outflow	Sediment accumulation	Bird consumption
Eckarfjärden								
min	9,732	3,272	158	-264	6,316	5,336	339	1
max	11,123	3,753	434	-1,236	7,219	6,119	15,083	676
best guess	10,427	3,512	233	-928	6,767	5,727	3,649	326
Bolundsfjärden								
min	27,942	19,551	340	-2,592	27,874	18,917	728	2
max	35,999	25,456	931	-3,157	36,113	24,794	32,367	1,451
best guess	31,971	22,502	501	-2,848	31,993	21,855	8,988	700
Gunnarsbo-Lillfjärden								
min	26,654	13,088	15	1,361	26,214	13,088	32	1
max	26,654	13,088	41	1,361	26,214	13,088	1,434	676
best guess	26,654	13,088	22	1,361	26,214	13,088	371	31
Labboträsk								
min	16,528	7,698	2	400	18,959	8,313	4	0,01
max	21,772	10,792	5	506	23,108	10,625	176	8
best guess	19,150	9,245	3	448	21,033	9,469	45	4
Frisksjön								
min	388	6,498	86	1,883	364	2,754	2,665	0,1
max	5,047	13,476	236	6,026	1,205	5,390	10,848	283
best guess	1,082	8,272	193	4,478	800	4,299	8,009	93

Table A12-2. Fluxes to/from lakes in Forsmark and Laxemar-Simpevarp. Eckarfjärden, Bolundsfjärden, Gällsboträsket, Norra Bassängen and Puttan are lakes in the Forsmark area, and the average Forsmark lake is mean values for the 5 lakes. Frisksjön represent the Laxemar-Simpevarp area. Fluxes are in g lake^{-1} year^{-1}.

Element	Flux (g year^{-1})	Eckarfjärden	Bolundsfjärden	Gällsboträsket	Norra Bassängen	Puttan	Average Forsmark Lake	Frisksjön
C	In through water	13,939,532	54,473,472	17,624,951	55,636,066	1,918,721	28,135,548	9,354,653
	In from atmosphere	233,308	500,683	10,771	39,198	32,807	163,355	193,283
	Out through water	12,494,644	53,848,483	17,005,475	55,298,689	1,558,525	28,040,938	5,099,212
	Accumulation	3,649,303	8,987,988	224,355	816,457	683,349	3,402,518	8,009,020
N	In through water	370,882	1,087,329	223,000	1,314,000	48,000	608,642	584,814
	In from atmosphere	67,872	145,653	3,133	11,403	9,544	47,521	65,798
	Out through water	370,932	1,207,728	222,882	1,323,098	47,612	634,450	424,463
	Accumulation	392,682	842,703	18,129	65,974	55,218	274,941	803,029
P	In through water	3,033	10,782	4,600	13,600	400	6,483	17,173
	In from atmosphere	2,292	4,919	106	385	322	1,605	2,762
	Out through water	3,049	12,792	4,632	13,660	418	6,910	7,974
	Accumulation	6,523	13,999	301	1,096	917	4,567	97,090
Ag	In through water							
	In from atmosphere							
	Out through water							
	Accumulation	257	551	12	43	36	180	5
Al	In through water							184,033
	In from atmosphere	3	7	0.2	1	0.5	2	2
	Out through water							100,165
	Accumulation	89,593	192,269	4,136	15,052	12,598	62,730	1,416,810
As	In through water							
	In from atmosphere							
	Out through water							
	Accumulation	48	103	2	8	7	33	210
B	In through water							
	In from atmosphere							
	Out through water							
	Accumulation	566	1,214	26	95	80	396	38

Element	Flux (g year^{-1})	Eckarfjärden	Bolundsfjärden	Gällsboträsket	Norra Bassängen	Puttan	Average Forsmark Lake	Frisksjön
Ba	In through water	8,018	21,812	8,304	23,446	811	12,478	13,420
	In from atmosphere							
	Out through water	5,723	21,665	7,887	23,440	566	11,856	13,420
	Accumulation	1,530	3,283	71	257	215	1,071	8,665
Be	In through water							
	In from atmosphere							
	Out through water							
	Accumulation	5	11	0	1	1	4	404
Br	In through water							
	In from atmosphere	263	565	12	44	37	184	8,558
	Out through water							
	Accumulation	378	810	17	63	53	264	1,050
Ca	In through water	19,091,100	51,932,521	19,773,000	64,935,000	1,932,000	31,532,724	3,940,331
	In from atmosphere	31,617	67,850	1,460	5,312	4,374	22,123	43,077
	Out through water	13,626,689	51,583,198	18,779,658	55,809,089	1,346,436	28,229,014	3,940,331
	Accumulation	883,901	1,896,868	40,807	148,503	124,292	618,874	439,516
Cd	In through water	0.4	10	1	12	0.3	5	26
	In from atmosphere							
	Out through water	0.4	11	1	12	0.3	5	14
	Accumulation	8	17	0	1	1	6	153
Ce	In through water	7	23	8	29	1	13	587
	In from atmosphere							
	Out through water	7	27	8	29	1	14	319
	Accumulation	639	1,372	30	107	90	448	12,274
Cl	In through water	1,629,657	22,201,954	6,289,000	89,588,000	1,494,000	24,240,522	3,484,357
	In from atmosphere	96,958	208,074	4,476	16,290	13,634	67,887	76,514
	Out through water	1,629,812	85,752,495	6,288,777	89,859,150	1,493,967	37,004,840	3,484,357
	Accumulation	10,661	22,879	492	1,791	1,499	7,465	38,741
Co	In through water	15	51	17	66	2	30	316
	In from atmosphere							
	Out through water	15	60	17	66	2	32	172
	Accumulation	35	74	2	6	5	24	977

Element	Flux (g year^{-1})	Eckarfjärden	Bolundsfjärden	Gällsboträsket	Norra Bassängen	Puttan	Average Forsmark Lake	Frisksjön
Cr	In through water	126	437	148	563	19	259	473
	In from atmosphere							
	Out through water	126	517	148	567	19	275	219
	Accumulation	188	403	9	32	26	131	1,875
Cs	In through water							
	In from atmosphere							
	Out through water							
	Accumulation	10	23	0	2	1	7	103
Cu	In through water	267	727	277	782	27	416	1,329
	In from atmosphere							
	Out through water	191	722	263	781	19	395	724
	Accumulation	363	778	17	61	51	254	3,142
Dy	In through water	6	19	7	25	1	11	152
	In from atmosphere							
	Out through water	6	23	7	25	1	12	152
	Accumulation	50	107	2	8	7	35	573
Er	In through water	4	15	5	19	1	9	100
	In from atmosphere							
	Out through water	4	18	5	19	1	9	100
	Accumulation	33	70	2	5	5	23	345
Eu	In through water	0.1	6	0	7	0.1	3	37
	In from atmosphere							
	Out through water	0.1	7	0	7	0.1	3	37
	Accumulation	7	14	0	1	1	5	182
F	In through water							
	In from atmosphere							7,267
	Out through water							
	Accumulation							

Element	Flux (g year^{-1})	Eckarfjärden	Bolundsfjärden	Gällsboträsket	Norra Bassängen	Puttan	Average Forsmark Lake	Frisksjön
Fe	In through water	37,425	129,257	43,734	166,658	5,725	76,560	588,670
	In from atmosphere	3,404	7,305	157	572	915	2,471	3,871
	Out through water	37,425	153,002	43,734	167,713	5,725	81,520	272,273
	Accumulation	124,233	266,605	5,735	20,872	17,469	86,983	1,431,293
Ga	In through water							
	In from atmosphere							
	Out through water							
	Accumulation	8	18	0	1	1	6	983
Gd	In through water	6	19	7	25	1	11	200
	In from atmosphere							
	Out through water	6	23	7	25	1	12	200
	Accumulation	27	59	1	5	4	19	805
Hf	In through water	6	17	7	15	1	9	46
	In from atmosphere							
	Out through water	3	13	6	15	0	7	21
	Accumulation	20	43	1	3	3	14	52
Hg	In through water	1	2	1	2	0	1	1
	In from atmosphere							
	Out through water	1	2	1	2	0	1	1
	Accumulation	1	2	0.04	0.1	0.1	1	7
Ho	In through water	1	5	2	6	0	3	32
	In from atmosphere							
	Out through water	1	6	2	6	0	3	32
	Accumulation	11	24	1	2	2	8	118
I	In through water	2,023	6,987	2,364	9,009	309	4,138	4,537
	In from atmosphere	53	113	2	9	7	37	31
	Out through water	2,023	8,270	2,364	9,066	309	4,406	3,424
	Accumulation	120	258	6	20	17	84	258

Element	Flux (g year^{-1})	Eckarfjärden	Bolundsfjärden	Gällsboträsket	Norra Bassängen	Puttan	Average Forsmark Lake	Frisksjön
K	In through water	712,900	2,189,250	724,000	3,904,000	73,000	1,520,630	429,889
	In from atmosphere	18,443	39,579	851	3,099	2,593	12,913	37,012
	Out through water	712,429	3,723,021	723,876	3,927,248	73,083	1,831,931	429,889
	Accumulation	52,454	112,568	2,422	8,813	7,376	36,727	271,145
La	In through water	25	87	30	113	4	52	1,252
	In from atmosphere							
	Out through water	25	103	30	113	4	55	1,252
	Accumulation	303	651	14	51	43	212	5,875
Li	In through water	712	3,390	724	3,905	73	1,761	
	In from atmosphere	0	0	0	0	0	0	150
	Out through water	712	3,723	724	3,927	73	1,832	
	Accumulation	158	339	7	27	22	111	868
Lu	In through water	0.4	9	1	11	0.3	4	17
	In from atmosphere							
	Out through water	0.4	10	1	11	0.3	5	17
	Accumulation	4	9	0	1	1	3	51
Mg	In through water	856,880	3,692,030	1,701,000	8,481,000	148,000	2,975,782	874,785
	In from atmosphere	8,642	18,546	399	1,429	1,215	6,046	13,365
	Out through water	857,290	8,193,406	1,701,163	8,503,909	148,248	3,880,803	874,785
	Accumulation	34,289	73,585	1,583	5,761	4,822	24,008	184,906
Mn	In through water	11,126	38,428	13,002	49,547	1,702	22,761	0
	In from atmosphere	2,467	5,294	114	414	347	1,727	1,444
	Out through water	11,126	45,487	13,002	49,861	1,702	24,236	0
	Accumulation	3,348	7,185	155	563	471	2,344	12,931
Mo	In through water	128	610	130	703	13	317	247
	In from atmosphere							
	Out through water	128	670	130	707	13	330	186
	Accumulation	206	443	10	35	29	145	281

Element	Flux (g year^{-1})	Eckarfjärden	Bolundsfjärden	Gällsboträsket	Norra Bassängen	Puttan	Average Forsmark Lake	Frisksjön
Na	In through water	2,003,152	17,936,737	3,616,000	56,545,000	1,302,000	16,280,578	2,055,802
	In from atmosphere	56,910	122,130	2,627	9,561	8,003	39,846	106,203
	Out through water	2,003,723	54,061,516	3,612,554	57,774,973	1,302,219	23,750,997	2,055,802
	Accumulation	30,611	65,693	1,413	5,143	4,305	21,433	140,082
Nb	In through water							
	In from atmosphere							
	Out through water							
	Accumulation	53	115	2	9	8	37	150
Nd	In through water	6	19	7	25	1	11	1,321
	In from atmosphere							
	Out through water	6	23	7	25	1	12	1,321
	Accumulation	305	655	14	51	43	214	6,338
Ni	In through water	76	494	106	563	10	250	1,525
	In from atmosphere							
	Out through water	76	541	106	565	10	260	830
	Accumulation	186	399	9	31	26	130	2,481
Pb	In through water	9	220	16	259	6	102	
	In from atmosphere							
	Out through water	9	243	16	260	6	107	
	Accumulation	379	814	18	64	53	265	1,721
Pr	In through water	26	91	31	117	4	54	329
	In from atmosphere							
	Out through water	26	108	31	118	4	57	329
	Accumulation	107	230	5	18	15	75	
Rb	In through water	620	2,949	630	3,397	64	1,532	850
	In from atmosphere							
	Out through water	620	3,239	630	3,417	64	1,594	850
	Accumulation	436	937	20	73	61	306	1,863

Element	Flux (g year^{-1})	Eckarfjärden	Bolundsfjärden	Gällsboträsket	Norra Bassängen	Puttan	Average Forsmark Lake	Frisksjön
S	In through water	2,553,160	4,390,937	1,316,408	20,860,000	127,981	5,849,697	4,704,939
	In from atmosphere	52,695	113,084	2,433	8,853	7,410	36,895	35,428
	Out through water	944,857	6,686,217	1,316,408	6,991,057	127,981	3,213,304	4,704,939
	Accumulation	115,981	248,898	5,355	194,86	16,309	81,206	1,129,631
Sb	In through water	19	92	20	105	2	48	
	In from atmosphere							
	Out through water	19	101	20	106	2	49	
	Accumulation	7	16	0	1	1	5	30
Sc	In through water	0	0	0	0	0	0	66
	In from atmosphere	0	0	0	0	0	0	0
	Out through water	0	0	0	0	0	0	66
	Accumulation	34	72	2	6	5	23	389
Se	In through water	0	0	0	0	0	0	0
	In from atmosphere	0	0	0	0	0	0	0
	Out through water	0	0	0	0	0	0	0
	Accumulation	15	31	1	2	2	10	50
Si	In through water	1,744,406	4,473,285	1,767,000	5,682,000	190,000	2,771,338	3,561,195
	In from atmosphere	1,581	3,393	73	266	222	1,107	3,352
	Out through water	842,005	3,577,086	1,548,471	3,947,457	87,949	2,000,594	1,938,281
	Accumulation	1,096,733	2,353,608	50,633	184,261	154,220	767,891	9,375,140
Sm	In through water	1	4	1	5	0	2	229
	In from atmosphere							
	Out through water	1	5	1	5	0	3	229
	Accumulation	51	109	2	9	7	36	1,023
Sn	In through water							
	In from atmosphere							
	Out through water							
	Accumulation	22	48	1	4	3	16	502

Element	Flux (g year⁻¹)	Eckarfjärden	Bolundsfjärden	Gällsboträsket	Norra Bassängen	Puttan	Average Forsmark Lake	Frisksjön
Sr	In through water	23,216	101,478	25,517	138,000	5,702	58,783	19,054
	In from atmosphere	887	1,904	41	149	125	621	519
	Out through water	15,152	100,184	28,481	133,464	3,583	56,173	19,054
	Accumulation	871	1,869	40	146	122	610	3,994
Ta	In through water							
	In from atmosphere							
	Out through water							
	Accumulation	6	14	0	1	1	4	12
Tb	In through water	1	21	2	25	1	10	22
	In from atmosphere							
	Out through water	1	23	2	25	1	10	12
	Accumulation	4	9	0	1	1	3	110
Th	In through water	6	19	7	25	1	11	52
	In from atmosphere	0.001	0.002	0.00004	0.0002	0.0001	0.001	0.001
	Out through water	6	23	7	25	1	12	28
	Accumulation	56	120	3	9	8	39	470
Ti	In through water							8
	In from atmosphere							
	Out through water							4
	Accumulation	7,254	15,567	335	1,219	1,020	5,079	5,073
Tl	In through water							
	In from atmosphere							
	Out through water							
	Accumulation	6	12	0	1	1	4	27
Tm	In through water	0.2	6	0.4	7	0.2	3	14
	In from atmosphere							
	Out through water	0.2	6	0.4	7	0.2	3	14
	Accumulation	4	10	0.2	1	1	3	55

Element	Flux (g year^{-1})	Eckarfjärden	Bolundsfjärden	Gällsboträsket	Norra Bassängen	Puttan	Average Forsmark Lake	Frisksjön
U	In through water	977	2,645	1,012	2,822	99	1,511	281
	In from atmosphere							
	Out through water	687	2,606	959	2,820	68	1,428	130
	Accumulation	474	1,017	22	80	67	332	652
V	In through water	55	191	65	246	8	113	590
	In from atmosphere							
	Out through water	55	226	65	248	8	120	273
	Accumulation	189	406	9	32	27	133	2,086
W	In through water							
	In from atmosphere							
	Out through water							
	Accumulation	31	66	1	5	4	22	1,505
Y	In through water	48	166	56	214	7	98	1,108
	In from atmosphere							
	Out through water	48	196	56	215	7	105	1,108
	Accumulation	176	378	8	30	25	123	4,021
Yb	In through water	5	16	5	20	1	9	103
	In from atmosphere							
	Out through water	5	19	5	21	1	10	103
	Accumulation	24	52	1	4	3	17	339
Zn	In through water	556	1,921	650	2,477	85	1,138	3,996
	In from atmosphere							
	Out through water	556	2,274	650	2,493	85	1,212	2,175
	Accumulation	1,920	4,120	89	323	270	1,344	9,773
Zr	In through water	159	407	161	364	17	222	972
	In from atmosphere	0	0	0	0	0	0	0
	Out through water	77	326	141	359	8	182	451
	Accumulation	363	778	17	61	51	254	3,035

Table A12-3. Values of atmospheric deposition (dry deposition and/or precipitation) used in mass balance models of Forsmark lakes. Data from 1) /Tröjbom and Söderbäck 2006b/, 2) /Phil-Karlsson et al. 2003/, 3) /Tyler and Olsson 2006/, 4) Sicada October 2007.

Element	Precipitation (mm year^{-1})	Deposition (g m^{-2} year^{-1})	Reference	Comment
C	559	1.25775	1	Precipitation, site data, mean from two stations (PFM002457 and PFM 002564)
N	559	0.36	2	Precipitation, Site data only includes data from 1 sampling occasion and therefore generic data is used. Station Jädraås
P	559	0.012158	1	Precipitation, site data, mean from two stations (PFM002457 and PFM 002564)
U	559	0.000002	3	Estimate of atmospheric deposition during the winter period in a deciduous forest in southern Sweden
Th	559	0.000005	3	Estimate of atmospheric deposition during the winter period in a deciduous forest in southern Sweden
I	559	0.00028	1	Precipitation, Based on two measurements at the site that both were below the detection limit of 1µg/l. Half the detection limit was assumed to be the deposition, which was in the lower range of the iodine deposition interval reported by /Sheppard et al. 2002/
Al	559	1.76E–05	1	Precipitation, site data, mean from two stations (PFM002457 and PFM 002564)
Br	559	0.001398	1	Precipitation, Based on 12 measurements at the site that all were below the detection limit of 5µg/l. Half the detection limit was assumed to be the deposition
Ca	559	0.1677	1	Precipitation, site data, mean from two stations (PFM002457 and PFM 002564)
Cl	559	0.51428	1	Precipitation, site data, mean from two stations (PFM002457 and PFM 002564)
Fe	559	0.018056	1	Precipitation, site data, mean from two stations (PFM002457 and PFM 002564)
Mg	559	0.045838	1	Precipitation, site data, mean from two stations (PFM002457 and PFM 002564)
K	559	0.097825	1	Precipitation, site data, mean from two stations (PFM002457 and PFM 002564)
Si	559	0.008385	1	Precipitation, Based on one measurements at the site that was below the detection limit of 30µg/l. Half the detection limit was assumed to be the deposition
Na	559	0.30186	1	Precipitation, site data, mean from two stations (PFM002457 and PFM 002564)
S	559	0.2795	1	Precipitation, site data, mean from two stations (PFM002457 and PFM 002564)
Mn	559	0.013085	4	Precipitation, Based on site investigation in Laxemar-Simpevarp but with precipitation amounts for Forsmark
Sr	559	0.004705	4	Precipitation, Based on site investigation in Laxemar-Simpevarp but with precipitation amounts for Forsmark

Table A12-4. Values of atmospheric deposition (dry deposition and/or precipitation) used in mass balance models of Frisksjön in Laxemar-Simpevarp. Data from 1) /Phil-Karlsson et al. 2008/, 2) /Knape 2001/, 3) /Tyler and Olsson 2006/, 4) /Tröjbom and Söderbäck 2006b/, 5) Sicada October 2007.

Element	Precipitation (mm $year^{-1}$)	Deposition (g m^{-2} $year^{-1}$)	Reference	Comment
C	600	1.88	1	Precipitation, generic data from station Rockneby in Kalmar län mean 2000–20007
N	600	0.64	1	Precipitation, generic data from station Rockneby in Kalmar län mean 2000–20007
P	600	0,027	2	Generic data from Äspö
U	600	0.000002	3	Estimate of atmospheric deposition during the winter period in a deciduous forest in southern Sweden
Th	600	0.000005	3	Estimate of atmospheric deposition during the winter period in a deciduous forest in southern Sweden
I	600	0.0003	4	Precipitation, Based on two measurements in Forsmark that both were below the detection limit of 1µg/l. Half the detection limit was assumed to be the deposition, which was in the lower range of the interval reported by /Sheppard et al. 2002/. Corrected for precipitation amount in Laxemar-Simpevarp
Al	600	1.89E–05	4	Precipitation, Based on site investigation in Forsmark but with precipitation amounts for Laxemar-Simpevarp
Br	600	0.083246	5	Precipitation, site data, mean from two stations (PSM002170 and PSM001516) n=105, Sep 2002–Oct 2007
Ca	600	0.419	5	Precipitation, site data, mean from two stations (PSM002170 and PSM001516) n=30, Sep 2002–Oct 2007
Cl	600	0.744231	5	Precipitation, site data, mean from two stations (PSM002170 and PSM001516) n=104, Sep 2002–Oct 2007. 1 outlier was removed from the original dataset
Fe	600	0.037649	5	Precipitation, site data, mean from two stations (PSM002170 and PSM001516) n=30, Sep 2002–Oct 2007
Mg	600	0.13	5	Precipitation, site data, mean from two stations (PSM002170 and PSM001516) n=30, Sep 2002–Oct 2007
K	600	0.36	5	Precipitation, site data, mean from two stations (PSM002170 and PSM001516) n=30, Sep 2002–Oct 2007
Si	600	0.0326	5	Precipitation, site data, mean from two stations (PSM002170 and PSM001516) n=30, Sep 2002–Oct 2007
Na	600	1.033	5	Precipitation, site data, mean from two stations (PSM002170 and PSM001516) n=30, Sep 2002–Oct 2007
S	600	0.3446	5	Precipitation, site data, mean from two stations (PSM002170 and PSM001516) n=30, Sep 2002–Oct 2007
Mn	600	0.014045	5	Precipitation, site data, mean from two stations (PSM002170 and PSM001516) n=29, Sep 2002–Oct 2007
Sr	600	0.00505	5	Precipitation, site data, mean from two stations (PSM002170 and PSM001516) n=30, Sep 2002–Oct 2007

Element	Precipitation (mm year^{-1})	Deposition (g m^{-2} year^{-1})	Reference	Comment
Li	600	0.00146	5	Precipitation, Based on 30 measurements at the site that was below the detection limit, half the detection limit was used in the estimate, Sep 2002–Nov 2017
F	600	0.070686	5	Precipitation, site data, mean from two stations (PSM002170 and PSM001516) n=30, Sep 2002–Oct 2007