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Site descriptive modelling SDM-site

Erik Wijnbladh, Svensk kärnbränslehantering AB

Karin Aquilonius, Studsvik Nuclear AB

Sören Floderus, Wider IP

December 2008

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co

Box 250, SE-101 24 Stockholm
Phone +46 8 459 84 00

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Preface

The Swedish Nuclear Fuel and Waste Management Company (SKB) is conducting site characterization 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. 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 influence or have influenced 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. Thay shall also provide a basis for the Environmental Impact Assessment.

The surface system consists of a number of disciplines that have been organized in and have worked together with in the project group SurfaceNet. The disciplines involved in site 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 of the description, beside a general description of site conditions, is 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 on a local and regional scale?
- How has the site evolved over time?
- Can we find evidence of deep groundwater discharge, and what processes are 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.) 2008a. /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.

The present report comprises an integrated description of the marine ecosystem.

Tobias Lindborg

Project leader, SurfaceNet

Summary

For siting of a geological repository, the Swedish Nuclear Fuel and Waste Management Co has undertaken site characterisation 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 marine 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 characterise and describe the marine ecosystems today and in the past in the Forsmark and Laxemar-Simpevarp areas; 2) to evaluate and visualise major pools, fluxes and sinks of elements within the marine ecosystems; and finally 3) to describe human impact on the marine ecosystems.

The report includes a thorough description of the major components in the marine ecosystems in Forsmark and Laxemar-Simpevarp, and covers the following areas: chemical and physical characteristics, climate and meteorology, morphology and regolith, biota in the marine ecosystem, human impact, water exchange and historical evolution at the sites. The site specific characteristics are compared with marine data from the Baltic region. Marine ecosystem models for carbon, and mass balances for a number of elements, have been calculated to further improve the understanding of the marine 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 marine ecosystems at the two areas, as well as a comparison between Forsmark and Laxemar-Simpevarp.

In Forsmark, the studied area has been divided into 28 to sub-basins based on todays´s bathymetry and future drainage areas. In Laxemar-Simpevarp, the studied area has been divided into 19 sub-basins based on the same methodology. In comparison with the Gulf of Bothnia and the Baltic Proper, salinity is somewhat lower in Forsmark and Laxemar-Simpevarp respectively. The nitrogen and phosphorus levels at the two sites are low to moderately high compared with environmental monitoring data for corresponding areas in the Baltic Sea. In Forsmark, nitrogen seems to be the limiting nutrient during the summer months. In Laxemar-Simpevarp, nitrogen seems to be the limiting nutrient in the outer areas and phosphorus in the inner bays. This coincides with the general conditions in the Bothnian Sea (Forsmark) and the Baltic Proper (Laxemar-Simpevarp). The annual mean water temperature in Forsmark is slightly higher than the mean for the Baltic Sea and slightly lower in Laxemar-Simpevarp. The sea level at Forsmark has since 2003 fluctuated between 0.6 m below and 1.3 m above the mean level, and the corresponding values for Laxemar-Simpevarp are 0.5 and 0.7 m. Because the coastline in Forsmark has a gentler slope than in Laxemar-Simpevarp, the sea level fluctuations have more marked effects on the landscape with a steeper slope.

In Forsmark the macrophyte vegetation in the photic zone is dominated by red algae and brown filamentous algae. In Laxemar-Simpevarp, the red algae community covers the largest area. The benthic biomass at the bottom sampling sites in Forsmark has been dominated by the Baltic mussel. In Laxemar-Simpevarp the sessile macro fauna attached to hard substrates is completely dominated by the blue mussel in terms of both biomass and abundance. Test fishing in Forsmark and Laxemar-Simpevarp show similar development as in other nearby coastal areas and herring and sprat are the dominant species in offshore areas at both sites. In the inner bays at the sites, perch and pike are the most frequent species.

Release of heated cooling water is probably the major human impact at the sites. The human impact at the two sites is of the same magnitude as in the region, although the nutrient load is generally greater in the Forsmark region (Uppsala County). Fishery represents mainly a larger-scale impact in both areas.

The oceanographic models that quantify water exchange in the coastal area at the two sites indicate a more rapid water exchange in Forsmark than in Laxemar-Simpevarp.

The biomass in Forsmark is dominated by the primary producers and is focused along the shoreline of the area. On average, the marine area in Forsmark shows a positive Net Ecosystem Production (NEP), although most of the area is heterotrophic. The coastal shallow basins tend to be autotrophic, whereas the more offshore basins are heterothropic. The largest carbon pool in all basins in Forsmark is the abiotic pools (i.e. sediment, DIC and DOC) followed by the macrophytes. The major carbon flux in the ecosystem is the advective flux caused by the movement of sea water. All biotic fluxes are small in comparison with the advective flux. The largest biotic flux is fixation of carbon by primary producers. On average 4% of the initially consumed carbon in the marine ecosystem food web is transferred to the top predators. For nitrogen, phosphorus and thorium, the major pool in the ecosystem is the sediment. For uranium the sediment pool and the dissolved pool are almost equally large, dominant pool for iodine the is the dissolved phase.

In Laxemar-Simpevarp the mean biomass is considerable higher than in Forsmark. A major difference between the sites is the high abundances of the blue mussels in the exposed basins with extensive hard-bottoms. The annual mean NEP in the whole marine area in Laxemar-Simpevarp is negative i.e. more carbon is released to the atmosphere than is fixed in biomass. However, not all basins are heterothropic coastal basins with high macrophyte biomasses are generally authothropic. The largest carbon pools in the area are the DIC-pool followed by the sediment pool and the filter feeders. Advective flux generates the largest carbon flux in the ecosystem followed by the biotic flux; consumption by filter feeders. Runoff, diffusion, burial and precipitation are generally small fluxes in the area. In average only 0.8% of the carbon initially consumed in the food web reaches the top predators.

Contents

1 Introduction

This report is a compilation of previously reported data and new data aimed at describing the marine ecosystems at the two sites Forsmark and Laxemar-Simpevarp, both of which are potential sites for a deep repository for spent nuclear fuel.

Several authors have contributed the original texts for this report.

Erik Wijnbladh, Karin Aquilonius and Sören Floderus are the principal authors of this report. Other authors have contributed to parts of the report. Anders Engquist (Åbo Akademi, Finland) wrote and modelled the oceanographic parts (Chapter 5) and Ida Carlén, Martin Iseaus and Anna Nikolopolous (Aqua Biota) wrote the parts concerning spatial distribution of biomass and physical parameters (parts of section 4.2). Annika Ryegård contributed to the process of modelling marine ecosystems in GIS. The description of the long-term evolution of the marine ecosystem in Chapter 7 comes mainly from the SKB reports /Söderbäck (ed) 2008/. Unless stated otherwise, all photographs in the report were taken by Erik Wijnbladh.

Many improvements on earlier versions of this report were suggested by Clare Bradshaw, Department of Systems Ecology, Stockholm University. However, the results of this report do not necessary conform to the opinions of the reviewers.

1.1 Background

Radioactive waste from nuclear power plants in Sweden is managed by the Swedish Nuclear Fuel and Waste Management Co, SKB. The parts of SKB's programme for the management of spent nuclear fuel in operation today (November 2008) are an interim storage facility and a transportation system. According to current plans, an application to build a final repository will be submitted at the end of 2010. The proposed concept for spent fuel disposal involves the use of copper canisters with a cast iron insert to contain the spent nuclear fuel. The canisters are surrounded by bentonite clay and will be deposited in a repository at a depth of approximately 500 m in water saturated, granitic rock. The repository is expected to hold the 9,000 tonnes of spent nuclear fuel forecast to arise from the Swedish nuclear power programme. This corresponds roughly to 4,500 canisters in the repository. SKB is currently pursuing site investigations for a final repository in the municipalities of Östhammar (Forsmark area) and Oskarshamn (Laxemar-Simpevarp area).

In order to be able to characterize the long-term safety of a deep repository, a safety report will be produced to support the application in 2010. A preliminary version of the safety report was published as SR-Can /SKB 2006a/. An updated and extended safety report will be available at the time for submission of the application in 2009. Prior to this, two extensive reports describing the sites will be published, each presenting a site descriptive model (SKB TR-08-05 for Forsmark and SKB TR-09-01 for Laxemar-Simpevarp) Each of these site descriptions are based on a number of disipline-specific background reports (see Figure 1-1). The present report describes the marine ecosystem in the Forsmark and Laxemar-Simpevarp area. It includes a detailed account of the input data, methodology and modeled results. Similar reports have been produced for the lake ecosystems /Nordén et al. 2008/ and the terrestrial ecosystems /Löfgren 2008/.

The reports on the terrestrial, limnic and marine ecosystems will be published in two editions, of which this is the first edition. The second edition will include chapters describing future conditions on the site, the radionuclide models and their parameterization.

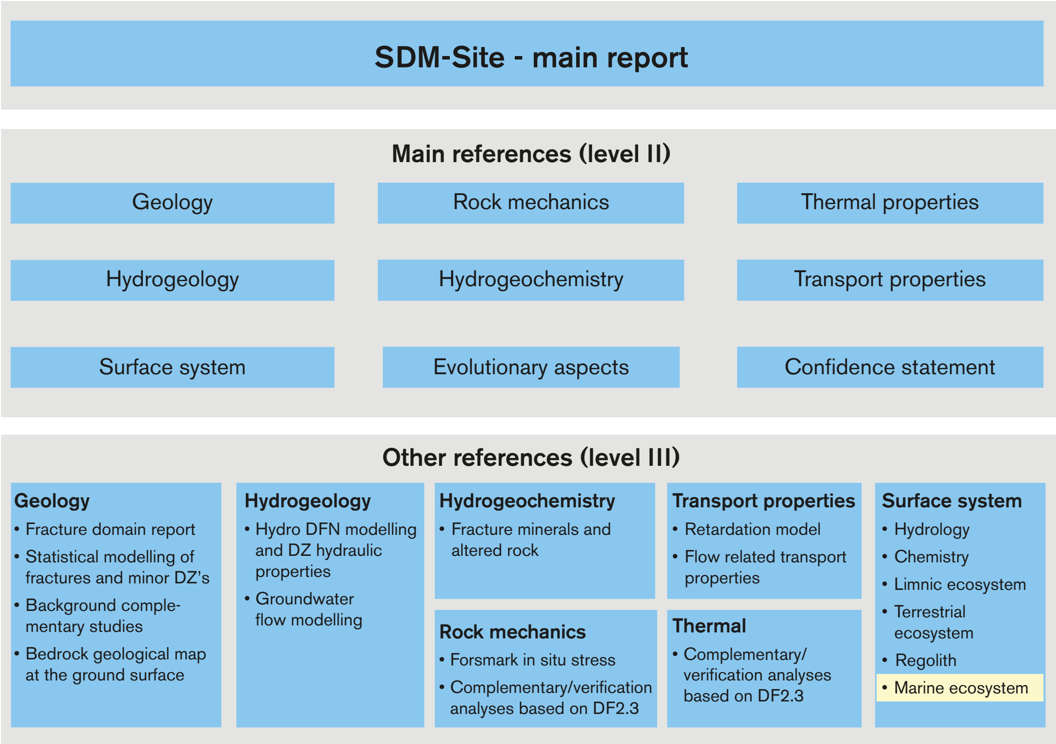


Figure 1-1. *Structure of the reports produced to serve as a basis for the Site Descriptive Models and the Safety Report. The present report is marked in yellow.*

1.2 Aims

The overall objective of this report is to describe the marine ecosystem at the two sites Forsmark and Laxemar-Simpevarp. The report contains descriptions and model results not published elsewhere, as well as summaries of site investigations presented in more detail in published reports. The main intention is to give the reader a coherent description of the marine ecosystems of the sites in the Forsmark and Laxemar-Simpevarp areas. In addition, this information is used to provide descriptions of mass balances, pools and fluxes of organic matter, water and a number of elements. These descriptions are intended to provide a thorough understanding of ecosystem patterns and processes at the two sites, and to identify the major pools and fluxes of carbon and other elements. This understanding and the quantitative descriptions will be used in the Safety Assessment to predict the fate of radionuclides in the surface ecosystems.

The major outputs of this first edition of the report can be summarized as:

- A compilation and overview of the different ecological studies conducted during the site investigations.
- A general description of the marine ecosystems and factors of importance in the current marine ecosystem.
- A historical description of the marine ecosystem.
- Ecosystem models describing pools and fluxes of carbon at a detailed ecosystem level.
- Ecosystem models describing pools and fluxes (mass balances) of a wide range of elements on a landscape level.

1.3 Geographical Setting

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

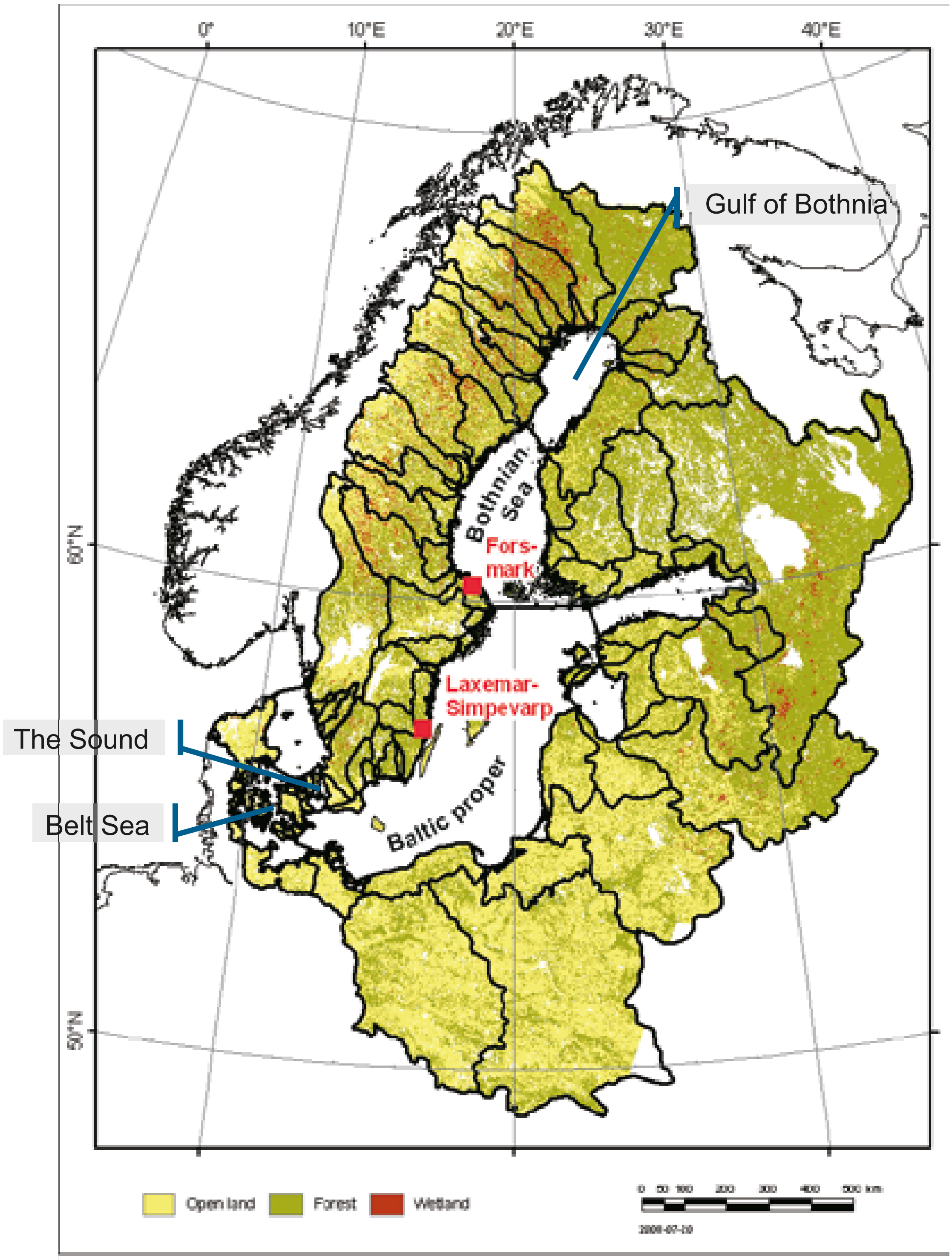


Figure 1-2. *Map of the Baltic Sea's catchment area, general land use and sub-catchments, and the location of the Forsmark and Laxemar-Simpevarp sites. GIS shapefiles from the Baltic Drainage Basin Project (BDBP) /GRID-Arendal 2005/. Related land use-classification grid data from the BALANS project /Malmberg 2001/.*

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

Both sites are located in the boreonemoral reqetation zone, which is characterised by a mixture of deciduous and coniferous tree species. The forrests at the sites are often dominated by pine and spruce.

The Baltic Sea is small on a global scale, but as one of the world's largest bodies of brackish water it is ecologically unique. The Baltic Sea is connected to the world's oceans by the narrow and shallow waters of the Sound (Öresund) and the Belt Sea. This limits the exchange of water with the North Sea, and means that the same water remains in the Baltic for up to 30 years – along with the organic and inorganic matter it contains. The Baltic Sea consists of a number of sub-basins, separated for the most part by shallow sills. These basins each have their own water exchange characteristics

With an average depth of just 53 metres, the Baltic Sea is much shallower than most of the world's seas. It contains 21,547 km^3 of water and every year rivers bring about 2% of this volume of water into the sea as runoff. The Baltic Sea's catchment area is almost four times larger than the sea itself /HELCOM 2007/, see Figure 1-2.

2 This report

This section provides guidance for the reader and puts the report in a broader context. We describe how the different sections are related 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 any accidentally released radionuclides and the exposure of humans and biota to these radionuclides. In the site descriptions, the landscape is divided into three ecosystems, the limnic, marine and terrestrial ecosystems. The definitions used to categorize these are presented in section 2.3. This report describes the marine ecosystems at the two sites Forsmark and Laxemar-Simpevarp area by summarizing and making interdisciplinary analyses of data from a large number of reports produced during the site investigations, Figure 2-1. The characteristics of the marine ecosystems are important for element accumulation and transport as described in this report.

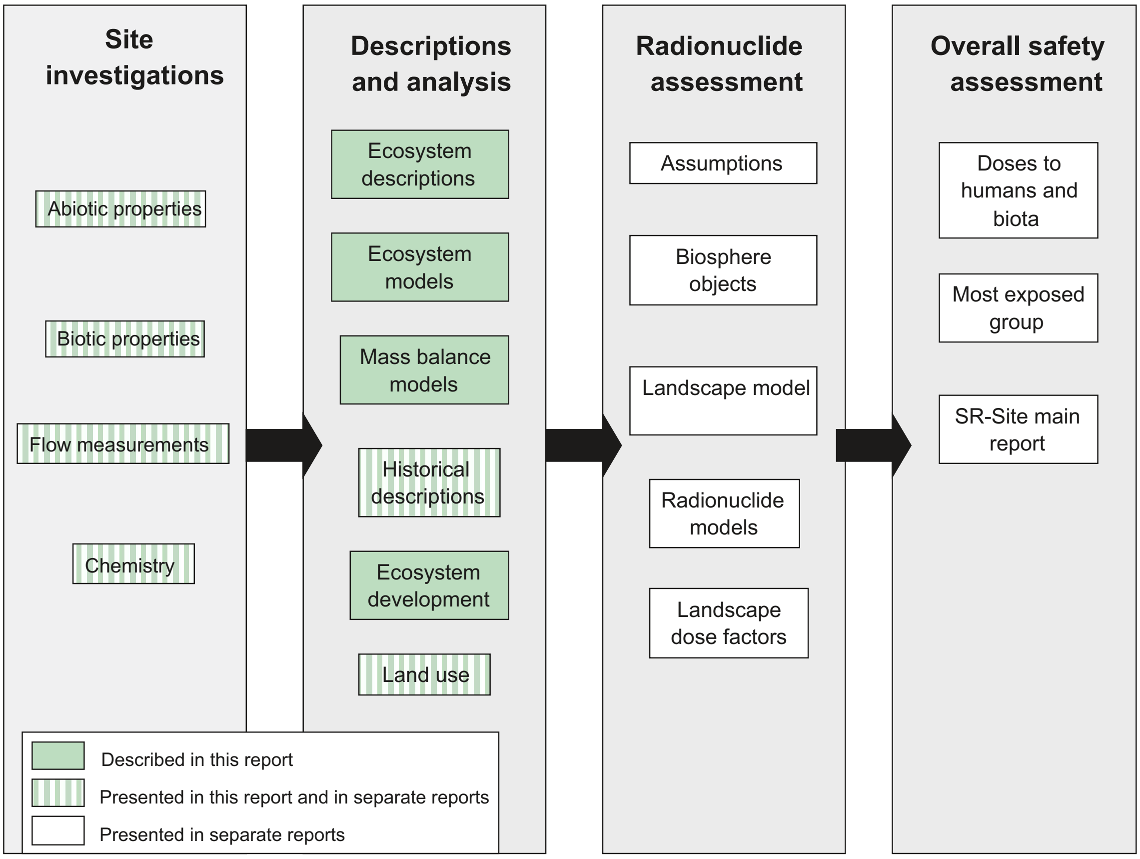


Figure 2-1. A schematic picture of how results from different parts of this report are used and how the results in this report feed into the biosphere dose modelling and safety assessment.

2.2 Contents of the report – a brief overview

Elements are transported and accumulated in the biosphere to different extents depending on the properties of the element and the conditions it is exposed to. The approach used in this report is to describe a number of different aspects of pools and fluxes of elements in the marine ecosystems of today as well as historical and future aspects that are regarded as important in the context of modelling radionuclide transfer and accumulation in a developing surface system.

The marine areas in Forsmark and Laxemar-Simpevarp were divided into a number of separate units called basins (see section 4-1). These delimitations were made in line with the overall strategy of the project to assess the long-term safety of a deep repository for nuclear waste /e.g. Lindborg et al. 2006/. Within the period of time assessed, a perspective of several thousand years, the landscape will be transformed, largely as a result of ongoing and predicted postglacial shoreline displacement in the area. Due to these processes, marine areas will turn into lakes, and lakes into wetlands and other terrestrial ecosystems, including agricultural areas. Elements in the marine ecosystem basins may thus accumulate in the geographical area and later be integrated in a limnic and eventually a terrestrial system.

The first chapters in this report (chapter 1–3) provide an overview and a synthesis of site data. The subsequent chapters describe different aspects of pools and fluxes of elements that are investigated and elaborated using site-specific data and literature in order to underpin a model describing element transport and accumulation (chapter 4–6). Chapter 7 describes the long-term evolution of the marine ecosystem and Chapter 8 discusses processes and interactions considered. The last part of the report (chapter 9–11) presents the dose models that are used to describe radionuclide transport and accumulation in different ecosystems. A brief summary of the content of the different chapters follows below.

Chapter 3, *Descriptions of marine ecosystem characteristics,* describes chemical, physical, biological and climatological characteristics. The sources for this chapter are primarily investigations conducted at the sites, but references are also made to other similar studies. Data presented in this chapter is the primary foundation for the model calculations described in the following chapters.

The structure and assumptions made in the ecosystem modelling are described in Chapter 4, *The marine ecosysystem – conceptual and quantitative carbon models.* This chapter includes a conceptual description of the marine ecosystem models and mass balance models as well as methods and references for calculations of input data to the models.

A separate chapter (chapter 5) is assigned to the *Oceanographic model.* It contains a brief description of the oceanographic features of the sites, the methods used and results from the modelling.

Chapter 6, *Marine ecosystem – ecosystem models, mass balances and elemental composition,* is the chapter where all ecosystem results are presented. Initially, the modelling results representing the spatial distribution of carbon in the considered marine ecosystems are presented. Then the results of mass balance calculations and the abundance and distribution in the ecosystem of carbon and other elements are presented, and finally five specifical basins from each site are described in more detail.

Chapter 7*, Long-term evolution of the marine ecosystem,* describes how the marine system has evolved at the sites and makes general predictions of its future evolution. This chapter will be completed with future evolution in version 2 of this report.

In *Couplings to the interaction matrix* (Chapter 8), the processes described in the "Interaction matrix" covered in this report are presented. This chapter briefly discusses how the processes are treated and where.

The conceptual structure of the marine models for calculation of doses to humans and biota is described in *Radionuclide model* (Chapter 9). This chapter will be completed in version 2 of this report.

In *Parameters for radionuclide and landscape models* (chapter 10), lists of parameters for dose calculation are presented. This chapter will be completed in version 2 of this report.

Chapter 11 contains a synthesis of the marine ecosystems at the two sites.

2.3 Delimitations and definitions

When the two sites are discussed in a general sense 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. 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 were defined, the Simpevarp subarea and the Laxemar subarea, and preliminary site descriptions were compiled 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 for the sake of clarity and to avoid confusion.

As mentioned earlier in this report, the site description divides the landscape into three ecosystems: the limnic, marine and terrestrial ecosystems. The main 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, water availability to plants and decomposition. 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 borderline between land and water is diffuse and difficult to identify. In most cases, the interface on a freshwater shore is clearly distinguished, covering a transect of a few metres (the littoral zone of a lake), whereas a sea shore, with larger fluctuations in water level, might cover a transect of tens of metres. 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 regarded as a transient stage in the succession of sea basins/lakes to land.

The definition of the marine ecosystem in this report is straightforward:

The ecosystem in the area below the water level at mean sea level that is delimited by the lower limit of the shoreline and has an exchange of water with the Baltic Sea, and that is above the bedrock. The uppermost 10 cm of the sediment is included in our definition of the marine ecosystem.

The shoreline sets the boundary between near-sea lakes, not connected to the sea at mean sea level, and the sea. In both Forsmark and Laxemar-Simpevarp, wetlands and small lakes are close to the shore and can be connected to the sea at high water levels. Field studies have been conducted in these areas to confirm the position of the shoreline, see /Brunberg et al. 2004a/ for Forsmark and /Brunberg et al. 2004b/ for the Laxemar-Simpevarp area. The definition of top sediment is discussed further in section 4.

Some major terms and concepts used in the report are presented below. The definitions are in accordance with /Chapin et al. 2002/ and /Begon et al. 1987/ unless otherwise stated.

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 quantifying these as either numbers of organisms, biomass or the inventory/concentration of some pertinent chemical element or abiotic component as dissolved matter, sediment etc.
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 having similar morphological, physiological, behavioral, biochemical, environmental response or trophic criteria.
Gross primary production (GPP)	Carbon input to ecosystems – that is, photosynthesis expressed at ecosystem scale (gC $m^{-2}yr^{-1}$).
Heterotroph	Organism that consumes organic matter produced by other organisms rather than producing organic matter from CO_2 and environmental energy; includes decomposers and consumers.
Mass balance	A model describing the import and export of elements or matter in a system.
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.

3 Descriptions of marine ecosystem characteristics

3.1 Chemical and physical characteristics

3.1.1 Introduction

The Baltic Sea is a semi-enclosed sea with a large net freshwater supply and a strong permanent halocline at 60–70 m. The Baltic Sea consists of three major sub-basins separated by narrow connections (thresholds/sills), namely from south to north: the Baltic Proper, the Bothnian Sea and the Gulf of Bothnia /Sjöberg ed. 1997/. Forsmark is situated in the Bothnian Sea and Laxemar-Simpevarp in the Baltic Proper.

In the site investigations, seawater has been sampled at Forsmark and Laxemar-Simpevarp, biweekly to monthly, since 2002 and analyzed for chemical and physical parameters. Sampling covers both the inner archipelago and the open sea. Since 2004 the sites have been sampled twelve times a year. Marine sampling sites in Forsmark and Laxemar-Simpevarp are shown in Appendix 1 a and b.

The seawater has been analyzed for a large number of parameters: electrical conductivity, pH, dissolved oxygen, salinity, turbidity, and water temperature. Chemical analyses of major constituents have also been performed: nutrient salts, carbon species, trace metals and isotopes. The surface water sampling and results are described in detail in /Nilsson et al. 2003, Nilsson and Borgiel 2004, Nilsson and Borgiel 2005, Nilsson and Borgiel 2007, Ericsson and Engdahl 2004, 2005, 2006/.

In the following sections, data from the site investigations are compared to data from the Baltic in general, with a special focus on the Bothnian Sea and the Baltic Proper. General trends for some chemical and physical parameters are presented below for the Bothnian Sea and the Baltic Proper. Data are mainly taken from SMHI's national environmental monitoring programme and from HELCOM.

3.1.2 Temperature, salinity and oxygen

Temperature, salinity and oxygen are physical background parameters that govern water quality, biodiversity and organism recruitment in a semi-enclosed water body such as the Baltic Sea. The seawater temperature varies seasonally and between years, and in the past few decades the summer temperature has shown a significant increase /Andersson and Andersson 2006/. The Baltic Sea is a relatively cold sea with a mean temperature of 5 °C. Due to the large variations in weather and wind during the year, the surface water temperature in the Baltic Sea varies from winter temperatures near zero to summer temperatures above 20 °C. The warmer surface temperature creates a strong thermocline. In the springtime the thermocline is close to the surface, but descends in the summer. In the southern parts of the Baltic, the summer thermocline is normally located at a depth of 20–30 m. In sheltered areas a secondary thermocline at a depth of around 2–3 m can develop, with temperatures above 20 °C. Storms that stir up the water break the thermocline in the autumn. In the deeper areas the temperature is fairly constant throughout the year at around 4–6 °C.

Baltic surface waters are strongly influenced by discharge of freshwater from land, runoff. Several large rivers discharge into the Baltic, creating a positive freshwater balance. Changes in runoff alter the salinity of surface waters, while inflows through the Sound and the Belt Sea alter the salinity of the deep water. Above the halocline the salinity is low and rather homogenous, and below the halocline there is a pronounced vertical stratification. The narrow and shallow passages between the Baltic Sea and the Kattegat limit the exchange of Baltic Sea water with saline water from the Kattegat. For this reason, salinity decreases from south to north in the Baltic Sea. In the Gulf of Bothnia the salinity is around 3.5 psu, in the Bothnian Sea around 5.5 psu and in the Baltic Proper around 7 psu.

The Baltic is highly stratified from the surface down to the halocline (60–70 m), from 7 psu above the halocline, increasing to 13 psu at the greatest depths (Baltic Proper). In the Bothnian Sea the salinity below the halocline fluctuates around 6 psu /Samuelsson 1996/. Stratification between the upper and lower layers inhibits surface and deep water mixing, thus preventing the oxygenated surface water from penetrating to great depth while hindering the transfer of phosphorus (which is abundant in the deep water) to the photic zone.

The salinity of the surface water (0–10 m) of the Bothnian Sea and the Baltic Proper has decreased in recent decades /Samuelsson 1996, Andersson and Andersson 2007/.

Statistics on temperature, pH, conductivity, salinity, oxgen and light penetration are shown in Tables 3-1 (Forsmark) and 3-2 (Laxemar-Simpevarp) and compared with data from the environmental monitoring programmes in the same areas /SKVF 2007, KVF 2007/.

Forsmark

In Forsmark the annual mean water temperature is 7.9°C, the mean summer and winter temperatures are 15.9°C and 2.2°C respectively. The sample points included in the site investigations are in relation to the rest of the Baltic considered as relatively shallow areas where the deep thermo cline is undeveloped. No evident secondary thermo cline in the shallow more sheltered samplings points can be seen in Forsmark.

The parameters do not vary significantly between sampling sites in Forsmark except for salinity where a gradient of freshwater influence can be seen from the inner bays (PFM00065, PFM00064) to the sampling sites further out (PFM0063, PFM00062). The mean salinity in the outer sampling site (PFM000082) 4.6 psu and the SKVF sites located even further offshore has a mean of 5.1 psu.

In comparison with the Gulf of Bothnia, the salinity in the Forsmark area (shallow bays near coast water) is somewhat lower, probably due to freshwater runoff from the land.

Laxemar-Simpevarp

The annual mean water temperature in the Laxemar-Simpevarp area is 7.2°C, while the mean summer and winter temperatures are 10.8°C and 4.5°C, respectively. The fact that the annual mean temperature in Forsmark is higher than Laxemar-Simpevarp, is most probably an effect of

Table 3-1. Descriptive statistics for temperature, salinity, conductivity, pH oxygen and light penetration at all sampling sites i Forsmark (PFM00062, PFM00063, PFM00064, PFM00065, PFM00082), from May 2002 until August 2006, in comparison with data from the national surveillance program during 2002–2005, in the Forsmark area, supplied by Svealands KustvattenVårdsFörbund (SKVF 2007).

	Mean	Median	Std. Dev.	Min	Max	25%–tile	75%–tile	N	SKVF 2002–2005
Water Temperature (C°)	7.9	6.1	6.7	–0.4	23.2	1.4	14	739	9.2
pH	7.9	7.9	0.3	6.9	8.9	7.8	8.1	731	7.9[1]
Conductivity (mS/m)	810	860	150	46	960	810	900	739	515[1]
Salinity (psu)	4.5	4.8	0.9	0.2	5.4	4.5	5	737	5.1
Oxygen (mg/l)	10.8	10.7	8.6	9.4	12.7	10.3	13.3	739	10.5
Sample depth (m)	4.2	4.1	1.6	0.9	7.3			743	19
Light penetration (m)	2.7	2.8	1.3	0.3	6.4	1.4	3.8	192	4.6

1. /Gustavson et al. 2000/.

Table 3-2. Statistics on temperature, salinity, conductivity, pH and oxygen at all sampling sites in Laxemar-Simpevarp (PSM PSM002060, PSM002061, PSM002062, PSM002063 and PSM002064), from May 2002 to August 2006, compared with data from the national monitoring programme 2001–2007 in the Simpevarp area, supplied by Kalmar läns KustvattenvårdsFörbund (KVF).

	Mean	Median	Std. Dev.	Min	Max	25%–tile	75%–tile	N	KVF 2001–2007
Water Temperature (C°)	7.2	6.0	5.1	–0.2	24	3.2	9.8	2,764	8.3
pH	7.7	7.8	0.4	6.6	9	7.5	8.0	2,577	–
Conductivity (mS/m)	1,130	1,160	110	200	1,300	1,100	1,200	2,700	–
Salinity (psu)	6.4	6.6	0.7	1.0	8	6.2	6.8	2,700	6.8
Oxygen (mg/l)	10.0	11.0	3.4	0.1	15	9	12	2,761	7.8
Sample depth (m)	9.4	7.0	7.6	0.5	30	3	14	2,634	8.3
Light penetration (m)	5.5	3.9	4.0	1	23	2.7	8	206	8.7

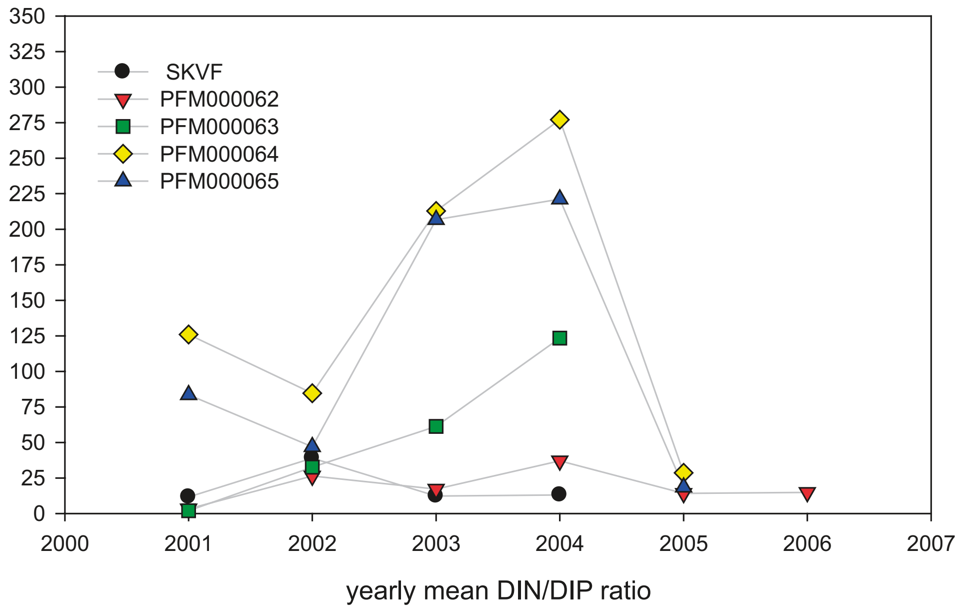
shallower sampling sites in Forsmark. Compared with the rest of the Baltic, the sampling points included in the site investigations are relatively shallow areas where the deep thermocline is undeveloped. No evident secondary thermocline in the shallow more sheltered samplings points can be seen in Laxemar-Simpevarp area.

The parameters do not vary significantly between sampling sites in Laxemar-Simpevarp except for salinity and light penetration. The mean salinity in the inner bays (PSM002062, PSM002064), is somewhat lower than at the more offshore sites (PSM002060 and PSM002061). The most off shore sampling site PSM002060 has a mean salinity in accordance with the environmental monitoring in the area, 6.8 psu /KVF 2007/. The light penetration in the bays is very shallow, the values from the off shore site PSM0002060 (mean light penetration 23 m) have large influence on the mean for the whole area.

3.1.3 Nutrients and carbon

Quantitatively, the three most important nutrient elements are nitrogen (chiefly as nitrate, NO_3^-), phosphorus (as phosphate PO_4^{3-}) and for those species that require it for construction of their skeleton, dissolved silica (SiO_2 for brevity, but mainly as $Si(OH)_4$. These nutrients are heavily utilized in the photic zone, where their availability can limit primary production, and they can be almost totally depleted in surface waters. Consumption and decomposition of organic matter sinking from surface waters return the nutrients to solution.

Inorganic nutrients, phosphate, nitrite, nitrate and silicate show clear annual cycles in the Baltic /Andersson and Andersson 2006/. In the winter when the uptake of biological nutrients is low, nutrient concentrations increase and reach maximum winter values, just before the onset of the spring bloom. In the spring and summer, most of the nutrients are taken up by plankton, and the concentration of the limiting inorganic component normally falls below the detection limit. The winter concentrations of nutrients in the surface layer normally vary as follows: phosphate from 15.5 $\mu g\ L^{-1}$ in Skagerrak to 1.9 $\mu g\ L^{-1}$ in the Gulf of Bothnia, with somewhat higher values in the Sound and in the Åland Sea. Nitrite and nitrate concentrations range from 42 $\mu g\ L^{-1}$ in the Åland Sea to 70 $\mu g\ L^{-1}$ in Skagerrak with higher concentrations of up to 98 $\mu g\ L^{-1}$ in the Sound, the Northern Baltic proper and in the Gulf of Bothnia /Andersson and Andersson 2006/. Total fractions of phosphate and nitrogen (tot-P and tot-N) also show an annual cycle in the surface layer, although it is not as pronounced as for the inorganic fractions. They also remain at a rather high level throughout the year. In the Baltic proper and in areas with sporadic water exchange, no typical variations occur over a year. In these areas, variations in nutrient concentrations are more closely linked to water exchange than seasonal variation /Andersson and Andersson 2006/.



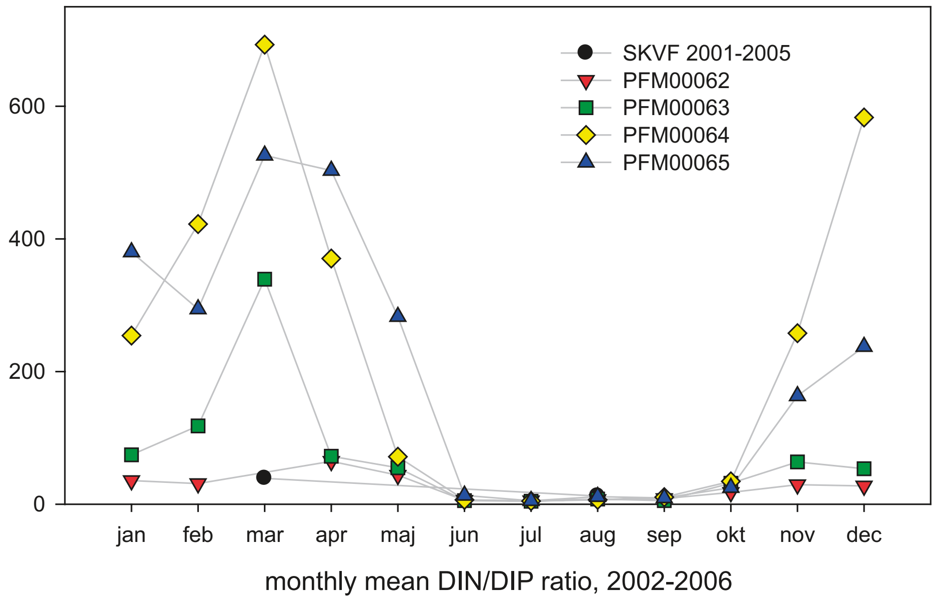


Figure 3-1. *Yearly mean (upper) and monthly mean (bottom graph) for the molar DIN/DIP ratio at PFM00062, PFM0006, PFM0006, PFM00064 and PFM00065 /Nilsson and Borgiel 2007/ and from national environmental monitoring in the area /SKVF 2007/ (only sampling points sampled at least once a month are included).*

In the Bothnian Sea (data from four stations), there are generally negative long term trends for P-tot and generally a positive trend for tot-N parameters. In the Western Gotland Basin (represented by two stations), there are generally positive long-term trends for tot-P and tot-N parameters /Andersson and Andersson 2006/.

POC can be an indirect rough measure of biomass, but consists of both dead and living material. The amount of carbon, particulate and dissolved organic (POC and DOC) and dissolved inorganic (DIC) in the Baltic is also strongly affected by runoff and precipitation.

Analyzed parameters reflecting the nutrient load in the coastal ecosystem at the sites are presented in Tables 3-3 (Forsmark) and 3-4 (Laxemar-Simpevarp).

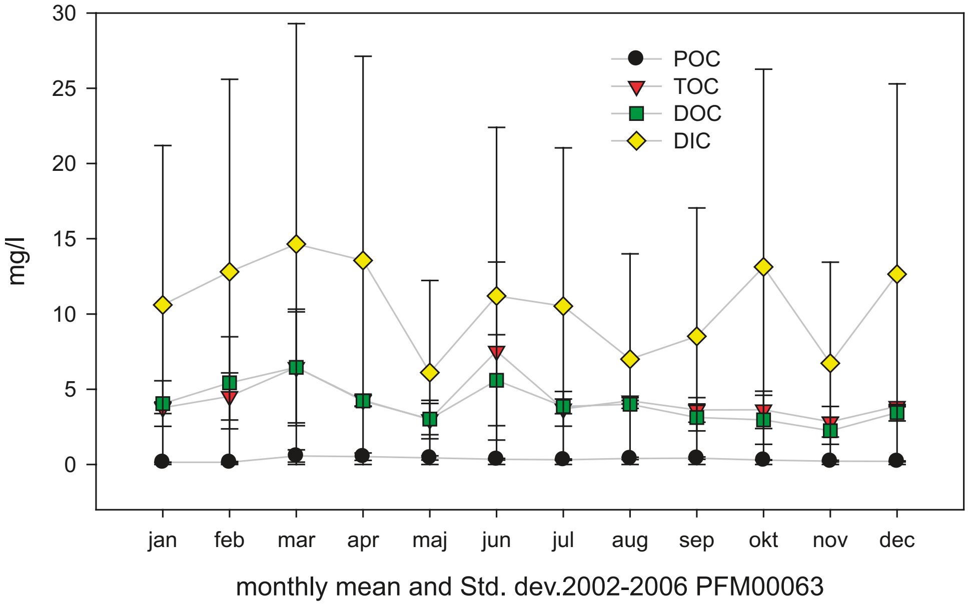


Figure 3-2. *Monthly mean and standard deviation for DIC, DOC, POC and TOC at PFM00063 in 2002-2006 /Nilsson and Borgiel 2007/.*

Table 3-3. Statistics on nutrients and carbon at all sampling sites in Forsmark (PFM00062, PFM00063, PFM00064, PFM00065, PFM00082), from May 2002 to August 2006 compared with environmental monitoring data from the same area in the Baltic. Note that the monitoring data is from further offshore than the samples in this study.

	Mean	Median	Std. dev.	Min	Max	N	25%–tile	75%–tile	Ref. from the Baltic
N-tot (µg/l)	472	325	387	218	2,750	267	273	490	269[1]
NO_3 (µg/l)	7	1	25	1	63	20	3	9	781
NO_2 (µg/l)	2	2	3	0	14	73	1	3	
NO_3+NO_2 (µg/l)	92	7	232	0	1,648	274	1	72	29[1]
NH_4 (ug/l)	13	3	26	0	185	274	2	10	4.81
NO_3+NO_2+ NH_4 (**DIN**)(µg/l)	101	12	244	0	1,710	286	2	71	0–158[1]
PON (µg/l)	65	53	45	11	317	263	35	77	
P-tot (µg/l)	17	15	8	7	59	267	11	21	12.4[1]
PO_4 (**DIP**)((µg/l)	2	1	2	1	13	274	1	2	1.12, 2.6[1]
POP (µg/l)	10	8	6	1	46	267	6	13	
SIO_2 (µg/l)	751	469	919	98	5,510	273	287	716	493[1], 1,010[2]. 36–557[3]
POC (µg/l)	427	335	293	80	2,170	260	230	514	20.2(uM)[2]
TOC (mg/l)	5	4	4	1	20	270	4	5	306(uM)[2]
DOC (mg/l)	5	4	3	1	21	270	3	5	190(uM)[2]
DIC (mg/l)	11	12	5	0.3	27	269	8	14	14–18ug/kg[4]
N/P[5]	**61**	**52**	**31**	**26**	**215**	**267**	**44**	**64**	**23[1]**
C/N[5]	**14**	**14**	**7**	**1**	**65**	**267**	**10**	**17**	
C/P[5]	**783**	**710**	**16**	**1**	**3,113**	**267**	**552**	**938**	
DIN/DIP[5]	**80**	**17**	**169**	**1**	**1,108**	**274**	**5**	**83**	

1. /SVKF 2007/.
2. /Gustafsson et al. 2000/.
3. /HELCOM 2007/.
4. /Thomas and Schneider 1999/.
5. Molar ratio.

Table 3-4. Statistics for nutrients and carbon at all sampling sites in Laxemar-Simpevarp (PSM002060, PSM002061, PSM002062[1], PSM002064), from May 2002 to December 2006 compared with environmental monitoring data from the same area in the Baltic. Note that the monitoring data is from further offshore than the samples in this study.

	Mean	Median	Std. dev.	Min.	Max.	N	25%–tile	75%–tile	KVF, SMHI etc
N-tot (µg/l)	**487**	**455**	**206**	**220**	**1,410**	**446**	**315**	**598**	**294 ug/l[2]**
NO_3 (µg/l)	99	84	100	0.3	523	38	31	128	17 ug/l[2]
NO_2 (ug/l)	4	3	4	0.2	23	111	0.8	6	2.8 ug/l[2]
NO_3+NO_2 (ug/l)	52	21	75	0.2	587	448	0.8	81	42–70
NH_4 (ug/l)	45	9	98	1	687	448	2	40	4.2 ug/l[2]
NO_3+NO_2+ NH_4 (**DIN**) (ug/l)	83	23	124	0.8	690	448	2	125	
PON (ug/l)	63	49	53	5	348	439	24	90	
P-tot (ug/l)	**29**	**23**	**28**	**12**	**376**	**448**	**20**	**27**	**28 ug/l[2] 84–98**
PO_4 (**DIP**) ug/l)	9	5	14	1	181	448	2	12	19 ug/l[2]
POP (ug/l)	13	9	22	1	198	441	5	13	
SIO_2 (ug/l)	1,100	579	1,197	32	7,130	448	344	1,380	84–1,344 ug/l[2]
POC (ug/l)	436	330	386	21	2,430	437	160	573	
TOC (mg/l)	6	5	3	3	26	450	4	7	59 ug/l[2]
DOC (mg/l)	6	5	3	2	26	449	4	7	
DIC (mg/l)	15	16	3	4	22	448	14	17	
N/P[3]	**44**	**41**	**20**	**0**	**107**	**448**	**29**	**59**	**16–150[2]**
C/N[3]	**15**	**15**	**3**	**5**	**23**	**446**	**13**	**17**	
C/P[3]	**654**	**571**	**335**	**30**	**1,944**	**448**	**430**	**820**	
DIN/DIP3	**69**	**12**	**209**	**18**	**3,894**	**448**	**3**	**71**	

1. The location of PSM002062 in Borholmsfjärden has been changed to a slightly deeper site, PSM007097, since May 2005, but in the calculations the site was considered the same as PSM002062.
2. Kalmarläns kustvattenvårdförbund (KVF), mean values during 2001–2007.
3. Molar ratio.

Forsmark

In Swedish waters the inorganic ratio N/P is normally below 16 (molar ratio), except in the Bothnian Bay where it can be as high as 150. In the site investigation area at Forsmark, the ratio has been between 26 and 215, with a annual mean of 61, which suggest that phosphorus is the limiting nutrient in this ecosystem. Although, looking at the seasonality during a year instead (figure 3-1), the DIN/DIP ratio is very low during summer months, suggesting that during this period N is the limiting nutrient. This is also supported by the blooms of nitrogen fixating cyanobacteria occurring in the area from time to time during summer. In comparison with Swedish Environmental Quality Criteria (EQC) /Naturvårdsverket 1999/ the mean and median values of total nitrogen concentration measured in Forsmark are regarded as low to moderately high, and the corresponding values for total phosphorus are regarded as low. The inorganic fractions of nitrogen (NH_4, NO_3 and NO_2) and phosphorus (PO_4) are also regarded as low in comparison with Swedish EQC.

General trends in the same area of the Baltic (SMHI data) are positive for dissolved inorganic nitrogen (DIN) and negative for total phosphorus (P-tot) /Andersson and Andersson 2006/.

No seasonal change in carbon concentrations is evident in the coastal area of Forsmark, Figure 3-2.

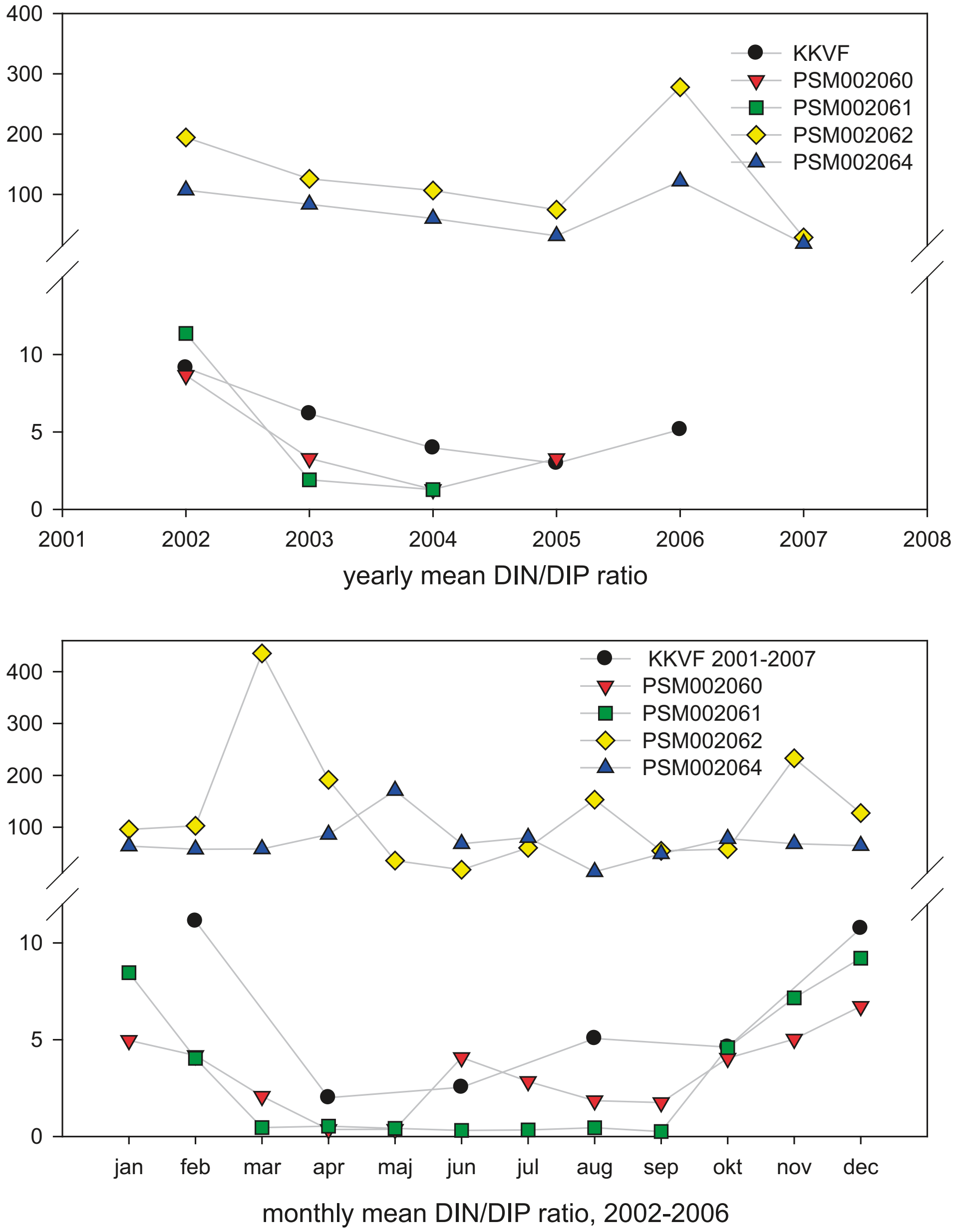


Figure 3-3. *Yearly mean (upper) and monthly mean (bottom graph) for molar DIN/DIP ratio at (PSM002060, PSM002061, PSM002062, PSM002064) during 2002–2006 and at a sampling site near Laxemar-Simpevarp in the environmental monitoring programme /KVF 2007/.*

Laxemar-Simpevarp

In Laxemar-Simpevarp nutrient and carbon concentrations differ between the bays (PSM002062, PSM002064) and the outer sampling sites (PSM002060, PSM002061), with higher nutrient concentrations in the bays. Concentrations and trends at the outer sampling sites were similar to environmental monitoring data for the area /KVF 2007/. Data for the whole area is presented in Table 3-4 and comparison between the various sampling sites is shown in Figure 3-3 and 3-4. General trends for the same area in the Baltic (Baltic Proper) are positive for dissolved inorganic nitrogen (DIN) and for total phosphorus (P-tot) /Andersson 2006/.

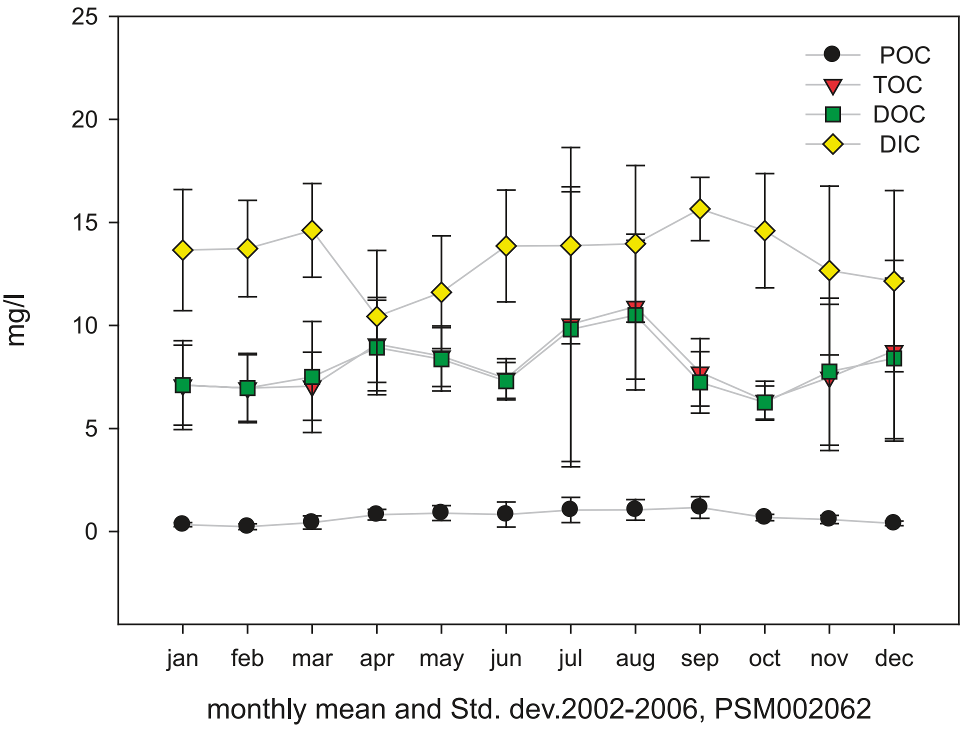


Figure 3-4. *Monthly mean for the DIC, DOC, POC and TOC at PSM002062, 2002–2006. /Ericsson and Engdahl 2006/.*

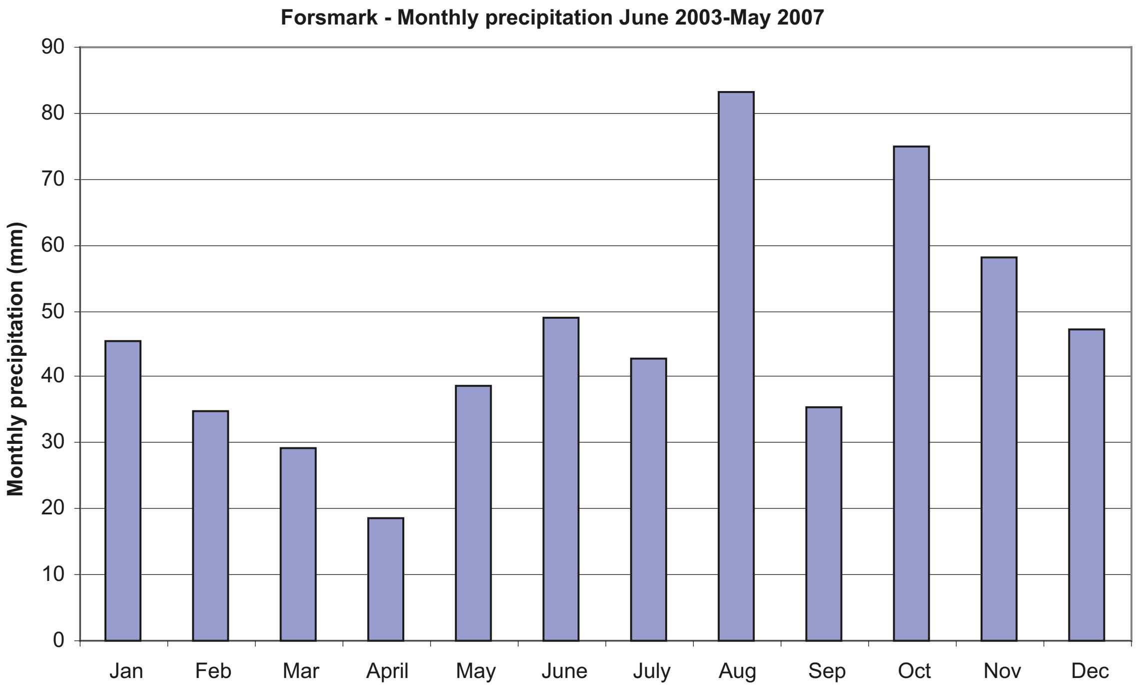


Figure 3-5. *Mean monthly precipitation (mm), June 2003–May 2007. From /Juston et al. 2007/.*

The DIN/DIP ratio is generally higher in bays in this regional area /KVF 2007/, which can also be seen in Laxemar-Simpevarp (Figures 3-3 and 3-4), where the coastal sampling stations show higher ratios. The seasonality in the DIN/DIP ratio is more pronounced in the outer sampling stations. It seem like phosphorus is the limiting nutrient in the bays and nitrogen in the more off shore areas.

In comparison with Swedish Environmental Quality Criteria (EQC) /Naturvårdsverket 1999/, the mean and median values for total nitrogen concentration measured in Laxemar-Simpevarp are regarded as low to moderately high, and the corresponding values for total phosphorus are regarded as low. The inorganic fractions of nitrogen (NO_3 and NO_2) and phosphorus (PO_4) are also regarded as low in comparison with Swedish EQC. Mean concentrations of PO_4 are, however, in the range for high values according to the Swedish EQC.

The variation of carbon concentration in coastal waters in the Laxemar-Simpevarp areas is highly dependent on runoff from land and shows no significant seasonality, Figure 3-4.

3.1.4 Major and minor constituents

Major constituents of seawater are those ions that occur in concentrations greater than 1 part per million (1×10^{-6}) ppm by weight. They account for over 99.9% of the salinity of seawater, which is generally defined as the sum of all the ions in seawater. The remainders of the ions present in seawater, are in the form of minor and trace constituents. The distinction between the two is somewhat ill-defined, but normally minor constituents are considered to be those with concentrations of between 1×10^{-6} and 1×10^{-9} by weight, and trace constituents to be those elements with concentrations of less than 1×10^{-9} by weight (1 part per billion or ppb).

Most of the major constituents exhibit conservative behaviour that is their concentrations in seawater are not significantly changed by the biological or chemical reactions that take place in seawater. Exceptions to the conservative behaviour among the major constituents are carbon (C), calcium (Ca) and silicon (Si).

The basic water analysis include the major constituents Na, K, Ca, Mg, Sr, S, SO_4^{2-}, Cl^-, Si and HCO_3^- as well as the minor constituents Fe, Li, Mn, F^-, I^- and HS^-. A selection of parameters is shown in Tables 3-5 (Forsmark) and 3-6 (Laxemar-Simpevarp), compared with data from other studies in the same or adjacent areas. Most major and minor constituents measured in the site investigations are of the same order of magnitude as reported elsewhere, which supports the accuracy of site investigation data.

Forsmark

Statistics for some major and minor constituents of seawater, sampled in Forsmark, are presented in Table 3-5. The concentrations are generally of the same order of magnitude as reported elsewhere.

Laxemar-Simpevarp

Statistics for some major and minor constituents of seawater, sampled in Laxemar-Simpevarp, are presented in Table 3-6. The concentrations are generally of the same order of magnitude as reported elsewhere.

3.1.5 Trace constituents – Forsmark and Laxemar-Simpevarp

In contrast to most major constituents, nearly all of the minor and trace dissolved constituents exhibit non-conservative behaviour, i.e. their concentrations are significantly changed by biological and chemical reactions in seawater.

Table 3-5. Statistics for some major and minor constituents in seawater at all sampling sites in Forsmark (PFM00062, PFM00063, PFM00064, PFM00065, PFM00082), from May 2002 to August 2006.

	Mean	Median	Std. Dev.	Min.	Max.	N	75%–tile	25%–tile	Ref
Na (mg/l)	1,300	1,400	290	70	1,600	262	1,500	1,400	1,040–2,230[1]
K (mg/l)	50	50	10	4	60	262	60	50	38.1–137[1]
Ca (mg/l)	70	70	6	40	90	262	80	70	49.7–101[1]
Mg (mg/l)	160	170	40	10	200	262	180	160	126–436[1]
HCO_3 (mg/l)	80	80	20	60	220	268	80	70	28[4]
Cl (mg/l)	2,500	2,600	550	120	3,000	270	2,700	2,500	1.95×10^{4}[4]
SO_4 (mg/l)	350	370	80	50	790	270	130	110	9.05×10^{2}[4]
Fe (µg/l)[2]	80	20	190	0.4	1,200	85	60	10	< 500–700[1]
Mn (µg/l)[2]	10	4	20	0.02	90	84	60	10	2–3[1]
Li (µg/l)	20	20	6	3	40	253	30	20	180[4]
Sr (µg/l)[2]	980	1,000	200	100	1,300	262	1,000	980	566–2,560[3]
I (µg/l)	10	9	8	4	80	195	12	9	60[4]

1. /Porcelli et al. 1997/.

2 Some (in some cases all) of the reported values from analyses were below the detection limit and reported as < values. To calculate a mean value these results were divided by 2.

3. /Andersson et al. 1992/.

4. /Bearman 2005/. Average value for all oceans.

Table 3-6. Statistics for some major and minor constituents in seawater at all sampling sites in Laxemar-Simpevarp (PSM002060, PSM002061, PSM002062[1], PSM002064), from October 2002 to December 2006.

	Mean	Median	Std. Dev.	Min.	Max.	N	75%–tile	25%–tile	Ref
Na (mg/l)	1,800	1,900	330	280	2,300	415	2,000	1,700	1,040–2,230[2]
K (mg/l)	70	70	10	10	90	415	80	60	38.1–137[2]
Ca (mg/l)	90	90	10	20	110	415	100	80	49.7–101[2]
Mg (mg/l)	210	230	40	30	270	415	240	200	126–436[2]
HCO_3 (mg/l)	90	90	20	20	120	415	90	80	28[5]
Cl (mg/l)	3,300	3,500	640	260	4,100	415	3,700	3,000	1.95×10^{4}[5]
SO_4 (mg/l)	470	500	90	50	620	415	530	430	9.05×10^{2}[5]
Fe (µg/l)[3]	80	20	190	1	2,900	414	70	10	< 500–700[2]
Mn (µg/l)[3]	420	5	600	0.5	84,000	414	20	2	2–3[2]
Li (µg/l)	30	30	9	9	50	414	30	30	180[5]
Sr (µg/l)	1,300	1,400	240	240	1,800	415	1,500	1,300	566–2,560[4]
I (µg/l)	20	10	7	7	40	81	20	10	60[5]

1. The location of PSM002062 in Borholmsfjärden has been changed to a slightly deeper site, PSM007097 since May 2005, but in the calculations the site was considered the same as PSM002062.

2. /Porcelli et al. 1997/.

3 Some (in some cases all) of the reported values from analyses were the below detection limit and reported as < values. To calculate a mean value these results were divided by 2.

4. /Andersson et al. *1992/.*

5. /Bearman 2005/. Average value for all oceans.

Concentrations of trace constituents in the Baltic Sea are higher than in the North Atlantic (regarded as less influenced by human impact), and in general concentrations of dissolved and particle-bound cadmium (Cd), lead (Pb) and zinc (Zn) are higher in the western Baltic Sea, while the concentrations of dissolved copper (Cu) and total mercury (Hg) are slightly elevated in the Baltic Proper compared with the rest of the Baltic /Pohl and Hennings 2003, HELCOM 2003/.

In contrast to uranium, which can be dissolved easily during weathering and transported as an ion, thorium is almost insoluble and is to a large extent transported in the particulate phase. Dissolved uranium in oxygen-saturated waters from the Baltic Sea correlates very well with salinity and thus shows a general conservative behaviour/Andersson et al. 1995/.

Concentrations of trace constituents from the site investigations are shown in Tables 3-7 (Forsmark) and 3-8 (Laxemar-Simpevarp), compared with (if found) other reported values from the Baltic. Some of the analyzed trace constituents at the sites are higher than reported values for the Baltic in general (Cd, Pb and Cu I Forsmark for example), probably due to the anthropogenic influence in the area.

3.1.6 Isotopes – Forsmark and Laxemar-Simpevarp

The results of the site investigations regarding U-, Th-, Rn and Ra- isotopes are presented in Tables 3-9 (Forsmark) and 3-10 (Laxemar-Simpevarp) and when possible (due to available data) are compared to other reported values from the Baltic. U-238 and Th-232 seem to be slightly higher in Forsmark than in the Baltic. In Laxemar-Simpevarp all values for U and Th were below detection limit and thus it is difficult to compare results.

3.2 Climate and meteorology

Climatological parameters such as precipitation and atmospheric deposition, ice cover and runoff are presented in this section. Water temperature at the sites is presented in the previous section, 3.1.2.

The Baltic marine area is located within the west wind zone where cyclones coming from the west or southwest dominate the weather. Periodically, cyclones from a more southerly direction enter the region. The temperature climate of the region is largely coupled to the latitude of the main cyclonic tracks, although cloud cover also plays an important role, especially in the winter.

Table 3-7. Statistics for some trace constituents at all sampling sites i Forsmark (PFM00062, PFM00063, PFM00064, PFM00065, PFM00082), from May 2002 to August 2006, compared with reported concentrations from the Baltic Sea in general /HELCOM 2007/.

ng/l	Mean	Median	Standard Deviation	Minimum	Maximum	N	Baltic Sea (HELCOM, ng/kg)
Hg[1]	2	1	2	1	10	58	5–6
Cd[1]	30	16	60	2	390	58	12–16
Pb[1]	300	100	600	10	3,100	58	12–20
Cu	1,500	830	3,200	200	24,700	58	500–700
Zn[1]	5,000	1,700	14,000	580	106,000	58	600–1,000
U[1]	1,000	760	580	550	2,700	50	3,200[2]
Th[1]	80	50	60	10	320	50	10[2]

1. Some (in some cases all) of the reported values from analyses were below the detection limit and reported as < values. To calculate a mean value these results were divided by 2.

2. /Bearman 2005/. Average value for all oceans.

Table 3-8. Statistics for some trace constituents at all sampling sites in Laxemar-Simpevarp (PSM002060, PSM002061, PSM002062,1 PSM002064) from May 2002 to August 2006, compared with reported concentrations from the Baltic Sea in general /HELCOM 2007/.

ng/l	Mean	Median	Standard Deviation	Minimum	Maximum	N	Baltic Sea (HELCOM, ng/kg)
Hg[2]	1	1	0.3	1	2.2	29	5–6
Cd[2]	20	10	10	10	40	29	12–16
Pb[2]	190	50	200	50	640	29	12–20
Cu[2]	760	750	320	100	1,560	29	500–700
Zn[2] **(ug/l)**	4	3	5	1	28	29	0.6–1.0
U	770	750	110	560	1,140	29	3,200[3]
Th	90	100	20	10	100	29	10[3]

1. The location of PSM002062 in Borholmsfjärden has been changed to a slightly deeper site, PSM007097, since May 2005, but in the calculations the site was considered the same as PSM002062.

2. Some (in some cases all) of the reported values from analyses were below the detection limit and reported as < values. To calculate a mean value these results were divided by 2.

3. /Bearman 2005/. Average value for all oceans.

Winds of storm force, i.e. at least 25 ms^{-1}, are almost exclusively associated with deep cyclones that form west of Scandinavia and mainly occur from September to March.

The water mass of the Baltic marine area has a strong impact on the local climate in the region, in particular influencing air temperature, precipitation, cloud cover, irradiation and winds, and in coastal areas leading to pronounced gradients /HELCOM 2002/.

3.2.1 Precipitation and atmospheric deposition

In the winter, most of the precipitation is frontal (i.e. falls in connection with fronts), especially inland. In the summer, around half of the precipitation can be characterized as convective and is commonly greater inland than at sea. Winds are closely related to the cyclones and the pressure gradient around these systems.

Table 3-9. Statistics for some isotopes at all sampling sites in Forsmark (PFM00062. PFM00063. PFM00064, PFM00065, PFM00082), from May 2002 to August 2006, compared with reported concentrations from the Baltic Sea in general.

(mBq/kg)	Mean	Median	Std. dev.	Min	Max	N	ref
U-238[1]	31	25	23	7	100	14	10–14[2]
U-235[1]	25	25	0	25	25	12	0.32–0.36[3]
U-234[1]	32	25	23	9	100	14	10–12.2[3]
Th-230[1]	27	25	23	0.25	100	14	40–4 400[3]
Th-232[1]	25	25	0	25	25	12	0.2–0.9[2]
Rn-222 (Bq/l)[1]	0.2	0.2	0.2	0.03	0.6	14	
Ra-226 (Bq/l)[1]	0.1	0.1	0.1	0.03	0.4	14	2–3[2]

1. Some (in some cases all) of the reported values from analyses were below the detection limit and reported as < values. To calculate a mean value these results were divided by 2.

2. /Porcelli et al. 2001/.

3. Szefer 2002.

Table 3-10. Statistics for some isotopes at all sampling sites in Laxemar-Simpevarp (PSM002060, PSM002061, PSM0020627, PSM002064, from May 2002 to August 2006, compared with reported concentrations from the Baltic Sea in general.

(mBq/kg)	Mean	Median	Std. dev.	Min	Max	N	ref
U-238[1]	25	25	0	25	25	8	10–14[2]
U-235 [1]	25	25	0	25	25	8	0.32–0.36[3]
U-234[1]	25	25	0	25	25	8	10–12.2[3]
Th-230[1]	25	25	0	25	25	8	40–4,400[3]
Th-232[1]	25	25	0	25	25	8	0.2–0.9 [2]
Rn-222 (Bq/l)[1]	0.2	0.1	0.2	0.008	1	8	
Ra-226 (Bq/l)[1]	0.08	0.03	0.1	0.008	0.4	8	2–3[2]

1. Some (in some cases all) of the reported values from analyses were below the detection limit and reported as < values. To calculate a mean value these results were divided by 2.
2. /Porcelli et al. 2001/.
3. /Szefer 2002/.

In general, the precipitation over the Baltic Sea is greater in the south than in the north, and it is also often greater closer to the coast than further out to sea. Despite their locations, Forsmark is situated in an area with a somewhat higher precipitation (600–700 mm y^{-1}) than Laxemar-Simpevarp (600 mm y^{-1}) /Sjöberg (ed) 1997/.

Forsmark

The regional mean annual precipitation in the Forsmark area has been estimated as 559 mm for the period 1961–1990 /Johansson and Öhman 2008/. 25–30% of the annual precipitation falls in the form of snow. The average monthly precipitation for the period June 2003–May 2007 is presented in Figure 3-5.

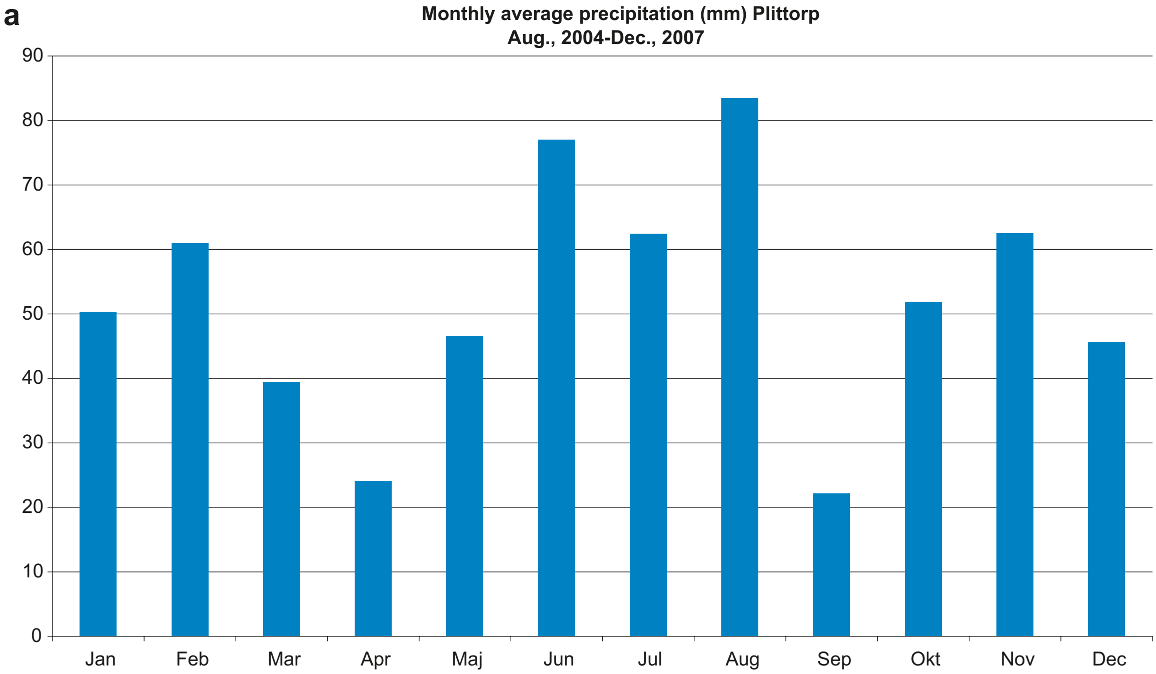
Laxemar-Simpevarp

The annual average precipitation at Äspö during the site investigation period was c. 520 mm, while the corresponding average for Plittorp was c. 620 mm for the period 2003–2007 /Werner et al. 2008/. The monthly precipitation for the period august 2004 to December 2007 at the two meteorological sampling stations in Laxemar-Simpevarp (for location see Appendix 1, b) is presented in Figure 3-6 a and b. Considering the common data period for the Äspö and Plittorp stations (2005–2007), the accumulated precipitation was c. 7% higher at Plittorp compared with Äspö.

3.2.2 Ice cover

Forsmark

The ice cover measurements were made on Lake Eckarfjärden and on a bay of the Baltic close to the Forsmark harbour. The Baltic Sea bay froze approximately a month later than Eckarfjärden, but had an ice break-up approximately at the same time as the lake. On average the Baltic Sea bay was covered with ice 98 days/season. The ice cover measurements are summarized in Table 3-11. For more details on the recordings, see /Aquilonius and Karlsson 2003, Heneryd 2004, 2005, 2006 and 2007/.



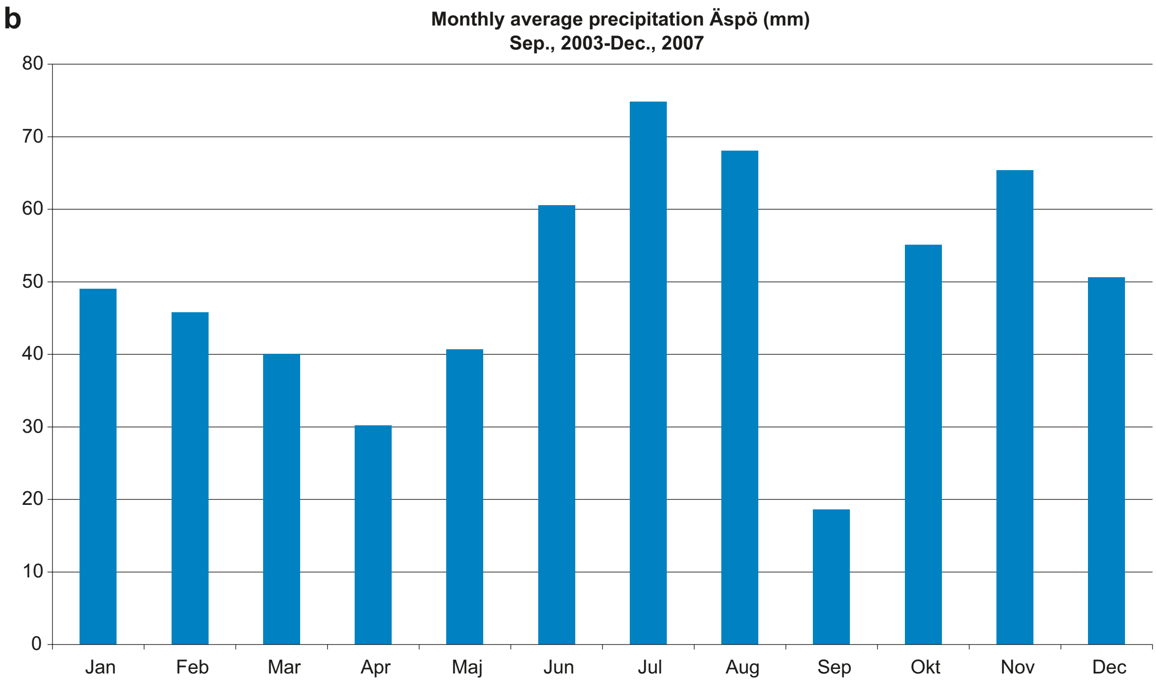


Figure 3-6 a and b. *Monthly precipitation (mm), August 2004–December 2007 at Plittorpsgöl (a) and Äspö (b). From /Werner et al. 2008/.*

Laxemar-Simpevarp

Ice freeze-up/break-up was inspected at three locations in the Baltic Sea: Äspö brygga (ASM100226), Kråkelund yttre (ASM100227), and Kråkelund inre (ASM100228). In addition, inspections were also made in Lake Jämsen (ASM100229). Table 3-12 summarizes these ice freeze-up/break-up data.

Table 3-11. Ice cover at Forsmark 2002/03–2006-07.

Baltic Sea bay at Forsmark harbour(AFM000072 and AFM001172)			
Winter period	**Period with observed ice (calendar)** **Ice freeze-up**	**Ice break-up**	**Period with observed ice (days)**
2002–2003	2003-01-07	2003-03-31	83
2003–2004	2003-12-17	2004-04-13	120
2004–2005	2004-12-21	2005-01-13	95
	2005-01-17	2005-04-07	
2005–2006	2005-12-12	2006-04-24	133
2006–2007	2007-01-22	2007-03-22	60

In general, the near-coastal sea bays (represented by ASM100226) are ice-covered 1–4 months each winter (from December/January to March/April). The ice conditions further offshore are variable, but generally with an ice cover from January to March.

3.2.3 Runoff from land – Forsmark and Laxemar-Simpevarp

Yearly riverine runoff to the Baltic marine area has fluctuated around 15,000 m^3s^{-1} since 1950. 1998 was the second wettest year since 1950 with the extreme value of 18,720 m^3s^{-1}. The riverine runoff to the Bothnian Sea is lower, around 3,000 m^3s^{-1}, than the riverine runoff to the Baltic Proper, around 3,500 m^3s^{-1} in the investigated time period from 1950–2002 /HELCOM 2002/.

An extensive monitoring programme has been carried out since 2002 in both Forsmark and Laxemar-Simpevarp, where stream discharge has been measured at 10 sites. Data on discharge and conductivity have been logged continuously and water samples for analysis have been collected every second week /Johansson and Juston 2007/. These data have been used to calculated specific figures for runoff for water and for 10 elements from individual catchment areas in Forsmark /Tröjbom and Söderbäck 2006b/, see Table 3-13, and in Laxemar-Simpevarp /Tröjbom and Söderbäck 2006a/, see Table 3-14.

Table 3-12. Summary of observed ice freeze-up/break up in Laxemar-Simpevarp area.

Winter period	Gauging station	Period with observed ice (calendar)	Period with observed ice (days)
2002–2003	ASM100226, (Baltic Sea; Äspö brygga)	2002-12-19–2003-03-27	99
2003–2004		2004-01-07–2004-03-10	62
2004–2005		2004-12-22–2005-01-23	32
		2005-01-28–2005-04-01	63
2005–2006		2005-12-20–2006-04-18	119
2006–2007		2007-01-29–2007-03-01	31
2002–2007	ASM100227 , (Baltic Sea; Kråkelund outer)	No ice	
2002–2003	ASM100228 , (Baltic Sea; Kråkelund inner)	2003-01-10–2003-03-21	71
2003–2005		No ice	
2005–2006		2006-01-02–2006-01-12	10
		2006-01-26–2006-02-03	8
		2006-03-17–2006-03-29	12
2006–2007		No ice	

Table 3-13. Mean runoff from all catchments areas in Forsmark /Tröjbom 2007/.

	Mean	Median	Std.dev.	Min	Max	N	SLU. 2007 (County of Uppsala)
water (m^3y^{-1} m^{-2})	0.6	0.2	1	0.2	5	43	
C ($gy^{-1}m^{-2}$)	10	3	19	2	84	43	3.5–17[1]
N ($gy^{-1}m^{-2}$)	0.2	–	–	–	–		0.2
P ($gy^{-1}m^{-2}$)	0.01	0.003	0.02	0.001	0.08	43	0.01

1. /Canhem et al. 2004/.

Runoff is greater in Forsmark than in Laxemar-Simpevarp for all parameters except nitrogen (N), which is of the same order of magnitude at both sites. In comparison with other reported runoff values /SLU 2007/, the runoff of C, N and phosphorus (P) is of the same order of magnitude as reported elsewhere.

3.2.4 Irradiation

Global irradiation is relatively evenly distributed over Sweden. The greatest differences are between values inland and at sea, with greater global irradiation over the sea. This is due to the differences in cloudiness. In the winter time the irradiation pattern is latitude-dependent. Normally, annual global irradiation in Sweden varies within 15% of the normal value of 800–1,100 kWh m^{-2} /Sjöberg (ed) 1997/.

Forsmark

Global irradiance was measured every second and mean values for 30 min were recorded continuously for one site in Forsmark: Högmasten /Wern and Jones 2007/ (Appendix 1a). Daily values vary between 0.30 MJ d^{-1} (in January) and 27 MJ d^{-1} (in July) with a mean of 9.3 MJ d^{-1} (Figure 3-7).

Laxemar-Simpevarp

Global irradiance was measured every second and mean values for 30 min were recorded continuously for one site in Laxemar-Simpevarp area: Äspö /Sjögren et al. 2007/. Daily values vary between 0.30 MJ d^{-1} (in January) and 27 MJ d^{-1} (in July) with a mean of 10.2 MJ d^{-1} (Figure 3-8).

Table 3-14. Mean runoff from all catchments areas in Laxemar-Simpevarp /Tröjbom 2008/.

	Mean	Median	Std.dev.	Min	Max	N	Other data from the region
water ($m^3y^{-1}m^{-2}$)	0.2	0.2	0.0004	0.2	0.2	19	
C ($gy^{-1}m^{-2}$)	3	4	2	0.004	5	19	3.5–17[1]
N ($gy^{-1}m^{-2}$)	0.2	0.2	0.1	0.0003	0.3	19	0.1
P ($gy^{-1}m^{-2}$)	0.005	0.01	0.004	0.00001	0.01	19	0.003

1. /Canhem et al. 2004/.

2. SLU, 2007 (County of Kalmar).

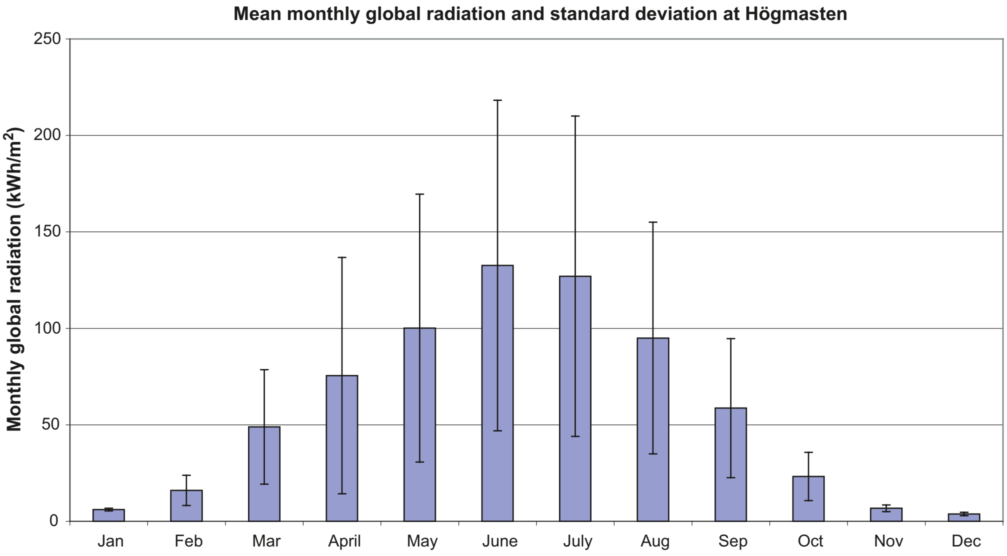


Figure 3-7. *Monthly averages of the global irradiation at Forsmark during 2003–2007, from /Wern and Jones 2007/.*

3.2.5 Sea level

The sea level in the Baltic Sea and the Gulf of Bothnia is influenced by several factors, of which the long-term factors are isostatic (changes due to land uplift) and eustatic (changes due to ocean level rise). Over shorter time periods, seiches (standing waves), freshwater runoff, changes in atmospheric pressure and winds create changes in water level. The variation in sea level is greatest in the autumn and winter, when the strongest winds appear. In the spring and summer, with a more stable weather pattern, the sea level varies to a lesser extent, mainly due to

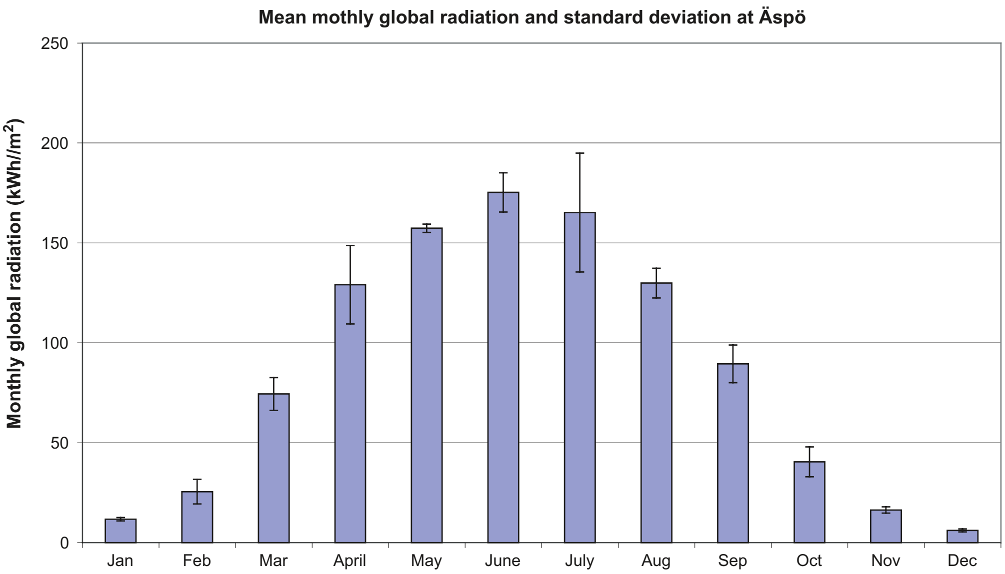


Figure 3-8. *Monthly averages of the global irradiation at Äspö, in the Laxemar-Simpevarp area during 2004–2007, from /Sjögren et al. 2007/.*

the atmospheric pressure. Tidal effects are small and overshadowed by the other factors. The sea level variations are relative to the mean sea level, which is calculated as a sum of the eustatic and isostatic changes. Annual mean sea level is the mean of measured sealevel relative to the zero elevation in the Swedish national elevation system RH70/RHB70.

Forsmark

Since January 2003 sea level has been measured at two sites every hour. The sea level has fluctuated between 0.62 m below and 1.27 m above mean sea level (Figure 3-9). Deviations above 1.0 metre are uncommon and were only recorded on one day (January 2007) during the period from January 2003 to April 2007. Statistics between 2003 and April 2007 at Forsmark are presented in Table 3-15. As the Forsmark coastline has a low-angle slope, a deviation of 0.5 m, which occurs on average every second year, has a marked effect on the landscape, Figure 3-10.

Laxemar-Simpevarp

Since 2004 sea level has been measured every hour /Werner et al. 2008/. The sea level has fluctuated between 0.5 m below and 0.7 m above mean. The narrower deviation range and the steeper general slope make the impact of sea-level variability less marked than at Forsmark, Figure 3-11 and Table 3-16.

3.3 Morphometry and regolith

The term regolith refers here to all loose materials covering igneous or sedimentary bedrock, e.g. till, gravel, sand, silt and clay, whether glacial or postglacial.

3.3.1 Bathymetry

Both the Forsmark and Laxemar-Simpevarp areas have low surface relief (< 25 m) associated with the subcambrian peneplains.

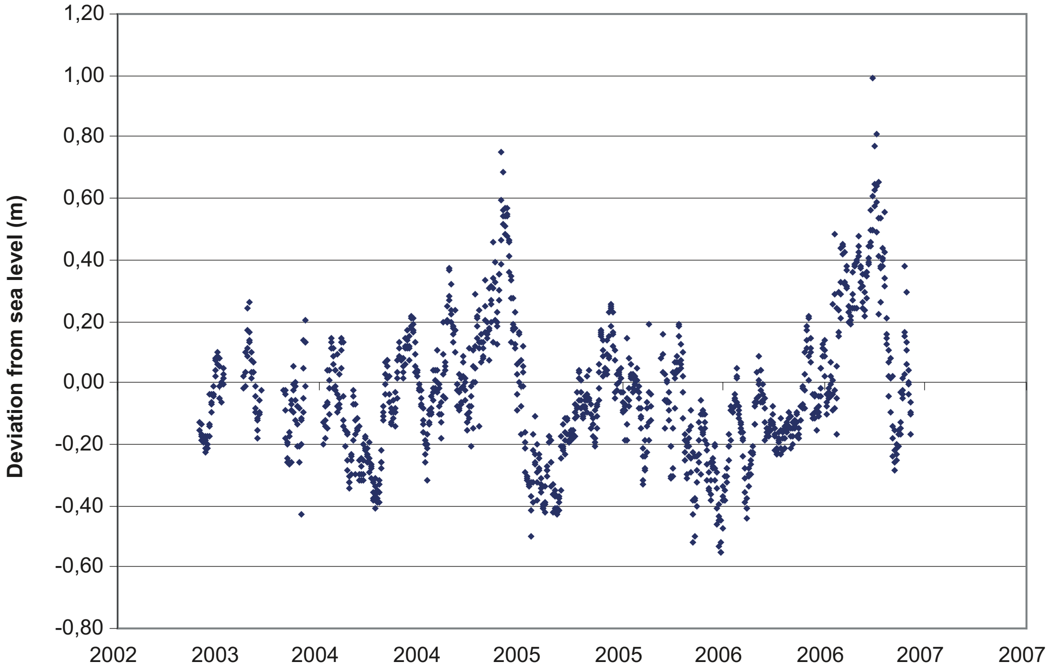


Figure 3-9. *Daily means of sea level deviation from January 2003 to April 2007 at the site PFM010039.*

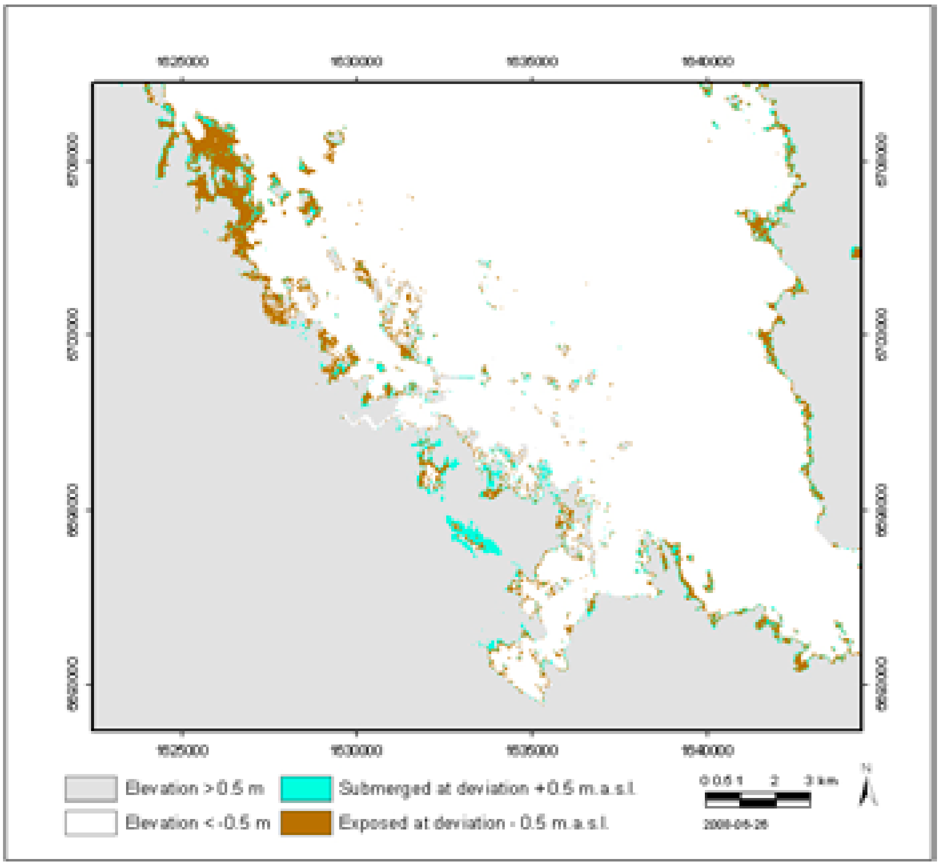


Figure 3-10. *Effects of a 0.5 m increase and of a 0.5 m decrease in sea level in Forsmark. Blue colour indicates area covered by seawater at sea level +0.5 m.a.s.l. (m above sea level), brown colour indicates area exposed to air at -0.5 m.a.s.l.*

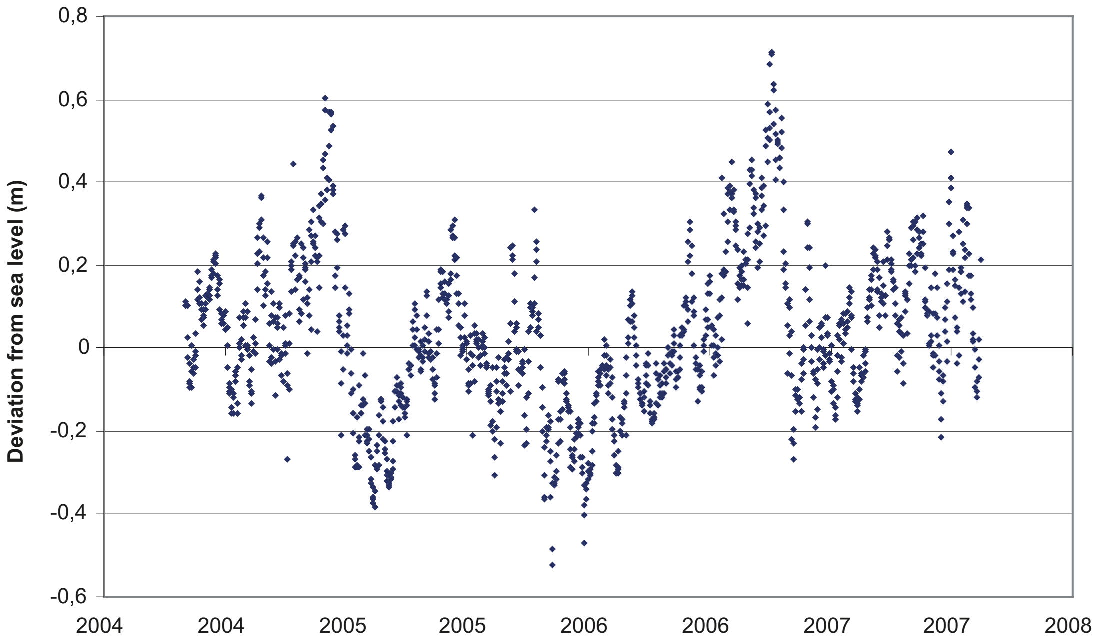


Figure 3-11. *Daily means of sea level deviation from January 2003 to April 2007 at the site PSM0000371.*

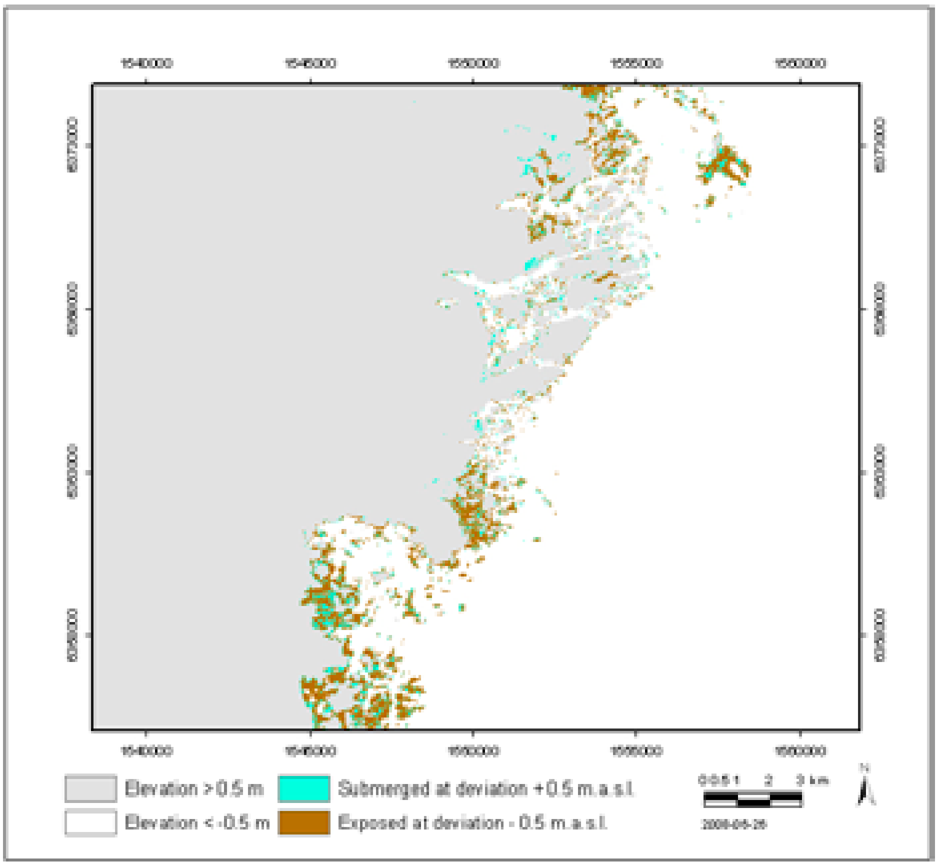


Figure 3-12. *Effects of a 0.5 m increase and of a 0.5 m decrease in sea level in Laxemar-Simpevarp. Blue colour indicates area covered by seawater at sea level 0.5 m a s l., brown colour indicates area exposed to air at –0.5 m.a.s.l.*

Forsmark

The region of Northern Uppland which includes the Forsmark area is on the peneplain which here includes the flattest parts of Sweden /Magnusson and Lundqvist 1957/. The Forsmark area is situated in a transition zone between flat coast to the north and a zone with fissure terrain and vertical displacements along faultlines to the south. The latter are related to the outline of the north-eastern shore of Öresundsgrepen, with its deeper part, the Gräsö trough.

The smaller-scale morphology of the Forsmark area is governed by a combination of bedrock structure and glacial morphology. The major bedrock lineaments run NW–SE, e.g. the Forsmark and Singö deformation zones, the former underlying the Forsmarksån River and the inner part of Kallrigafjärden Bay, the latter underlying Stånggrundsfjärden Basin. A third distinct lineament runs perpendicular to the other two underlying the major axis of Kallrigafjärden Bay (Figure 3-13).

The combined effect of rapid uplift and low relief has contributed to the formation of the present archipelago, which is relatively narrow despite the shallow depth of the basin depressions. Elevation profiles (Figure 3-13) show the peneplain with its low relative relief (< 10 m) and gentle 1:500 slope towards the NW. The lineaments affect the division of the western part of Öregrundsgrepen into basins with mean depth 8.5 m (marine basins 102–104, 106–108, 110–112, 116–118, 120–121, 123, 126, 134, 145–146, 150 and 152; for basin partitioning, see section 5.3, figure 5-2). The rest of Öregrundsgrepen dominated by the Gräsö trough has a mean depth in its eastern part of 19 m (marine basins 100, 105, 109 and 113–115).

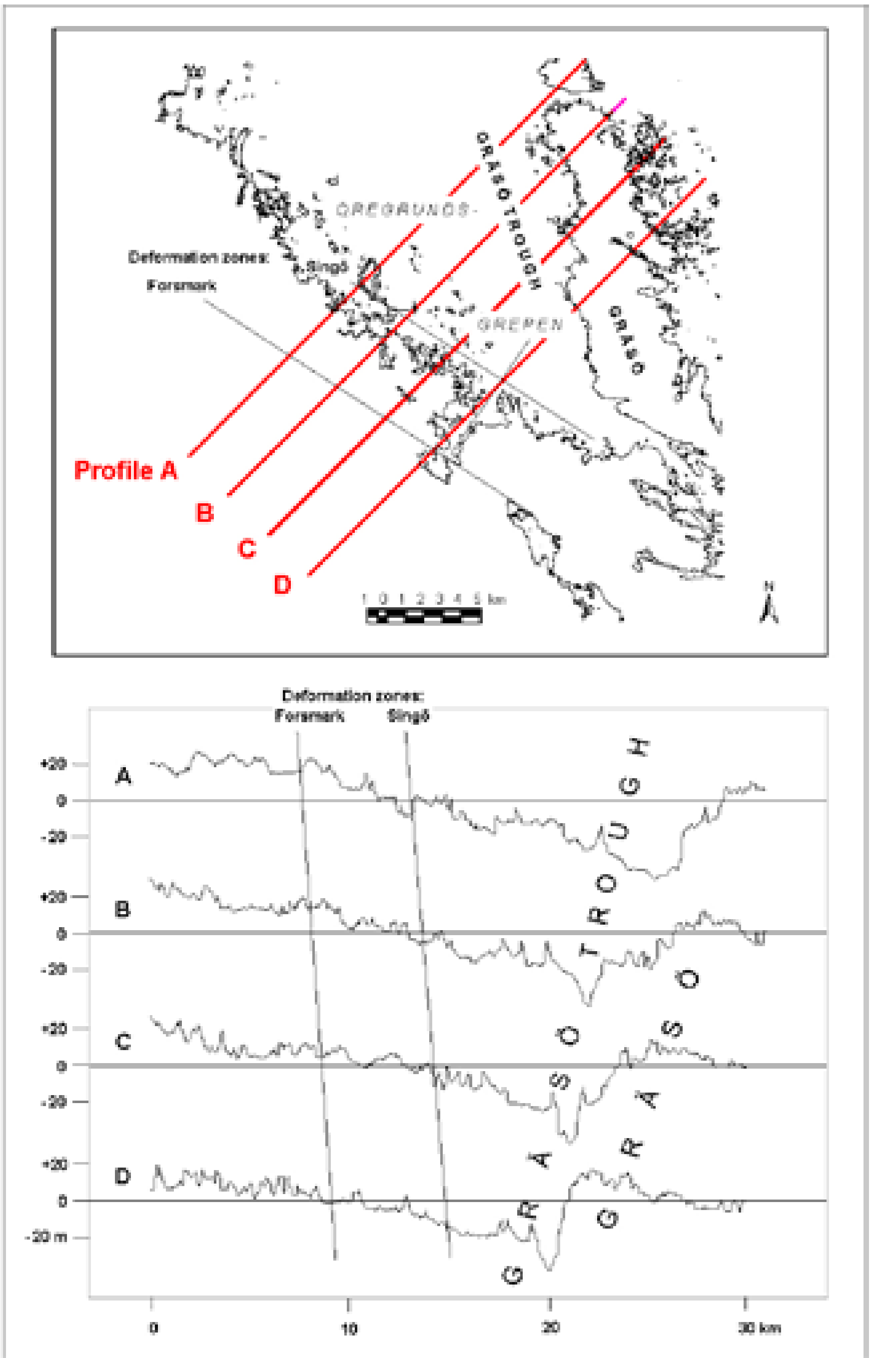


Figure 3-13. *Elevation profiles, 3 km apart, across Öregrundsgrepen through the Forsmark area with the major bedrock lineaments indicated.*

Detailed bathymetry surveys have been performed in Forsmark using side scan and multi-beam sonar in deep areas /Elhammer and Sandkvist 2005/ and single-beam sonar in shallow coastal areas /Brunberg et al. 2004/. These data, together with older data (e.g. isolines from sea charts) have been compiled into a large point dataset, see Figure 3-14. This dataset, together with a corresponding dataset on land, has been used to perform kriging interpolation to create a digital elevation model (DEM) of high accuracy /Brydsten and Strömgren 2004/, see Figure 4-1, Section 4. The methodology and input data are described in detail in /Brydsten and Strömgren 2004/.

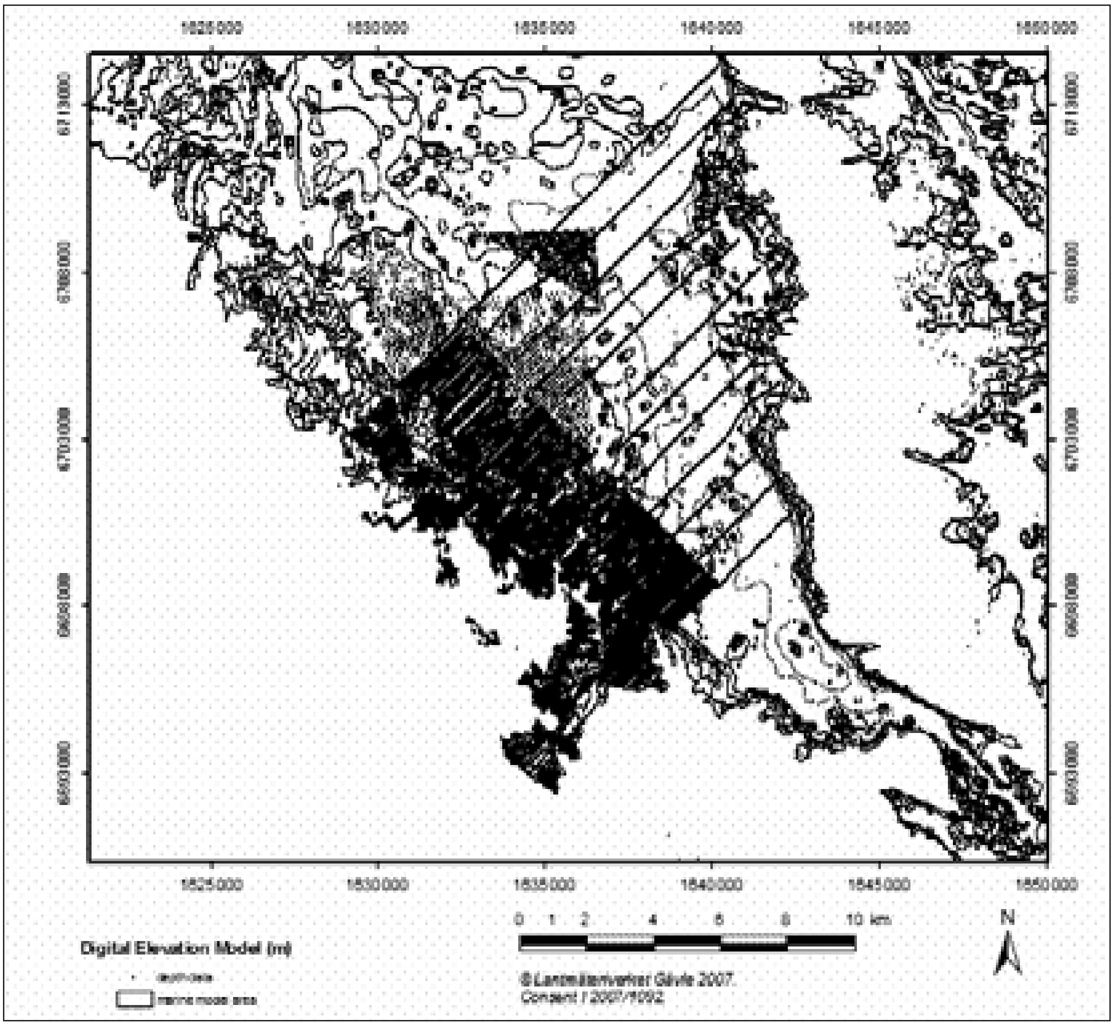


__Figure 3-14.__ Distribution of point data in the marine area used to generate the digital elevation model (DEM) for the Forsmark area.

Laxemar-Simpevarp

The Laxemar-Simpevarp area, forming part of the fissure valley terrain of south and central Sweden /Rudberg 1970/, lies east of the peneplain. The relief is low near the present coast-line and increases with a 1/400 slope to 25–50 m in the landward part of the area. See Figure 3-15.

Detailed bathymetry surveys were performed using depth soundings /Ingvarson et al. 2004, Elhammer and Sandkvist 2003/ and a digital elevation model (DEM) of high accuracy was created by /Brydsten and Strömgren 2005/, See Figure 4-2.

The coastal area off Laxemar-Simpevarp may thus be clearly divided into:

(1) the inner, sheltered bays, notably Bussviken, Granholmsfjärden, Borholmsfjärden and partly sheltered Figeholmsfjärden, and

(2) the exposed coast making up part of the north-western Kalmar sound, with two slightly deeper troughs running N-S and SW-NE.

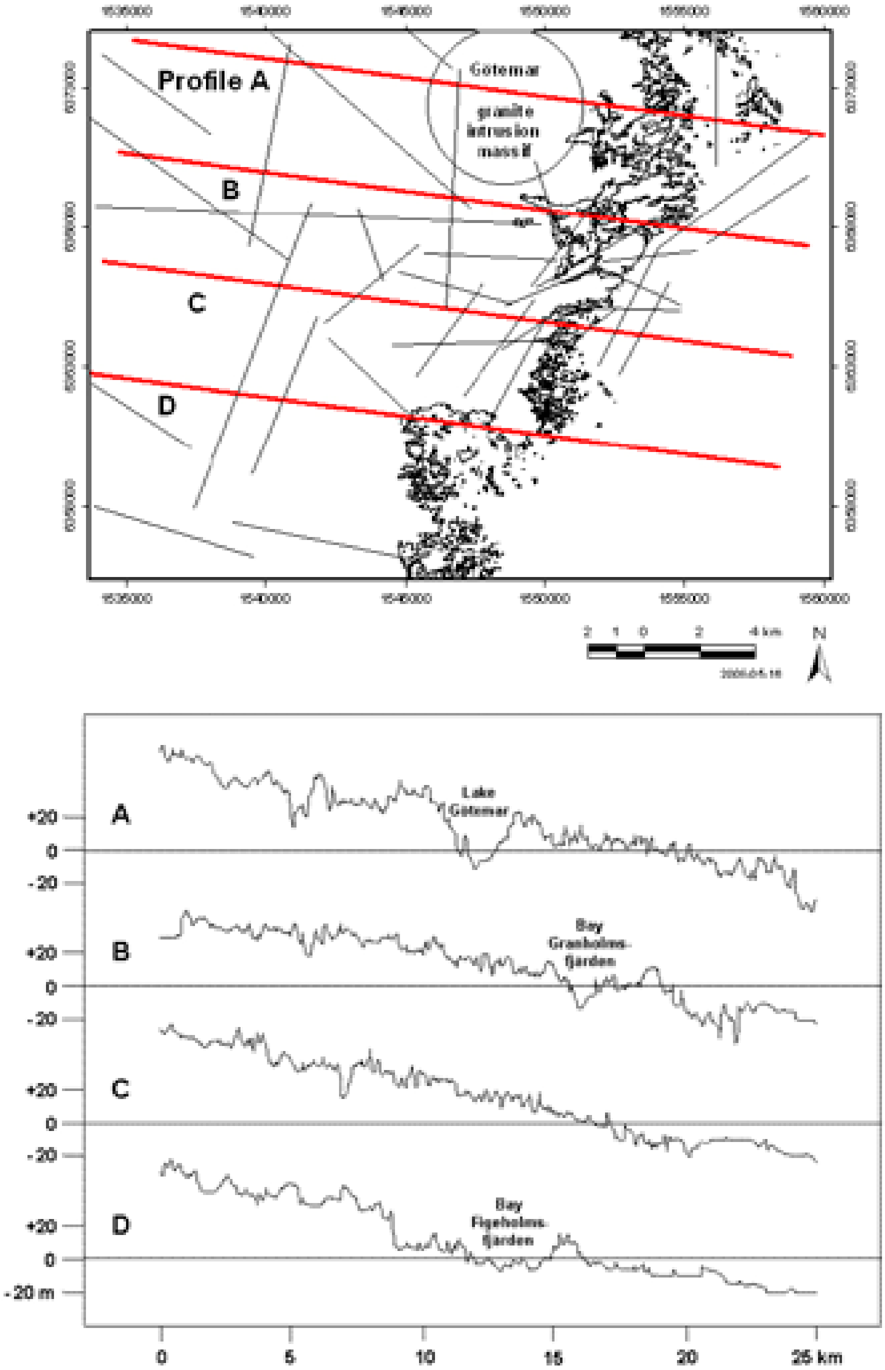


Figure 3-15. Elevation profiles, 4 km apart, across the Laxemar-Simpevarp area with the major bedrock lineaments indicated.

3.3.2 Sediment conditions

Forsmark

Mapping of the distribution and thickness of marine sediments in the Forsmark area was carried out using side-scan sonar, seismics, coring and sampling in areas deeper than 3 m /Elhammar and Sandkvist 2003/ and using probing (for surveying penetration resistance), coring and grab sampling in the shallow lagoonal areas /Ising 2006/. The position of seismic lanes and of stations where cores and grabs were taken and probings made are shown in Figure 3-16.

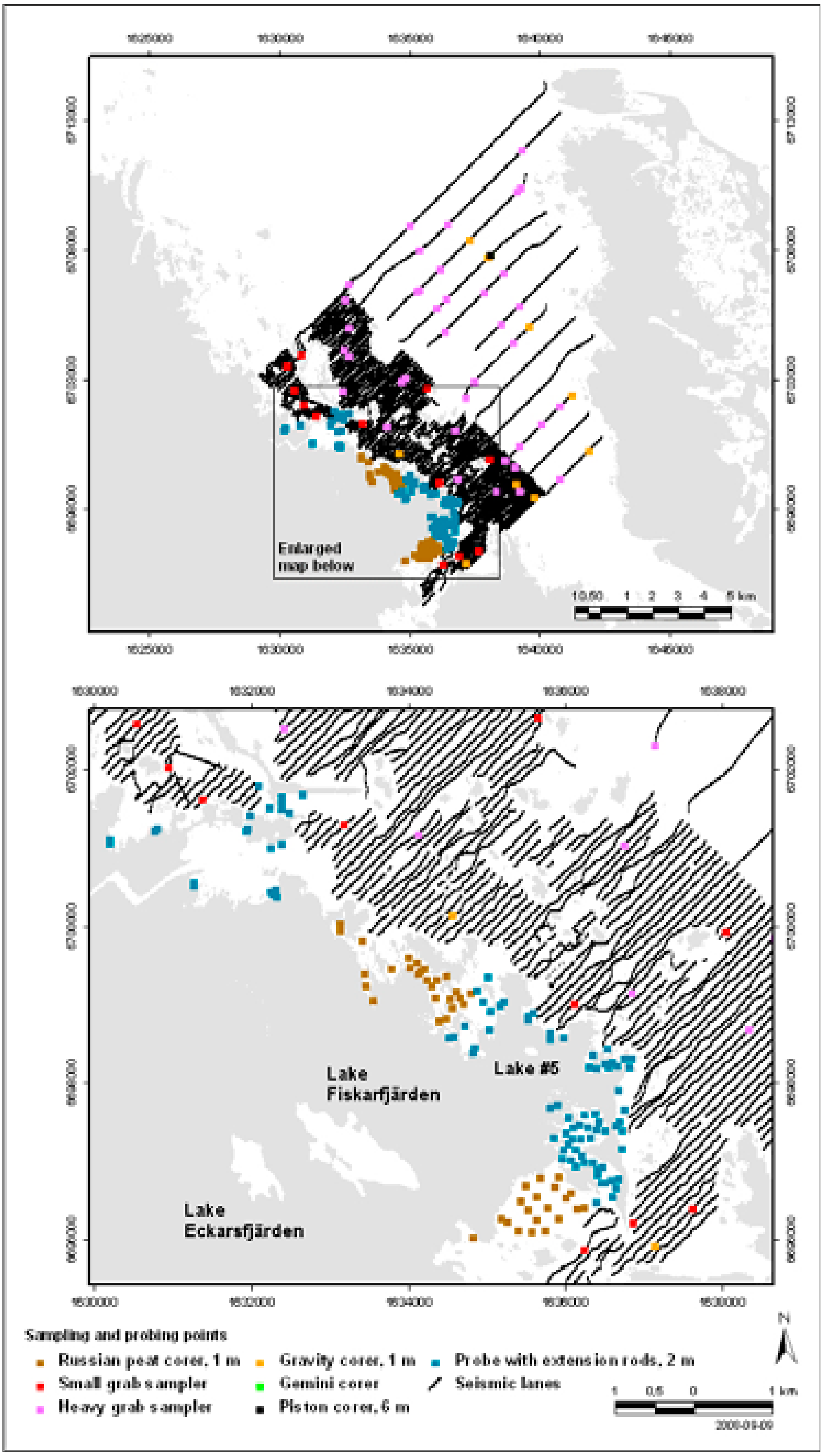


Figure 3-16. *Seismic lanes, sampling and probing points. Hard bottoms probed are not included.*

During glaciations, lineaments are prone to be carved out depending on the flow direction, hydrology and bottom temperature of the ice sheet. Due to the deeper aquatic environment during the latest deglaciation, irregularities and any such depressions were subsequently filled in and smoothed out in the Forsmark area by deposition of subglacial till, glaciofluvial sediments and subaquatic deposition of varved (heavy) glacial and further transported postglacial clay. Glacifluvial activity formed longitudinal deposits such as the Börstil esker crossing both Kallrigafjärden and Tixelfjärden. The thickness of the glacial clay is shown by the seismic mapping and modelling (Figure 3-17). It is also in the three lineaments and the Gräsö trough that the overall thickness of the regolith is the greatest, up to 10–20 m (Figure 3-18).

As deposits were raised above sea level, occasional episodes of eustatic sea level rise have resulted at least three times in prolonged periods of shoreline reworking and sheltering, 4,600 to 3,800 yrs BP, 2,500 to 2,200 yrs BP and 1,100 to 850 yrs BP /Hedenström and Risberg 2003/. However, the longer-term isostatic uplift in the Forsmark area, 6 mm y^{-1}, has been too rapid for shoreline processes to rework sorted glaciofluvial material into any larger-scale constructive beach morphologies.

In the coastal zone, final retention of elements through permanent burial takes place at accumulation bottoms, i.e., in marine postglacial fine matter deposits also referred to as A-bottoms or depocenters. Their formation is controlled by input, erosion, resuspension, transport and deposition of fine sediments, i.e. slow-falling aggregates and single particles made up of both organic and fine inorganic matter.

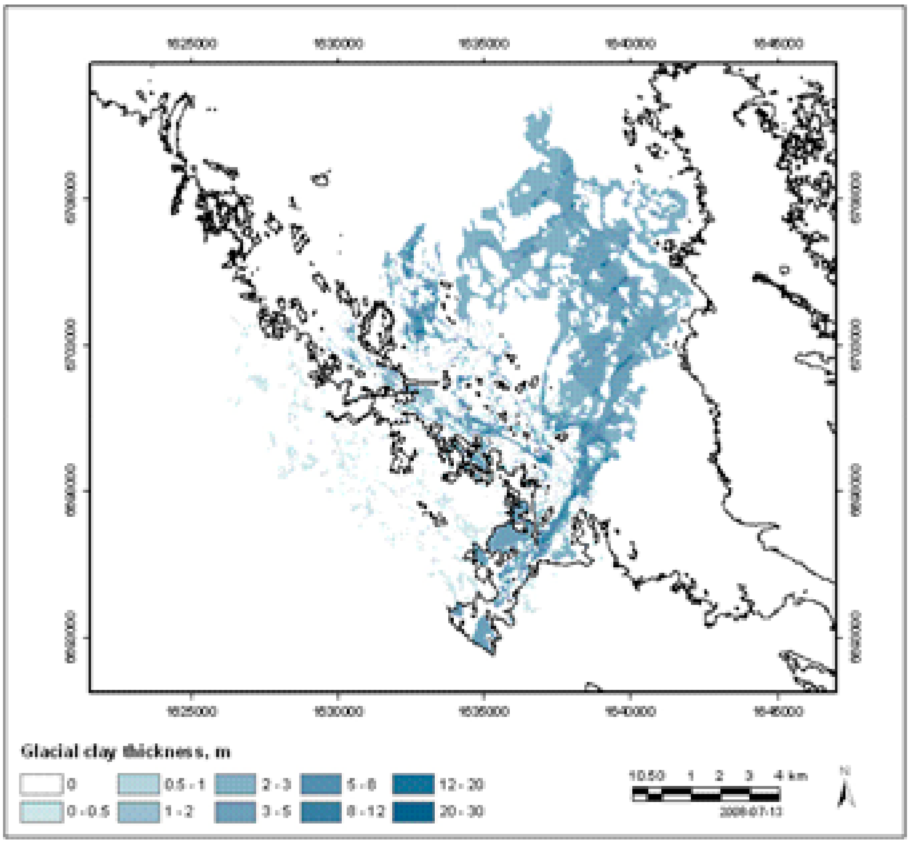


Figure 3-17. *Thickness of the present glacial clay deposits in the Forsmark area as derived through the modeling /Hedenström 2008/ based on coring and seismic investigation data /Elhammar and Sandkvist 2003, Ising 2006/.*

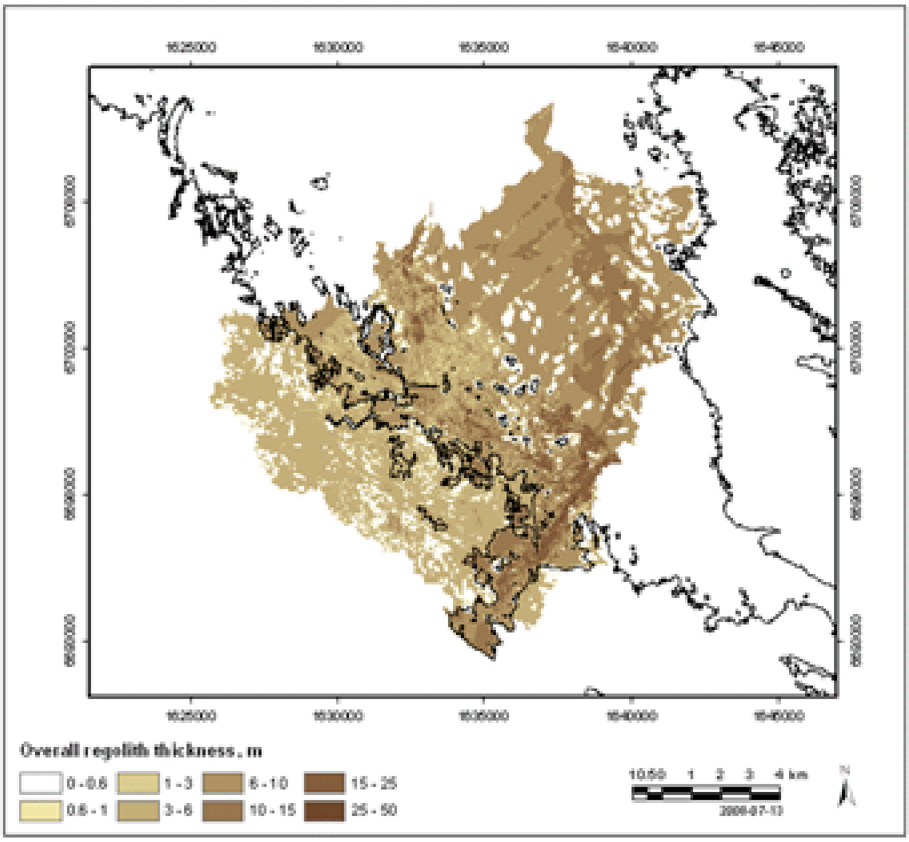


Figure 3-18. *Overall thickness of the present marine regolith in the Forsmark area as derived through the modelling /Hedenström 2008/ based on coring and seismic investigation data /Elhammar and Sandkvist 2003, Ising 2006/.*

Following deposition of glacial clay in connection with the deglaciation stage, raised till deposits were washed and eroded by wave action during the subsequent isostatic uplift. Coarse materials were then sorted into postglacial gravel and sand layers. Their finer fractions were generally carried further offshore and "focused" towards depressions where they may be deposited as A-bottoms with high organic content (postglacial mud; Figure 3-19). A steady supply of fine particles is contributed from glacial clays being eroded as they approach shallow depth during uplift.

As noted by /Sohlenius et al. 2004/ the Forsmark area has been particularly well exposed to coastal abrasive and transport processes. Cores taken in the present shallow lagoons show glacial clays underlying postglacial clay, but with signs of erosion having taken place since the earliest shoaling phases, and with postglacial clays often missing or otherwise thin. One exception is the area south-east of Lake Fiskarfjärden. Glacial clays throughout the rest of the area are mostly covered by a thin layer of sand or gravel instead of by postglacial silt, clay or gyttja, except in the eastern part of Öregrundsgrepen (Figure 3-20).

The present extent of marine A-bottoms in the Forsmark area is limited. In the western part of Öregrundsgrepen, such bottoms are found only to the north-west of Norra Asphällssundet Basin and in the two lagoonal areas to the south-east: Tixelfjärden and Kallrigafjärden /Ising 2006/.

Further offshore, fine sediments are found over larger areas, covering the Gräsö trough and the adjacent broad lineament exttending from the Gräsö trough in the direction of Kallrigafjärden.

As for the origin of offshore A-bottom particles, these can originate from both shallow and deeper waters. Cesium-134, sPCB and sDDT measurements in the Stockholm archipelago have shown 6–8 times higher burial rates in the Stockholm archipelago compared to offshore A-bottoms, indicating import of contaminants from open sea to archipelago /Meili et al. 2000/.

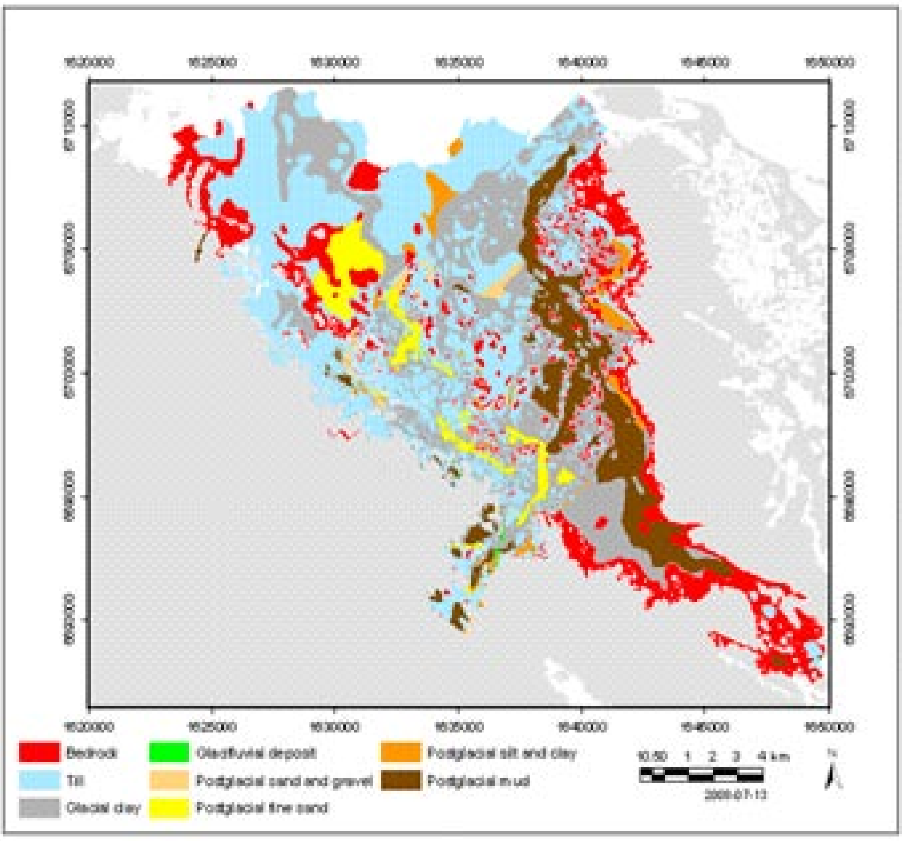


Figure 3-19. *Overview of the genesis and composition of the dominant fraction of the seabed in the Forsmark area, mapped in the outer regional model area by /Elhammer and Sandkvist 2003/ and in the shallow-water lagoonal areas by Ising /2006/, and modelled by /Hedenström 2008/.*

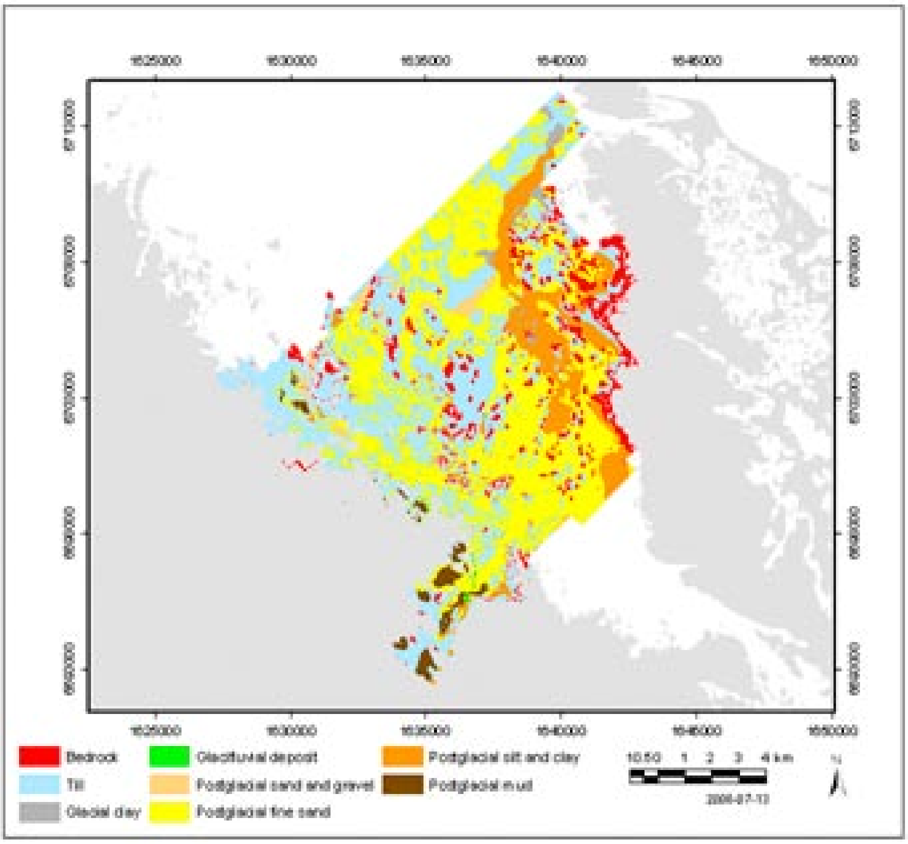


Figure 3-20. *Overview of the seabed in the Forsmark regional model area, showing the thin, uppermost layer where this differs from the dominant fraction /Elhammer and Sandkvist 2003, Ising 2006/.*

Such transport in Öregrundsgrepen most likely happens during southerly winds as bottom water and its load of resuspended particles is advected inward along the Gräsö trough.

A-bottom development also shows longer-term trends related to uplift. Using a wave-ray model, /Brydsten 1999/ investigated the theoretical extent of fine-matter deposition for 500 year intervals. A function of near-bed velocities caused by incident waves and their resulting long-shore currents, this was expressed and mapped as maximum resuspendable grain size (MRGS). When resulting MRGS histories were compared with actual stratigraphy, an MRGS of 20 µm was identified as a wave energy level roughly dividing bottoms of erosion and transport (ET-bottoms) from A-bottoms. MRGS histories described how the area's bottoms have in general seen diminishing wave energy levels over the last 2,000–3,000 years, due to increasing sheltering caused by the ongoing shoaling. They also suggested that such theoretical A-bottom conditions already extend over roughly twice the area actually mapped as fine matter deposits, in which case such mapping is either incomplete or discrepancies result from how the wave incidence is formulated.

Measurements of burial in the Forsmark area are from:

(1) lake core studies of the earliest postglacial conditions /Hedenström 2003, Hedenström and Risberg 2003/ with sediments accumulating at between 0.2 and 4 (mostly 0.5 to 1.5) mmy^{-1},

(2) /Risberg's 2005/ analysis of the 6 m piston core from the outer Gräsö trough (Figure 3-19) which showed carbon burial rates decreasing towards present rates from possibly up to one order of magnitude higher rates prevailing throughout the Holocene climatic optimum, i.e. before the sub-recent sheltering,

(3) /Sternbeck et al. 2006/5 who used ^{210}Pb measurements to estimate recent to sub-recent average mass accumulation rates in Tixelfjärden and Kallrigafjärden at approximately 1,000 $gm^{-2}y^{-1}$ with C and N burial rates at 14 and 1.6 $gm^{-2}y^{-1}$, respectively.

By comparison, carbon burial rates as measured by /Jonsson et al. 2000/ in the Baltic Proper are moderately high at 10–50 gC $m^{-2}y^{-1}$.

A-bottoms exposed today are moderately organic fines, showing oxic or suboxic conditions down to a few cm depths.

Laxemar-Simpevarp

As summarized in Figure 3-21 (from /Nyman 2005/), the inner sheltered bays were studied by sediment coring and grab sampling /Risberg 2002, Nilsson 2004, Sternbeck et al. 2006/ and by means of echo sounding, side scan sonar and shallow seismics /Ingvarson et al. 2004/. The exposed coast was surveyed by means of side-scan sonar, seismics, sediment coring and grab sampling /Elhammar and Sandkvist 2005b, Ingvarsson et al. 2004/, including analyses of two 5–6 m long piston cores /Kaislahti et al. 2006/. Overall sediment depth and stratigraphy of the regolith were modelled by /Nyman 2005/.

The sediments in the Laxemar-Simpevarp area are more typical of an exposed bedrock-fissure coast, showing mud accumulation in the sheltered bays and bedrock, till and boulders along the exposed coast, where residual glacial clay is found only in two minor troughs, in pockets and in fissures /Ingvarson et al. 2004/. Glaciofluvial material is found along the Tuna esker running N-S in the western part of the area, and in the minor Misterhult and Gässhult esker running NW-SE perpendicular to the coast. The thickness of the clays is shown in Figure 3-22 and the thickness of the overall regolith in Figure 3-23. Furthermore, Figure 3-24 shows the composition of the dominant fraction of the marine bottom while Figure 3-25 shows the composition of an upper thin layer, silt or sand, where this differs from that of the bulk, typically the glacial clay.

Carbon sequestration (burial) rates estimated by /Kaislahti et al. 2006/ from one of the two long piston cores taken in the offshore deeper trough running SW-NE from Kråkelund (station PSM002123, depth 40 m) increased during the Holocene from < 5 gC $m^{-2}yr^{-1}$ towards 56 gC $m^{-2}yr^{-1}$ in the sub recent Littorina phase. Rates measured by /Sternbeck et al. 2006/ in the sheltered bays were also high, 74–95 gC $m^{-2}yr^{-1}$ compared to those measured in the same study in sheltered locations in the Forsmark area (14 gC $m^{-2}yr^{-1}$), as well as those measured by /Jonsson et al. 2000/ in the Baltic Proper (10–50 gC $m^{-2}y^{-1}$).

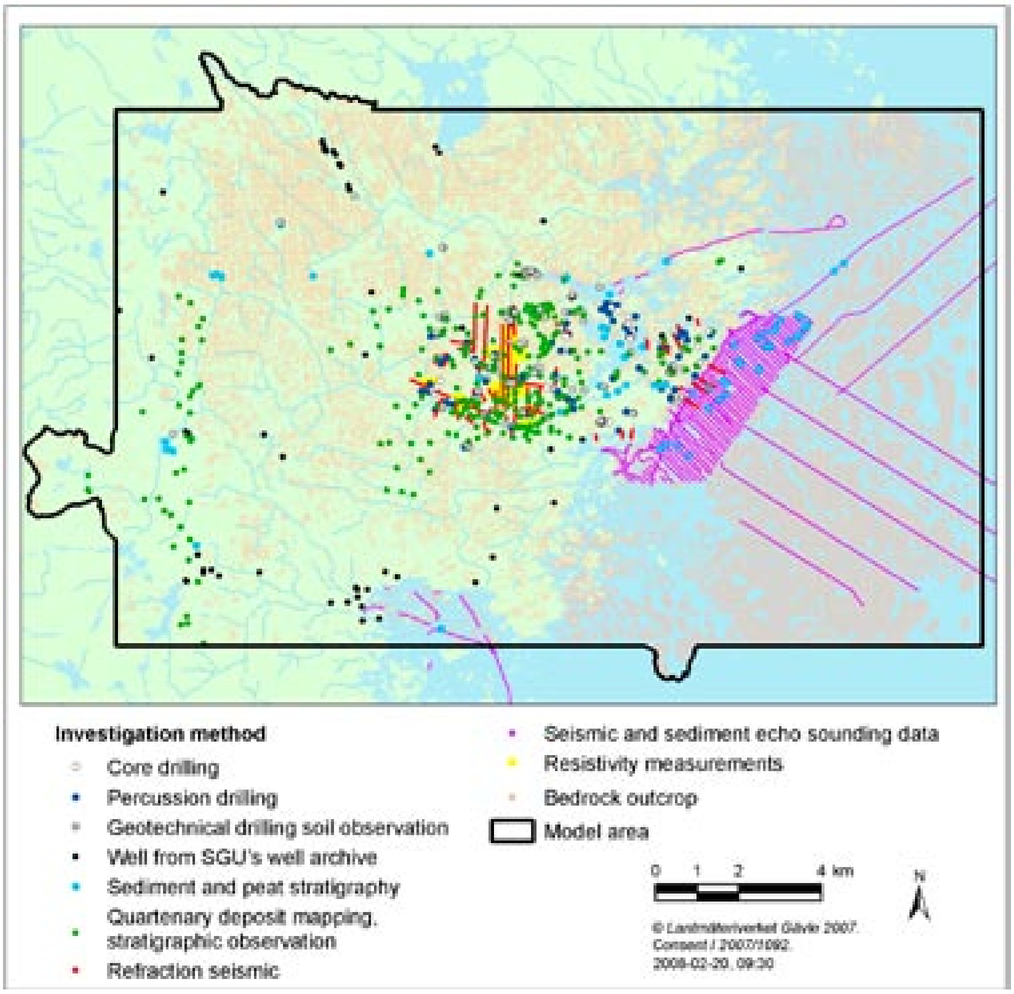


Figure 3-21. Overview of the main marine seismic lanes (purple) and sampling points (light blue) in the Laxemar-Simpevarp area. From /Sohlenius et al. 2008/.

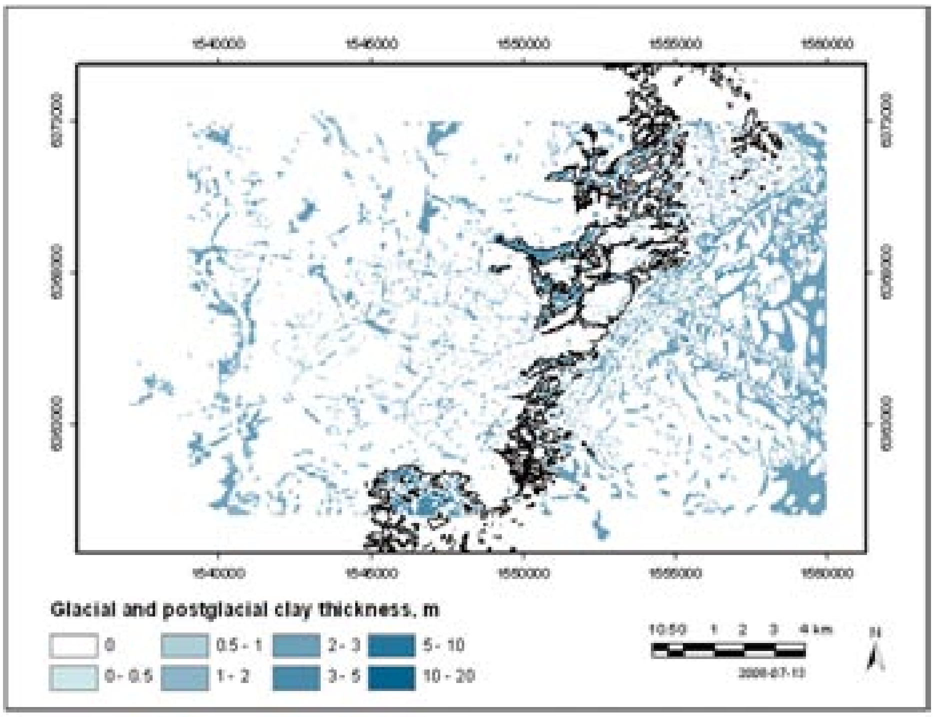


Figure 3-22. Thickness of the present glacial and postglacial clay deposits in the Laxemar-Simpevarp area, based on data presented and modeled in /Sohlenius et al. 2008/.

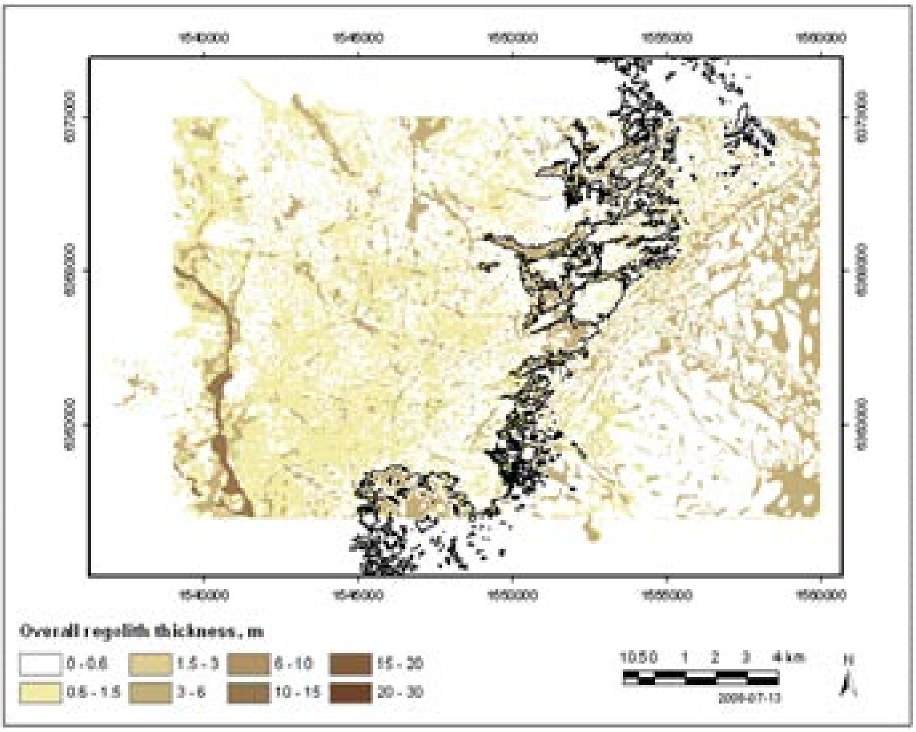


Figure 3-23. *Overall thickness of the regolith in the Laxemar-Simpevarp area, based on data presented and modeled in /Sohlenius et al. 2008/.*

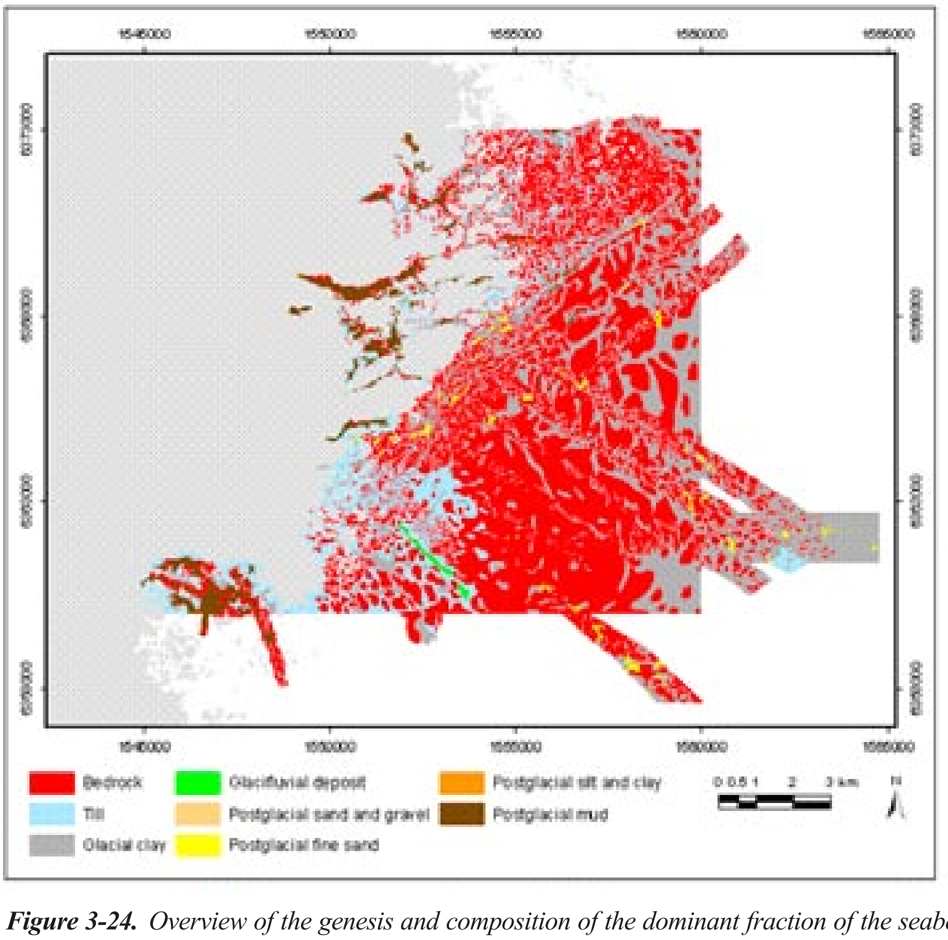


Figure 3-24. *Overview of the genesis and composition of the dominant fraction of the seabed in the Laxemar-Simpevarp area. Stratigraphy and sediment distribution based on data from /Sohlenius et al. 2008/.*

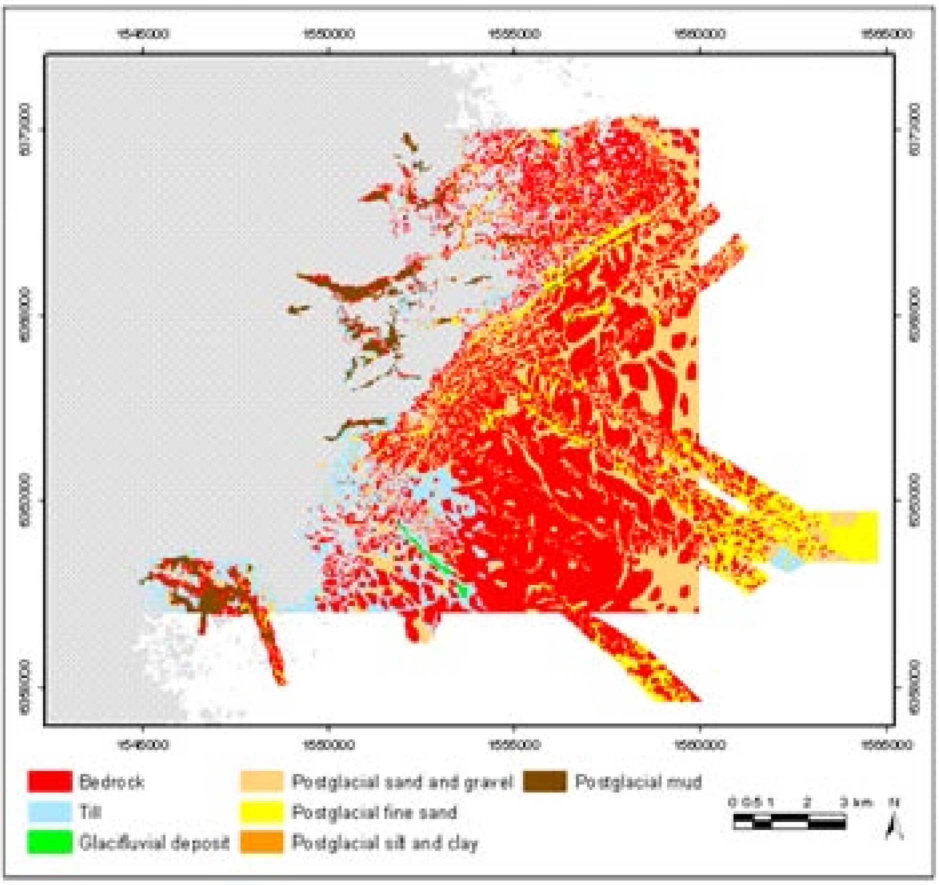


Figure 3-25. Overview of the seabed in the Laxemar-Simpevarp regional model area, showing the thin, uppermost layer where this differs from the dominant fraction. Stratigraphy and sediment distribution based on data from /Sohlenius et al. 2008/.

3.4 Biota in the marine ecosystem

Compared with fully marine environments, the Baltic Sea with its brackish water has a very poor flora and fauna. The Baltic is inhabited by a mix of marine and freshwater species adapted to the brackish conditions. Where salinity levels are low, in the Baltic´s northern and eastern waters, fewer marine species can thrive and marine habitats are dominated by freshwater species, especially in estuaries and coastal waters. In southern areas with higher salinity, marine species dominate.

The following section contains a brief description of biotic components of the ecosystems (producers and consumers in the functional groups) at the two sites. The data mainly come from the SKB site investigation programme. In some cases, data reported elsewhere in investigations at the sites or in nearby areas of the Bothnian Sea and the Baltic proper have been used for comparison and for showing long time series in Appendix 4 a list of species mentioned in report is present.

3.4.1 Habitats and functional groups

The marine ecosystems at the sites include three major environments: semi-enclosed bays affected to a varying degree by the freshwater effluence, coastal archipelago with sheltered areas, and Baltic Sea habitat exposed to sea currents and wave action. The following habitats occur in these environments: pelagic, soft bottom and hard bottom habitats. In a traditional sense, pelagic means "open sea" /e.g. Kaiser et al. 2005/ and is characterized by an absence of contact with bottom or shore /Horne and Goldman 1994/. Here, pelagic habitat refers to the open water, even in small in-shore basins. The organisms represented in the habitats were divided here into functional groups comprising primary producers and consumers, see Table 3-17.

Table 3-15. Statistics for sea level changes at the monitoring station *PFM010039* in Forsmark. Positive values indicate changes above the 10-year mean while negative values indicate changes below this mean value.

	Mean	Median	Std. Dev.	Min	Max	25%–tile	75%–tile	N
Forsmark	0.02	0.01	0.2	–0.6	1.3	–0.12	0.14	43,800

3.4.2 Macrophytes and microphytobenthos

The producers in the benthic habitat, the phytobenthos, consist of large photosynthesizing algae and vascular plants (macrophytes) and microscopic unicellular organisms (microphytes including cyanobacteria). They are limited to the photic zone, which extends from the surface down to a maximum depth of approximately 30 m and in areas with low visibility less than 10 m.

In the photic zone, sediment-associated microalgae (microphytobenthos) can be expected to influence the exchange of carbon and nutrients at the sediment-water interface. Considerable microphytobenthic biomass and primary productivity have been documented at depths of 15–20 m in coastal temperate areas /Sundbäck et al. 1991/.

Forsmark

A number of surveys aimed at gathering information on the vegetation communities have been carried out as a part of SKB's site investigations. In 2004, a total of 59 diving transects were performed and 30 quantitative samples were taken, resulting in coverage (percent sea floor coverage) and biomass data of macrophytes /Borgiel 2005/. Forty-eight video recordings of the sea floor were also made during a marine geological survey /Elhammer and Sandkvist 2005/ over large parts of Öregrundsgrepen, although these were sparsely distributed. Three diving transects aimed at gathering quantitative and semi-quantitative (macrophyte coverage estimates) were performed in the exposed areas in 1998 /Kautsky et al. 1999/. These data, plus complementary data from other sources, have been used in two analyses producing a benthic vegetation map in the coastal area (Figure. 3-26) /Fredriksson 2005/.

Large parts of the Forsmark marine area are open sea and are delimited by the steep sloping island of Gräsö in the east and the gradual slope of the mainland to the south-west (see map Appendix 1, a). The area to the east and south of the Forsmark area is best known and is described here. Most of the area consists of shallow exposed hard bottoms (boulders or bedrock) interspersed with deeper valleys with soft bottoms. The photic zone is roughly between the surface and twice the average water transparency[1], and as the average water transparency is not more than 3.4 to 3.6 m in the coastal zone, large areas deeper than 7 m lack vegetation cover. The vegetation in the photic zone is dominated by red algae (e.g. *Polysiphonia nigrescens*) and brown filamentous algae (e.g. *Spacelaria arctica*) and the larger *Fucus vesiculosus* (Figure 3-27). In the sub-littoral zone, green algae such as *Cladophora glomerata* are present as well as the moss Fontinalis dalecarlica. This moss is frequently observed in the Gulf of Bothnia but does not occur in the Baltic Proper /Borgiel 2005, Kautsky et al. 1999, Lindahl et al. 1983/.

Table 3-16. Statistics for sea level changes at the monitoring station *PSM0000371*. Positive values indicate changes above the mean while negative values indicate changes below this mean value.

	Mean	Median	Std. Dev.	Min	Max	25%–tile	75%–tile	N
	0.03	0.01	0.2	–0.5	0.7	–0.05	0.2	1,314

[1] Measured as Secchi depth

Table 3-17. Functional groups in the marine ecosystem.

Functional group	Description/comment	Primary producer/consumer
Macrophytes	Phytobenthos – Large photosynthesizing algae and vascular plants	Primary producer
Microphytobenthos	Phytobenthos – microscopic unicellular photosynthesizing organisms	Primary producer
Phytoplankton	Free living, pelagic, photosynthesizing organisms	Primary producer
Benthic bacteria	Heterotrophic bacteria living on sea floor and in sediment	Consumers
Benthic fauna	Macroscopic heterotrophic organisms living in (infauna) or on (epifauna) the sediment	Consumers
Zooplankton	Macroscopic free living, pelagic, hetero-trophic organisms	Consumers
Bacterioplankton	Free living, pelagic, heterotrophic bacteria	Consumers
Fish		Consumers
Birds		Consumers
Mammals	Here seals	Consumers

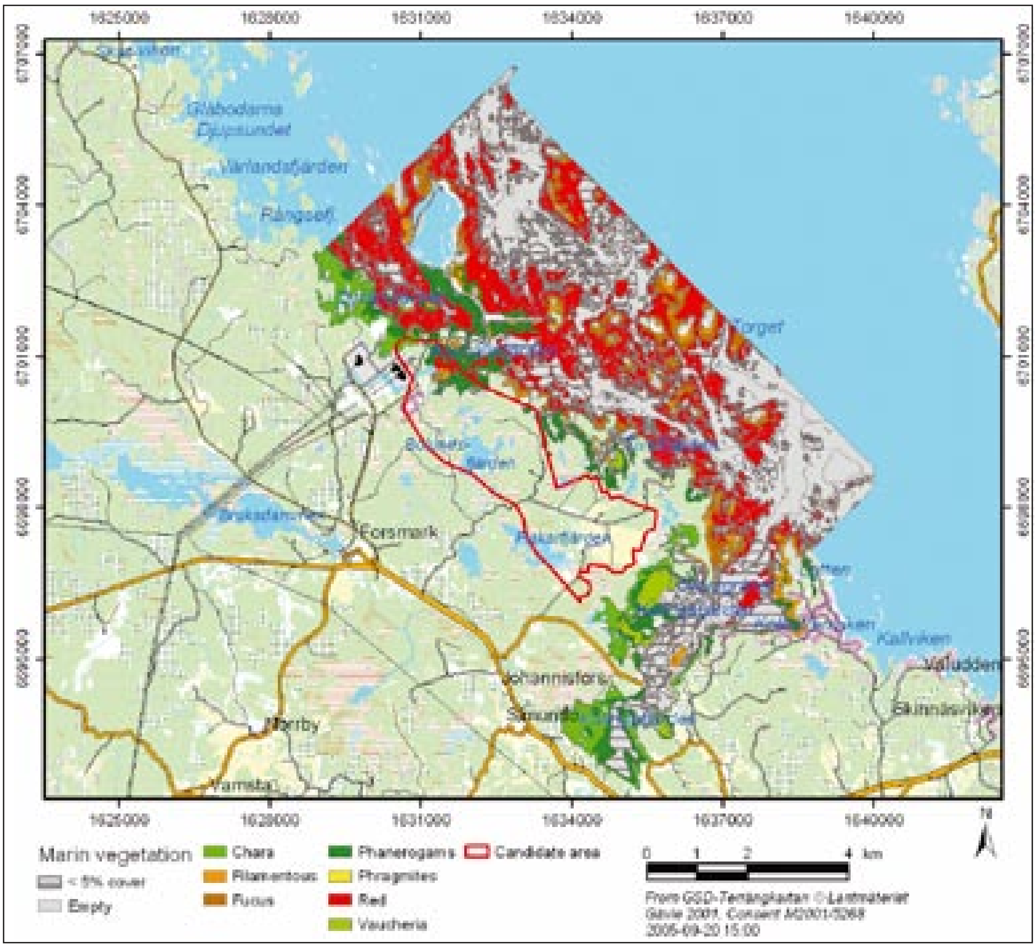


Figure 3-26. Vegetation communities in Forsmark presented by /Fredriksson 2004/.

Figure 3-27. *Fucus vesiculosus and brown filamentous algae on bedrock at 1 m depth at the island of Marträd, located 6 km east of the Forsmark power plant.*

A few bays are more or less secluded from wave exposure and host soft bottom communities, e.g. Kallrigafjärden in the south and Asphällsfjärden by the Forsmark power plant. In these areas, soft bottom dwelling phanerogams (e.g. *Potamogeton pectinatus*, see Figure 3-28) and *Charophyceae* (e.g. *Chara tomentosa*) dominate the macrophytes in the shallow areas. In deeper areas in Tixelfjärden and Kallrigafjärden, the *Xanthophyceae* alga *Vaucheria dichotoma* is found in high densities. The water transparency is lower here than in the exposed areas (only 1.1–1.5 m) in Kallriga and Tixelfjärden, so areas below 2 m are vegetation-free or have only low densities of vegetation /Borgiel 2005, Kautsky et al. 1999/.

In the photic zone, the seabed is also covered to a large extent by a layer of microalgae, mainly diatoms. Biomass estimates and primary production for microphytobenthos in Forsmark have been reported by /Snoeijs 1986/. Biomass values ranged between 12–17 gC m^{-2} and primary production between 25–46 gC m^{-2} $year^{-1}$ at three sites outside the Biotest basin in Forsmark.

In the inner parts of Kallrigafjärden, large belts of emergent macrophytes (mainly reed, *Phragmites australis*) delimit the sea from land. These belts forms a boundary between land and sea and are further described in the wetland section in /Löfgren 2008/.

Benthic primary production and respiration were measured in a study in May, July and August 2005 /Borgiel et al. 2006/ at four sites (n=5 at each site) on four different macrophytes communities: red algae, *Vaucheria sp., Chara sp.* and vascular plants (*Zanichellia sp.*), see Appendix 1, a. The measurements were made using oxygen meters recording oxygen concentration every 15 min during a period of 24 h. Changes in oxygen concentration were used to calculate primary production during the light period and respiration during the dark period. The results showed high respiration and negative net primary production for the communities in several of the measurements. *Vaucheria sp.* and Chara sp. show negative net primary production (NPP) early in the season and positive NPP later on, while the opposite pattern seems to be valid for Red algae, see Table 3-18.

Figure 3-28. *Potamogeton pectinatus on a soft bottom at a depth of approximately 2 m in Asphällsfjärden.*

Laxemar-Simpevarp

Several studies aimed at gathering information about the vegetation communities have been carried out in Laxemar-Simpevarp as a part of SKB's site investigations. In 2002 a general survey of 1,274 independent sites was performed including recordings of macrophytes species and coverage (percent coverage of sea floor), 20 diving transects and 57 quantitative samples. In a marine geological study, 40 video recordings of the sea floor and qualitative grab samples were taken the same year /Elhammer and Sandkvist 2005b, Tobiasson 2003/. As part of a monitoring programme, three sites within the area are being monitored every year by the Swedish board of Fisheries /KVF 2007/.

Table 3-18. Average Biomass, Respiration (R) and Net Primary Production (NPP), measured in five replicates at the four sites in the Forsmark area.

	Period	Biomass (mg dw m^{-2})	Biomass (mg C m^{-2})	R (mg O_2 m^{-2} h^{-1})	NPP (mg O_2 m^{-2} h^{-1})
Chara sp.	May	2.4	0.3	77	–20
PFM006016	July	44	6.0	133	–1.5
	August	31	4.1	99	12
Vaucheria sp.	May	294	115	105	–21
PFM006017	July	580	227	26	5.9
	August	493	193	27	11
Vascular plants	May	0		29	–0.55
PFM006018	July	–		–	–
	August	–		–	–
Red algae	May	116	41	80	6.3
PFM006019	July	91	32	83	–8.6
	August	–		–	–

These data, plus complementary data from other sources, have been used in two analyses showing the benthic vegetation as a map in the coastal area / Fredriksson and Tobiasson 2003, Carlén et al. 2007/ (Figure 3-30). The vegetation map was drawn by hand (also using sea charts and a marine geology map), and the accuracy is dependent on the density of the observations – generally higher in the inner bays and coastal areas and lower in the offshore area. The modelled grids /Carlén et al. 2007/ were made using spatial modelling (GRASP) and several spatially varying datasets such as average annual temperature, wave exposure etc.

From the general survey, nine different vegetation communities were defined on the basis of dominant species or higher taxa (Figure. 3-30). The red algae community covered the largest area, followed by the *Potamogeton pectinatus* community, *Chara sp* and *Fucus vesiculosus.* The vegetation communities consist of sub-areas of different species composition and degree of coverage. Occurring species, species composition and methods are presented in more detail in /Fredriksson and Tobiasson 2003/.

The benthic area in Laxemar-Simpevarp can be divided into three areas with more or less distinct characteristics with regard to structuring factors such as wave exposure, light penetration and substrate type. These areas are: secluded bays (e.g. Borholmsfjärden and Granholmsfjärden), shallow exposed archipelago (in the south-east area) and deep exposed areas (the coast and water mass outside Simpevarp, Ävrö and Upplångö). The bays are characterized by low visibility (yearly average of 2–3 m) and low wave exposure, while the archipelago and the outer exposed areas have an average annual visibility of 4 to 7 and 12 m, respectively.

The inner soft bottom parts of the archipelago north of Laxemar-Simpevarp (around the island of Äspö) are dominated by *Chara sp*. West of Ävrö, a large area is covered by *Xanthophyceae* generally *Vaucheria dichotoma*. On corresponding bottoms in the southern area, the vegetation is dominated by vascular plant communities, mostly *P. pectinatus* and *Zostera marina*. The sheltered inner coastal waters, particularly south of Laxemar-Simpevarp, are dominated by *P. pectinatus* (Figure 3-28*)*.

Further out towards more exposed areas *P. pectinatus* and *Z. marina* occur together in a patchy distribution. On hard substrates, in shallow areas, the vegetation is dominated by *Fucus vesiculosus* (Figure 3-31), and in deeper areas red algae cover the hard substrates (Figure 3-32) /Fredriksson and Tobiasson 2003/. Low abundances of *Fucus sp.* are recorded to a depth of approximately 10 m and red algae down to approximately 30 m /Tobiasson 2003/.

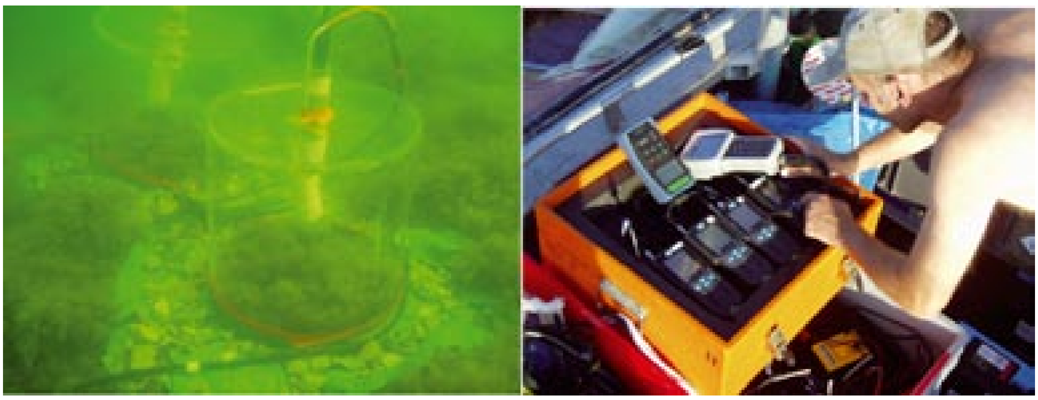


Figure 3-29. *Measurements of benthic primary production and respiration in a red algae community /Borgiel et al. 2006/. Photo: Micke Borgiel.*

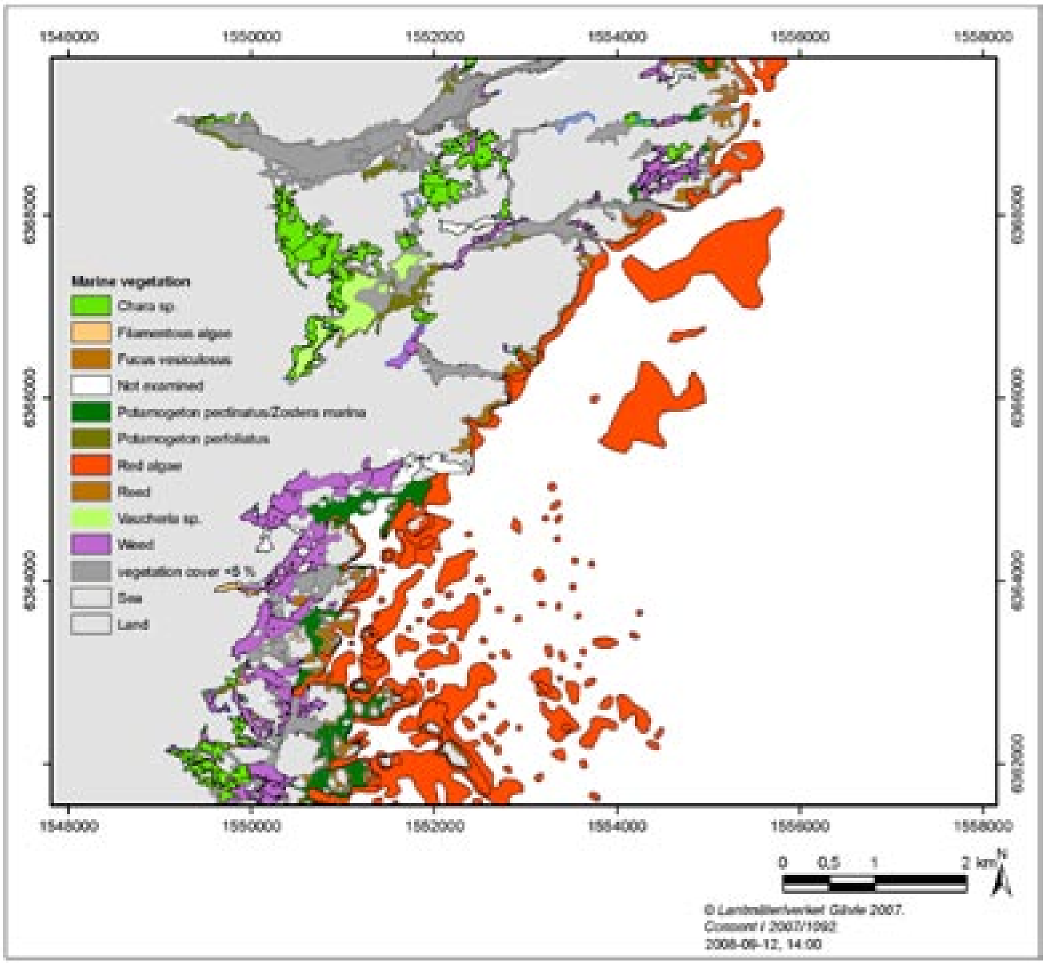


Figure 3-30. *Marine vegetation communities presented by /Fredriksson and Tobiasson 2003/.*

Figure 3-31. *Fucus vesiculosus habitat in the Laxemar-Simpevarp marine basin.*

Figure 3-32. Red algae on hard bottom substrate in the Laxemar-Simpevarp marine basin.

Primary production and respiration were measured in nine of the identified macrophyte communities (see Appendix 1, b)/Wijnbladh and Plantman 2006/. Net primary production was found in July to be in the range 17–95 mgC $m^{-2}h^{-1}$ during the daytime and respiration in the range 5–80 mgC $m^{-2}h^{-1}$. At three sites, primary production and respiration were studied during a period of one year, and the estimated annual net primary production was lower than a previously model based on literature data /Wijnbladh et al. 2006/. Biomass, respiration and NPP are presented for three of the sites in Table 3-19, and one of the *Vaucheria sp.* sites where NPP measurements were performed is shown in Figure 3-33.

Table 3-19. Average Biomass, and annual Respiration (R) and Net Primary Production (NPP) in the three out of nine sites in the Laxemar-Simpevarp area.

	Period	Biomass (mg DW m^{-2})	Biomass (mg C m^{-2})	R (mg O_2 m^{-2} $year^{-1}$)	NPP (g C_2 m^{-2} $year^{-1}$)
Potamogeton pectinatus PSM007093	Jan, Apr, May, July, Aug	2.5	0.8	–96	28
Mixed PSM007094	‘’	27	8.3	–168	16
Chara sp PSM007095	‘’	63	8.5	–131	21

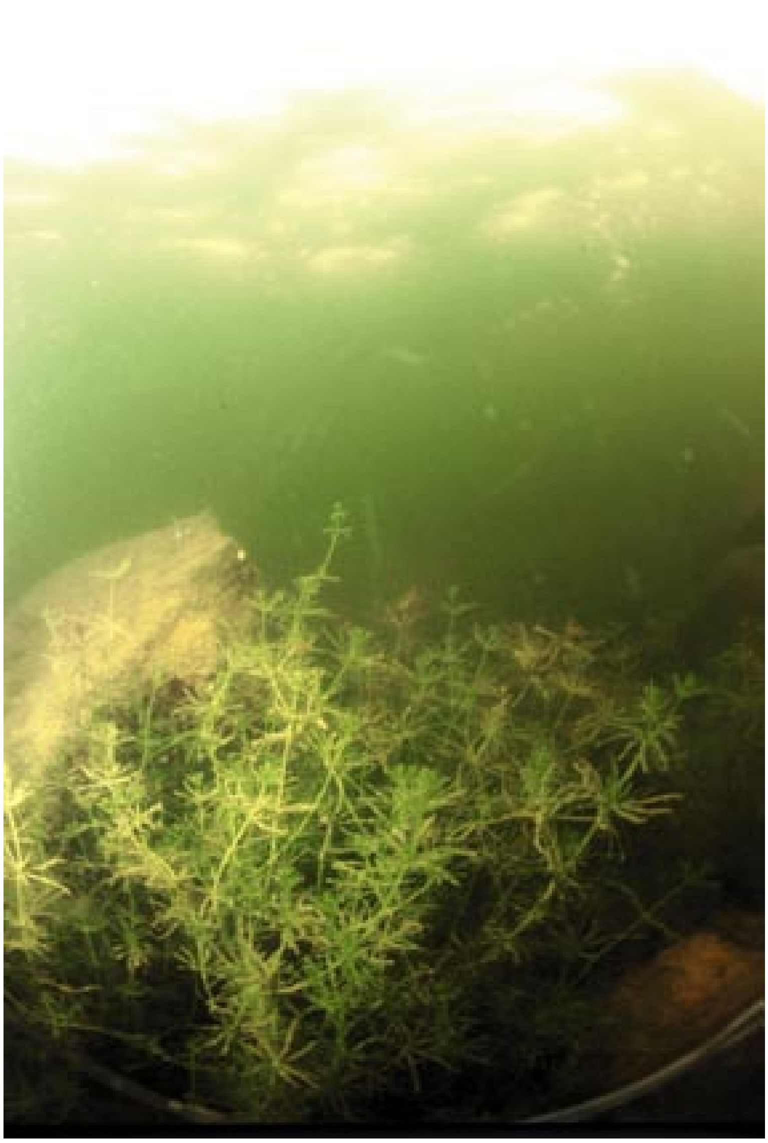


Figure 3-33. A Vaucheria sp. site in the Laxemar-Simpevarp area, where benthic primary production and respiration were measured.

3.4.3 Phytoplankton

Phytoplankton species composition as well as biomass varies throughout the year. Generally in the Baltic, the spring bloom as well as the autumn maxima is dominated by diatoms. After the spring bloom of diatoms, dinoflagellates and other smaller flagellates become more important later to be followed by maximum densities of cyanobacteria and zooplankton.

Amounts of nutrients along with temperature variation and amount of light form the basis for phytoplankton succession. The spring bloom of phytoplankton begins following ice break-up. The intensity of the spring bloom reflects the size of the nutrient reserves. The spring bloom species of diatoms and dinoflagellates consume most of the phosphorus and nitrogen nutrients that were accumulated in the water mass during the previous winter. In the open sea, the spring bloom is often limited by the supply of nitrogen, while in the near-shore coastal zone the limiting nutrients are more often phosphorus and silica.

After the spring bloom, primary production in the water column decreases and the concentrations of phytoplankton are low during the summer, due to lower nutrient supplies and grazing by zooplankton. Large blooms of cyanobacteria often occur later in the summer in warm and calm weather. The recent situation with excessive cyanobacterial blooms in the Baltic Proper thriving off an excess of phosphorus may, however, have diminished the importance of both the major spring bloom and the minor fall bloom and their associated sedimentation, especially in the less phosphorus-rich Bothnian Sea /Larsson et al. 2006/.

When available, data on phytoplankton from the investigations at the sites or in nearby areas are compared with data from SKB's site investigations. Sampling and analyses of species abundance and biomass of phytoplankton were performed in the site investigations in 2003 and 2004 at both sites /Huononen and Borgiel, 2005, Sundberg et al. 2004/. Chlorophyll sampling (a relative measure of phytoplankton biomass in the water) was performed regularly at the sites along with measurement of hydrology parameters in the site investigation programme between 2002 and 2006 /Nilsson and Borgiel 2007, Ericsson and Engdahl 2006/.

Forsmark

The reported average biomass value for phytoplankton in Öregrundsgrepen between June 1972 and May 1973 was 0.5 gC m^{-2} /Eriksson et al. 1977/.

In Öregrundsgrepen 1977–1978, the spring bloom of phytoplankton was dominated by diatoms and dinoflagellates. The vernal maximum culminated in late April–early May. Maximum values per 24 hours of phytoplankton biomass, chlorophyll and primary production were about 50 g ww m^{-2}, 100 mg chl a m^{-2} and 600 mgC m^{-2}, respectively. Annual phytoplankton production was estimated to be 59 gC m^{-2} (1977). At that time this rate of primary production was about half of the production rate in the northern Baltic Proper, but 5–6 times higher than production in the Gulf of Bothnia /Lindahl and Wallström 1980/.

In a more sheltered bay of Öregrundsgrepen, Asphällsfjärden (PFM00062), which was studied in 2003–2004, the diatoms dominated only during the late winter growth period, while the autotrophic red tide ciliate *Mesodinium rubrum* dominated the spring maximum as well as the late fall decline and the winter minimum. The mean carbon biomass for phytoplankton during 2003–2004 was 14 mgC m^{-3} at the station PFM00062 /Huononen and Borgiel 2005/.

Monthly means for the period 2002–2006 of chlorophyll, nutrients and light penetration in Tixelfjärden at Forsmark are shown in Figure 3-34. Chlorophyll values from Forsmark are considered quite low compared with data from Swedish Environmental Quality Criteria (EQC), which during 1995 to 2003 varied between 5.4– 8.0 ugL^{-1} in the southern Bothnian Sea /Larsson et al. 2006/.

Laxemar-Simpevarp

The phytoplankton community at the three investigated sites was in Laxemar-Simpevarp dominated by diatoms during the spring bloom while in July, Dinophytes (Dinoflagellates) and cyanobacteria were the most abundant groups /Sundberg et al. 2004/.

The phytoplankton biomass at all sampled sites varied between 0.03–1.2 mg ww L^{-1} and the mean value was 0.3 mg ww L^{-1}, equivalent to 60 g C m^{-3} (assuming 20% carbon content) calculated from /Sundberg et al. 2004/.

Monthly means of chlorophyll, nutrients and light penetration during the period 2002–2006 in Borholmsfjärden (PSM002062) in Laxemar-Simpevarp are shown in Figure 3-35. According to EQC, the concentrations of chlorophyll during this period were high /Naturvårdsverket 1999/.

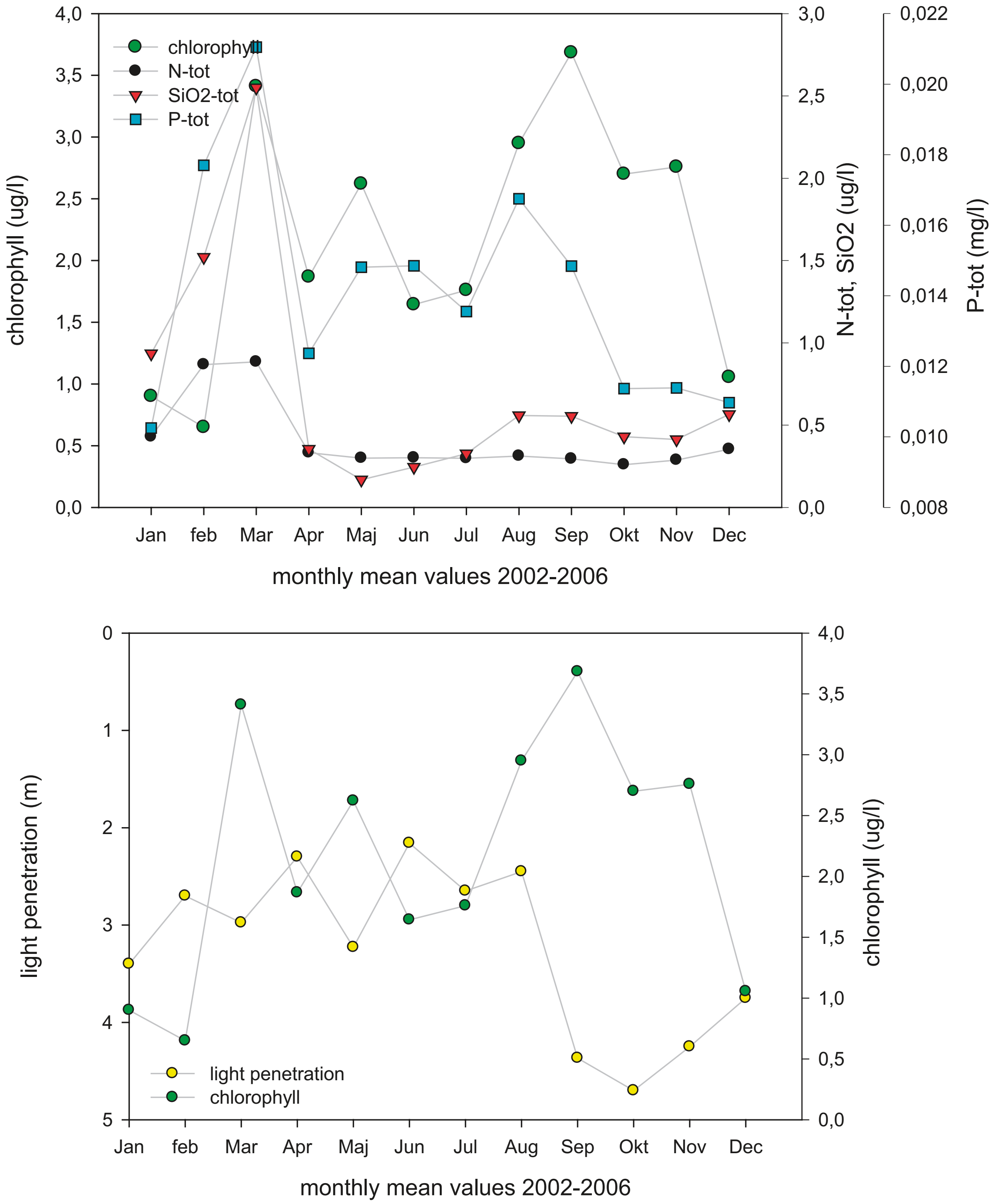
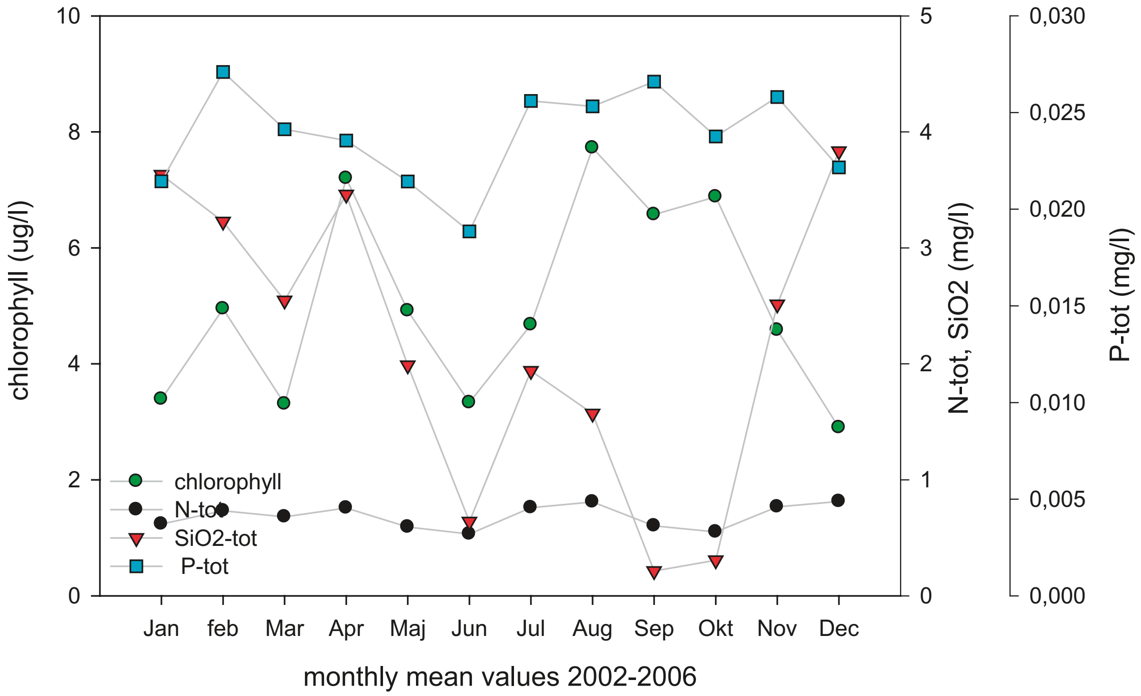


Figure. 3-34. *Monthly mean value of chlorophyll compared with P-tot, N-tot and* SiO_2 *(upper graph) and light penetration (bottom graph) in Tixelfjärden (PFM000063) for the period 2002–2006. Data from site investigations by SKB /Huononen and Borgiel 2006/.*



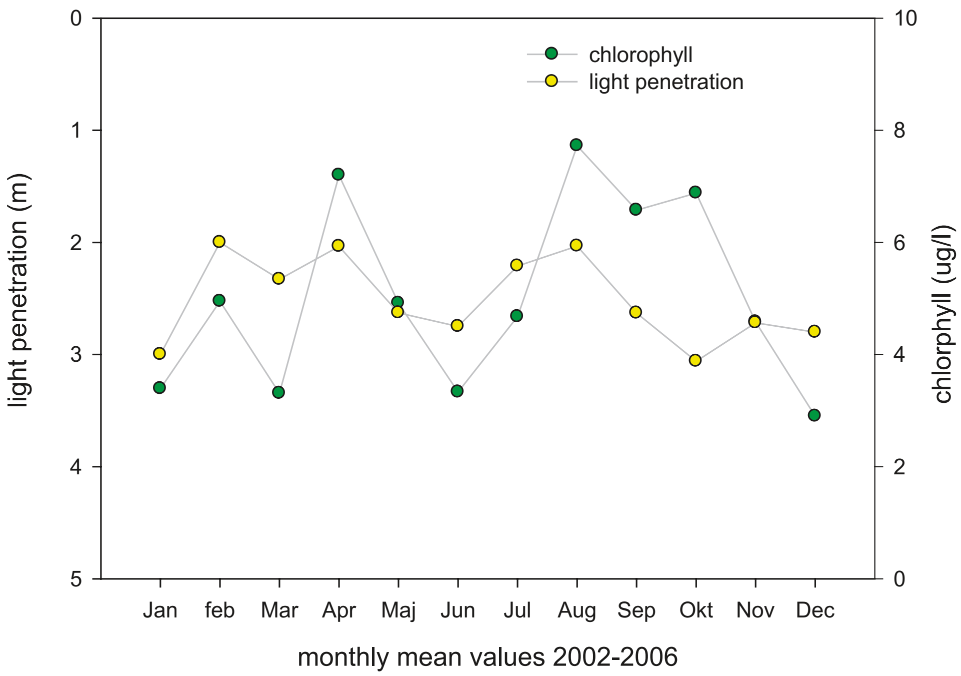


Figure 3-35. *Monthly mean value of chlorophyll compared with inorganic P, inorganic N and* SiO_2 *(upper graph) and light penetration (bottom graph) in Borholmsfjärden (PSM002064) for the period 2002–2007. Data from site investigations by SKB /Ericsson and Engdahl 2007.*

3.4.4 Benthic bacteria

Benthic (heterotrophic) bacteria are found in all benthic habitats, both on the sea floor and in the sediment. Benthic cyanobacteria, or blue-green algae, are photosynthesising organisms and therefore included in the previously discussed microphytes, see section 3.4.2.

Abundance and biomass of benthic bacteria were surveyed in a study in the summer of 2006 in Laxemar-Simpevarp and Forsmark /Andersson et al. 2006/, see Table 3-20. Sediment cores were taken from a boat, or by hand by SCUBA divers. The top 5 cm was collected from the samples, and bacteria larger than 0.22 µm were counted using an epifluorescence microscope. The number of cells was between 3.03 and 7.29 $\times 10^9$ cells/ml in Laxemar-Simpevarp and between 1.15 and 4.28 $\times 10^9$ cells/ml at two sites in Forsmark. Biomass data are calculated for an average of 5 cm sediment depth.

The abundance found was higher than in other studies performed at greater depths /Andersson et al. 2006/. Abundance of benthic bacteria was studied by /Jørgensen and Revsbech 1989/ at ten sites between Kattegat and the Baltic and results ranged from 0.025 to 1 $\times 10^9$ at depths of between 14 and 200 m. In the Baltic Sea, /Mohammadi et al. 1993/ found benthic bacteria biomasses in the summer of 1.06 gC m^{-2} (SD 0.44), recalculated for 5 cm sediment depth, in deep sea (> 100 m depth) sediment.

3.4.5 Benthic fauna

Benthic fauna, bottom fauna or sometimes benthos refers to the macroscopic animals that live in (infauna) or on (epifauna) the bottom substrate. Here, benthic fauna refers to all macro- and meiofauna in this habitat, including fauna living on vegetation, except benthic fish, which are treated separately.

The biomass and abundance of benthic fauna are dependent on factors such as type and characteristics of substrate, salinity, oxygen, temperature etc and due to the importance of substrate they are often classified as soft bottom and hard bottom living. This division is also practical for sampling reasons and hence used widely, including in the studies referred to below.

In the Baltic and Bothnian Seas, the species and abundances of benthic fauna are clearly dependent on salinity: marine species diversity decreases northwards along the salinity gradient, and freshwater species dominate in the northern Bothnian Sea and the Bothnian Bay /Sjöberg ed. 1997/. Water with a salinity of 5 to 6 psu (e.g. Forsmark) is considered to harbour the fewest species.

Table 3-20. Abundance and biomass of benthic bacteria found in studies in Forsmark and Laxemar-Simpevarp, summer of 2006.

	Mean	Median	Std. Dev.	Min	Max	N
Forsmark						
cells/ml	2.7 10^9	2.9 10^9	1.4 10^9	1.3 10^9	4.3 10^9	5
gC m^{-2}	3.5	4.6	1.8	1.4	5.1	5
Laxemar-Simpevarp						
cells/ml	4.8 10^9	4.6 10^9	1.4 10^9	3.0 10^9	7.3 10^9	8
gC m^{-2}	6.5	5.5	3.0	3.4	12.2	8

Forsmark

Several studies on benthic biomass have been performed in the Forsmark area /Borgiel 2005, Sandström et al. 2002, Odelström et al. 2001, Wallström and Persson 1997, Swedish Board of Fisheries 2007/. Data from the various investigations are presented in Table 3-21.

The environmental surveys performed in the Forsmark area by the Swedish Board of Fisheries (SBF) also include benthic fauna. The development of benthic fauna in the Forsmark area has been monitored since the end of the 1970s. An increase in benthic biomass and species diversity has been seen since the start of the monitoring (Figure 3-36). The increase in total biomass can also be seen elsewhere in the Baltic, probably due to the increased nutrient load. In soft bottoms (at 16 m depth) the biomass has varied from slightly above 50 g ww m^{-2} to around 270 g ww m^{-2}. The biomass at the soft bottom sampling sites has been dominated by the Baltic mussel (*Macoma baltica*), and in deeper areas another important species has been *Monoporeia affinis,* Figure 3-37. Since 1997 when *Marenzellaria viridis* showed up for the first time in Forsmark, it has become more and more important in terms of biomass. In 2004 *M. viridis* represented 27% of the total biomass at some stations /Adill et al. 2005/.

The benthic fauna in the county of Uppsala was investigated at 10 sites in 2000 /Odelström et al. 2001/. At 9 of the 10 sites 5–7 taxa were found, while at one site in the Östhammarsfjärden only 2 taxa were found. The abundance of individuals per m^{-2} varied between 16 (Southern Östhammars-fjärden) and 4,431(Kallrigafjärden). The biomass varied between < 1 and 190 gm^{-2}. The detrivore *M. baltica* was found at 8 of 10 sites, where it completely dominated the biomass. The biomass of the mussels varied between 5 and 189 g m^{-2}, Table 3-21.

Table 3-21. Abundance, biomass and number of taxa from various investigations performed in the Forsmark area.

	Mean	Min.	Max.
/Odelström et al. 2001/	*Soft bottom fauna (County of Uppsala)(n=10)*		
Abundance (ind m^{-2})	1,614	16	4,431
Biomass (d w g m^{-2})*	14	0	39
Biomass (g C m^{-2})*	4	0	12
Number of taxa	6	2	7
/Borgiel 2005/	*Vegetation associated soft bottom fauna (Forsmark) (n=30)*		
Abundance (ind m^{-2})			
Biomass (d w g m^{-2})	28	2	93
Biomass (g C m^{-2})*	8.3	0.6	28
Number of taxa	9	2	19
/Borgiel 2005/	*Soft bottom fauna (Forsmark) (Tixelfjärden (Kallrigafjärden) n=20)*		
Abundance (ind m^{-2})	2,276 (3,178)		
Biomass (d w g m^{-2})	8.8 (11)	6.4	44
Biomass (g C m^{-2})*	2.6 (3.3)	1.9	13
Number of taxa	5.6 (6.2)	2	9
/Sandman et al. 2005/	*Hard bottom fauna (Forsmark)*		
Abundance (ind m^{-2})			
Biomass (d w g m^{-2})	16		
Biomass (g C m^{-2})*	5		
Number of taxa			
/Swedish Board of Fisheries 2006/	*Soft bottom fauna (16 m/41 m depth) (Forsmark 1973–2006)*		
Abundance (ind m^{-2})			
Biomass (d w g m^{-2})*		~ 11	~ 55
Biomass (g C m^{-2})*		~ 3.3	~ 17
Number of taxa		4	7

* Calculated from g ww according to /Kautsky 1995b/.

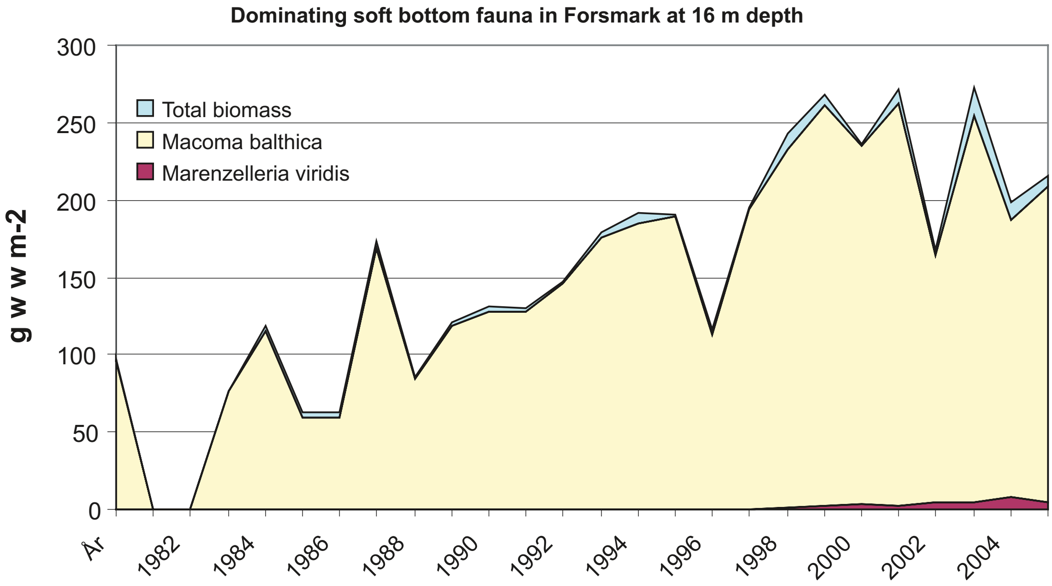


Figure 3-36. *Benthic soft bottom fauna at one sampling station in the Forsmark area at a depth of 16 m during the period 1981–2006 (data from the /Swedish Board of Fish*eries 2007/). *Note that the benthic fauna was not sampled in 1982 and do not indicated abscence of benthic fauna.*

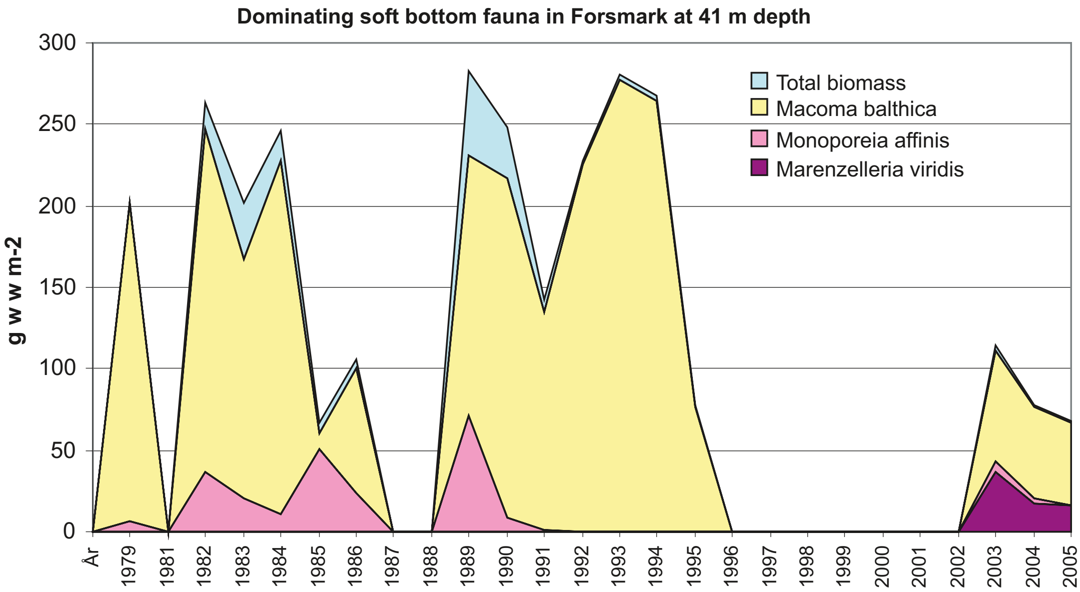


Figure 3-37. *Benthic soft bottom fauna at one sampling station in the Forsmark area at a depth of 41 m during the period 1979–2006 (data from the /Swedish Board of Fisheries 2007/). Note that some years have not been sampled and do not indicate an absence of benthic fauna.*

/Borgiel 2005/ studied benthic macrophyte communities and vegetation-associated bottom fauna as well as soft bottom macrofauna in SKB's site investigation programme. The total biomass of the vegetation-associated fauna was in the range from 6 to 60 g d w m^{-2} and was dominated by detrivores, especially the snail *Hydrobia sp.* and the mussel *M. baltica*.

The soft bottom community (benthos) was less abundant in terms of biomass; its mean biomass was 8.8 and 11 g dw m^{-2}, in the two investigated bays respectively. In the soft bottom community, the same species dominated the benthic fauna as in the vegetation-associated bottom fauna communities, i.e. detrivores like *Hydrobia sp* and *M. baltica*. In /Sandman et al. in prep/ mean biomasses for hard bottom substrates in the Forsmark area (Grasö) are 15.5 g dw m^{-2}, see Table 3-21.

The reported values from all investigations are of the same order of magnitude, ranging from 0.6 gC m^{-2} to 28 gC m^{-2}, with the highest values reported for vegetation-associated soft bottom fauna.

Laxemar-Simpevarp

Several studies on benthic biomass have been performed in the Laxemar-Simpevarp area /Fredriksson 2004, Fredriksson 2005, Swedish Board of Fisheries (SBF) 2005, Andersson et al. 2005, Kustvattenkommittén i Kalmar län (KVF) 2007/. Data from the various investigations are presented in Table 3-22.

Systematic investigations of the benthic fauna in the county of Kalmar have been performed by the University of Kalmar since the 1960s. Long-term trends in the benthic fauna show a slow but significant increase in biomass and species diversity. The biomass decreased slightly for a few years in the beginning of the 21st century, only to increase again in 2005. Species diversity has increased from a mean of 6 species to around 10 in 2000 /KVF 2007/.

Soft bottom macrofauna in the Laxemar-Simpevarp area has been monitored since the early sixties by the Swedish Board of Fisheries. Three species dominate the benthic fauna in the area: *Mytilus edulis* and *M. baltica,* and in deeper areas also *Monoporeia affinis*. The number of species found has increased since the beginning of the monitoring from 4 to around 14, and the biomass has varied between 75 g ww m^{-2} and 170 g ww m^{-2}. Biomass was less than normal in the deeper stations in the early 1990s, and an oxygen deficit was observed during some of the years. Abundance declined in the deeper stations in the area in the late 1980s due to a sharp decrease in the abundance of the small crustacean *M. affinis*. This species had not recovered completely by the end of the investigated period. A long term increase in abundance was observed in the shallow stations in both areas, mostly due to a favourable trend for the mussels *M. edulis* and *M. baltica* /Andersson et al. 2005/.

Benthic fauna was studied within the site investigation programme in Laxemar-Simpevarp by /Fredriksson 2004, Fredriksson 2005/.

Table 3-22. Abundance, biomass and number of taxa from various investigations performed in the Laxemar-Simpevarp area.

	Mean	Min.	Max.
/KVF 2003/	*Soft bottom fauna (County of Kalmar, n=62)*		
Abundance (ind m^{-2})	1,501	33	11,273
Biomass (d w g m^{-2})*	12	0.4	58
Biomass (g C m^{-2})*	4	0.1	17
Number of taxa	11	5	24
/SBF 2005/	*Soft bottom fauna (Laxemar-Simpevarp)*		
Abundance (ind m^{-2})			
Biomass (d w g m^{-2})		15	35
Biomass (g C m^{-2})*		5	11
Number of taxa		4	14
/Fredriksson 2004/	*Soft bottom fauna (Laxemar-Simpevarp, n-45)*		
Abundance (ind m^{-2})	2,440	150	12,000
Biomass (d w g m^{-2})	13	0.1	83
Biomass (g C m^{-2})*	4	0.03	25
Number of taxa	8	3	18
/Fredriksson 2005/	*Hard bottom fauna (Laxemar-Simpevarp)*		
Abundance (ind m^{-2})			72,643
Biomass (d w g m^{-2})		76	1,520
Biomass (g C m^{-2})*		9	140
Number of taxa			

In soft bottoms, the filter feeding bivalve *M. baltica* clearly made the largest contribution to the total biomass in all areas. The most frequent taxa in the samples from the archipelago north Simpevarp were *Chironomidae* and *M. baltica*. *Chironomidae* was also the most prominent contributor to the total abundance and made *Insecta* the largest taxonomic group in terms of abundance. The most frequent taxa in the archipelago south of Simpevarp were *Chironomidae* and *Hydrobia sp.,* which were present in all of the samples from that area /Fredriksson 2004/.

The sessile macrofauna, attached to hard substrates (hard bottom fauna), is completely dominated by *M. edulis* (Figure 3-38) in terms of both biomass and abundance. Usually, hard bottom substrate changed into a soft substrate at a water depth of between ten and thirteen metres at the visited locations. The total estimated biomass of *M. edulis* in the whole area studied was approximately 4,500 metric tons, or 96% of the total sessile epifaunal biomass /Fredriksson 2005/.

The soft bottom fauna investigated in SKB's site investigations was well in accordance with other reported biomass estimates, see Table 3-22.

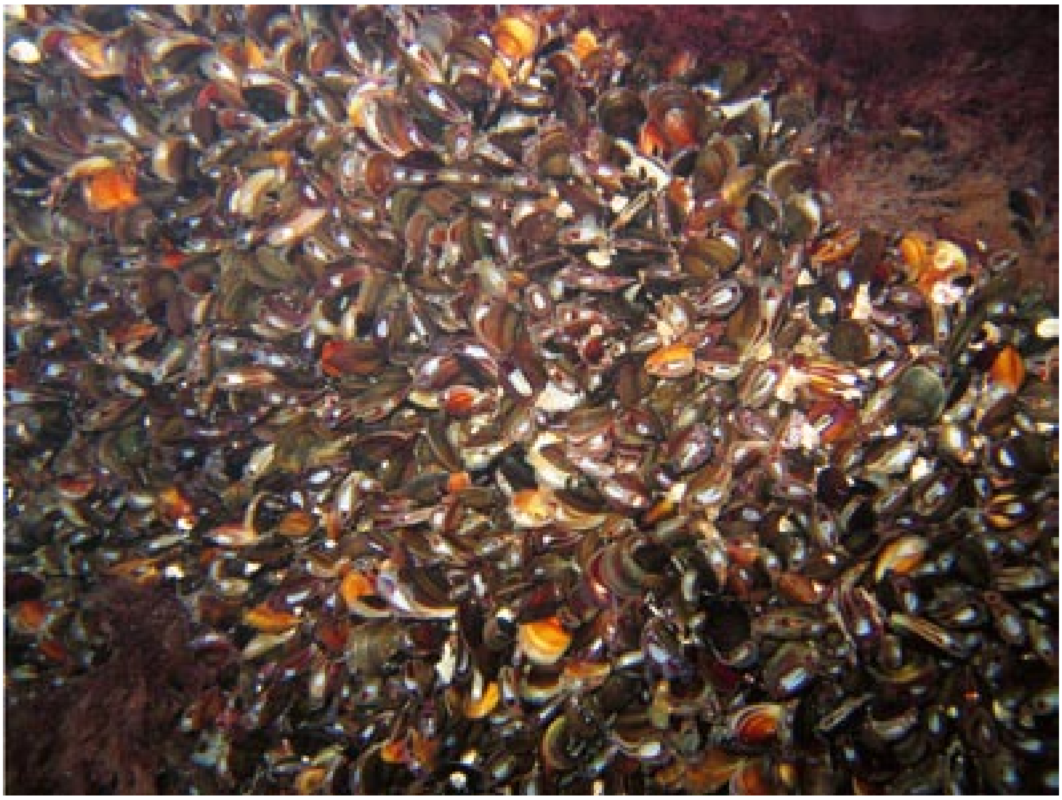


Figure 3-38. *Blue mussels (Mytilus edulis) on a bottom in Laxemar-Simpevarp.*

3.4.6 Zooplankton

The most common zooplankton taxa in the Baltic are the small crustaceans, copepods and cladocerans, but rotifers, ciliates and larvae from other organisms (e.g. the blue mussel *Mytilus edulis*) are also present. During and after the spring bloom of phytoplankton, the zooplankton biomass increases in the pelagic zone. The zooplankton maximum generally occurs in July–August in the Baltic and is dominated by copepods, which comprise 80% of the zooplankton biomass /Lindahl et al. 1983/. The species composition of zooplankton generally follows changes in salinity, with nerictic copepod species favoured by higher salinity while the opposite is true for freshwater groups /Vourinen et al. 1998/.

The most abundant copepod species in Forsmark and Laxemar-Simpevarp was *Acartia bifilosa*, while the cladoceran *Bosmina coregoni* occasionally occurred abundantly /Karås 1992/. /Karås 1992/ recorded the number of individuals in the cooling water intake and outlet at the nuclear power plants (Laxemar-Simpevarp 1975 and 1976, Forsmark 1984 and 1986). The number of zooplankton in the inlet water had a maximum in July in Forsmark and in August in Laxemar-Simpevarp. The number of individual zooplankton was five times higher in the inlet water in Forsmark than in the inlet water in Laxemar-Simpevarp.

Forsmark

Several studies of zooplankton have been performed in Öregrundsgrepen /Eriksson 1971, Eriksson et al. 1977, (in the nearby Åland sea) Lindahl et al. 1983, (the Baltic Sea) Olsonen 2007/, and in site investigations performed by SKB /Huononen and Borgiel 2005/.

In the summer of 1970 (86 hauls), the zooplankton biomass and species diversity maximum occurred in August, with the highest densities in the inner parts of Öregrundsgrepen. Zooplankton abundances were also higher than in adjacent Baltic areas, especially in August. The zooplankton carbon biomasses reported in these studies shows a wide range of variation from 0.366 gC m^{-2} (Öregrundsgrepen 1972–1973, 2–3 hauls per month year-round) /Eriksson 1971/ to 1.8 gC m^{-2} (Åland sea) /Lindahl et al. 1983/. The Finnish Institute of Marine Research /Olsonen 2007/ reported zooplankton biomasses in the Baltic Sea outside Forsmark in the late summer 2007. The biomass of the most important crustacean zooplankton taxa was around 2.7 gC m^{-2}, dominated by the copepod *Acartia sp*.

In the biweekly site investigation study performed during 2003–2004, copepods dominated the zooplankton fauna and the biomass maximum occurred in October. The zooplankton carbon biomass in Asphällsfjärden Bay varied between 0.6 and 9.4 mgC m^{-3} (mean 4.5 mgC m^{-3}) /Huononen and Borgiel 2005/ at a sample depth of 4 m, which seems low in comparison with the older investigations. However, it is not completely comparable due to different units (per m^{-2} and m^{-3}, respectively).

Laxemar-Simpevarp

Biomass values for zooplankton in the Nordic parts of the Baltic Proper in the late summer 2007, reported by the Finnish Institute of Marine Research /Olsonen 2007/, ranged between 4 and 6 gC m^{-2} . To the authors' knowledge, no studies reporting zooplankton biomasses in Laxemar-Simpevarp have been available for comparison with site investigation data reported by /Sundberg et al. 2004/. Other studies concerning the zooplankton fauna in Laxemar-Simpevarp have been performed, but they only regarding species composition.

The zooplankton communities at the investigated sites in the Laxemar-Simpevarp archipelago, consists mainly of macrozooplankton, were dominated in the winter and spring by copepods but showed a more diverse composition in the summer with cladocerans, rotifers and larvae of some benthic macroinvertebrates in the summer. The highest biomasses were found in July. The biomass varied between 0.01 and 0.4 mg d w L^{-1} with a mean of 0.05 mg d w L^{-1} /Sundberg et al. 2004/, corresponding to 40 mg w w L^{-1}, in turn corresponding to 2 gC/m^{-3} (assuming 5% of the wet weight to be carbon), which is of the same order of magnitude as reported by /Olsonen 2007/, but not completely comparable due to a difference in units (gC m^{-2} and gC m^{-3}).

3.4.7 Bacterioplankton

Bacterioplankton are bacteria free living in the pelagic habitat, here consisting of all heterotrophic bacteria living in the water column. Cyanobacteria, or blue-green algae are photosynthesising organism and therefore included in Phytoplankton, see section 3.4.2.

Abundance and biomass of bacterioplankton were studied in summer 2006 in Laxemar-Simpevarp and Forsmark /Andersson et al. 2006/, see Table 3-23. Surface water samples (0–2 m) were collected and all bacterioplankton larger than 0.22 µm were counted with an epifluorescence microscope. The biomass was within the range found in the summer in the Gulf of Finland in the Baltic Sea (11–36 mgC m^{-3} /Kuparinen, 1987/) and abundances were similar to those reported as averages for one year in other temperate areas, e.g. 1 10^9 L^{-1} in the North Sea /Rheintaler et al. 2005/; 1.1 10 L^{-1} in Massachusetts Bay /Toolan 2001/.

4.5.8 Fish

The Baltic fish fauna is often referred to as cold- or warm-water species, due to the optimal temperatures for the various species. Warm water species usually include species with a freshwater origin, such as perch (*Perca fluviatilis*), roach (*Rutilus rutilus*) and white bream (*Blicca bjoerkna*), but also carp (*Cuprinidae*), pike (*Esox lucius*) and eel (*Anguilla anguilla*). Warm-water species have a temperature optimum around 20°C and are generally stationary in the coastal zone. Cold-water fish include species such as cod (*Gadus morhua*), sprat (*Sprattus sprattus*), herring (*Clupea harengus*), bull routs (*Myoxocephalus scorpius*) and eelpout (*Zoarces viviparous*). They have a preference for cold water and generally avoid water with temperatures above 10–15°C. They generally spend most of their life in the open sea.

The Baltic fish fauna is a mixture of freshwater and marine species, where the freshwater species inhabit coastal and northern areas and marine species dominate offshore and in southern areas. Since the beginning of the 1990s, recruitment of pike and perch has decreased dramatically in the whole Baltic, in some places by as much as 80–90% /Bernes and Naylor 2005/.

The most abundant species in the Baltic are sprat, herring and cod; these species represent 80–90% of the total annual catch in the Baltic /Mackenzie et al. 1996/ and about 80% of the total fish biomass /Hjerna and Hansson 2002/. In recent years the cod population has decreased dramatically in the entire Baltic Sea, and today it represents much less of the total catch and fish biomass than in the earlier studies. The Baltic herring population has also declined steadily since the early 1980s, but there seems to have been some recovery since the beginning of 2000 /Bernes and Naylor 2005/.

Table 3-23. Biomass and abundance of bacterioplankton in Forsmark and Laxemar-Simpevarp in summer 2006.

	Mean	Median	Std. Dev.	Min	Max	25%–tile	75%–tile	N
Forsmark								
Biomass (mgC m^{-3})	24	22	7.2	15.	37	20	28	9
Cells L^{-1}	1.8 10^6	1.8 10^6	5.5 10^6	1.2 10^6	2.8 10^6	1.3 10^6	2.2 10^6	9
Laxemar-Simpevarp								
Biomass (mgC m^{-3})	25	25	2.4	22	27	24	26	3
Cells L^{-1}	1.3 10^6	1.3 10^6	1.6 10^6	1.2 10^6	1.5 10^6	1.3 10^6	1.4 10^6	3

Herring and sprat are the dominant zooplanktivores. Herring migrate to coastal areas for spawning on bottom substrates, but they spend most of their life cycle in the open sea. Sprats spend their entire life in the open sea and spawn pelagically, as do cod. About half of the cod diet consists of benthos /Hjerna and Hansson 2002/. The decline of cod in the entire Baltic Sea since the early 1980s has affected the whole ecosystem since cod is an important top predator. The sprat population has benefited from the cod decline and is now the dominant pelagic fish species in the Baltic. The growing sprat population might also be the explanation for the decreasing recruitment of perch and pike, since sprat feed on zooplankton, which is the main food for pike and perch larvae /Bernes and Naylor 2005/.

The estimated biomass of pelagic fish populations for two years from the southern Baltic was 0.5 g m^{-2} (std.dev. 0.5), corresponding to 0.2 gC m^{-2} /Thiel 1996/.

Forsmark

A number of investigations regarding fish populations, abundance and biomass have been conducted in the Forsmark area /Adill et al. 2005, Lindahl et al. 1983/ and within SKB's site investigations /Heibo and Karås 2005, Axenrot and Hansson 2004/.

Biological monitoring of the fish population in the Forsmark area has been performed by the Swedish Board of Fisheries since the 1980s. Due to sampling technique and depth, it has focused mainly on the population of warm-water species in shallow waters. Perch is the dominant species in the Forsmark area. In 2006, perch accounted for 75% of the species caught /Adill et al. 2005/, Figure 3-39.

Biomass estimates were made in shallow areas of the nearby Gräsö archipelago in the 1980s. The biomass maximum was estimated to be between 10 and 15 g m^{-2}, with a mean value for the whole area of 1–5 g m^{-2} (0.5–2.5 gC m^{-2}) /Lindahl et al. 1983/.

The estimates of fish biomass made in SKB's site investigations /Heibo and Karås 2005 and Axenrot and Hansson 2004/ are of the same order of magnitude as in previous investigations.

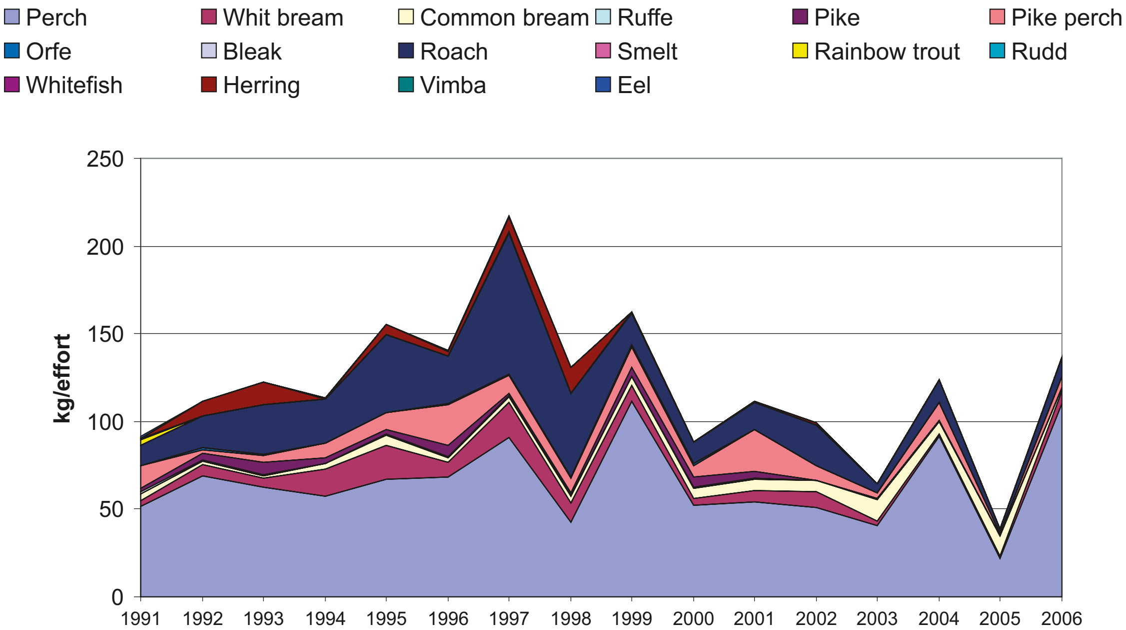


Figure 3-39. *The different species caught during test fishing for monitoring of the fish population in the Forsmark area. Data from the /Swedish Board of Fisheries 2006/.*

Data were compiled by the Swedish Board of Fisheries concerning the coastal fish community in Forsmark and estimates of fish biomasses in the area were reported /Heibo and Karås 2005/. The fish biomass varied between 60 and 70 kg ha^{-1}/ (3–3.5 gC m^{-2}). Herring, stickleback, goby and sprat were the dominant fish species.

Fish abundances, biomass, densities and species composition were investigated in the outer parts of the archipelago in Forsmark and compared with two reference areas /Axenrot and Hansson 2004/. Herring dominated the fish fauna. The biomasses were twice as high in Forsmark as in the reference area of Gudinge (north of Forsmark). In the other reference area, Öregrund, fish abundances were eight times higher than in Forsmark, although densities were about the same. The calculated fish biomasses in Forsmark, Gudinge and Öregrund in May were 0.003, 0.001 and 0.009 kg m^{-2}, respectively, and in August/September 0.004, 0.002 and 0.003 kg m^{-2}, respectively (0.5–5 gC m^{-2}).

Laxemar-Simpevarp

A number of investigations regarding fish populations, abundance and biomass have been conducted in the Laxemar-Simpevarp area /Andersson et al. 2005 and KVF 2007/ and within SKB's site investigations /Enderlein 2005, Adill and Andersson 2006/.

Biological monitoring has been performed in the recipient monitoring programme for the nuclear power plant (OKG) in Laxemar-Simpevarp since 1962 by the Swedish Board of Fisheries. Perch, roach and white bream have consistently dominated the catches in the monitoring of warm-water species in the Laxemar-Simpevarp area. A total of 25 species have been caught during the time period in the area. The total test-fishing catch, exhibits a major increase since the beginning of the period /Andersson et al. 2005/.

Investigations of the cold-water species in the outer archipelago began in 1970. A total of 31 species were found, and 90% of the catch consisted of herring. Other species caught were cod, roach, eelpout and bull rout. Herring abundance increased rapidly in the 1980s, and a peak in the early 1990s was followed by a negative trend. Abundance of cod increased dramatically in the 1970s. In the late 1980s catches fell to very low levels, which prevailed during the rest of the period studied. The trend occurred in the eastern Baltic stock, although the decline near the Swedish coast was greater /Andersson et al. 2005/.

Environmental monitoring in the county of Kalmar includes investigation of the fish populations. Perch, roach and vimba are the main species caught during the marine fish survey in the county of Kalmar /KVF 2007/.

In SKB's site investigations, pelagic fish (dominated by cold-water species) in offshore areas were investigated on three occasions in the summer of 2004 in the Laxemar-Simpevarp area. The estimated biomass on these three occasions was 50, 21 and 57 kg ha^{-1}, respectively (2.5, 1 and 1.3 gC m^{-2}). The most numerous species was sprat, followed by herring, stickleback and dab /Enderlein 2005/.

The coastal fish population (dominated by warm-water species) in Borholmsfjärden (PSM002062) was investigated within SKB's site investigation programme in 2005. The study resulted in estimates of total fish biomass. The total fish biomass (not including eel) was estimated to be 79 kg ha^{-1} and 69 kg ha^{-1}, (3.4–3.9 gC m^{-2}) in the spring and summer respectively. The estimated eel biomass was 1.8 kg ha^{-1} (0.09 gC m^{-2}). The contribution of piscivorous fish, mainly perch and pike, was 58% in the spring and 74% in the late summer. Adult bream and tench were common and dominated the cyprinid biomass /Adill and Andersson 2006/.

3.4.9 Birds

A detailed account of the variability of bird in the Baltic region was provided by /Birdlife International 2000/. Some 340 species are found regularly in the region. Many of them are water fowl living in the Baltic Sea. Others, such as waders, live in the coastal area or surrounding wetland. Compared to other marine environments the Baltic is rich in species, due to its combination of marine and freshwater birds.

Most of the bird species migrate between winter grounds and nesting grounds in the spring and summer. Thus, most birds leave the Baltic to winter further south. However, large numbers of long-tailed duck overwinter in the southern Baltic, as do tufted duck, mute swan, Canada goose and herring gull.

The eider duck is the most numerous of all waterfowl in the Baltic. It is very widespread, being absent only from the inner parts of the Gulf of Bothnia and the Gulf of Finland. Its main food is blue mussel.

In the Western Gotland Basin, deep basins (areas deeper than 50 m) are the most common bird habitat. Outside the breeding season, gulls and auks dominate these areas.

In the transitional zone between the coastal zone and the deep water basins, the sub-littoral, the bird fauna is dominated by pelagic feeders such as divers and auks during the non-breeding season. Densities of divers and sea ducks can increase dramatically in cold winters.

The littoral zone is highly diverse as a habitat and is important for a large number of non-breeding waterfowl. However, the distribution of wintering waterfowl in the near-coastal zone, as well as around islands, is typically dispersed, and with the exception of Steller's eider the near-coastal areas do not support the main concentrations of any waterfowl in the Baltic Sea during normal winters.

The most important habitat for a number of animals including waterfowl is the offshore banks. They are shallower than 25 m but separated from the shore by deeper water (sub-littoral zone). Piscivorous birds such as the black guillemot have their main concentrations on the shores of the Baltic Proper. In addition, the shores of the Baltic Proper support large numbers of long-tailed duck.

Important concentrations of a wide range of shallow-water species are found in the lagoons during the non-breeding season. These species are benthivores, herbivores such as mute swan and carnivores such as scaup, as well as piscivores such as smew.

In the site investigations at Forsmark and Laxemar-Simpevarp, the bird fauna has been investigated and monitored on a yearly basis since 2002. The general aim has been to monitor the possible effects of the site investigations on bird numbers and breeding results.

Forsmark

Among the 169 coastal and marine important bird areas (IBAs) identified in the Baltic Sea, one IBA is situated near Forsmark in the Gräsö archipelago east of Gräsö Island (60°20'N 18°30'E). Here, in 1996, there were 2,000–3,000 cormorants (*Phalacrocorax carbo*), 20–28 white-tailed eagle (*Haliaeetus albicilla*), 75–85 Caspian tern (*Sterna caspia)* and 90–100 common tern (*Sterna hirundo*) /BirdLife International 2000/.

The Forsmark subarea also contains high densities of both common and rarer species /Green 2005 and 2006/. Of eleven monitored species listed in the Swedish Red List and in the Birds Directive, three piscivores forage or breed in the marine environment: osprey, white-tailed eagle and black-throated diver.

Laxemar-Simpevarp

Two IBAs are situated in the Western Gotland Basin, in the vicinity of Laxemar-Simpevarp (Oskarshamn 57°15'N, 16°30'E, Skäggenäs-Mönsterås 56°54'N, 16°28'E) /Birdlife International 2000/.

Between 340 and 15,135 tufted ducks (*Aythya fuligula*) were observed during the period 1987–1999 in Oskarshamn /Birdlife International 2000/. During the same time period, between 0 and 19,165 tufted ducks (*Aythya fuligula*), between 0 and 450 smews (*Mergus albellus*) and between 0 and 4,885 goosanders (*Mergus merganser*) were observed in Skäggenäs-Mönsterås /Birdlife International 2000/.

3.4.10 Mammals

Three species of seal live in the Baltic: the grey seal (*Halichoerus grypus*), the ringed seal (*Pusa hispida*) and the harbour seal (*Phoca vitulina*). The grey seal is the largest and the ringed seal is the smallest species.

The ringed seal is mainly found in the Bothnian Sea, the Gulf of Bothnia, the Gulf of Finland and the Gulf of Riga but is seldom found in the southern parts of the Baltic. The grey seal lives in the archipelagos along the Baltic coast. During the ice-free period of the year the seals are found on shallow rocks in the archipelago. The harbour seal inhabits only the southernmost part of the Baltic.

In 2005, a total of 18,300 grey seals inhabited the Baltic Sea, of which 6,600 were in Sweden. During the period 1990–2005 the Swedish grey seal population has shown a 7.9% increase in numbers /Karlsson and Helander 2005/.

3.5 Chemical composition of marine biota

The chemical composition of various marine biota in the marine ecosystems in Forsmark and Laxemar-Simpevarp was analyzed in SKB's site investigation programme by /Bradshaw and Kumblad, Engdahl et al. 2006 respectively/. Samples from functional groups except bacteria, birds and mammals in the marine ecosystems were analyzed, a total of 33 samples in Forsmark and 24 in Laxemar-Simpevarp (Tables 3-24 and 3-25). Some radioisotopes were also analyses but is presented elsewhere /Roos et al. 2007/.

Table 3-24. Number of samples of different biota in the marine ecosystem in Forsmark (PSM000063).

Type of sample / Name	Number of samples
Plankton	
Phytoplankton	3
Zooplankton	1
Microphytobenthic flora	
Benthic microalgae	2
Benthic flora	
Fucus vesiculosus (macrophyte)	3
Pilayella littoralis (macrophyte)	3
Potamogeton pectinatus (macrophyte)	3
Benthic herbivores	
Theodoxus fluviatilis	2
Idotea spp.	2
Benthic filter feeders	
Cerastoderma glaucum	2
Macoma baltica	3
Fish	
Rutilus rutilus (planktivore)	3
Gymnocephalus cernuus (benthic omnivore)	3
Osmerus eperlanus (piscivore)	3

Table 3-25. Number of samples of different biota in the marine ecosystem in coastal areas in Laxemar-Simpevarp.

Type of sample / Name	Number of samples
Plankton	–
Microphyobenthos	–
Benthic flora	–
Fucus vesiculosus (macrophyte)	3
Chara sp. (macrophyte)	3
Potamogeton pectinatus (macrophyte)	3
Filamentous green algae *(macrophyte)*	3
Benthic herbivores	–
Benthic filter feeders	
Mytilus edulis	3
Fish	
Clupea harengus (zooplanktivore)	3
Pleuronectus flesus (Benthic omnivore)	3
Perca fluviatilis (Piscivore)	3

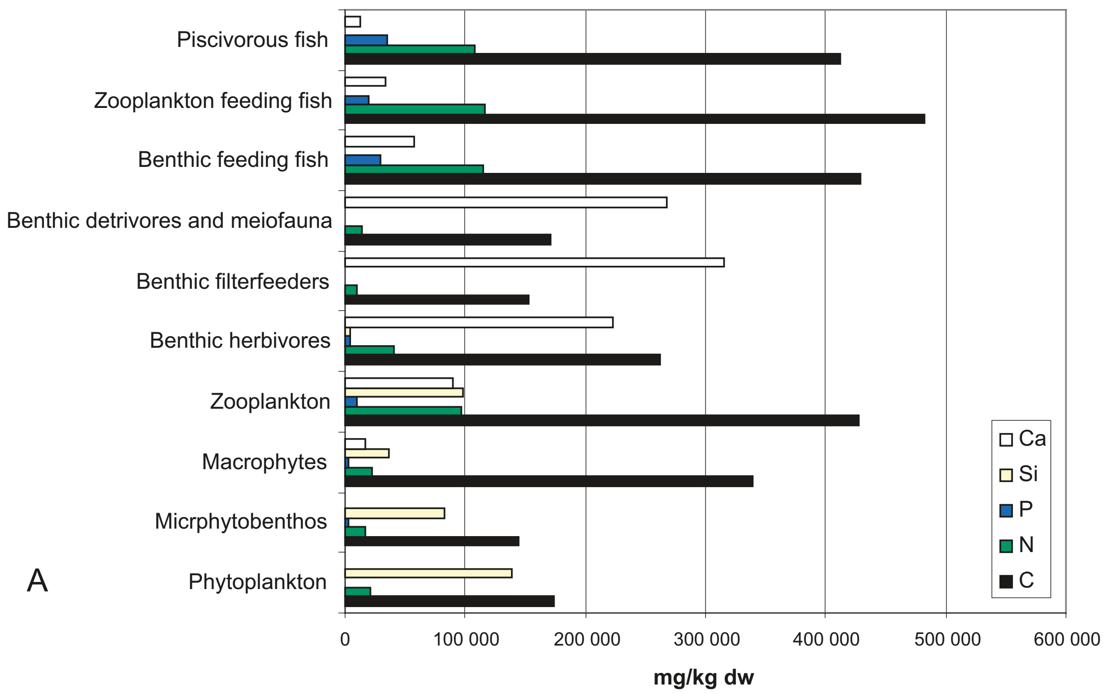
The chemical composition of marine biota is affected by biological processes such as uptake and excretion, respiration, photosynthesis and predation and reflects to a great extent the chemical composition of the environment (seawater or sediment), the trophic level and the type of organisms. The principal chemical constituents that make up the soft tissues of all organisms are oxygen, hydrogen, carbon, nitrogen and phosphorus (oxygen and hydrogen have not been analyzed in this study). Depending on the organism and the habitat, various organisms utilize additional elements to varying degrees. For example, organisms that form hard parts utilize elements such as calcium and silicon to a greater extent than others.

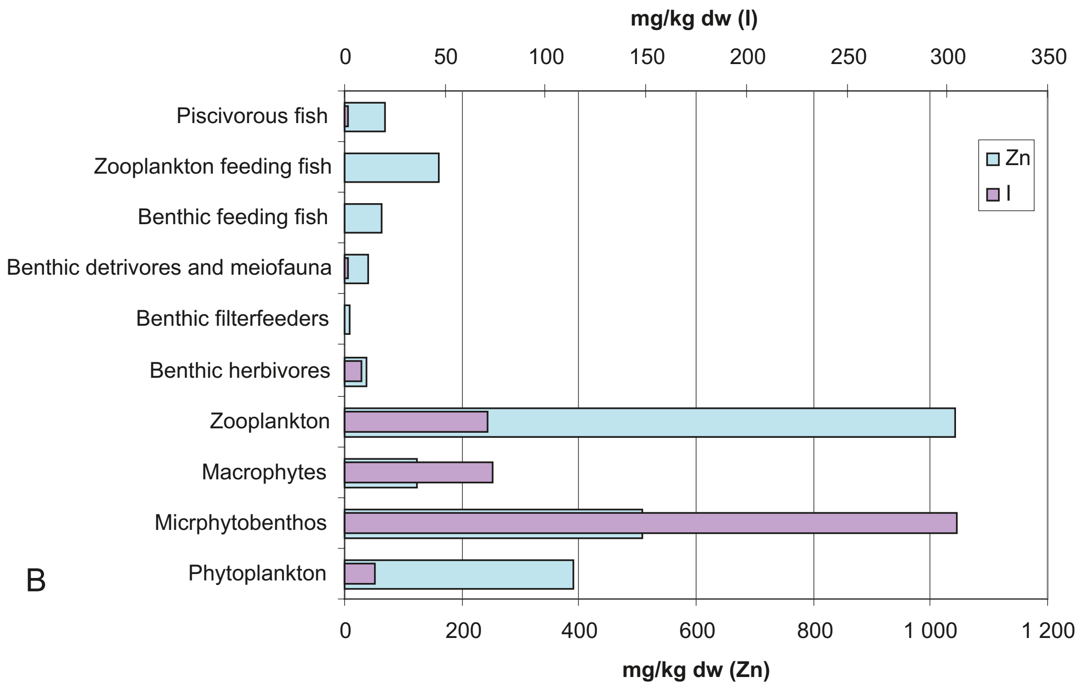
The biotic samples from the two marine ecosystems of Forsmark and Laxemar-Simpevarp were analyzed for 49 and 63 elements, respectively. The compiled data for all analyzed elements are presented in Appendix 5. Concentrations of elements from the various chemical groups – C, N, P (non-metals), I (halogens) Si (metalloids), Ca (alkaline earth metals), Zn (metals), Ho (lanthanides) and Th (actinides) – are presented in Figures 3-40 and 3-41 according to functional group. For many of the trace elements (and sometimes for other elements as well), the results of the analyses are below the detection limit. In these cases, a value half of the detection limit was used in the calculations of mean concentrations (estimated mean).

3.5.1 Forsmark

Marine biota were sampled in the spring of 2005 /Bradshaw and Kumblad 2008/. In this study the elemental composition of biota, water and sediment from a shallow bay (PSM000063, see Appendix 1) was analyzed for 49 different elements (Al, As, Ba, Br, C, Ca, Cd, Ce, Cl, Co, Cr, Cs, Cu, Dy, Er, Eu, F, Fe, Gd, Hg, Ho, I, K, Li, Lu, Mg, Mn, N, Na, Nd, Ni, P, Pb, Pm, Pr, Ra, Rb, S, Se, Si, Sm, Tb, Th, Ti, Tm, V, Yb, Zn, Zr).

The number of samples of each functional group is shown in Table 3-24. The concentrations of C, N, P, I, Si, Ca, Zn, Ho and Th are presented in Figure 3-40 for the functional groups of the marine ecosystem.


Piscivorous fish
Zooplankton feeding fish
Benthic feeding fish
Benthic detrivores and meiofauna
Benthic filterfeeders
Benthic herbivores
Zooplankton
Macrophytes
Micrphytobenthos
Phytoplankton
A
Ca
Si
P
N
C
0
100 000
200 000
300 000
400 000
500 000
600 000
mg/kg dw


mg/kg dw (I)
0
50
100
150
200
250
300
350
Piscivorous fish
Zooplankton feeding fish
Benthic feeding fish
Benthic detrivores and meiofauna
Benthic filterfeeders
Benthic herbivores
Zooplankton
Macrophytes
Micrphytobenthos
Phytoplankton
B
Zn
I
0
200
400
600
800
1 000
1 200
mg/kg dw (Zn)

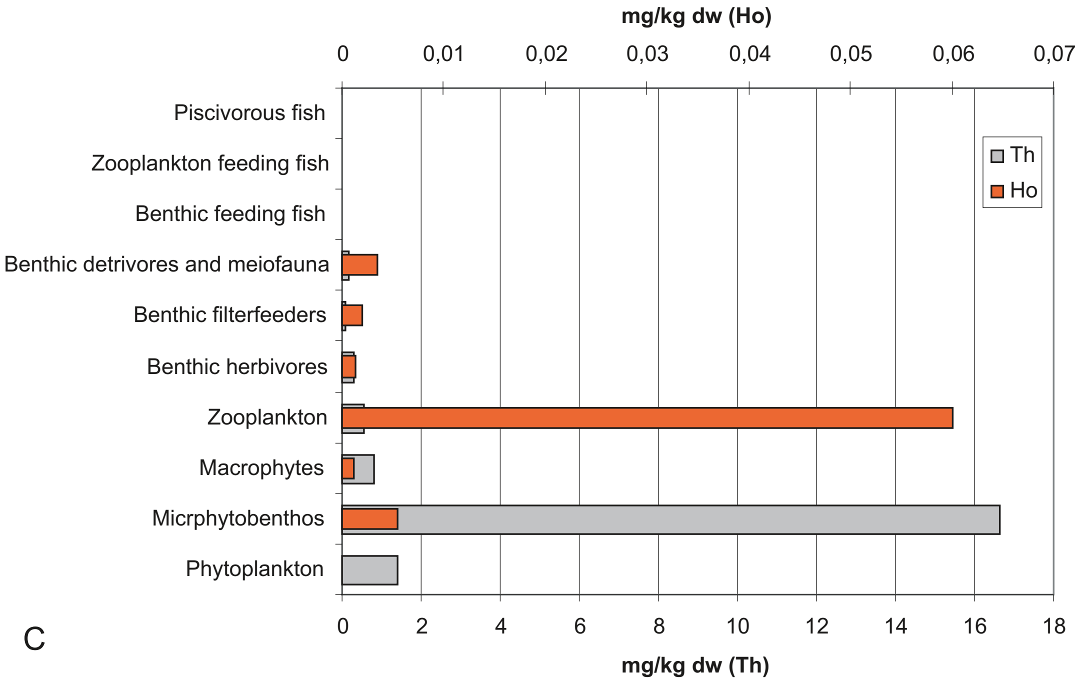
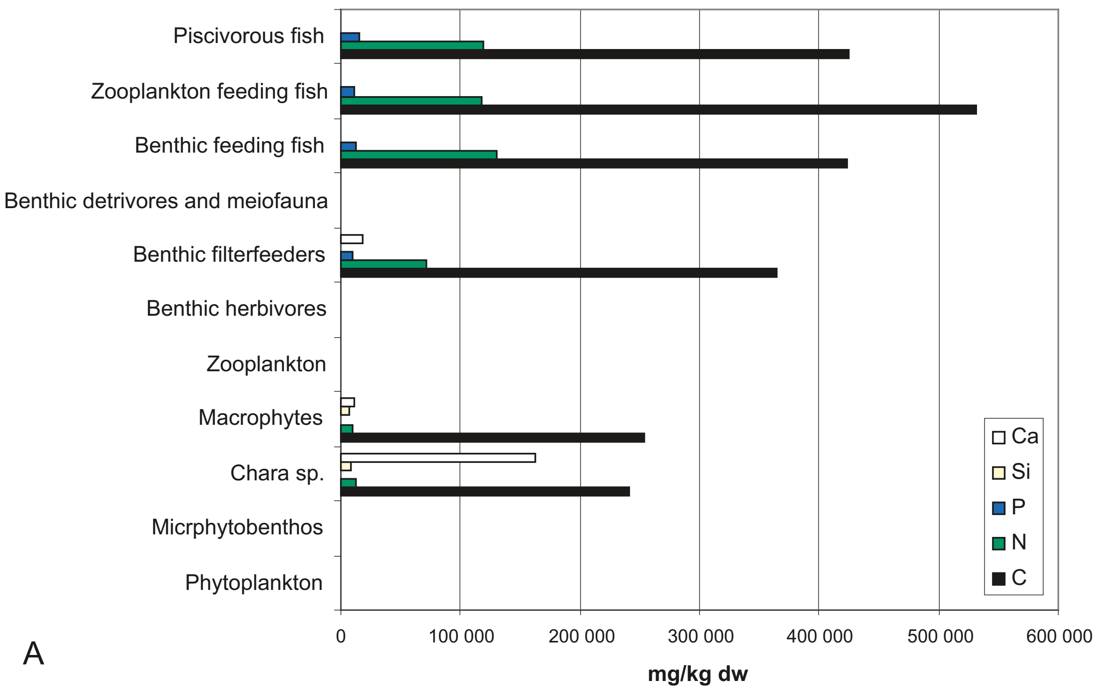
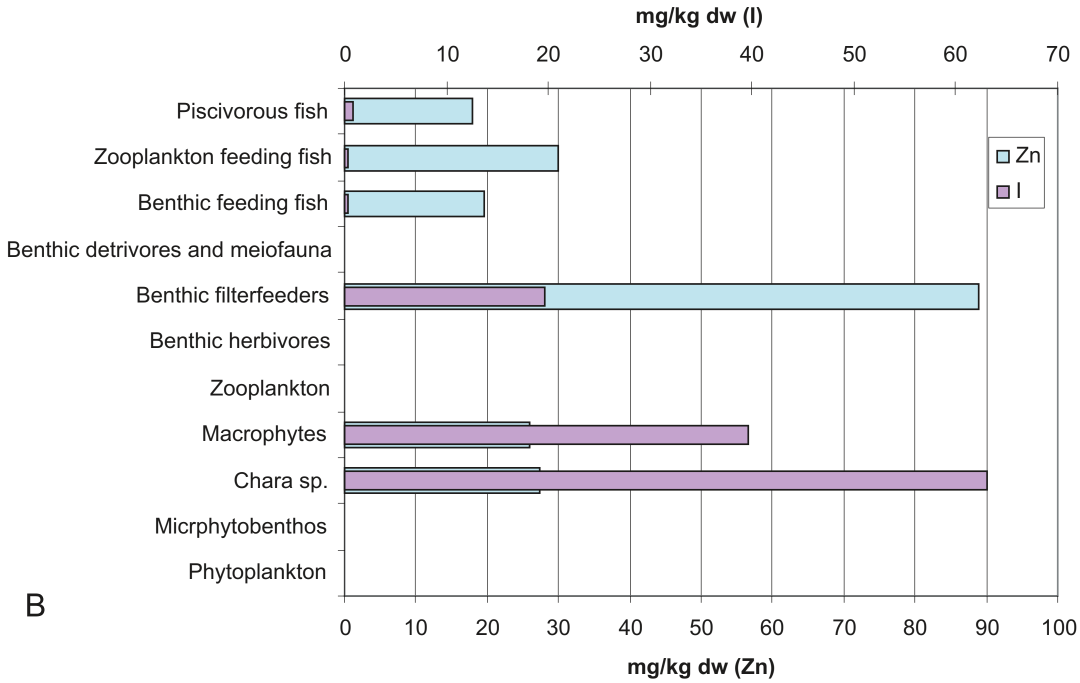


Figure 3-40. *Concentrations of various elements (C,N ,P, Si, Ca (a), Zn, I (b), Ho and Th (c)) in marine biota of the functional groups in the marine ecosystem in Forsmark 2005 (PFM000063). Note the different scales on the axis***.** *Ho and Th concentrations in fish were reported below detection limit and is therefore presented as best estimate, i.e. reported value diveded by two.*





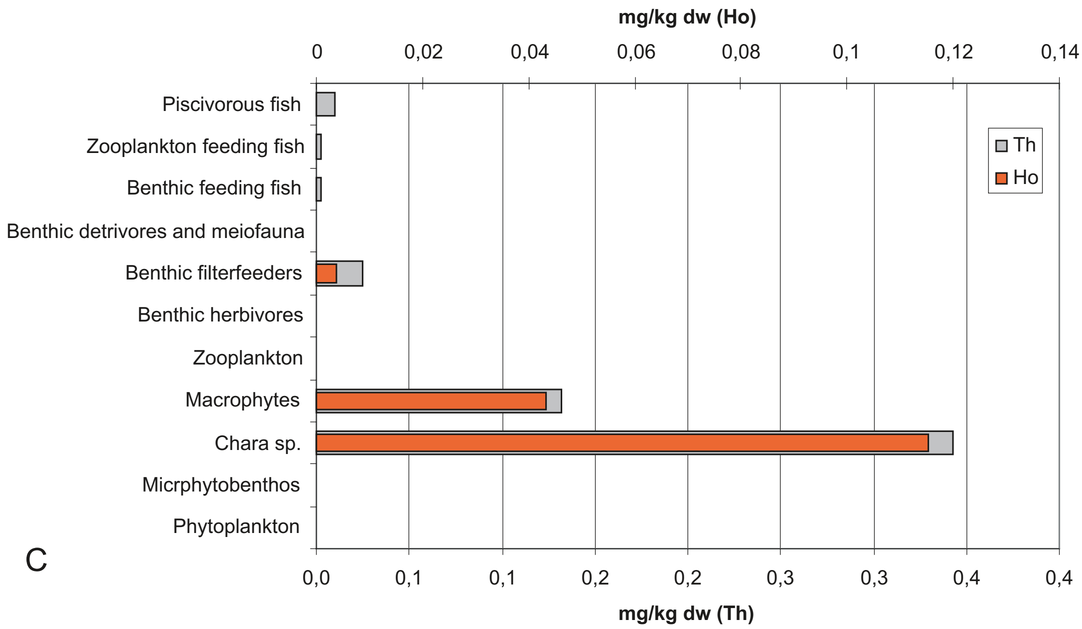


Figure. 3-41. *Concentrations of various elements (C, N ,P, Si, Ca (a), Zn, I (b), Ho and Th (c)) in marine biota of the functional groups in the coastal marine ecosystem in Laxemar-Simpevarp. Note the different scales on the axis and the fact that not all functional groups were analyzed in Laxemar-Simpevarp, in contrast to Forsmark. Ho and Th in fish were reported below detection limit and has therefore been diveded by 2 and is presented as best estimate.*

The average carbon concentration in the functional groups varied between 140 gC/kg dw (microphytobenthos) and 480 gC/kg dw (zooplankton feeding fish) and was generally highest in zooplankton and fish. This distribution also applied to N, although in lower concentrations. The P concentrations were highest in fish and were quite evenly distributed between the piscivorous, zooplanktivorous and benthivorous fishes. The largest biotic pool for Si was in producers and in zooplankton. The other functional groups had concentrations several orders of magnitude lower. Ca concentrations were highest in benthic fauna, probably due to a large proportion of organisms with hard parts, such as mussels.

Iodine concentrations were highest in microphytobenthos, followed by macrophytes and zooplankton, with about half the concentration in microphytobenthos. The highest Zn concentrations were found in zooplankton followed by microphytobenthos and phytoplankton. Zn concentrations in the other functional groups were much lower. Ho occurs in very low concentrations in the marine environment. Among the functional groups analyzed, zooplankton organisms had the highest values. Th also occurs in low concentrations, but in this case microphytobenthos organisms exhibit the highest concentrations.

3.5.2 Laxemar-Simpevarp

Aquatic biota from marine functional groups were sampled and analyzed in /Engdahl et al. 2006, Ternsell 2006/ for 63 elements (C, N, Ag, Al, As, B, Ba, Be, Br, Ca, Cd, Ce, Cl, Co, Cr, Cs, Cu, Dy, Er, Eu, Fe, Ga, Gd, Hf, Hg, Ho, I, K, La, Li, Lu, Mg, Mn, Mo, Na, Nb, Nd, Ni, P, Pb, Pr, Rb, S, Sb, Sc, Si, Sm, Sn, Sr, Ta, Tb, Th, Ti, Tl, Tm, U, V, W, Y, Yb, Zn and Zr). Not all functional groups in the marine ecosystem were sampled in Laxemar-Simpevarp. Chara sp. is categorized as a macrophyte but is presented alone since it shows great differences in chemical composition in comparison with other macrophytes, especially with regard to Ca.

The number of samples from the analyzed functional group is shown in Table 3-25. The concentrations of C, N, P, I, Si, Ca, Zn, Ho and Th are presented in Figure 3-41 for the functional groups that were analyzed in the marine ecosystem in Laxemar-Simpevarp.

The average carbon concentration in the functional groups analyzed in Laxemar-Simpevarp varied between 253 gC/kg dw (macrophytes) and 530 gC/kg dw (zooplanktivorous fish) and were generally highest in fish. The carbon concentration in *Chara sp*. was of the same order of magnitude as for other macrophytes. N and P concentrations were also highest in the fish groups. The Si concentration in the analyzed groups varied between 142 mg $kgdw^{-1}$ (benthic feeding fish) and 8,033 mg $kgdw^{-1}$ (*Chara sp.*). Other macrophytes also had quite high concentrations of Si. But it is when Ca concentrations are compared that *Chara sp.* really sticks out. The concentration of Ca in *Chara. sp*. is over 200 times higher than the Ca concentration in fish and 9 times higher than the Ca concentration in filter feeders (without shells). The highest concentration of I, as well as of Ho and Th, was also found in *Chara sp*. Zn showed the highest concentration in filter feeders.

3.6 Human impact

3.6.1 Industry and forestry

Forsmark

Since the area was raised above sea level, land use in the Forsmark area as a factor behind emissions to the marine environment was dominated by the use of the region's iron ore mines, at Dannemora since the 16^{th} century and at Ramhäll since the 18th century, until the iron works in Forsmark were shut down in the 1890s. Following the iron era, and mainly due to the general scarcity of rich soils /Miliander et al. 2004a/, the area was sparsely settled until the construction of the nuclear power plant in the 1970s.

Industrial emissions related to the iron works were restricted to the dams, lakes and rivers in their vicinity, for example Bruksdammen Lake, the Forsmarksån River and Kallrigafjärden Bay.

/Jonsson et al. 1993, Wulff et al. 1993/ were able to identify the presence of polluting emissions from the pulp bleach industry in open Bothnian Sea sediments. The nearest industrial plants are Stora Cell, Skutskär, situated in Gävlebukten Bay near the mouth of the Dalälven River, and Karlit in Lövstabukten Bay (Figure 3-42). Emissions included mercury and organochlorines, but they have gradually been reduced or eliminated. Direct mercury emissions from Stora Cell and Korsnäsverken (near the city of Gävle) in Gävlebukten ceased in 1977 and 1982, respectively /Persson et al. 1993/.

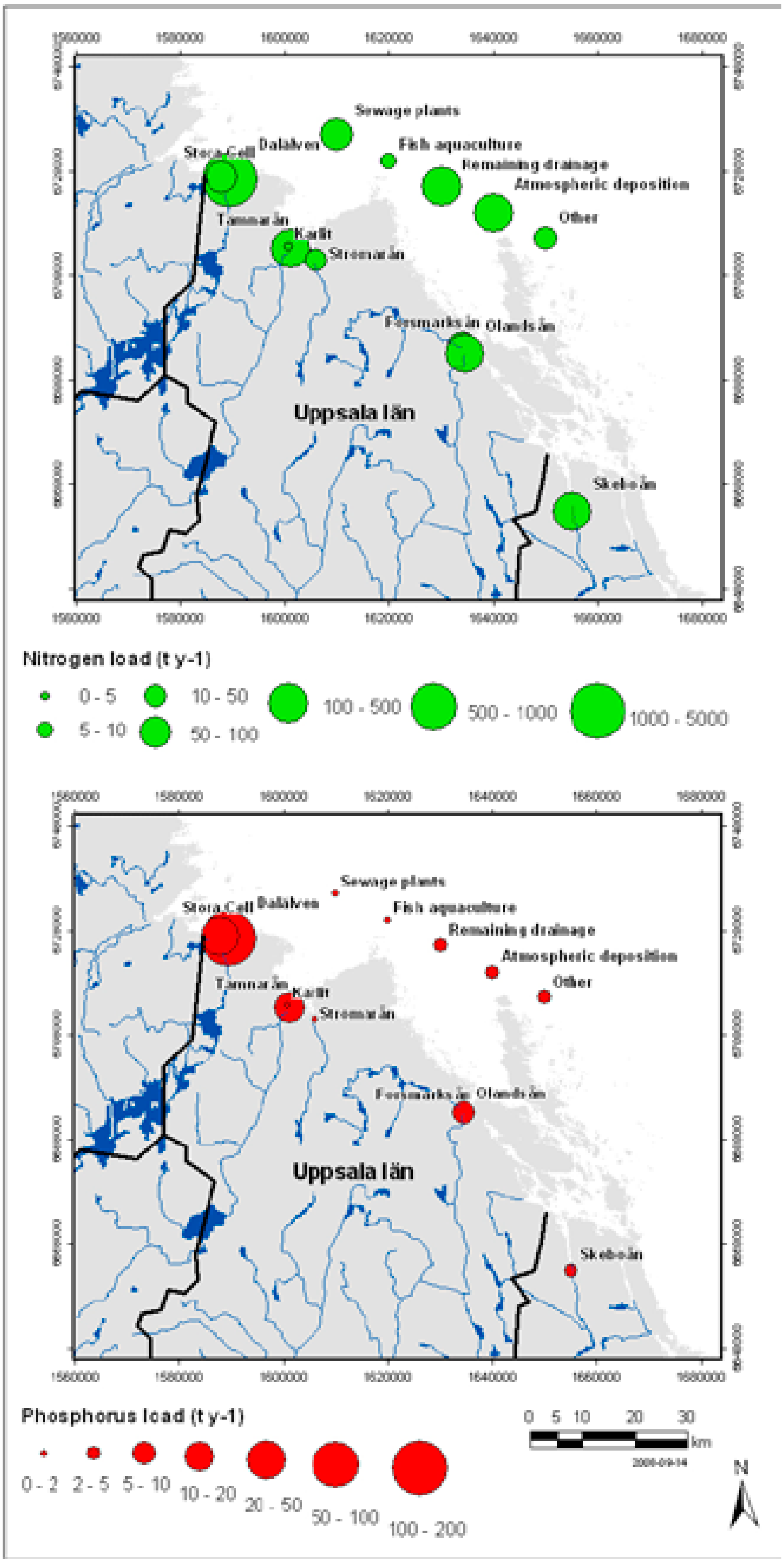


Figure 3-42. *Annual load of nitrogen and phosphorus to coastal Uppsala county from coastal point sources (mills, rivers and streams) and five additional, diffuse terrestrial and coastal sources (not including the deep-water source).*

/Jonsson et al. 1993/ found elevated contaminant concentrations on sediment accumulation bottoms (A-bottoms) within 30–50 km of pulp mills. In view of the similar findings of /Meili et al. 2000/ that archipelagic A-bottoms may well trap contaminants and co-transported organic matter from adjacent regional and offshore areas, and since these contaminants have not been analyzed in Forsmark area sediments, the possibility cannot be ruled out that Forsmark area A-bottoms could also trap contaminants originating from industries on the Bothnian Sea coast further to the north.

Laxemar-Simpevarp

By comparison to Forsmark, the Laxemar-Simpevarp area is a part of and directly influenced by a more versatile industrial province, Småland. Along the northern coast of Kalmar county, this has led to emissions of heavy metals in particular from pulp mills and mining and metallurgical industries /Jansson 2005/.

However, the immediate surroundings of the Laxemar-Simpevarp area in Misterhult parish etc have a history without any major local industrial impact and have traditionally been predominantly occupied with forestry and agriculture /Miliander et al. 2004b/.

3.6.2 Agriculture and nutrient load

Forsmark

Both forestry and agriculture related to the iron mills probably had limited regional effects due to emissions /Miliander et al. 2004a/. Even today, a significant part of the nitrogen and phosphorus entering the coastal zone in Uppland arrives with rivers and streams. Table 3-26 and Figure 3-42 summarize and permit comparison of the contributions of the various coastal sources of nitrogen and phosphorus in the Forsmark area.

Table 3-26. Data on nitrogen and phosphorus emissions from coastal Uppsala county, compiled from /Persson et al. 1993, Wallström 1999/.

	Mean discharge $m3\ s^{-1}$	Nitrogen ton y-1	%	Phosphorous ton y-1	%
Sources					
Mills					
Stora Cell, Skutskär		85	1.3	25	9.9
Karlit, Karlholmsbruk		5	0.1	1.5	0.6
Sewage plants		87	1.4	1.5	0.6
Fish aquaculture		7.5	0.1	1.2	0.5
Rivers and streams					
Dalälven	355	4,550	71.3	180	71.1
Tämnarån	10	420	6.6	12	4.7
Strömarån	1.3	45	0.7	2.0	0.8
Forsmarksån	2.8	95	1.5	2.0	0.8
Olandsån	6.0	245	3.8	9.0	3.6
Skeboån	4.4	110	1.7	5.0	2.0
Remaining near-coastal drainage		228	3.6	4.4	1.7
Atmospheric deposition		456	7.1	5.0	2.0
Other		45	0.7	4.5	1.8
SUM		6,379	100	253	100

Nutrient enrichment also emanates from larger-scale urban and industrial sewage and agricultural fertilization, but the local contribution is minor in comparison /Svealands Kustvattenvårdsförbund 2001/. Due to a general counter-clockwise circulation, the south-west Bothnian Sea and the Forsmark area are influenced by the Bothnian Sea coast, but also by the open Bothnian Sea, which is in turn influenced by water from the open Baltic Proper entering via the Åland archipelago /Walve and Larsson 2005/. The Baltic Proper is more eutrophicated than the Bothnian Sea /Andersen et al. 2005/, with high levels of phosphorus, and its primary production is nitrogen-limited, which favours nitrogen fixation and frequent cyanobacterial blooms in the summer /Larsson et al. 2006/.

As a result, the open Bothnian Sea has shown moderately decreasing water clarity as measured by Secchi depth readings, which have been reduced by about 3 m (from ~ 10 to 7 m), or 35%, especially during the period 1930–1970 /Laamanen et al. 2004/. Only a few coast-to-offshore nutrient gradients have been studied here, however.

In the coastal zone, /Kautsky et al. 1986/ discovered that the lower depth limit of the *Fucus vesiculosus* belt had been moved several metres closer to the water surface in comparison with /Waern's 1973/ observations, made in the 1960s. Meanwhile, chlorophyll *a* concentrations have increased considerably, which are interpreted as signs of large-scale eutrophication /Larsson et al. 2006/. Increased turbidity may also have caused a shift in Baltic herring spawning grounds /Anéer 1987/.

The overall status /Larsson et al. 2006/ of Öregrundsgrepen has proved better than that of the Östhammar-Singö archipelago immediately to the south. In lieu of local explanations, this fact has been interpreted as a possible effect of more nutrient- and particle-rich bottom water arriving there from Öregrundsgrepen through the narrow Öregrund sound.

Further north along the Bothnian Sea coast, the influence of humic substances from freshwater increases /Jonsson et al. 1993/. This has an effect similar to nutrient enrichment, since bacterioplankton are also able to feed on humic substances /Kuparinen et al. 1996/.

Laxemar-Simpevarp

Table 3-27 and Figure 3-43 summarize and permit comparisons of the contribution of the various sources of nitrogen and phosphorus to the Laxemar-Simpevarp area. Data compiled from /County administative board of Kalmar 2000/.

3.6.3 Shipping and dredging

Exotic species introduced through shipping are probably present in the area's ecosystems. As an example, the benthic polychaete worm *Marenzellaria viridis* has spread north after having established a presence in the Baltic proper /Cederwall et al. 2007/. As yet, the effect of this species on existing Baltic species and ecosystems is uncertain.

Forsmark

Flads and gloes in the Forsmark area are in need local protective measures. The practice of broadening flad and glo inlets to create sheltered boat jetties, and the use of toxic repellents on boat hulls in those areas, are jeopardizing the sequence of events behind the formation of the unique, clear water *Chara sp.* habitat, related in turn to fish recruitment /Wallström and Persson 1997/.

Table 3-27. Data on nitrogen and phosphorous emissions to the North Kalmarsund, Västervik and Misterhult archipelagos (see map Fig. 3-43). Data compiled from /County Administrative Board of Kalmar 2000/.

	Mean discharge m3 s^{-1}	Nitrogen t y-1	%	Phosphorous t y-1	%
Sources					
Industry directly		206	7.0	27	30
Sewage plants		379	13	6.5	7.2
Fish aquaculture		8.1	0.3	1.0	1.2
Streams					
Vindån	1.9	45	1.5	1.8	2.0
Storån	2.6	78	2.7	2.7	3.0
Botorpsströmmen	4.9	123	4.2	2.5	2.8
Marströmmen	1.8	43	1.5	1.0	1.1
Virån	2.9	61	2.1	1.2	1.3
Emån	27.6	674	23	15.1	17
Alsterån	9.8	210	7.1	4.1	4.6
Snärjebäcken	1.5	89	3.0	1.1	1.2
Remaining near-coastal drainage		594	20	17	20
Atmospheric deposition		431	15	7.8	8.7
SUM		2,941	100	89	100

Laxemar-Simpevarp

Regarding the Laxemar-Simpevarp area, no situation similar to the above is described in /Jansson's 2005/ account of the environmental status of coastal areas in Kalmar County.

3.6.4 Cooling water emissions

The major coastal impact of the nuclear reactors is the warm-water plume created by the release of the heated cooling water. In particular, apparent signs of eutrophication may be due to the combined effect of elevated nutrients and heat dynamics, caused by dampening of the upward nutrient entrainment and by declining bottom-water oxygen concentrations /Larsson et al. 2006, based on data from Hemström 1993/.

Forsmark

The excess temperature of the Forsmark cooling water is about 8°C /Sandström et al. 2002, Ingemansson and Lindahl 2005/. It is discharged into the relatively enclosed Biotest Lake (1 km^2 area and 2.5 m mean depth) at a rate of approximately 135 m^{3}s^{-1}. An increase to 165–170 m^{3}s^{-1} is being planned. From there, the water is released into the open sea.

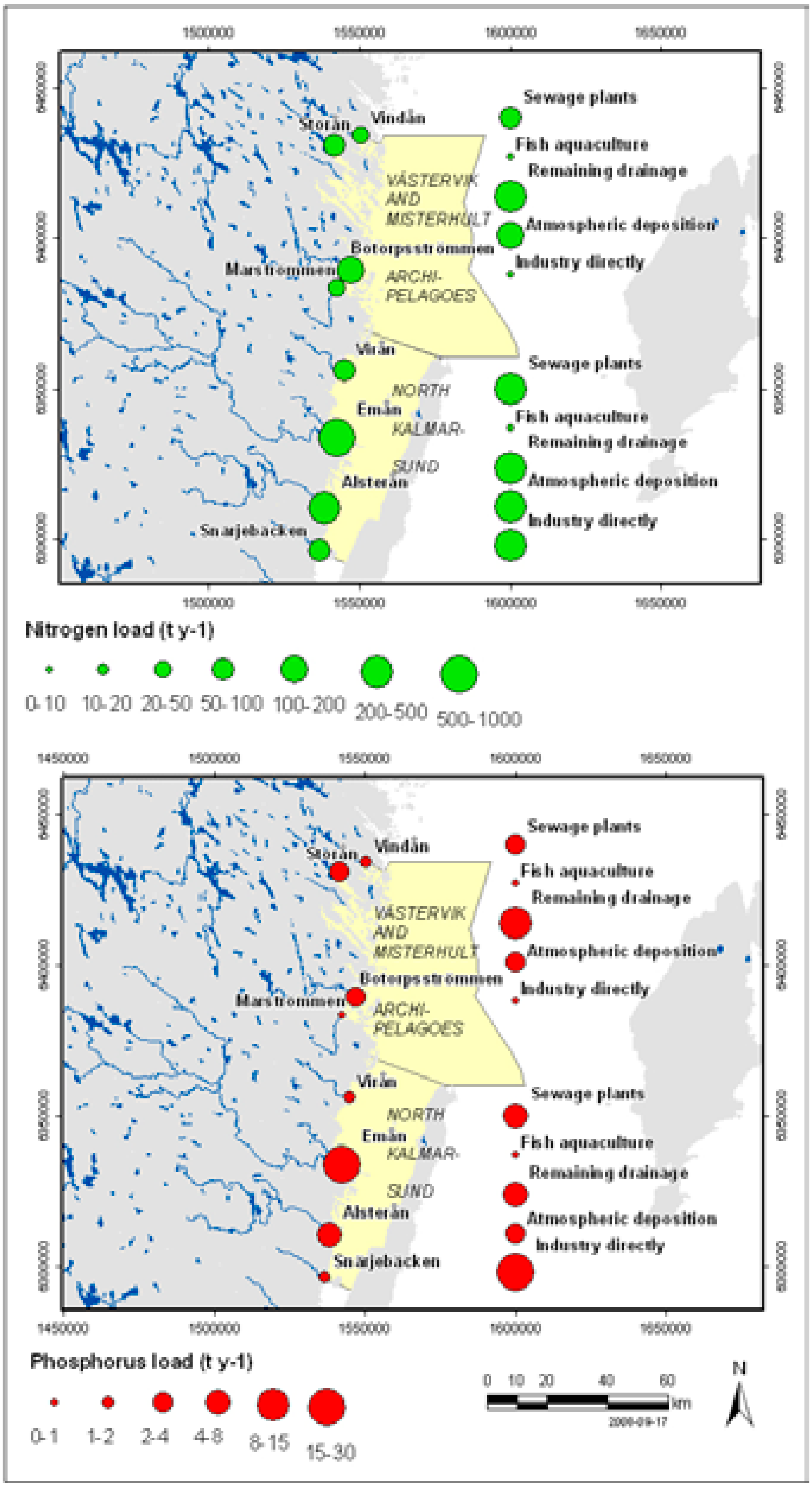


Figure 3-43. Annual load of nitrogen and phosphorus in two coastal areas north of (Västervik and Misterhult archipelagos) and south of (North Kalmarsund) the Laxemar-Simpevarp area, from rivers and streams, and from five additional coastal sources (not including the deep-water source).

The size and spread of the cooling-water plume depending on the weather situation has been simulated /Ingemansson and Lindahl 2005/. The coastal area that could be affected by an increase in temperature of at least 3–4°C is less than 1 km^2, while the area that could be affected by an increase in temperature of at least 1°C is approximately 30 km^2 (Figure 3-44).

Laxemar-Simpevarp

The heated cooling water from the three units is discharged into the primary recipient, Hamnefjärden. Hamnefjärden is connected to the surrounding coast via a sound (50 m wide and 5 m deep). The discharge rate is around 90–100 m^3s^{-1}, which creates a jet of water in the recipient and thereby effective mixing. The excess temperature of the cooling water is about 10–12°C /Edman and Lindahl 2007/.

The size and spread of the affected coastal area is determined by the climate and weather situation, most importantly the wind direction. The coastal area that could be affected by an increase in temperature of at least 1°C is between 17 and 20 km^2, see Figure 3-45, although under normal weather conditions the affected area is around 6 km^2 /Edman and Lindahl 2007/.

3.6.5 Fishery

The total commercial fish catch has been stable or increasing in the Bothnian Sea during the period 1994–2002, while in the Baltic Proper it has decreased by 80% during the same period /Ljunggren et al. 2005, Sjöstrand 2007/.

Forsmark

The Forsmark area is affected more by larger-scale fishery than by local exploitation.

The two commercially most important types of fish caught in the Bothnian Sea, Baltic herring and migrating fish, are clearly affected by fishery, the former by overfishing (in particular by-catches due to trawling), the latter by hydropower regulation /Karås 1993/. The introduction of safer fishing gear has ameliorated the effect of trawling on seal and otter mortality, as well as that of bycatches on Baltic herring and migrating fish. The latter type of pressure was also reduced by a tightening of trawling-zone limitations in 2004 /Sjöstrand 2007/.

In a comparison between coastal areas in the Bothnian Sea /Ådjers et al. 2006, Appelberg et al. 2007/, the Forsmark area did not show a status markedly below average on any of five indices as estimated in 2003–2005: Species richness, trophic level of fish communities, total biomass, mean weight per individual, European perch biomass and European eel biomass. On trophic level, the area showed significantly higher than average status.

Laxemar-Simpevarp

Kalmar county fishermen are responsible for more commercial fishery than the rest of the Swedish east coast taken together, with fishermen registered in Borgholm and Västervik catching most of the fish. This makes it the fifth largest fishing county in Sweden /Miliander et al. 2004/. This catch is mostly offshore.

Among coastal areas, higher catches are reported in the larger Laxemar-Simpevarp area (EU grid 44G) than in the Västervik-Misterhult archipelago's grid to the north (neighbouring EU grid 44G6). In a comparison between coastal areas in the Baltic Proper conducted in 2003–2005 /Ådjers et al. 2006, Appelberg et al. 2007/, Kvädöfjärden in the Västervik archipelago showed a status markedly below average on the index for European eel biomass, and a status markedly above average on species richness.

Also the estimated catch per area by recreational fishery is relatively small in Misterhult parish, 39.6 kg km^{-2}, compared with both Oskarshamn municipality and Kalmar county where it is 3–4 times greater /Miliander et al. 2004/.

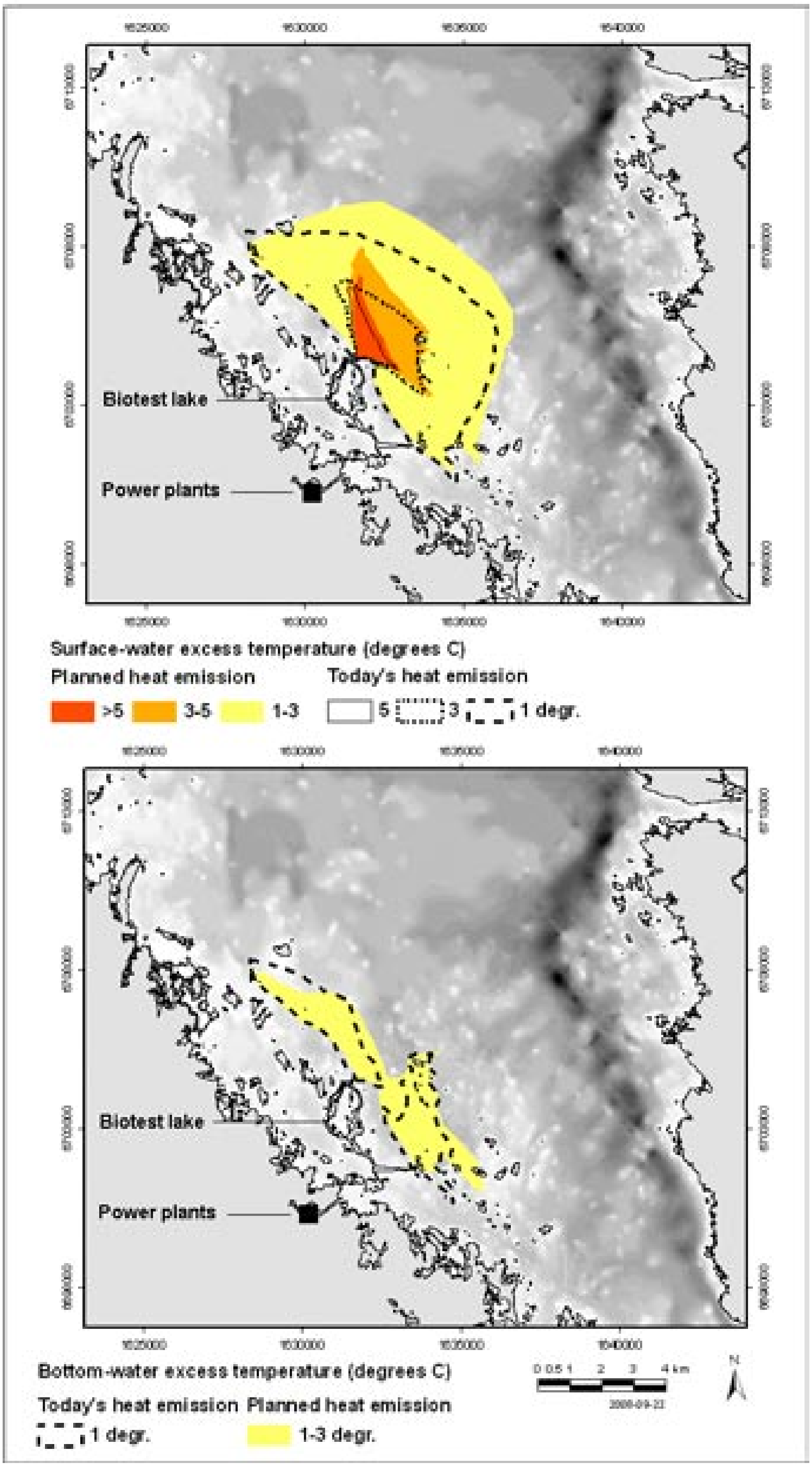


Figure 3-44. *The area of surface water (above) and bottom water (below) outside Forsmark that could be affected by an increase in temperature of at least 1°C, given current and planned heat emissions (outlines from /Ingemansson and Lindahl 2005/, redrawn).*

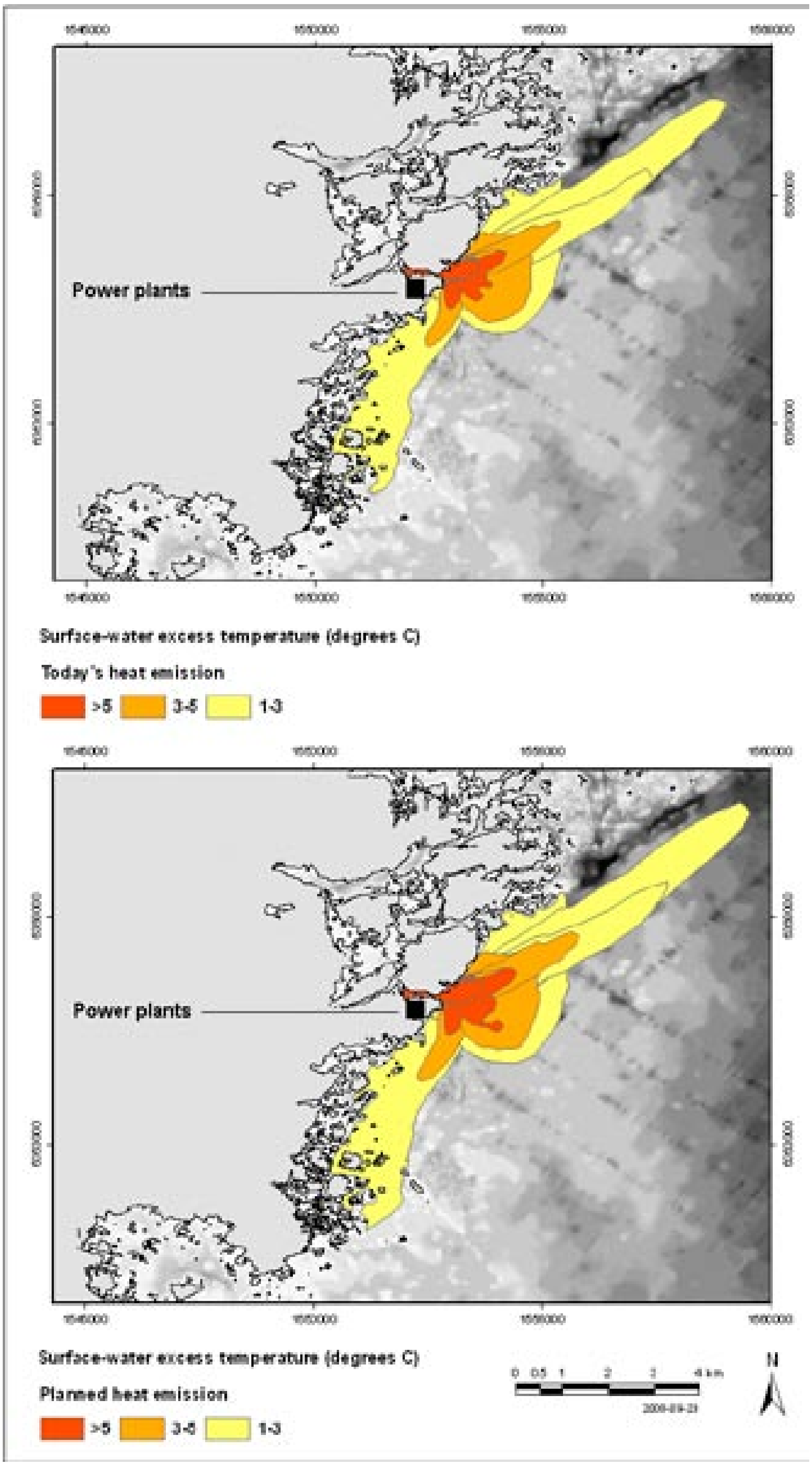


Figure 3-45. Heat plumes modeled as resulting from four characteristic wind situations in the Laxemar-Simpevarp subarea, showing coastal areas influenced by at least 1°C of increased temperature due to cooling water emissions, from /Karlsson and Lindahl 2003/.

4 The marine ecosystem – conceptual and quantitative carbon models

The marine ecosystem and its characteristics were conceptualized in marine ecosystem models for quantifying pools and fluxes of matter in the Forsmark and Laxemar-Simpevarp areas. The models were based on grids with a spatial resolution of 20×20 m. The models were built to describe the fluxes of matter within delimited basins between functional groups in the ecosystem, and between the basins and the surrounding environment, the terrestrial ecosystem and the adjacent sea. The system is assumed to be in a steady, non-seasonal, state and all input data are based on annual means.

The model is non-dynamic and there are no feedbacks between processes in the system. The processes of each unit or functional group are driven by independent data on biomass, concentrations, irradiance and temperature measured in the field. The parameters used in the calculations have been interpolated to the 20 m grid by using a number of different methods which are described below (sections 4.2 and 4.3). Model output is presented for the whole area and for the individual basins, per square metre or per basin. The pools and fluxes of matter have been studied in detail using carbon as a proxy.

To get an overview of the major pools and fluxes and to strengthen the conclusions from the marine ecosystem model, coarse-grained mass balances identifying the major pools and fluxes have been studied for carbon (C), nitrogen (N), iodine (I), uranium (U) and thorium (Th).

The elemental composition of the major pools in the ecosystem was also calculated for 49 elements based on analyses performed in the site investigations done by SKB.

The studied area in Forsmark has been divided in 28 sub-basins (called basins below) based on today's bathymetry and future drainage areas. The studied area in Laxemar-Simpevarp has been divided into 19 sub-basins using the same methodology. The basins are presented in Figures 4-1 and 4-2 for Forsmark and Laxemar-Simpevarp, respectively, together with the digital elevation model for the marine area.

4.1 Conceptual model

4.1.1 Basin delimitations

Most of the separate basins (Figure 4-1 and Figure 4-2) are not clearly separated today by islands or even clear bathymetric thresholds, but have an open border to several other basins. The delimitation was done to suit the overall aim of the project to assess the long-term safety of a deep repository for nuclear waste. Within the period of time assessed, the landscape will change form, partly due to the ongoing shoreline displacement in the area.

The delimitations of the basins are the boundaries to drainage areas of future lakes that are predicted to arise within the coming 18,000 years. Changes in water depths in the sea are calculated using the shore level displacement equations published in /Påsse 1997/. Shore displacement is calculated as glacio-isostatic uplift (U) minus global eustatic sea level rise (E). The detailed method for identification of basin delimitations is described in /Brydsten 2006/. The drainage area is calculated as the sum of upstream watersheds with final discharge in the separate marine basins, excluding the actual area of the marine basin.

Physical characteristics of the basins are presented in Table 4-1, for Forsmark and in Table 4-2 for Laxemar-Simpevarp.

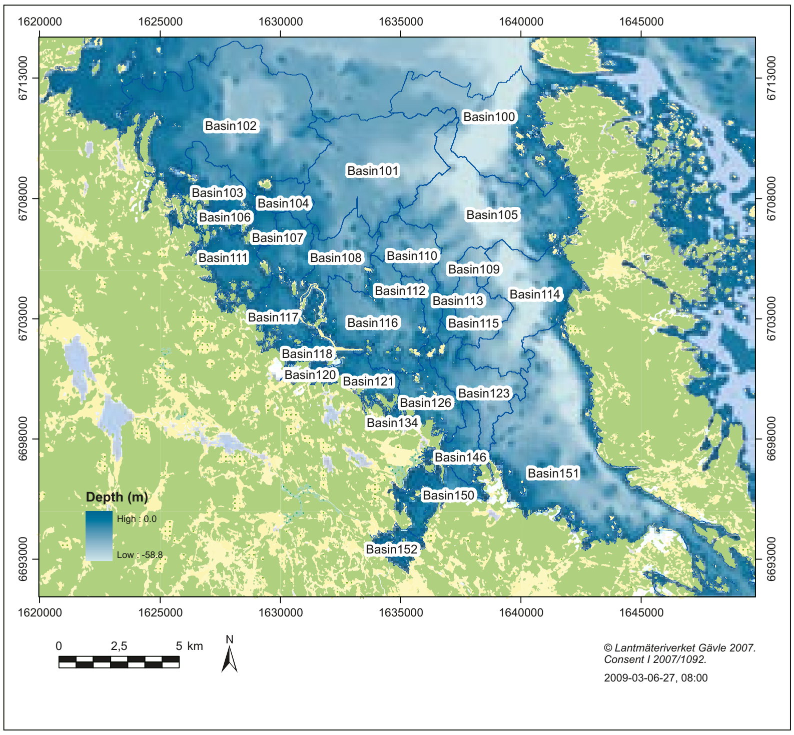


Figure 4-1. The bathymetry in the Forsmark area and the marine basins.

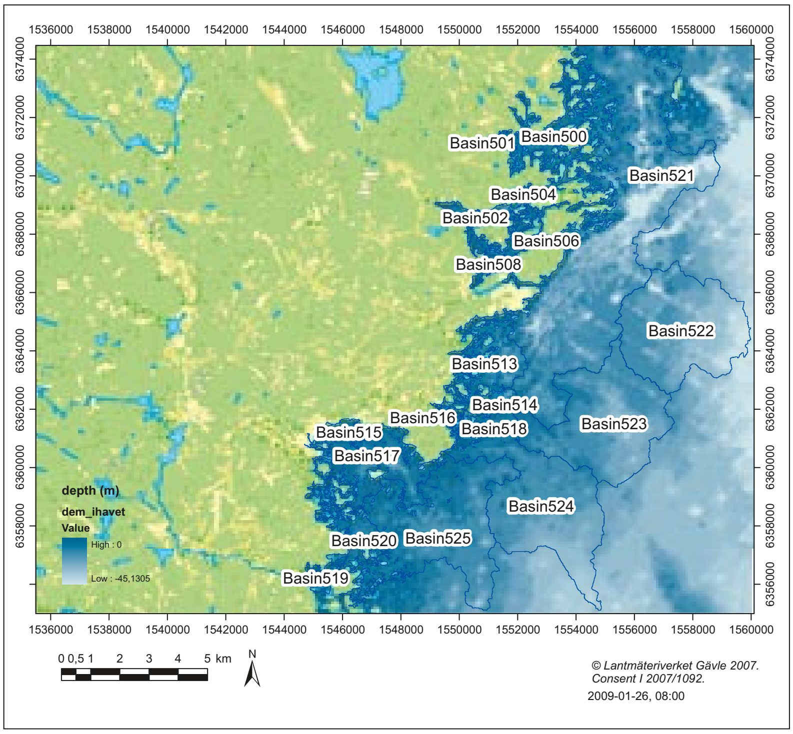


Figure 4-2. The bathymetry in the Laxemar-Simpevarp area and the marine basins.

Table 4-1. Area, mean depth, volume, drainage area and average age of water (AvA; see section 5 of the marine basins in the Forsmark area) of the marine basins in the Forsmark area.

Basin name	Area (km^2)	Mean depth (m)	Volume ($\times 10^6\ m^3$)	Drainage area (km^2)	AvA (days)
Basin 100	18	19	358	4.5	0.34
Basin 101	22	16	352	0	0.39
Basin 102	34	11	371	31	0.68
Basin 103	5.7	5.5	31	0.6	0.13
Basin 104	2.7	7.7	21	0.05	0.07
Basin 105	23	18	413	5.1	0.49
Basin 106	1.4	4.5	6.2	0.05	0.14
Basin 107	4.6	7.0	32	0.2	0.22
Basin 108	7.2	11	76	0.4	0.19
Basin 109	1.5	19	29	0	0.04
Basin 110	7.1	12	88	0.1	0.12
Basin 111	6.7	3.3	22	12	0.99
Basin 112	0.70	11	7.6	0	0.02
Basin 113	1.6	13	20	0	0.03
Basin 114	14	19	273	4.9	0.44
Basin 115	4.2	16	68	0	0.12
Basin 116	14	9.5	128	0.6	0.74
Basin 117	5.8	3.7	21	10	1.4
Basin 118	1.5	3.1	4.4	0.55	0.67
Basin 120	0.7	2.5	1.8	9.6	0.33
Basin 121	3.7	5.5	20	10	0.27
Basin 123	7.3	14	99	0.43	0.12
Basin 126	5.4	7.5	41	1.8	0.24
Basin 134	0.59	1.8	1.1	1.4	0.02
Basin 146	3.4	7.7	26	0.42	0.09
Basin 150	5.9	3.6	21	9.8	0.69
Basin 151	42	13	554	50	4.5
Basin 152	2.1	1.4	3.1	1 275	0.52

Table 4-2. Area, mean depth, volume, drainage area and average age of water (AvA; see section 5 of the marine basins in the Laxemar-Simpevarp area) of the marine basins in the Laxemar-Simpevarp area.

Basin name	Area (km^2)	Mean depth (m)	Volume ($\times 10^6\ m^3$)	Drainage area (km^2)	AvA (days)
Basin 500	2.9	–12	5.8	13	4.3
Basin 501	0.33	–6.9	1.1	1.8	16
Basin 502	1.1	–16	5.5	35	24
Basin 504	0.61	–12	2.2	1.9	5.9
Basin 506	0.33	–11	1.1	0.95	2.8
Basin 508	1.4	–3.2	2.4	47	10
Basin 513	4.1	–1.9	18	7.1	0.29
Basin 514	0.95	–3.6	4.3	0.22	0.31
Basin 515	0.87	–4.8	2.9	2.6	6.9
Basin 516	0.48	–3.3	0.07	2.7	9.3
Basin 517	6.7	–1.7	24	32	1.0
Basin 518	0.76	–4.3	2.9	0.14	0.4
Basin 519	0.59	–4.5	0.14	139	8.0
Basin 520	2.3	–0.10	5.6	12	0.4
Basin 521	38	–3.7	426	8.2	0.81
Basin 522	14	–3.3	216	0	0.19
Basin 523	14	–3.5	161	0.01	0.27
Basin 524	15	–2.4	171	0.35	0.14
Basin 525	15	–0.22	106	1.2	0.31

4.1.2 Ecosystem model

The marine ecosystem model is based on a food web that consists of biotic pools (primary producers and consumers), abiotic pools (sediment, particulate and dissolved matter) and fluxes of matter in the ecosystem (primary production, respiration, consumption, sedimentation, advection and runoff). The classification scheme of which groups to use and how to divide the organisms among them was similar to the model structure used by /Kumblad et al. 2003/ but modified. The primary producers included in the model were benthic micro- and macrophytes and phytoplankton, and the consumers were bacterioplankton, zooplankton, fish (benthivores, zooplanktivores and piscivores), benthic fauna (herbivores, filter feeders, carnivores and detritivores), benthic bacteria, mammals and birds and consumption of fish by humans (see Table 3-17 in section 3.4.1 and Figures 4-3 and 4-4).

The marine environment is commonly divided into benthic and pelagic habitats and the organisms and pools are assumed to be divided between them. In the sections presenting results (section 6), we have kept these divisions to permit comparison between the two habitats.

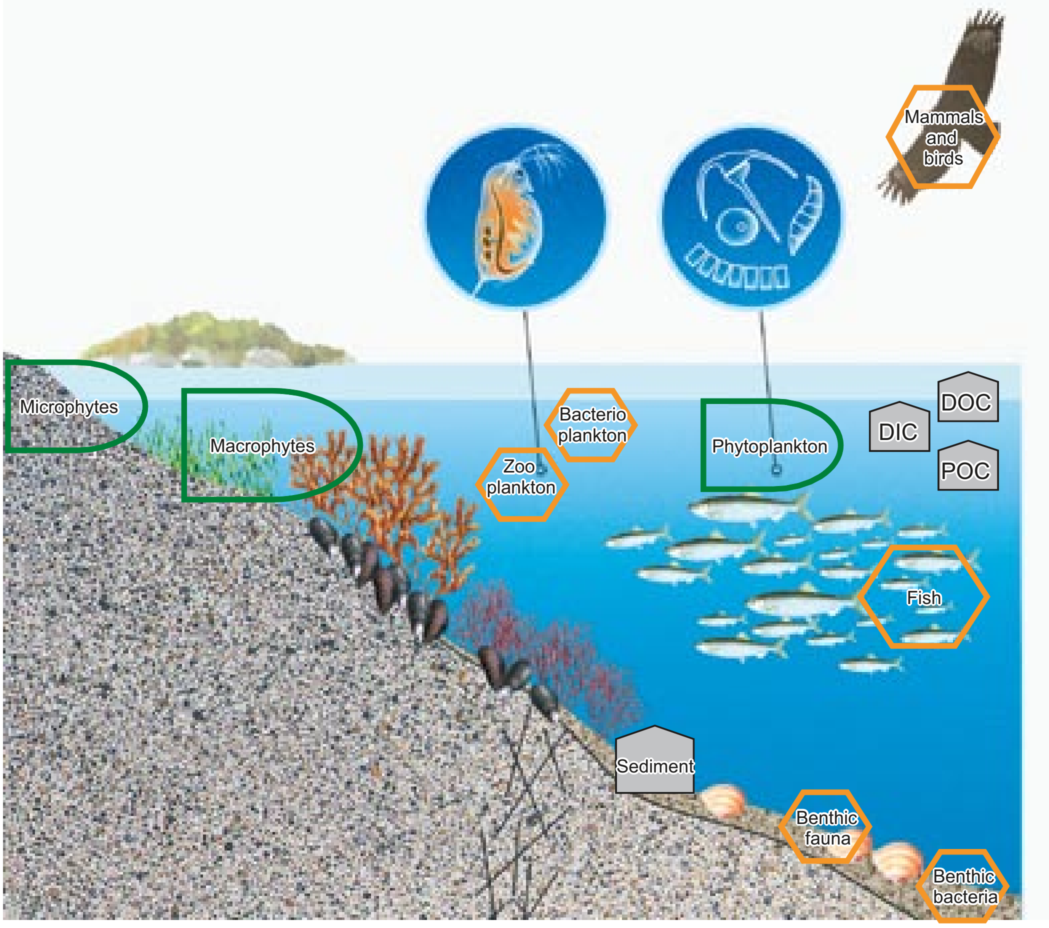


__Figure 4-3.__ Illustration of marine ecosystem and food web units – functional groups and abiotic pools. Benthic fauna includes the functional groups benthic filter feeders, benthic herbivores, benthic detrivores and meiofauna, and benthic carnivores. Mammals and birds include seals, humans and birds feeding in the marine habitat.

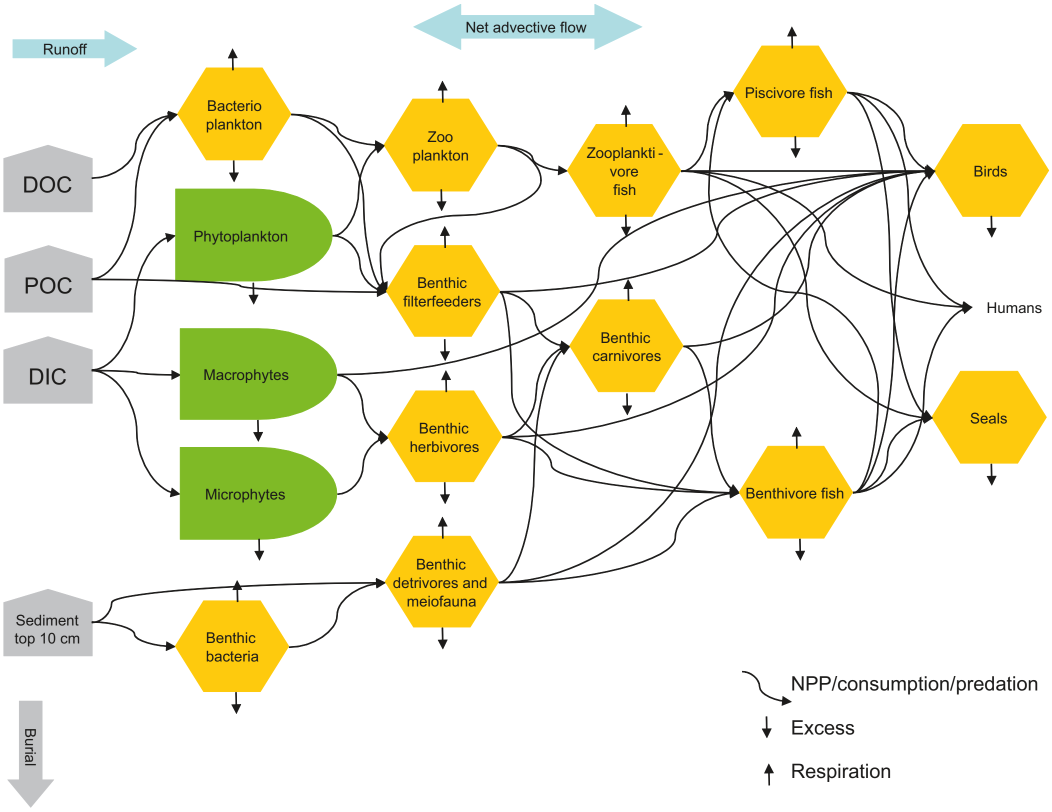


Figure 4-4. *Conceptual illustration of the food web-based marine ecosystem model. Boxes denote pools of matter while arrows denote fluxes: NPP = Net Primary Production, Excess = NPP/consumption minus respiration minus grazing/predation, POC = particulate organic matter, DOC = dissolved organic matter and DIC = dissolved inorganic matter. "Humans" refers to consumption of fish by humans.*

The marine ecosystem can further be divided into aphotic and photic zones, soft bottom and hard bottom benthic communities and other divisions. These terms are used in the report for descriptions (in section 3), but as physical and organism characteristics are often continuous rather than discrete, we have striven to use parameters along a continuum, an example being using light attenuation to estimate primary production rather than using a measure of photic or aphotic area. However, when lack of detailed data has limited this method, distributions and estimates have been made based on discrete variables, e.g. the lower depth limit of primary producers.

Units of the ecosystem – functional groups

In this section definitions and explanations of the food web, fluxes and terms used in the marine ecosystem model are presented. The parameterization of the various pools and fluxes are presented in section 4.2 and 4.3.

Primary producers

Primary producers are all autotrophic organisms in the ecosystem. They are divided into:

1. Large benthic algae and plants – macrophytes,
2. Unicellular benthic autotrophs – microphytobenthos
3. Pelagic primary autotrophs – phytoplankton.

Any epiphytic primary producers are assumed to be included in the estimates of primary production and biomass of the macroalgae. In the inner parts of bays, large belts of emergent macrophytes (e.g. reed, *Phragmites australis*) delimit the sea from land. These belts form a boundary between land and sea and are further described and included in the wetland section in /Löfgren 2008/. Any reed located outside this boundary in the sea is included in the macrophytes.

The primary producers in the food web of the marine ecosystem model constitute biomasses that are spatially distributed in the studied areas. The fluxes associated with the primary producers in the marine ecosystem model are Primary Production (PP), when carbon is fixed in the process of photosynthesis, and autotrophic Respiration (R), or Net Primary Production (NPP, NPP = PP-R) (Figure 4-4).

In the marine ecosystem model, all primary producers are assumed to use dissolved carbon for photosynthesis.

Consumers

Consumers are defined as all heterotrophic organisms in the ecosystem, i.e. herbivores, carnivores and detrivores. In the quantitative marine ecosystem model, these organisms are divided into;

1. Benthic bacteria,
2. Benthic fauna (herbivores, filter feeders, detrivores including meiofauna and carnivores),
3. Zooplankton,
4. Bacterioplankton,
5. Fish (zooplankton feeding, benthic feeding and piscivorous fish),
6. Mammals (seals),
7. Birds and
8. Human consumption.

The consumers in the food web of the marine ecosystem model constitute biomasses that are spatially distributed at the studied areas, except for humans, which are included merely as an outflux of matter due to human consumption (or rather catch) of fish. The fluxes associated with the consumers in the marine ecosystem model are consumption and heterotrophic Respiration (R) (Figure 4-4).

Bacteria play an important role in the remineralization of dead organic material and recirculation of nutrients. Their species composition is not known but is assumed to be insignificant for the budget calculations. Because bacteria on different substrates are assumed to assimilate carbon from different pools and to be eaten at different rates, they have been divided into two groups: bacterioplankton (living in the pelagic) and benthic bacteria (living in and on the sea floor).

The benthic fauna was classified into four groups: (i) benthic filter feeders dominated by molluscs feeding on planktonic organisms and particulate matter; (ii) benthic detrivores feeding on benthic bacteria and benthic organic matter in the sediment; (iii) benthic herbivores feeding on macro- and microphytes, and (iv) benthic carnivores feeding on the other groups (i-iii) of benthic fauna.

Zooplankton is a heterogeneous group with respect to organism size, life cycle and food choice. However, that level of detail has been omitted in this budget, as it was assumed to be of no importance for the carbon budget calculations.

Fish were divided into the functional groups zooplanktivorous fish (feeding on zooplankton), benthivorous fish (feeding on benthic fauna) and piscivorous fish (feeding on fish). See also section 4.2.8 for classification of species.

Mammals (i.e. seals) and humans feed on fish, birds feed on fish and benthic fauna, and they all thereby contribute to the flux of matter in the marine ecosystem model.

Abiotic pools

The abiotic pools in the marine ecosystem model comprise sediment, particulate matter and dissolved matter.

Sediment was divided into two parts: the bioactive layer, where the upper 0–10 cm (a default modelling value for the bioactive layer in accumulation bottoms in coastal areas in the Baltic /Håkanson et al. 2004/) was assumed to be the active part of the system, while sediment below 10 cm was treated as being outside the system. Pore water was included in the sediment pool and was not regarded as a separate pool in the model.

Particulate matter (POC when containing carbon) is assumed to be evenly distributed in the water column (but have a spatial variation) and it does not include living planktonic organisms.

Dissolved matter can be organic (DOC) or inorganic (DIC). DOC and DIC are assumed to be evenly distributed in the water column.

Food-web matrix

In Figure 4-4 conceptual presentation of the food-web model is found. In Table 4-3 the primary production and consumption relationship between the biotic and abiotic pools in the system are revealed.

For the groups feeding on two or more other groups (all consumers except zooplanktivore fish and benthic bacteria), the proportion of consumption was determined by the availability of biomass. The assumption was that consumers do not discriminate between food sources, but feed on the most abundant source. Due to the spatial variation of biomass, the proportion of consumption was individually calculated for each grid cell.

Table 4-3. Food web matrix, describing the interactions between the biotic components in the ecosystem. The groups represented by the rows use the groups represented by x-marks in the columns as source of matter in primary production (P1–P3) or consumption (C1–C9).

	P1	P2	P3	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	DIC	DOC	POC	Sediment
P1, Macrophytes														x			
P2, Microphytes														x			
P3, Phytoplankton														x			
C1, Benthic bacteria																	x
C2, Benthic herbivores	x	x															
C3, Benthic filter feeders			x						x	x						x	
C4, Benthic detrivores and meiofauna				x													x
C5, Benthic carnivores					x	x	x										
C6, Zooplankton			x							x							
C7, Bacterioplankton															x	x	
C8, Benthivore fish					x	x	x	x									
C9, Zooplanktivore fish									x								
C10, Piscivore fish											x	x					
C11, Bird	x				x	x	x	x			x	x	x				
C12, Seal											x	x	x				
C13, Humans											x	x	x				

All primary producers (except emergent macrophytes), i.e. macrophytes, microphytobenthos and phytoplankton, were assumed to assimilate 100% of their carbon demand from the dissolved inorganic carbon pool (DIC).

Benthic bacteria were assumed to assimilate carbon from sediment and bacterioplankton was assumed to assimilate carbon from POC and DOC.

Benthic herbivores were assumed to consume macrophytes and microphytobenthos. Benthic filter feeders were assumed to consume POC, phytoplankton, bacterioplankton and zooplankton. Benthic detritivores were assumed to consume sediment and benthic bacteria. Benthic carnivores the were assumed to consume other benthic fauna groups, i.e. benthic herbivores, filter feeders and detritivores.

Zooplankton was assumed to consume phytoplankton and bacterioplankton.

Fish feeding on zooplankton were assumed to consume only zooplankton and not phytoplankton or bacterioplankton, as these groups are assumed to be too small to be ingested. Fish feeding on benthic fauna were assumed to consume benthic fauna (benthic herbivores, filter feeders, detrivores and carnivores). Piscivore fish were assumed to eat only fish.

Birds were assumed to feed on benthic macrophytes, benthic fauna or on fish. Their food choice was dependent on the spatial distribution of the functional groups they feed on. Between the surface and a depth of 5 m, 98% of the birds were benthivores and were therefore assumed to consume benthic organism (macrophytes and benthic fauna). Below 5 m, 48% of the birds were assumed to be benthivores and 52% piscivores.

Fluxes in the ecosystem

The fluxes in the marine ecosystem model are biotic (net primary production, respiration and consumption) and abiotic (runoff, advective flux, groundwater inflow, burial, diffusion and deposition). Parameterization of the fluxes is described in section 4.3, except for advective flux which is described in section 5 of this report).

Net Primary Production (NPP) is Gross Primary Production (GPP) minus Respiration (R) by primary producers and comprises the conversion of inorganic dissolved carbon (DIC) in the water column to organic carbon via photosynthesis. GPP and R of primary producers are not calculated separately in the model but included in NPP.

Respiration (R) comprises heterotrophic cell respiration and is calculated for all consumers, living in the water, i.e. excluding mammals, birds and humans.

Consumption (C) comprises the consumption of other organisms by a functional group and is calculated for all consumers.

Excess (E) is the remainder of the carbon/energy budget comprising primary production (or for consumers consumption) minus predation and respiration. It includes secondary production, excretion and faeces, and mortality. Since the model is assumed to be static in terms of biomass development, all excess is assumed to be an input to the pools, sediment, POC and DOC. The DIC pool is assumed to be in equilibrium with atmospheric carbon.

Advective fluxes comprise flows of water, and matter transported by water, between the different basins. Advective fluxes are calculated by two different models driven by factors such as runoff, atmospheric pressure, wind speed etc and are described in Chapter 5 of this report.

Runoff, or discharge, comprises fluxes of water or other matter transported by water from surrounding watersheds or drainage areas.

Burial is the export from surface sediment (top 10 cm) to deeper sediment (10 cm), considered to be outside the modelled ecosystem. Groundwater inflow comprises net inflow of water from the near-surface hydrological domain /Follin et al. 2007/. Positive net inflow occurs in areas where groundwater discharges into the basins and negative net inflow occurs where there is a net outflow from the basins to the groundwater. Data for this is however not included in the massbalance calculations.

4.1.3 Mass balance

To get an overview of major pools and fluxes within the marine ecosystem, mass balance calculations were performed for carbon (C), nitrogen (N), phosphorus (P), iodine (I), thorium (Th) and uranium (U). The mass balance models for the marine ecosystem comprise pools and major fluxes of matter in the marine ecosystems in Forsmark and Laxemar-Simpevarp. The mass balance calculations include the same pools (biotic and abiotic) as the marine ecosystem model, but the pools are clumped in primary producers and consumers. The major fluxes into and out of the ecosystem (runoff, deposition net advective flow, burial, total net primary production (NPP) and total respiration (R)) are also the same as in the marine ecosystem model (see previous section). But no fluxes within the functional groups of the ecosystem are included in the mass balance calculations. NPP was considered for C and for N and P based on estimates calculated from the Redfield ratio. Respiration was included in carbon balances. These processes were not known for other element balances and so were not included, see Figure 4-5 and Table 4-22.

Some identified processes may potentially influence the mass balance, but are not included in the mass balance calculations, e.g. gas exchange between water and atmosphere (i.e. evaporation, transpiration and volatilization although diffusion was included for carbon).

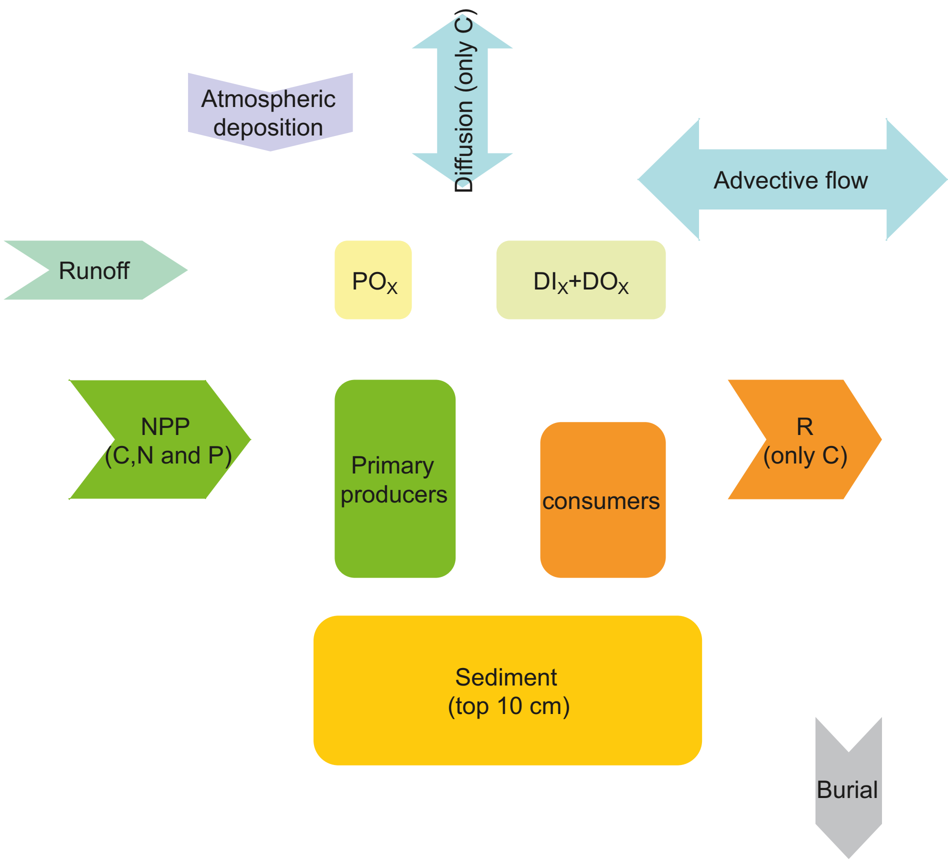


Figure 4-5. *Conceptual model for calculating mass balances for elements showing considered pools and fluxes considered for the elements (C, N, P, I ,Th and U).X in the figure could represent any of these elements. The same structure was used for all elements, except that NPP was only considered for C, N and P and R only for C.*

These processes may be of importance for some elements such as N and I, but for the majority of elements they are probably of minor importance. Migration of organisms, e.g. fish, may be of importance, for example for N, but with regard to the biomass of fish in comparison with other volumes in the ecosystem, this process is probably of minor importance. (Table 4-4).

4.1.4 Elemental composition

To identify major pools in the functional groups and abiotic pools in marine ecosystems, the elemental compositions of organisms, sediment and water were analyzed within SKB's site investigation programme /Nilsson 2004, Bradshaw and Kumblad 2008, Engdahl et al. 2006, Engdahl 2008/. In Forsmark and in Laxemar-Simpevarp 49 and 63 elements were analyzed respectively. Results on the elemental compositions of organisms are presented in section 3.5 and 3.6.

From analyses of carbon (C) and other elements (X) in the various organisms and abiotic samples in the ecosystem, a C:X ratio for each functional group or abiotic pool was derived. This C:X ratios were then used to calculate the mass of each element in the various abiotic and biotic pools.

Table 4-4. Pools and fluxes considered in the mass balance models for C,N, P, I, TH and U.

Fluxes to the system	Process	Mass balance carbon, remarks	Mass balance other elements, remarks
In through water	Runoff	X	X
In through water	Advective flow	X	X
In from atmosphere	Net Primary Production	X	Not applicable
In from atmosphere	Precipitation, deposition	X	Considered for C, N and P
In from atmosphere	Gas exchange atmos-phere/water	X	Not considered
Diffusive inflow	E.g. migration of organisms	Not considered	Not considered
Fluxes from the system			
Out through water	Advective flow	X	X
Out to atmosphere	Respiration	X	Not applicable
Out to atmosphere	Evaporation/transpiration/ volatilization	Not considered	Not considered
Diffusive outflow	E.g. Migration of organisms	Not considered	Not considered
Accumulation	Burial	X	X
Pools			Considered for most elements
Producers		X	X
Consumers		X	X
sediment upper (top 10 cm)		X	X
Sediment deep (> 10 cm)		Not considered	Not considered
Particulate		X	X
Dissolved		X	X

4.2 Parameterization of biotic properties

4.2.1 Macrophytes

Macrophyte biomasses in both Forsmark (7 communities) and Laxemar-Simpevarp (8 communities) were modelled in detail for separate vegetation communities named after dominant species or taxa found at the sites(Table 4-5). Modelling methods and assumtions is extensively described in /Carlén et al. 2007/. The seventh vegetation community in Forsmark dominated by *Fucus sp*. was not modelled, since the data density was too low. Instead, semi-quantitative cover data from 10 transects were used to generate the biomass distribution for the ecosystem model.

The extent of the modelling area is the same as for the digital elevation models for Forsmark and Laxemar-Simpevarp. Predictors and resulting models are in 20x20 m grids.

Point and transect data from field surveys were used for modelling. Transect data were converted to give one data point for every meter of the transect length. This procedure has proven effective when modelling marine biota /Sandman et al. in prep/.

Modelling for all macrophytes except *Fucus vesiculosus* and emergent macrophytes was done in GRASP (Generalized Regression Analysis and Spatial Predictions), a set of S-PLUS/R functions developed for modelling and analysis of the spatial distribution of species /Lehmann et al. 2002/. GRASP communicates with ArcView, and resulting distribution maps are in ArcView format.

GRASP uses GAM, generalized additive models /Hastie and Tibshirani 1990/, to fit predictor variables independently by means of non-parametric smooth functions. The best model is selected by a stepwise procedure where progressively simpler models are compared with a measure such as Akaike's Information Criterion. Abundance modelling was used here, and the results are presented in the form of grids with estimates of biomass (in this case gC m^{-2}) for each grid cell.

Table 4-5. Vegetation communities/functional groups of macrophytes in Forsmark and Laxemar-Simpevarp.

Vegetation community	Forsmark	Laxemar-Simpevarp
Filamentous brown and green algae (mostly *Pilayella*)	x	x
Chara sp.		
(mostly *Chara sp.*, but also *Najas marina* if present together with *Chara sp.*)	x	x
Phanerogams		
(*P. pectinatus, P. perfoliatus, Myriophyllom, Caltriche, Zanichellia* if dominant together or alone)	x	x
Potamogeton perfoliatus		
(if present alone, otherwise under former group)	x	x
Vaucheria sp		
(if alone or dominant)	x	x
Red algae		
(if dominant)	x	x
Fucus sp.	x	x
Zostera marina		x

Macrophyte biomass – both sites

Data used in Forsmark in the modelling of macrophytes were mainly collected in August–September 2004 and consist of dive transects, general survey dive transects and point sampling with an Ekman grab sampler /Borgiel 2005/. However, to get better coverage further out from shore, video survey point data from 2002 were also used /Tobiasson 2003/. In all, 7,145 data points were used in modelling, 7,080 of which were created by dividing dive transect data into one-metre segments (Figure 4-6).

The data used in the modelling of macrophytes in Laxemar-Simpevarp were mainly collected in September–November 2002 during dive transects and a general survey using boat, water field glasses and rake /Fredriksson and Tobiasson 2003/. However, to get better coverage further out from shore, video survey point data from 2002 were used /Tobiasson 2003/. In all, 2,965 data points were used in the modelling, 1,632 of which were created by dividing dive transect data into one-metre segments (Figure 4-7).

For each data point in the dataset, the vegetation was assigned to one of the vegetation communities/functional groups depending on the dominant species/family according to percent cover degree /Fredriksson 2005/. Before modelling, percent cover was converted to grams dry weight per m^2 (g dw m^{-2}) using a specific conversion factor for each community /Fredriksson 2005/, and then from g dw m^{-2} to gram carbon per m^2 (gC m^{-2}) using species/family-specific conversion factors /Kautsky 1995b/ for each of the contributing taxa. The conversion factors are shown in Table 4-6.

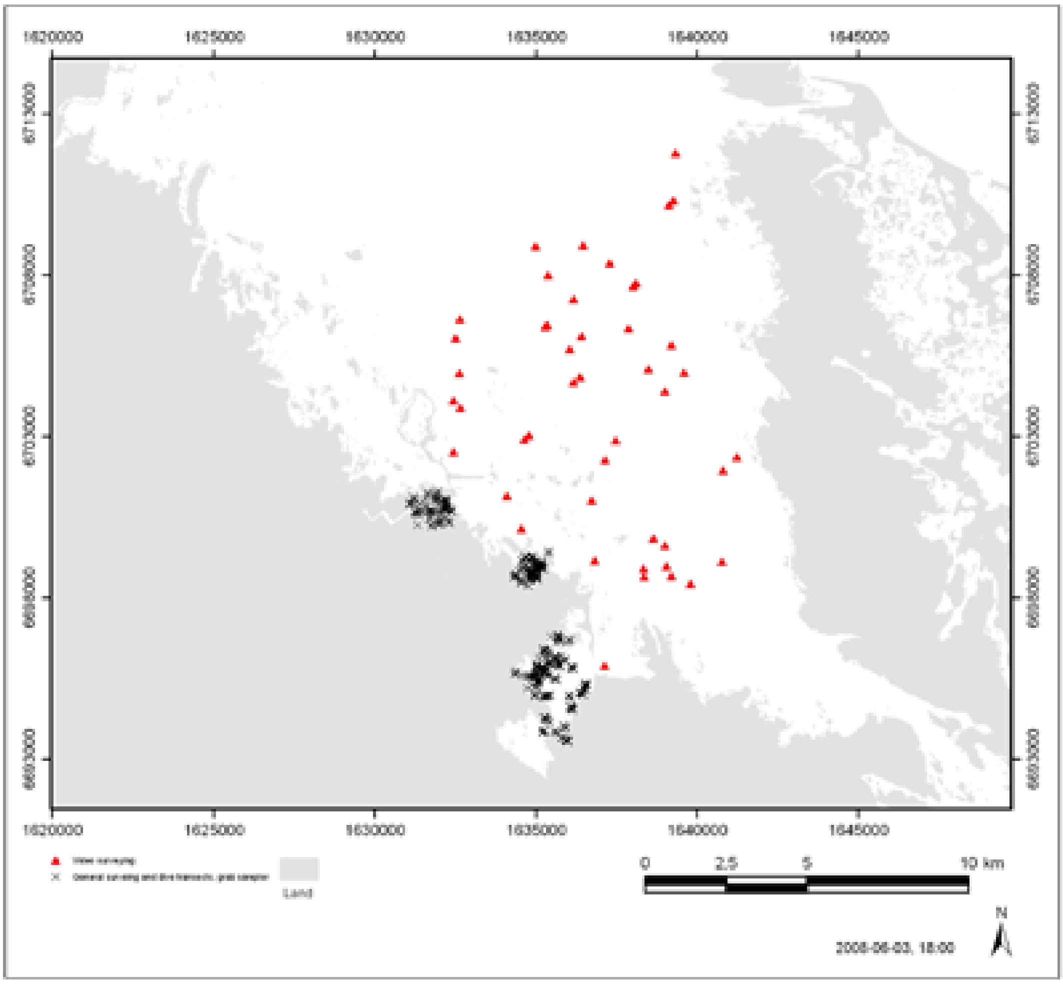


***Figure 4-6.** Field data used in the modelling of macrophyte biomass in the Forsmark area.*

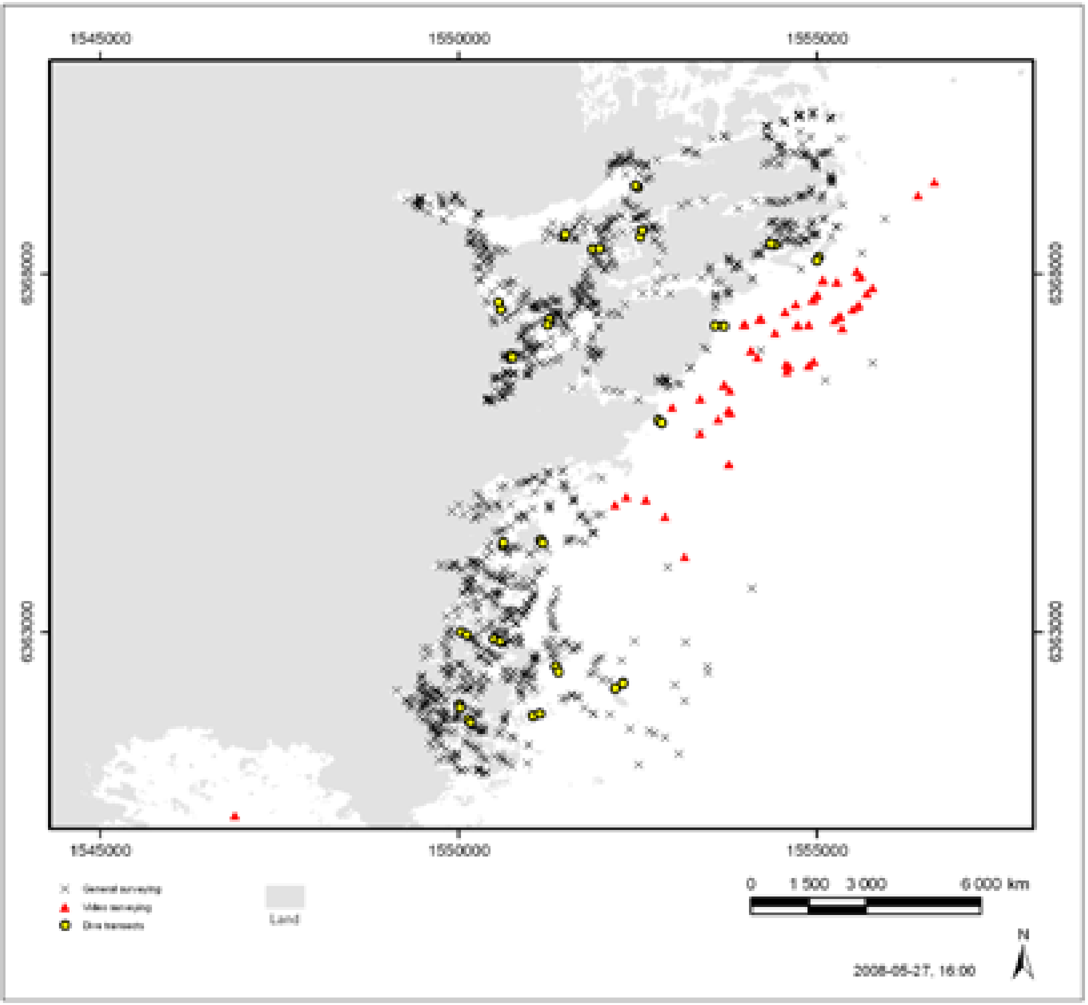


Figure 4-7. Field data used in the modelling of macrophyte biomass in the Laxemar-Simpevarp area.

Table 4-6. Conversion factors for the macrophyte species groups present in the Forsmark /Fredriksson 2005/ and Laxemar-Simpevarp areas /Fredriksson and Tobiasson 2003/. Conversion factor from g dw m^{-2} to gC m^{-2} from /Kautsky 1995b/.

	Conversion factor from percent cover to g dw m^{-2}	Conversion factor from g dw/m^2 to gC m^{-2}	Conversion factor to yearly mean
Forsmark			
Filamentous brown and green algae	0.29	~ 0.3	x 2
Chara sp.	1.6	~ 0.14	x 0.5
Phanerogams	0.59	~ 0.3	x 0.5
Vaucheria sp.	4.0	~ 0.4	x 1
Red algae	0.74	~ 0.35	x 0.5
Laxemar-Simpevarp			
Filamentous brown and green algae	0.5	~ 0.3	x 2
Chara sp.	3.5	~ 0.25	x 0.5
Phanerogams	1.6	~ 0.35	x 0.5
Vaucheria sp	3.1	~ 0.4	x 1
Red algae	1.7	~ 0.35	x 2
Fucus sp.	8.8	~ 0.35	x 1
Zostera marina	1.7	~ 0.35	x 1

The data points assigned to the group *Potamogeton perfoliatus* at both sites were so few that they were modelled together with the phanerogam group. The vegetation communities/functional groups represented in the ecosystem model in Forsmark were, filamentous brown and green algae, *Chara* sp, phanerogams, *Vaucheria sp*. and red algae.. The vegetation communities/functional groups represented in the ecosystem model in Laxemar-Simpevarp were filamentous brown and green algae, *Chara sp*, phanerogams, *Vaucheria sp,* red algae, *Fucus sp*. and *Zostera sp*.

The initial modelling was done using data from surveys performed in August and September (in Forsmark), and September–November (in Laxemar-Simpevarp), so the resulting biomass of carbon per square metre was not representative of the annual mean. In /Kiirikki 1996/ the variation in percent cover degree for a number of algae at Tvärminne, Northern Baltic Proper, is shown over a period of three years. This dataset, together with information on algal lifecycles /Tolstoy and Österlund 2003/, was used to estimate the approximate length of the vegetation period for the vegetation groups and to roughly convert the modelled biomasses into yearly means. This process is described for each vegetation group below. Conversion factors are given in Table 4-6.

The vegetation cover maximum for most annual species is reached in June–August. However, the annual species considered here are present for most part of the year. The yearly average is therefore calculated as ½ of the modelled maximum. Phanerogams and *Chara sp.* were considered annual groups in this case.

Filamentous brown and green algae are dominated by *Pilayella sp.* at the sites. *Pilayella sp.* has a vegetation period that extends over a larger proportion of the year, approximately from February to August, with a peak around March or April. The yearly average was calculated as twice the modelled biomass from August (in Forsmark) and from September–November (in Laxemar-Simpevarp).

Vaucheria sp. is a perennial and is present and growing throughout the year. The yearly average is considered to be the same as the modelled biomass. In Forsmark, *Vaucheria sp*. was only found in Kallrigafjärden (Basin M150 and 152), so the modelled biomass was set to zero in all other areas.

Table 4-7. Limitations in depth and wave exposure for the macrophyte species/ Functional groups present in the Forsmark and Laxemar-Simpevarp area.

	Delimitation in depth (m)	Delimitation in log-transformed wave exposure
Forsmark		
Filamentous brown and green algae	20	–
Chara sp.	4	–
Phanerogams	5	–
Vaucheria sp.	7	> 10.15
Red algae	25	–
Laxemar-Simpevarp		
Filamentous brown and green algae	20	–
Chara sp	4	–
Phanerogams	4	–
Vaucheria sp	7	> 7.95
Red algae	–	–
Fucus sp.	7	–
Zostera marina	5	< 9.00

Most red algae in this study were perennials, for example *Ceramium tenuicorne*. They are present the whole year but have a biomass maximum during June to August. The yearly average was calculated as half the modelled maximum.

Zostera marina is a perennial species which is present year-round. The yearly average is considered to be the same as the modelled biomass.

Fucus vesiculosus is a perennial species and is present all year. The yearly average is considered to be the same as the modelled biomass.

Available predictors in the modelling of macrophytes in Forsmark and Laxemar-Simpevarp were depth, slope, aspect, bottom temperature, pelagic temperature, Secchi depth, wave exposure, light percentage at the bottom and days with solar insulation above 5 MJ. The wave exposure grid was log transformed and this grid was used throughout the modelling.

Because field data cover was denser in shallow waters than in deep waters, the models could not always distinguish at what depth algae no longer are present. To avoid having algae too deep, biomass below a certain depth was set to zero. The depth limits for the different functional groups were set according to literature /Tolstoy and Österlund 2003, Leinikki et al. 2004, Mossberg et al. 1992/, and are shown in Table 4-7.

Data cover was also less dense in areas of both low and high wave exposure. This is probably the reason that the model for *Vaucheria sp.* failed to capture the fact that this taxon is exclusively found in very sheltered areas. Therefore, a limit was also set for *Vaucheria sp*. in wave exposure. This limit was set by finding the highest log-transformed wave exposure for *Vaucheria sp*. presence and rounding this number up to the nearest five hundred. Above this value *Vaucheria sp.* biomass was set to zero. The same problem was evident for *Zostera marina* (in Laxemar-Simpevarp), where the model did not capture the fact that *Zostera marina* needs at least moderate wave exposure. Disregarding a few outliers, the lower limit was found and rounded down to the nearest five hundred. Below this limit, *Zostera marina* biomass was set to zero.

Fucus vesiculosus biomass in Forsmark

Data density for *Fucus vesiculosus* was lower and not enough for GRASP modelling in Forsmark. Semi-quantitative cover (%) data on *F. vesiculosus* are found in 10 transects in the Forsmark area from four studies /Borgiel 2004, Borgiel 2005, Kautsky et al. 1999, Wallström et al. 2000/, six of which were used in this study. Four of the transects are located in Asphällsfjärden, and as these are affected by the intake channel for the nuclear power plants, the environmental conditions are assumed to be atypical with regard to abiotic factors (e.g. water transparency) determining the distribution of macroalgae. Depth, substrate and wave exposure (or correlated characteristics) are among the structuring factors for *F. vesiculosus* /e.g. Isæus 2004, Kautsky et al. 1986/ and depth determines the maximum depth distribution. These factors were used to find probable habitats for *F. vesiculosus*.

Observed cover (%) of *F. vesiculosus* was plotted against depth and wave exposure index presented in /Carlén et al. 2007/. *F. vesiculosus* was found in areas with a wave exposure index (SWM) of between 100,000 and 300,000 and a depth of between 0 and 7 m. The distribution, increasing from the surface and decreasing at depths deeper than 4 to 6 m, is similar to that found by /Kautsky et al. 1986/. A curve was fitted to data on cover (C) of *F. vesiculosus* at depth intervals (D) 0–1 m, 1–2 m etc. (Figure 4-8) according to:

$$C = \left(1.33 \cdot D^2\right) - 11.14\,D$$

Further, *F. vesiculosus* was assumed to be present on hard substrates and distributed according to the structuring factors of depth, substrate and wave exposure. The relationship between cover and dry weight /Fredriksson and Tobiasson 2003/ and between dry weight and carbon /Engdahl et al. 2007/ was used to calculate the biomass of *F. vesiculosus* (gC m^{-2}) in Forsmark.

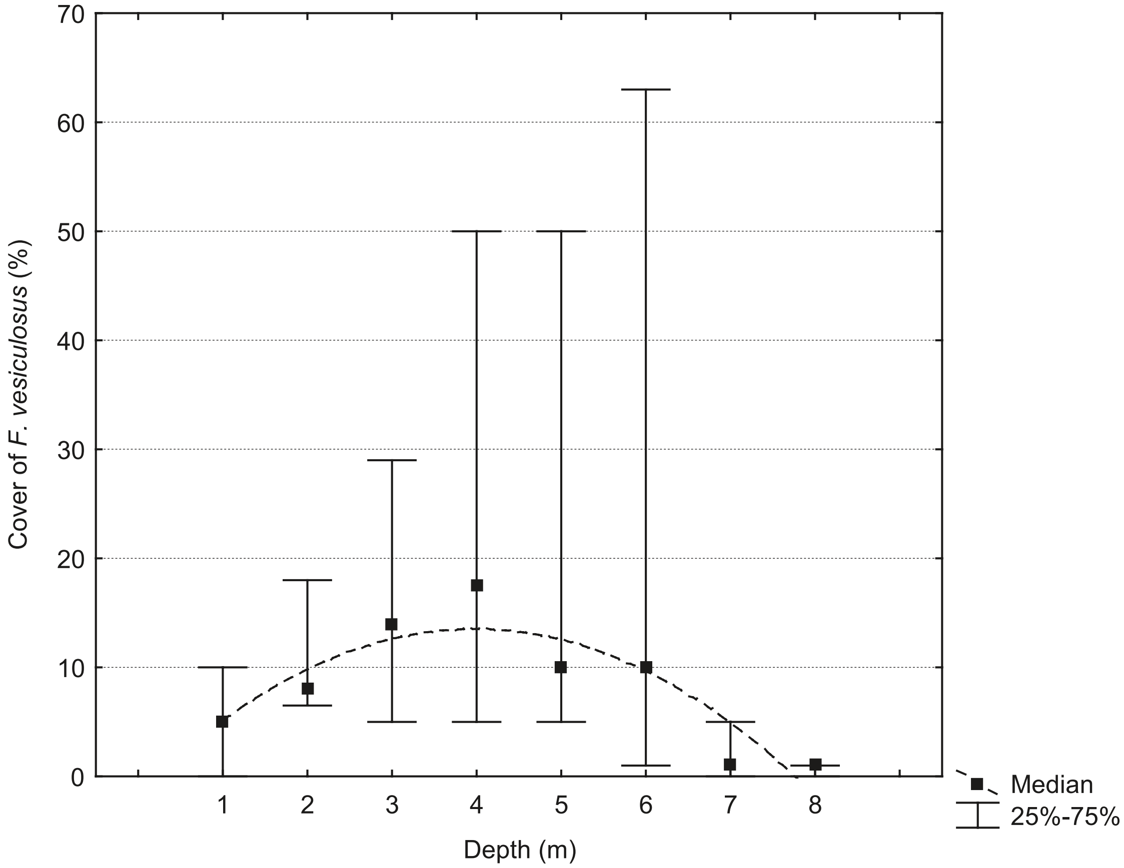


Figure 4-8. *Median cover, 25 and 75% percentiles, of F. vesiculosus at different depth intervals (1; 0–1, 2; 1–2 etc).*

Emergent macrophytes – both sites

Emergent macrophytes are present in the shore zone in the shallow, secluded bays in the coastal area. They are present in shallow water or in wet terrestrial areas. As the upper delimitation of the marine ecosystem is the mean seawater level in the elevation model, most emergent macrophytes are not included. However as these plants (mainly reed, *Phragmites australis*) have relatively high primary production, it is likely that they contribute to some extent to the organic matter transport to the marine system and excluding them would probably underestimate the input of carbon to the system. For this reason, all emergent macrophytes within an area submerged by water at the 95th percentile of positive deviation (0.50 m) from average mean sea level are included as a source of organic matter for the system.

Occurrences of emergent macrophytes were obtained from satellite interpretations of vegetation communities by /Boresjö Bronge and Wester 2003/ as "Open wetland, reed-dominated" (three different moisture classes).

Primary production of macrophytes – both sites

Several studies of *in situ* measured primary production were performed to obtain productivity figures for the seven different vegetation communities, see Table 4-8. For most vegetation communities, net primary production (NPP) was related to daily irradiance. In some cases the relationship was weak, but as no correlations with other parameters were found either, these figures were used.

Table 4-8. Primary production conversion factors for the different vegetation communities, where I is average irradiance (MJ PAR d-1). Note the different units.

Vegetation community	factor	unit	Original data references
Filamentous	20.91	mgC gC^{-1} I^{-1} day^{-1}	/Paalme and Kukk 2003, Guterstam et al. 1978, Wallentinus 1978/
Chara sp.	10.61	mgC gC^{-1} I^{-1} day^{-1}	/Torn et al. 2006, Karlsson and Andersson 2006, Borgiel 2006, Wijnbladh and Plantman 2006/
Phanerogams	19.41	mgC gC^{-1} I^{-1}	/Wijnbladh and Plantman 2006/
Vaucheria sp.	67	gC m^{-2} $year^{-1}$ when B > 25 gC m^{-2}	/Borgiel 2006/
Red algae	10.40	mgC m^{-2} I^{-1} day^{-1}	/Paalme and Kukk 2003, Wallentinus 1978, Borgiel 2006/
Fucus vesiculosus	3.30	mgC gC^{-1} I^{-1} day^{-1}	/Guterstam et al. 1978, Guterstam 1979, Lindblad et al. 1984, Paalme and Kukk 2003/
Zostera	2.37	mgC gC^{-1} I^{-1}	/Wijnbladh and Plantman 2006/

Generally, if productivity in the references was given in other units than gC, the measure was converted using conversions between gC and g dw found in /Engdahl et al. 2007/ or /Kautsky 1996/ and productivity (gC^{-1} h^{-1}) was converted to daily figures (gC^{-1} d^{-1}) using average hours of irradiance data from the reported date of experiment in the references. Daily irradiance (MJ $m^{-2}d^{-1}$) was calculated from depth (D) and daily irradiance at the surface ($I_{surface}$) and average light attenuation in Laxemar-Simpevarp /Lindborg ed. 2006, section 4.3.3/ according to:

$$\sum I_{surface} \cdot e^{-0.79 \cdot D}$$

If not given in the reference, daily irradiance was estimated from average Forsmark or Laxemar-Simpevarp datasets, depending on latitude in the Baltic area.

When NPP was not reported separately, NPP was calculated from measured GPP using a relationship for GP:R of 10:1 found by /Binzer and Sand-Jensen 2006/ from 134 studies of phytoelements, primary production and respiration.

Below is a description of the production of separate vegetation communities and how they are correlated to irradiance. "N" in the section below refers to number of separate measurements or measuring period and does not include sub samples.

Three studies of daily NPP for *Pilayella littoralis* (n=5) *Cladophora glomerata* (n=5) and *Enteromorpha intestinalis* (n=2) /Paalme and Kukk 2003, Guterstam et al. 1978 and Wallentinus 1978/ were used to calculate factors for NPP of filamentous brown and green algae (Table 4-8). NPP was, albeit weakly, correlated to irradiance (r^2 = 0.22). The weak relationship is probably due to the different species having varying life strategies.

Factors for calculating NPP of the *Chara sp.* communities in four studies of daily NPP for *Chara tomentosa* (n=4) /Torn et al. 2006/ and *Chara* sp. (n=15) / Karlsson and Andersson 2006, Borgiel 2006, Wijnbladh and Plantman 2006/ were correlated to daily irradiance (Table 4-8). NPP was positively correlated to irradiance (r^2 = 0.45), Figure 4-9.

NPP in phanerogam communities was measured by /Wijnbladh and Plantman 2006/ in communities dominated by *P. pectinatus* during 2005 and 2006 (Figure 4-10 and Table 4-8). In July and October there was a good correlation between biomass and NPP, while in August the correlation was weaker.

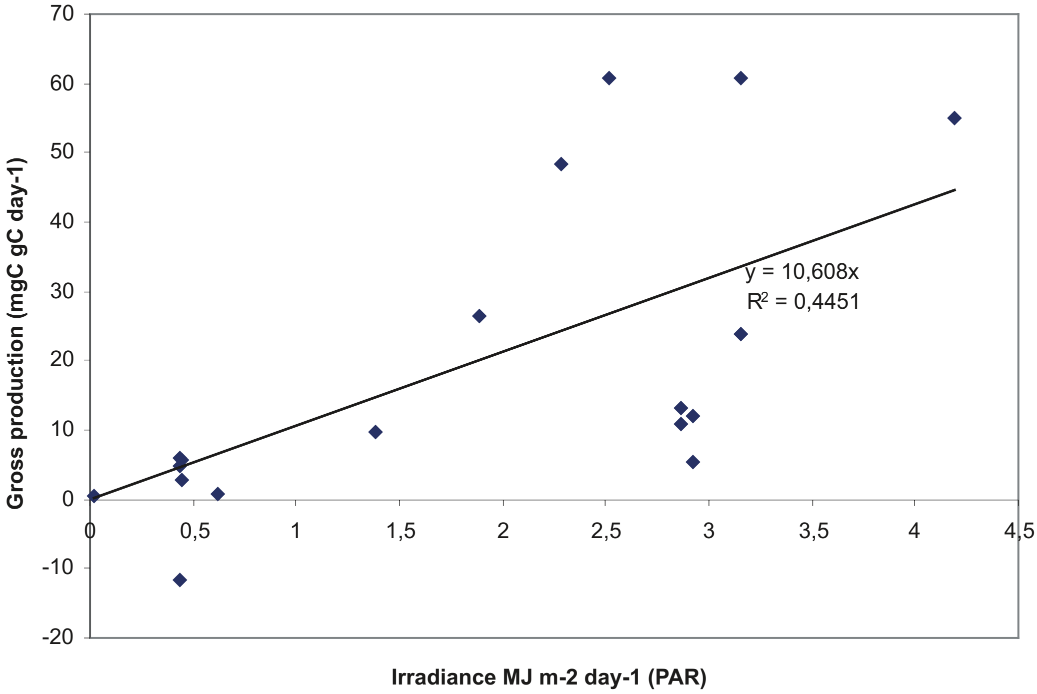


Figure 4-9. *Gross primary production of Chara sp. (mgC gC^{-1} day^{-1}) and daily in situ irradiance (MJ PAR m^{-2} day^{-1}) from four different studies.*

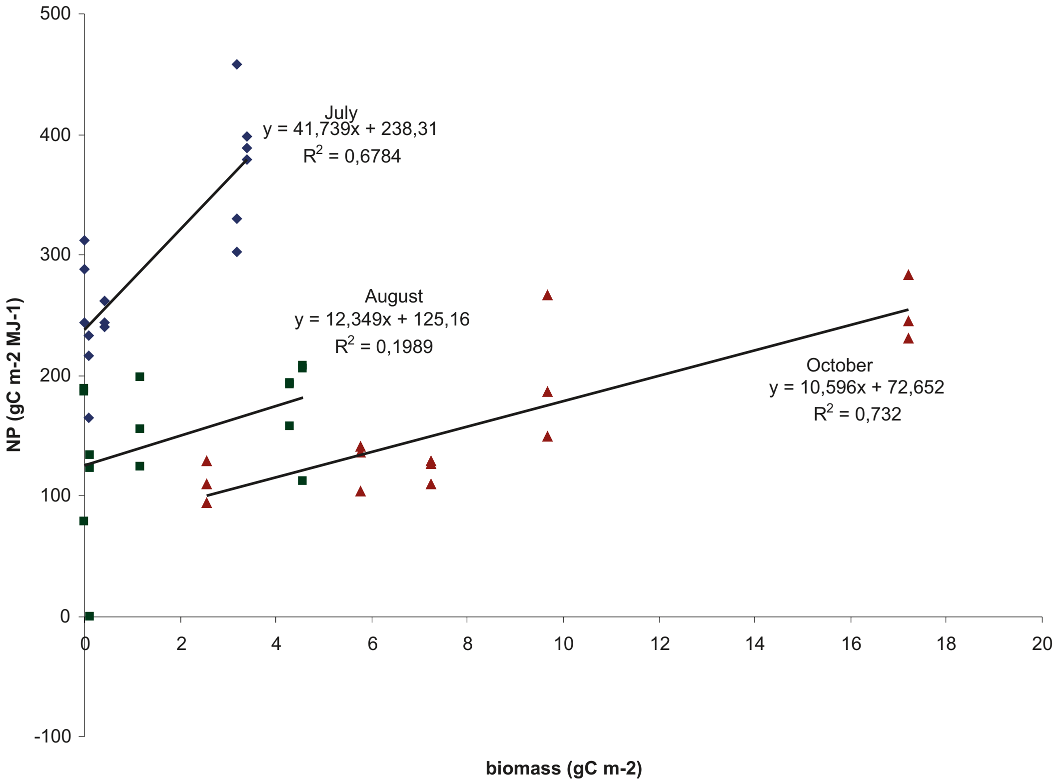


Figure 4-10. *Net primary production of Potamogeton pectinatus. (mgC m–2 MJ^{-1}) and biomass (gC m^{-2}) at different periods from the study by /Wijnbladh and Plantman 2007/.*

Values for *Vaucheria sp*. communities were obtained from NPP measurements performed in the Baltic within the SKB Site Investigation programme at Forsmark (n=10 sites) /Borgiel 2006/. The study was only performed at two occasions, so no reliable correlation to irradiance was obtained. Instead, monthly NPP was estimated for the site (biomass: 152 gC m^{-2}) and annual production was estimated using interpolation in relation to average monthly irradiance. Annual NPP was calculated to be 67 gC m^{-2} and assumed to be an average valid for all areas with a biomass equal to or exceeding 25 gC m^{-2} (Table 4-8).

For red algae communities, data from three studies of daily NPP for *Furcellaria lumbricalis* (n=4 sites) /Paalme and Kukk 2003, Wallentinus 1978/ and *Phyllophora truncate* (n=1) /Wallentinus 1978/ and red algae community (n=1) /Borgiel 2006/ displayed no correlation to daily irradiance. Red algae have a wide depth range, so the studies cited represent several depths. It is likely that algae present at larger depths are better adapted to poor light conditions, so it is not surprising to find a lack of P-I relationship for this diverse group. For production calculation, average daily NPP was assumed to be present at all light conditions. Factors for calculating NPP of filamentous algae are found in Table 4-8.

Daily *in situ* measured NPP from four studies of *F. vesiculosus* (n=72) /Guterstam et al. 1978, Guterstam 1979, Lindblad et al. 1984, Paalme and Kukk 2003/ were correlated to daily irradiance. NPP was positively correlated to irradiance (r^2 = 0.57), see Figure 4-11 and Table 4-8.

For *Z. marina* data from measurements performed by /Wijnbladh and Plantman 2006/ during 2005 and 2006 were used (Figure 4-12).

Incorporation by nitrogen (N) and phosphorus (P) during photosynthesis were estimated according to the Redfield ratio, C:N:P = 106:16:1. The Redfield ratio is the molecular ratio of carbon, nitrogen and phosphorus in phytoplankton /Redfield 1934/. This was applied to the production of the functional groups of all primary producers and was done to give an indication of the amount of N and P in the NPP flux. It is not intended to be valid for the actual amount of N and P which is incorporated during photosynthesis.

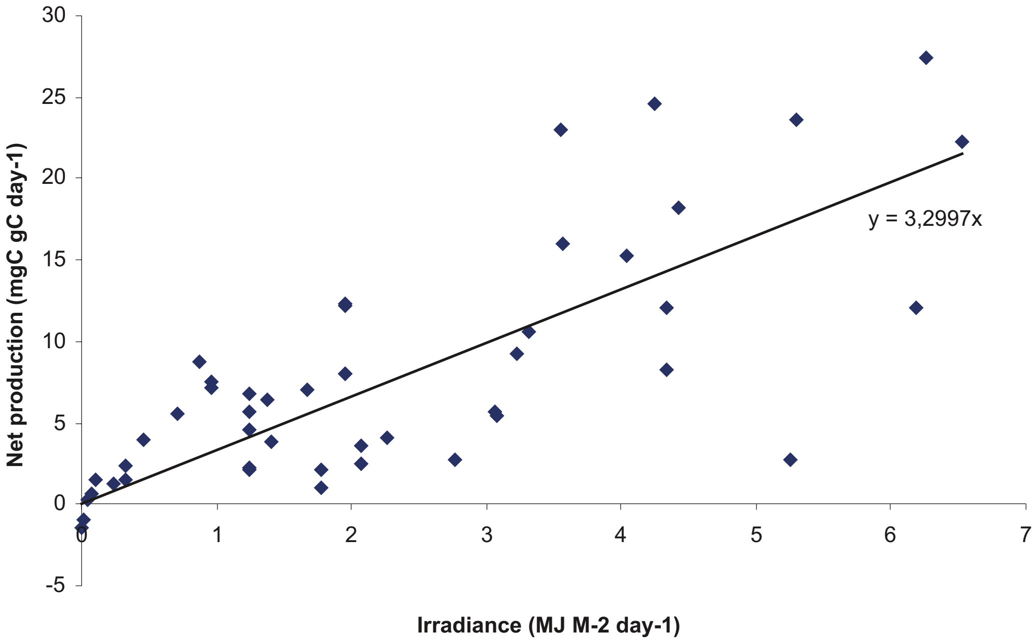


Figure 4-11. *Net primary production of Fucus vesiculosus (mgC $gC^{-1}d^{-1}$) and daily in situ irradiance (MJ PAR $m^{-2}d^{-1}$) from four studies. (r^2 = 0.57).*

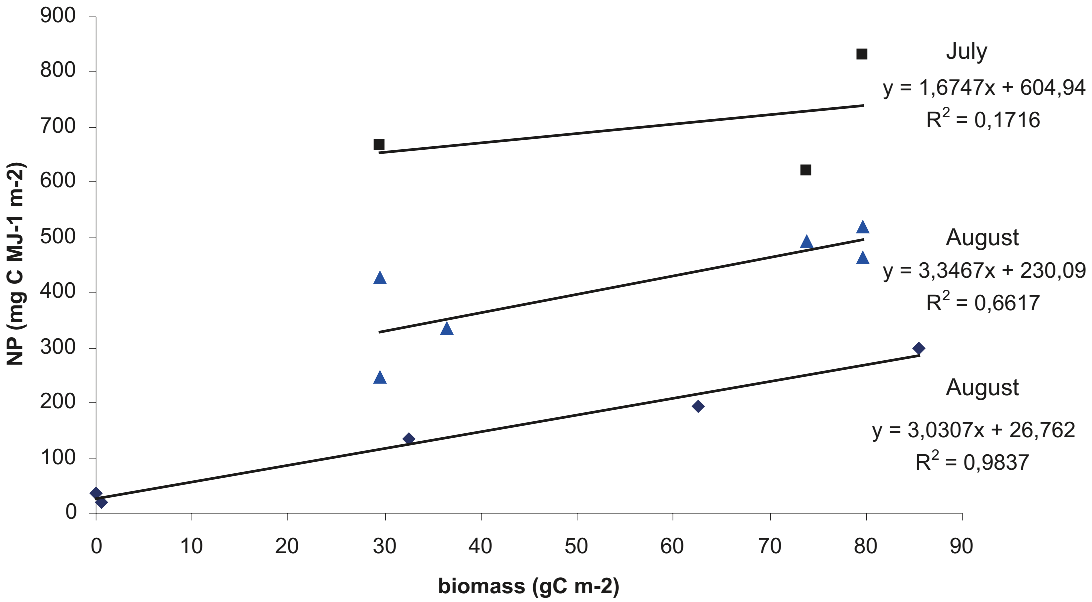


Figure 4-12. *Net primary production of Zostera marina (mgC m^{-2} MJ^{-1}) and biomass (gC m^{-2}) at different periods from the study by /Wijnbladh and Plantman 2006/.*

4.2.2 Microphytes – both sites

Biomasses of microphytobenthos were measured *in situ* by /Snoeijs 1986/ and were assumed to be evenly distributed in the photic zone. Biomasses at Forsmark and Laxemar-Simpevarp were estimated from GP/B quotas (k = 12.9) from /Snoeijs 1986/, which are similar to average GP/B quotas (12.1) for other reported biomass and production measurements.

Microphytobenthos primary production was estimated by /Borgiel et al. 2007/ (Forsmark) and /Wijnbladh and Plantman 2006/ (Laxemar-Simpevarp). NPP was assumed to be dependent on *in situ* irradiance and potential substrate. All substrates were assumed to be possible substrates except dense (> 50% cover) vegetation communities. Vegetation is a possible and in some cases a plausible substrate for microphytobenthos but is assumed to be included in macrophyte primary production and hence excluded as a separate item.

$$D \cdot I \cdot LA \cdot x$$

Where D is depth (m), I is measured irradiance over water (MJ m^{-2}), LA is light attenuation (%) (se section 4.3.4) and x is a constant (x = 24.57) obtained from a relationship found between light and measured Net Primary Production on eight occasions (including five samples on each occasion) in the Simpevarp area /Wijnbladh and Plantman 2006/, see Figure 4-13.

4.2.3 Phytoplankton – both sites

Three factors were accounted for in modelling of phytoplankton biomass and production: (1) deepwater nutrients, (2) coastal nutrients and (3) specific stratified estuarine situations.

Firstly, the summary of available phytoplankton measurements at the study sites suggests an overall correlation between phytoplankton abundance and availability of higher concentrations of nutrients (notably phosphorus) below the upper thermocline or halocline. A lower mean phytoplankton biomass concentration is seen, for example, in the shallower Asphällsfjärden compared with the central Öregrundsgrepen, which is more directly in contact with water below

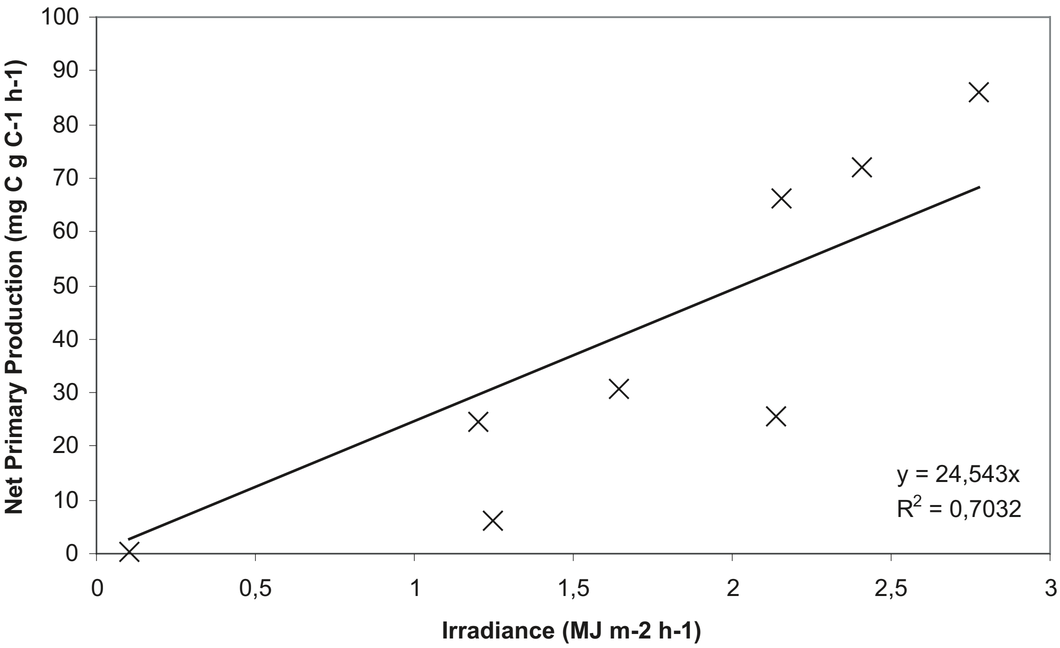


Figure 4-13. *Net primary production by microphytobenthos (mgC $gC^{-1}h^{-1}$) and daily in situ irradiance (MJ PAR $m^{-2}h^{-1}$) from one study. (r^2 = 0.70).*

the spring thermocline. An overall rough fit between observations and morphology was obtained when the phytoplankton biomass (in gC m^{-3}, on a yearly basis) based on this contribution was modelled as

= 0.5/p = 0.025 for d > p

= 0.5/p–0.03 (1–exp((0.0002 / s) × (d–p)) for b < d < p

= 0 for d < b

where d is water depth, p is the depth of the thermocline (= 20 m), s is the overall coastal slope (1/500 in Forsmark and 1/400 in Laxemar-Simpevarp, see section 3.3.1) and b sets a depth limit for deepwater influence at b = ((ln (1–((0.5 / p) / 0.03))) / (0.0002 / s)) + p.

The deepwater nutrient contribution to the mean phytoplankton biomass was thus described as reaching a maximum where the depth > 20, then exponentially decreasing towards zero at a depth dependent on the overall slope.

Secondly, lower wave incidence and associated mixing in sheltered areas play a vital role for triggering the onset and intensity of the spring bloom /Eilola 1998/. The Simplified Wave Model exposure index (SWM) /Isæus 2004/ was therefore used to describe an additional diffuse contribution to phytoplankton biomass from coastal runoff, thus calculated (in gC m^{-3}) as

$$\frac{6 - \log SWM}{150}$$ in Forsmark, and

$$\frac{6 - \log SWM}{75}$$ in the less oligotrophic Laxemar-Simpevarp area

Thirdly, an estuarine contribution was assumed in the two cases with marked river-nutrient enriched estuarine stratification, namely in Kallrigafjärden (Forsmark area) and the innermost part of Borholmsfjärden (Laxemar-Simpevarp area), and derived as in Table 4-9.

In the spatial analysis, both areas were divided into two sub-areas along the estuarine gradient, plus a third outer transition zone off Kallrigafjärden. In the innermost sub-areas, the estuarine contribution to phytoplankton biomass (in gC m^{-3}) was modelled as

0.17–(0.0000175 × SWM) in Kallrigafjärden, and

0.07–(0.0000133 × SWM in Borholmsfjärden

and in the outer subareas as (0.02 × d2) + 0.01 in both areas, where d2 = 2 where water depth d > 2, and d2 = d where d < 2.

The three contributions were added to yield the total phytoplankton biomass in gC m^{-3}. Areal biomass (gC m^{-2}) was then obtained by multiplying by the water depth d (where d < 20) or 20 (where d > 20).

Table 4-9. Derivation of the estuarine contribution to primary production and biomass from runoff in Kallrigafjärden Bay (Forsmark subarea) and Borholmsfjärden Bay (Laxemar-Simpevarp subarea).

quantity	Kallrigafjärden Bay				Borholmsfjärden Bay				units
	innermost part		**entire bay**		**innermost part**		**south basin**		
Freshwater inflow, q	8.8	1	8.8	1	0.19	2	0.19	2	m^3s^{-1}
Ambient freshwater PO4-P conc., P	0.15	3	0.15	3	0.26	4	0.26	4	uM P
Recipient area, a	2.2	5	7.6	6	0.18		0.93		km^2
Surface layer thickness, h	1.6	5	1.9	6	3.0		4.0		m
Volume above pycnocline, v = ha	0.0035		0.014		0.00053		0.0037		km^3
Recipient flushing time, t = v/q	4.6		19		32		225		d
Phytoplankton rate of PO4-P removal,[7] V	0.18		0.18		0.27		0.27		d^{-1}
PO4-P removal during flushing, p = P(1–(1–V)^t)	0.087		0.14		0.26		0.26		uM P
Carbon equivalence[8], p/t	8.8		3.5		3.7		0.53		gC $m^{-3}y^{-1}$
Fluvial-based primary prod., p/th	14		6.6		11		2.1		gC $m^{-2}y^{-1}$
Production/Biomass ratio[9], r	70		70		70		70		y^{-1}
Fluvial-based biomass per area, p/thr	0.20		0.094		0.16		0.030		gC m^{-2}
Fluvial-based biomass per volume, p/tr	0.13		0.051		0.053		0.0076		gC m^{-3}

[1] /Persson et al. 1993/.

[2] Product of catchment size (sum of catchments 9 and 10) and the regional relationship discharge:catchment size (from Emån) /Goffeng 1977/.

[3] Mean PO_4-P concentration in 1972–2006 in Forsmarksån Johannisfors 4.5 µg L^{-1} /IMA 2007/.

[4] Mean PO_4-P concentration at PSM002085 and PSM002087 /Tröjbom and Söderbäck 2006ab/.

[5] Data for recipient Kallriga I in /Håkanson et al. 1984/.

[6] Data for recipient Kallriga II in /Håkanson et al. 1984/.

[7] Estimated using Michaelis-Menten uptake kinetics ($V = V_mP/(K_s+P)$) with a maximum specific PO_4-P uptake V_m at 0.8 d–1 /Lessin et al. 2007/ and a half saturation constant for PO_4-P, K_s at 0.5 µM /Fisher et al. 1988/,

[8] using Redfield molar ratio C:P = 106:1.

[9] For new production /Harvey et al. 2003/.

Annual average phytoplankton production (in gC $m^{-2}y^{-1}$) was obtained by multiplying areal biomass by an overall production/biomass (P/B) ratio set at 101 and 98 y^{-1} in Forsmark and Laxemar-Simpevarp, respectively, based on annual average of ratios listed by /Harvey et al. 2003/, in turn based on /Sandberg et al. 2000/, based on /Elmgren's 1984/ and /Wulff and Ulanowicz 1989/.

4.2.4 Benthic bacteria – both sites

Benthic bacteria biomass in the top 5 cm of sediment was measured by /Andersson et al. 2006/ in marine basins in Forsmark and in Laxemar-Simpevarp. The mean biomasses from these investigations were used in the calculations.

Bacterial biomass samples from shallow (less than 20 m depth) less exposed (n=4) soft bottoms in Forsmark were found to correlate ($r^2 = 0.99$) to wave exposure index (SWM). SWM is the Simplified Wave Model exposure index according to /Isæus 2004/. The correlation was used to generate the spatial distribution of bacteria on the site, with the SWM grid.

In Laxemar-Simpevarp the correlation was weaker, so the mean bacterial biomass (6.53 gC m^{-2}, n=8) was used for all the less exposed (SWM < 20,000, representing coastal marine areas) soft bottoms on the site to model the spatial distribution of benthic bacteria.

For soft bottoms representing offshore areas where the SWM index exceeds 20,000, the average found by /Mohammadi et al. 1993/ in the Bothnian Bay, 2.13 gC m^{-2}, was used for both Forsmark and Laxemar-Simpevarp.

Studies of bacterial density in sediment by /Jørgensen and Revsbech 1989/ in Öresund were used to model the depth distribution of bacteria in the soft bottoms. /Jørgensen and Revsbech 1989/ found decreasing density with sediment depth. Their figures show that 20.5% of the bacteria in 10 cm of sediment were found below 5 cm and 79.5% above 5 cm, and calculations of their data generated a factor (1.26) for modelling of the depth distribution of the total bacterial biomass in the top 10 cm of the soft bottom sediment.

The bacterial biomass in Forsmark on shallow less exposed soft bottom sediment was modelled according to:

$$Biomass = [13.938 - (2.325 \cdot LogSWM)] \cdot 1.26$$

The bacterial biomass in Forsmark and Laxemar-Simpevarp offshore on deeper soft bottom sediment was modelled according to:

$$Biomass = [2.13 \cdot SWM > 20000)] \cdot 1.26$$

where SWM is the wave exposure index.

The bacterial biomass in Laxemar-Simpevarp on shallow less exposed soft bottom sediment was modelled according to:

$$Biomass = [6.53 \cdot SWM < 20000)] \cdot 1.26$$

where SWM is the wave exposure index.

Hard bottom substrate was assumed to have one tenth of the average bacterial biomass calculated for soft bottoms according to:

$$Biomass = [2.13 \cdot SWM > 20000)] \cdot 1.26 \cdot 0.1$$

for deeper more exposed offshore hard bottoms at both sites, and according to:

$$Biomass = [13.938 - (2.325 \cdot LogSWM)] \cdot 1.26 \cdot 0.1$$

for shallower areas in Forsmark and according to:

$$Biomass = [6.53 \cdot SWM < 20000)] \cdot 1.26 \cdot 0.1$$

for less exposed areas in Laxemar-Simpevarp.

Respiration (R) was calculated using the grids for annual average temperature and biomass (see above) together with specific values (for each functional group) describing specific respiration in relation to biomass. The specific respiration figures were given in gC gC^{-1} d^{-1} and had to be summarized to gC gC^{-1} d^{-1} $year^{-1}$ before calculation, since the grids for temperature and biomass are annual mean values.

Consumption was calculated with a C/R-factor (2) for benthic bacteria from /Kumblad et al. 2003/.

4.2.5 Benthic fauna – both sites

Benthic fauna was diveded into four functional groups: carnivores, detrivores, filter feeders and herbivores. Species were grouped into each of these groups using classifications in /Kautsky 1995b/. Biomass was calculated for these groups from average values obtained from four studies in the area /Borgiel 2005, Kautsky et al. 1999, Odelström et al. 2001/ including unpublished monitoring data (1993 or 1997 to 2006) from the National Board of Fisheries, parts of which are reported in annual reports /e.g. Mo 2002, 2003, Sandström et al. 2002/. Data from three sample sites south of the area (Gräsö area) were used to compensate for the lack of data from deep soft-bottom communities /Lindahl et al. 1983/.

Benthic detritivores also include meiofauna, an organism group that has not been studied in the areas. Data from studies in the northern Baltic Proper, the Askö area, southeast of Stockholm, were therefore used in the calculations /Ankar and Elmgren 1978/.

The functional group benthic omnivores (represented by crustaceans such as *Gammarus sp.* and *Idothea* sp.) was divided into benthic carnivores and benthic herbivores (50% in each).

Distribution of benthic fauna biomass data was done depending on vegetation community or substrate type according to the diagram in Figure 4-14. Substrate type was classified as described in section 4.3.7 and vegetation type as defined earlier in this section.

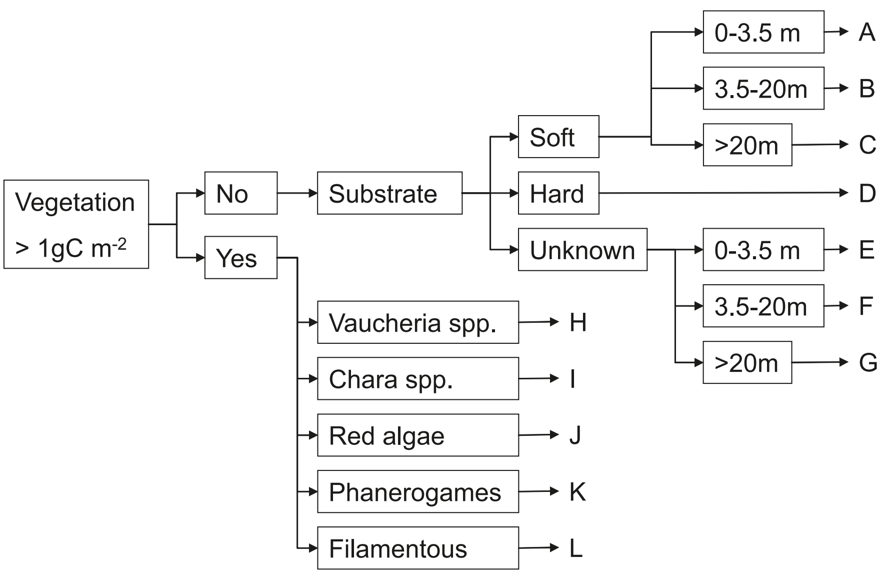


Figure 4-14. *Classification of vegetation community or substrate type used to distribute benthic biomass.*

Biomasses for each of the four functional benthic fauna groups were assigned average values from the compiled dataset according to bottom class A-L (see Table 4-10). In areas with vegetation > 1 gC m^{-2}, the biomass of the benthic fauna was calculated as follows:

$$Biomass = \left(\frac{B_H}{\sum_H^L B} \right) \cdot F_H + \left(\frac{B_I}{\sum_H^L B} \right) \cdot F_I + \left(\frac{B_J}{\sum_H^L B} \right) \cdot F_J + \left(\frac{B_K}{\sum_H^L B} \right) \cdot F_K + \left(\frac{B_L}{\sum_H^L B} \right) \cdot F_L$$

where B_X is the vegetation biomass in each cell and F_X is the benthic fauna biomass for vegetation community X. The values of F for the vegetation communities and other substrate types A to L are found in Table 4-10.

This method was repeated for the four functional groups in Forsmark and for three of the functional groups in Laxemar-Simpevarp (Table 4-10).

Hard bottom fauna in Laxemar-Simpevarp were investigated specifically in /Tobiasson 2003, Fredriksson and Tobiasson 2003, Fredriksson 2005/. Based on data from the investigations, covering degree of *M. edulis* was correlated to depth, and a relationship between cover degree, biomass and total share of biomass by the various functional groups was also found. These relationships were used to calculate the spatial distribution of hard bottom fauna in Laxemar-Simpevarp, according to:

$$Biomass = B \ \cdot F_L$$

Respiration was calculated using the grids for annual average temperature and biomass (see above) together with specific values (for each functional group) describing specific respiration in relation to biomass. The specific respiration figures were given in gC gC^{-1} d^{-1} and had to be summarized to gC gC^{-1} d^{-1} $year^{-1}$ before calculation, since the grids for temperature and biomass are annual mean values. Consumption was calculated with a C/R-factor (3) for benthic fauna from /Kumblad et al. 2003/.

Table 4-10. Benthic fauna biomass (gC m^{-2}) in bottom class A-L (see Figure 4-14).

	Carnivores	Detrivores	Filter feeders	Herbivores	Sample size (incl. sub samples)
A	0.06	4.19	0.02	0.25	5 (17, 2724)[1]
B	0.66	2.04	0.41	0	5 (17, 2724)[1]
C	0.68	2.88	0	0	2
D	0.23	1.93	0.83	0.95	(13)
E	0.12	3.93	0.95	0.99	Av[2]
F	0.37	2.65	1.03	0	Av[2]
G	0.57	3.00	0.94	0	Av[2]
H	0.17	4.39	0.55	0.27	2 (6)
I	0.18	11.32	0.49	2.23	1 (3)
J	0.26	3.29	3.34	2.91	20 (44)
K	0.15	9.21	0.50	0.89	3 (7)
L	0.06	6.58	1.52	1.64	8 (29)

1. Five sites, in all 17 subsamples and 2,726 samples during the period 1980–2005.

2. *Av* is Average for occurrence of soft and hard substrate in the area.

4.2.6 Zooplankton – both sites

For the model to roughly describe measured mean concentrations of zooplankton (biomass per volume in gC m^{-3}) /Eriksson et al. 1977, Huononen and Borgiel 2005/, this value was set at 1/3 of the volume for phytoplankton. As with phytoplankton, areal biomass (gC m^{-2}) was obtained by multiplying the obtained value by the water depth d (where d < 20 m) or 20 (where d > 20 m).

To estimate zooplankton consumption and respiration (in gC $m^{-2}y^{-1}$) Q/B (consumption/biomass), ratios of 222 and 307 y^{-1} were used for the Forsmark area and the Laxemar-Simpevarp area, respectively, and R/B (respiration/biomass) ratios of 90 and 126 y^{-1}, respectively, based on measurements /Sandberg et al. 2000, Harvey et al. 2003/.

4.2.7 Bacterioplankton

Bacterioplankton biomass shows much less spatial and temporal variability than phytoplankton biomass. It was measured by /Andersson et al. 2006/ and a mean concentration in the surface water (above the thermocline) can be modelled uniformly at 0.025 gC m^{-3} in both Forsmark and Laxemar-Simpevarp, which is similar to the spring values reported by /Kuparinen et al. 1996/. The latter also reported low bacterioplankton growth in the deeper pelagic, so the areal biomass (in gC m^{-2}) was expressed as 0.025 × d (water depth) for d < 20 m and 0.025 × 20 for d > 20 m.

Forsmark

For mapping yearly bacterioplankton consumption and respiration (in gC $m^{-2}y^{-1}$), consumption/biomass (Q/B) and respiration/biomass (R/B) ratios of 257 and 114 y^{-1}, respectively, for the Bothnian Sea were used /Sandberg et al. 2000, Harvey et al. 2003/. Thus, consumption was set equal to biomass × 257 y^{-1} and respiration to biomass × 114 y^{-1}. The difference, biomass × 143 y^{-1}, represents bacterioplankton production.

Laxemar-Simpevarp

Similarly, in Laxemar-Simpevarp, Q/B and R/B ratios for the Baltic Proper of 248 and 105 y^{-1}, respectively, were used, based on measurements /Sandberg et al. 2000, Harvey et al. 2003/. Thus, consumption was set to equal biomass × 248 and respiration to biomass × 105 (in gC $m^{-2}y^{-1}$). The difference represents the same level of bacterioplankton production as that used for Forsmark, biomass × 143 y^{-1}.

4.2.8 Fish

The fish species at both sites were divided into three functional groups: zooplanktivorous (zooplankton-feeding) fish, benthivorous (benthic-feeding) fish and piscivorous (fish-feeding) fish, according to /Lindborg 2006/. Divisions were made in the dataset from /Heibo and Karås 2005/. (Table 4-11).

Table 4-11. Fish divided into three functional groups; zooplanctivorous, benhtivorous and piscivorous (piscivorous) feeders.

Functional group	Zooplanktivorous	Benthivorous	Piscivorous
Species	Sik (Baltic whitefish), Löja, (Bleak), Strömming (Baltic herring), Skarpsill (Sprat), Nors (Smelt)	Björkna (Silver Bream), Braxen (Bream), Gers (Ruffe), Mört (Roach), Sarv (Rudd), Vimma (Vimba), Hornsimpa (Fourhorned sculpin), Sutare (Tench), Tånglake (Viviparous blenny), Stensimpa (Bullhead)	Id (Ide), Abborre (Eurasian Perch) Gädda (Northern Pike), Gös (European pike-perch), Lake (Burbot)

Forsmark

The method for modelling of fish in Forsmark is extensively described in /Carlén et al. 2007/ Modelling was done in GRASP (Generalized Regression Analysis and Spatial Predictions), a set of S-PLUS/R functions developed for modelling and analysis of the spatial distribution of species /Lehmann et al. 2002/. GRASP communicates with ArcView, and resulting distribution maps are in ArcView format.

GRASP uses GAM, generalized additive models /Hastie and Tibshirani 1990/ to fit predictor variables independently by means of non-parametric smooth functions. The best model is selected by a stepwise procedure where progressively simpler models are compared with a measure such as Akaike's Information Criterion. Abundance modelling was used here, which gives results in the form of grids with abundance estimates (in this case gC m^{-2}) for each grid cell.

Three sets of data were used to spatially model fish biomass in the investigated area: two studies on pelagic fish populations from August to September 2004 using Coastal survey nets and Nordic nets (data from the Swedish Board of Fisheries, Abrahamsson and Karås 2005, Heibo and Karås 2005), and one study on demersal fish from August to September 2006 using hydroacoustics and trawling (Sture Hansson, pers. comm.). In all, 309 data points were used in modelling.

Estimates of fish biomass per hectare were calculated by multiplying biomass per net and night of fishing by the constant 17. This conversion factor is used for Nordic nets of the size 82.35 square metres. Coastal nets were further multiplied by 0.7843 to compensate for the smaller size of these nets. These conversion factors are highly uncertain but were used in the absence of other available methods /Heibo and Karås 2005/.

The values were converted from wet weight to dry weight using conversion factors from /Engdahl et al. 2006/, and then to gC using species-specific conversion factors from /Kautsky 1995b/. Conversion factors are shown in Table 4-12.

Modelling was done using data from surveys during August and September. However, there is no detailed knowledge about the yearly variation of fish stocks, and therefore no correction to achieve a yearly mean has been attempted.

Available predictors in the modelling of fish biomass in the Forsmark area were depth, slope, aspect, bottom temperature, pelagic temperature, Secchi depth, wave exposure (SWM, log-transformed), light percentage at the bottom and days above 5 MJ, all described in section 4.3. Macrophyte grids from the modelling above were also used as predictor layers /Carlén et al. 2007/.

As the food preference of perch has a great impact on the proportions of functional groups of the fish, a special effort was made to estimate this in Forsmark. In /Figure 3-1 in Heibo and Karås 2005, Figure 3-1/ food preference is presented for each size group. Planktivory is dominant in sizes up to 7 cm, larger fish are benthivorous up to 15 cm and to a small extent piscivorous. Half of the food of fish larger than 25 cm is other fish. Based on fish catches in Forsmark in 2004 and a weight-size ratio / Figure 3-1, 4-4, Heibo and Karås 2005/, it was estimated that less than 1% of the perch biomass was planktivorous, 85% was benthivorous and 15% was piscivorous. Of the modelled "piscivorous" fish, perch constituted approximately 77%. Therefore, to

Table 4-12. Conversion factors for fish species groups in the Forsmark area.

	Conversion factor from ww m^{-2} to g dw m^{-2}	Conversion factor from g dw m^{-2} to gC m^{-2} (for exact numbers for each species see Kautsky 1995b)
Zooplanktivorous	0.209	~ 0.5
Benthivorous	0.209	~ 0.5
Piscivorous	0.209	~ 0.5

obtain a more reliable estimate of the biomass of true piscivores, the modelled piscivores were recalculated according to:

$$\mathrm{P} = (P_m \cdot 0.23) + P_m \cdot 0.77 \cdot 0.15$$

where P is the piscivorous fish biomass and P_m is the originally modelled biomass.

The difference between the originally modelled and the recalculated piscivorous fish biomass was added to the benthivorous group.

Laxemar-Simpevarp

The detailed spatial resolution of fish data was not available in Laxemar-Simpevarp, so another method was used.

Different methods for inshore and offshore areas were used. Offshore area was defined on the basis of wave exposure: a clear gradient is found at SWM > 20,000, where inshore areas are separated from offshore areas. Data from Hydroacoustics and trawling /Enderlein 2005/ were used for offshore areas and data from a thorough programme including several separate methods was used for modelling fish one basin in the inshore area /Adill and Andersson 2006/. Both studies presented fish density.

To estimate piscivorous fish, the proportion between zooplankton-feeding fish and piscivorous fish found in catches by the Swedish Board of Fisheries (*SW: Fiskeriverket*) between zooplankton feeding fish and piscivorous fish was used. The biomass of benthivorous fish was estimated in the same way for inshore and offshore areas. Fish densities for different vegetation and bottom types were estimated by /Jansson et al. 1985/ by diving and counting *in situ* in an archipelago south of Stockholm (Askö area). These figures were set in proportion to those found by modelling of the various vegetation communities(see earlier in this section) as follows:

$$Biomass = \left(\frac{B_A}{\sum_{VI}^{A} B}\right) \cdot F_A + \left(\frac{B_V}{\sum_{VI}^{A} B}\right) \cdot F_V + \left(\frac{B_I}{\sum_{VI}^{A} B}\right) \cdot F_I + \left(\frac{B_{II}}{\sum_{VI}^{A} B}\right) \cdot F_{II} + \left(\frac{B_{III}}{\sum_{VI}^{A} B}\right) \cdot F_{III} \left(\frac{B_{VI}}{\sum_{VI}^{A} B}\right) \cdot F_{VI}$$

where B_X is the vegetation biomass in each cell and F_X is the fish biomass for each vegetation or bottom type X. The values of F for the vegetation communities are shown in Table 4-13.

Table 4-13. Fish biomasses for various vegetation communities.

Code	Bottom type (this study)	Vegetation type /Jansson et al. 1985/	Biomass (gC m^{-2})
A	Chara spp.	Average	0.418
V	Zostera spp.	Potamogeton-Ruppia	0.11
V	Phanerogams	Potamogeton-Ruppia	0.11
I	Filamentous	Annual belt	0.1
II	Fucus spp.	Fucus belt	0.43
III	Red algae	Red-algal belt	0.21
VI	Vaucheria spp.	Deep soft bottoms	0.6

As the fish associated with bottom type was assumed to be benthivorous (all of the dominant species were benthic feeding species in /Jansson et al. 1985/), piscivorous and zooplanktivorous fish in inshore areas were calculated from the proportions of these groups found in the beach seine catches in the study by /Adill and Andersson 2006/. The ratio of benthivorous to piscivorous fish was found to be 1:0.3 and zooplankton-feeding to benthic-feeding 1:0.29.

No trends of biomass versus physical variables were found for the few individual samples from the hydroacoustic lines sampling, so an average for offshore areas was used to estimate pelagic fish. The average (0.424 gC m^{-2}) was taken from /Enderlein 2005/ representing zooplanktivorous species (mainly sprat and herring) that were evenly distributed in the offshore areas. Piscivorous fishes were calculated using the proportions of these groups found in reported catches from pelagic waters outside Simpevarp /Swedish Board of Fisheries unpubl./. The ratio of zooplankton-feeding fish to piscivorous fish was found to be 1:0.04.

4.2.9 Birds and mammals

Birds biomass and consumption – both sites

The biomass of each bird species was calculated as body weight × the number of adults per breeding territory × the number of breeding territories in the area, as compiled by /Löfgren and Nordén 2008/. This fresh-weight biomass (in kg) was multiplied by the factor 511 kJ per 100 g wet weight /KTL 2007/, then divided by the conversion factor 45.806 kJ per gC /Humphreys 1979/ and the area of the foraging environment (in Forsmark, 20 km^2 for 0–5 m water depth and 83 km^2 for 0–20 m; in Laxemar-Simpevarp, 21 km^2 for 0–5 m water depth and 89 km^2 for 0–20 m), thus:

$$B = \frac{FW \cdot 511}{A \cdot 45.806 \cdot 10^5}$$

where B is Biomass in gC m^{-2}, FW is biomass in kg fresh weight, A is area in $km^{2.}$

Bird consumption was estimated via field metabolic rates (FMR), where FMR is represented by the exponential relationship.

FMR (in kJd^{-1}) = body weight (in g) × a^b .

with the values for the constants a and b depending on bird metabolism category as listed in Table 4-14.

The FMR values (kJd^{-1}) were multiplied by the breeding period in days to yield the FMR in kJy^{-1}.

The total FMR in kJy^{-1} was divided by 45.806 kJ per gC /Humphreys 1979/, then further divided by the relevant area to obtain bird consumption in gC $m^{-2}y^{-1}$ for each bird group and habitat (0–5 m and 5–20 m water depth, respectively).

Table 4-14. Power relation constants a and b for each bird-metabolism category /Nagy et al. 1999/.

	a	b
Carnivores and obligate herbivores	10.5	0.681
Order Charadriiformes	8.13	0.77
Order Pelicaniformes (Great cormorant only)	4.54	0.844
Remaining omnivores except eider	9.36	0.628
Eider + remaining piscivores and insectivores	14.25	0.659

Forsmark

Areal biomass and consumption was calculated using data /Green 2005, 2006, Löfgren 2008/ for 44 species of birds breeding in or near the marine environment of the Forsmark area, and foraging in its shallow-water zone (0–5 m depth, with areal extent 20 km^2). Eight of these species were also spatially allocated to the 5–20 m depth zone (areal extent 63 km^2).

The resulting aquatic environment bird biomass was 0.0257 gC m^{-2} for the shallow zone ($d < 5$ m) and 0.00118 gC m^{-2} for the deeper zone (5 m $< d <$ 20 m).

The FMR-derived bird consumption was 4.07 gC $m^{-2}y^{-1}$ for the shallow zone ($d < 5$ m) and 0.171 gC $m^{-2}y^{-1}$ for the deeper zone (5 m $< d <$ 20 m).

Laxemar-Simpevarp

Areal biomass and consumption was calculated using data /Löfgren 2008/ on the 39 species of bird breeding in or near the marine environment of the Laxemar-Simpevarp area, and foraging in its shallow-water zone, 0–5 m depth, with areal extent 21 km^2. Nine of these species were spatially allocated also to the 5–20 m depth zone with areal extent 68 km^2.

The biomass was 0.0216 gC m^{-2} for the shallow zone ($d < 5$ m) and 0.000183 gC m^{-2} for the deeper zone (5 m $< d <$ 20 m).

The FMR-derived bird consumption was 3.11 gC $m^{-2}y^{-1}$ for the shallow zone ($d < 5$ m) and 0.0170 gC $m^{-2}y^{-1}$ for the deeper zone (5 m $< d <$ 20 m).

Seal biomass and consumption – both sites

Grey seal (Halichoerus grypus) is the dominant species of seal in the area. A second species, ringed seal (Phoca hispida), is present but much less abundant /Karlsson 2003/.

Based on a photo ID survey undertaken at all major seal haul-outs in the northern Baltic Proper and the Gulf of Bothnia, the number of seals along 200 km of the SW Bothnian Sea coastline was estimated at 4,940 /Hiby et al. 2007/. Furthermore, the seals are very mobile, capable of moving several 100 km or feeding for prolonged periods fairly close to the haul-out sites /Karlsson 2003/. Since the grey seal also dives to depths up to 100 m with a mean depth of 25 m /Sjöberg 1999/, its foraging biomass and consumption were allocated uniformly across a 20 km wide coastal zone along the 200 km coast, including Öregrundsgrepen, suggesting a foraging seal density of approximately 1.2 seals km^{-2}, with a mean seal body weight of 100 kg (O. Hjerne. pers. comm.), a seal caloric value of 535 kJ hg^{-1} /USDA 2006; Alaska native ringed seal/ and a conversion factor of 45.806 kJ/gC /Humphreys 1979/ this corresponds to an areal seal biomass of 0.0144 gC m^{-2}.

Studies of seal diet composition based on digestive tract content indicate that the fraction of herring, increasing with the decline of the cod population, today constitutes 73 and 48% of the weight of the seal diet in the Bothnian Sea and Baltic Proper, respectively /Lundström et al. 2007/. Based on diet, the total consumption of herring biomass in the Northern Baltic proper was 6,600 ton per 5,700 seals (O. Hjerne. pers. comm*.),* /Bergström et al. 2006/. Comprising 73% of the diet in that geographical area, this would correspond to a total fish consumption of 1.6 tons y^{-1} or 4.4 kg d^{-1}. Using a herring caloric value at 491 kJ hg^{-1} /KTL 2007/, the corresponding carbon consumption is 170 kg C y^{-1}, or, with the above areal seal density, 0.21 gC $m^{-2}\,y^{-1}$.

An alternative estimate of consumption is offered by the compilation of field metabolic rates, FMR, for mammals suggesting FMR = 4.82 $M_b^{0.734}$ /Nagy 2005/ where M_b is the body weight in g and FMR is expressed in kJ d^{-1}. When applied to a 100 kg seal, this relationship yields a field metabolic rate of 22,545 kJ d^{-1}, equivalent to 0.22 gC m^{-2} y^{-1} in the above area.

While in good agreement, the former of the two estimates is judged to be a less accurate estimate of the actual consumption per individual in the SW Bothnian Sea, as compared to the Baltic Proper. The figure applied, 0.22 gC m^{-2} y^{-1}, is therefore mainly an FMR-based estimate for the Forsmark area.

The corresponding figure chosen for the Laxemar-Simpevarp area /Hiby et al. 2007; south of geographical area A/ was 780 seals over a 100x20 km coastal stretch (seal density 0.39 km^{-2}), equivalent to an areal carbon biomass of 0.0046 gC m^{-2}. The diet-based consumption estimate is then 2.4 t y^{-1} or 6.6 kg d^{-1} with an equivalent carbon consumption of 260 kg C y^{-1} or 0.10 gC m^{-2} y^{-1} and an FMR-based estimate of 0.070 gC m^{-2} y^{-1}. As the Laxemar-Simpevarp area is situated to the south of area A along a gradient with declining grey seal abundance, the lower of two estimates, 0.070 gC m^{-2} y^{-1}, was applied.

Human fish consumption – both sites

Catch statistics reported in kg ww $year^{-1}$ in a 1x1 minute rectangle (1.694 km^{-2} in Forsmark, 1.835 km^{-2} in Laxemar-Simpevarp) were kindly provided by Swedish Board of Fisheries (Håkan Westerberg, pers. comm.).

Of the eight fish species caught as a result of commercial and recreational fishery in the southern Bothnian Sea /Ask and Westerberg 2006/ – perch, pike, pike-perch, salmon, common whitefish, herring, eel and sea trout – the detailed statistics suggest eel and salmon are not caught in Öregrundsgrepen. Furthermore, one position in the centre (at 60°25’N: 18°20’E) shows exceptionally high values. It was assumed that this position represents the entire central Öregrundsgrepen. The position was therefore removed and its value divided between and added to the rest of the non-zero values in the area (20 other positions between 60°20’ and 60°30’N) in proportion to these values.

Using conversion factors of 490 kJ/$hgww^{-1}$ (www.fineli.fi) and 45.8 kJ/gC /Humphrey 1979/, the total catch in gC m^{-2} y^{-1} is then distributed as in Figure 4-15 and Figure 4-16.

4.2.10 Respiration and Consumption

Respiration was calculated from biomass and average annual temperature. Respiration of organisms that reside in the pelagic was calculated using the pelagic temperature grid, and for benthic-living organisms, the benthic temperature grid. Calculations of the temperature in the pelagic and benthos are presented in section 4.3.

Respiration was calculated using established conversion factors (from T, degree days to respiration) on specific respiration ($gC \times gC^{-1} \times day^{-1}$) normalized for 20ºC /Kautsky 1995b/ using the relationship:

$$Degreedays = \frac{T \cdot 365}{20}$$

where T was the annual mean of temperature.

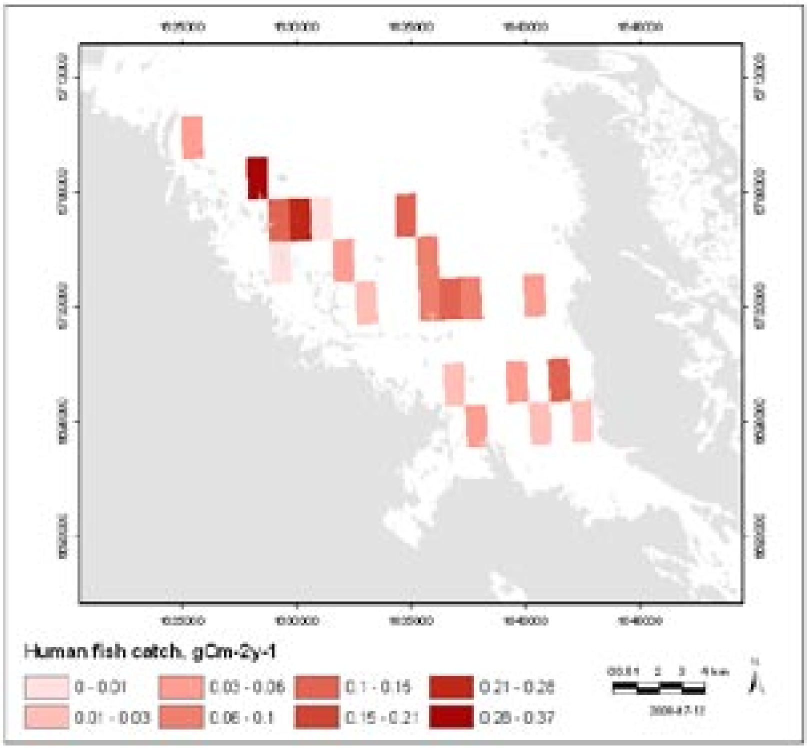


***Figure 4-15.** The distribution of fish catch by humans in the Forsmark area (in gC m^{-2} y^{-1}); sum of perch, pike, pike-perch, common whitefish, herring and sea trout as reported to the Swedish Board of Fisheries (Håkan Westerberg, pers. comm.) and slightly modified with regard to one position. Areas in white have no reported catch of the species.*

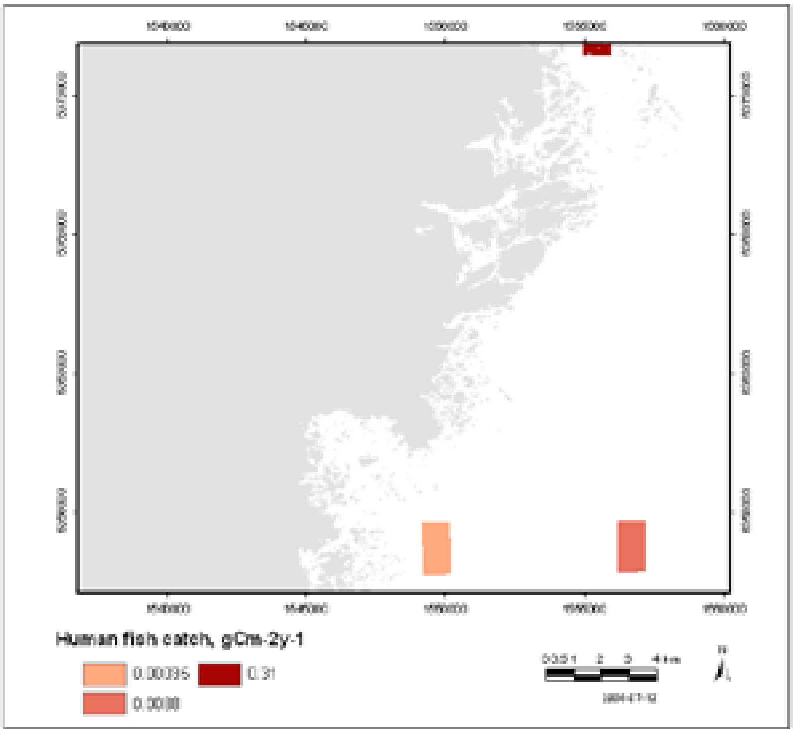


***Figure 4-16.** The distribution of fish catch by humans (in gC m^{-2} y^{-1}); sum of perch, pike, pike-perch, common whitefish, herring and sea trout as reported to the Swedish Board of Fisheries (Håkan Westerberg, pers. comm.) in the Laxemar-Simpevarp area. Areas in white have no reported catch of the species.*

Consumption was estimated from respiration using reported conversion factors from earlier modelling in the Forsmark area, and human consumption from fishery catch, see Table 4-15.

Table 4-15. Consumption/respiration ratio used to calculate consumption from respiration.

Functional group	C/R factor
Zooplankton, benthic fauna,	3 /Kumblad et al. 2003/
Bacterioplankton, benthic bacteria	2 /Kumblad et al. 2003/
Fish	1.73 /Kumblad et al. 2005/
Humans	Consumption calculated from fishery catch.

4.3 Parameterization of abiotic properties

4.3.1 Particulate and dissolved matter – Forsmark

Concentrations of particulate organic carbon (POC) were found to be higher at sheltered stations in the Forsmark area and lower in exposed areas. POC concentration was found to be related (weakly, $r^2 = 0.43$) to wave exposure index (SWM). SWM is the Simplified Wave Model exposure index according to /Isæus 2004/.

POC concentration was multiplied by the DEM (Digital Elevation Model) to obtain an area-dependent POC density grid. The site PFM000062 was excluded as it is likely not to be representative of the ambient wave exposure (as the cooling water is located nearby).

Mean concentrations of DOC (surface and bottom water) was found to be related to POC ($r^2 = 0.77$; $POC = 1.8783e^{2.2109x}$, where x = DOC). Figures on DOC concentration were multiplied by the POC grid to obtain an area-dependent density grid.

Mean concentrations of DIC (surface and bottom water) were found to be related to modelled temperature ($R^2 = 0.67$; $DIC = 5.2533x–25.924$), where x=T). DIC concentrations were multiplied by the DEM to obtain an area-dependent DIC density grid. The site PFM000062 was excluded as it is likely not to be representative of the ambient wave exposure (as the cooling water is located nearby).

4.3.2 Particulate and dissolved matter – Laxemar-Simpevarp

In Laxemar-Simpevarp there was no relationship between the wave exposure index (SWM) and the measured concentrations of POC, DOC and DIC. Mean values of the parameters at sampling sites representative of coastal marine areas were therefore used together with the SWM grid and the DEM to calculate the spatial distribution of POC, DOC and DIC. Coastal marine areas were defined by SWM-index < 20,000.

For offshore basins, mean values of POC, DOC and DIC in the most offshore sampling site were used together with the SWM grid and the DEM. Offshore areas were defined by SWM index > 20,000.

4.3.3 Irradiance – both sites

The same method was used for Forsmark and Laxemar-Simpevarp.

To calculate the percentage of global irradiation (T) reaching the bottom, a script in ArcView was used, where the depth is Z and the light penetration depth is s. N and M are constants corresponding to $I_{surface}$ and κ mentioned in the text and Z is the depth.:

$$T = N \times e^{(M \times Z/s)}$$

In addition to a digital elevation model, the script requires a grid of the penetration depth and the light attenuation coefficients as input values. The derivation of these grids and coefficients is detailed below.

Global irradiation was assumed to consist of 45% photosynthetic active irradiation (PAR), so this figure was used to convert figures of global irradiation to PAR. PAR was needed for correlations to primary production.

Light penetration depth (s) – both sites

Measurements of the penetration depth in the marine environment were available from seven sampling sites in the Forsmark area (PFM000062-65, 82–84) and from five sites in the Laxemar-Simpevarp area (PSM002060-64) for the years 2002 to 2006. All these measurements were used together to calculate penetration depth grids for Forsmark and Laxemar-Simpevarp.

As a first step these data were compiled into monthly mean values. Some of the stations were monitored more frequently than others, so the monthly averages are based on a varying number of observations.

For the Forsmark sites there is a concentration of curves around two levels of penetration depth: 3–4 m and about 1.5 m. The curves with values around 4 m all represent stations located in the more open waters in the north (stations 62, 63 and 82) while the curves around 1.5 m penetration depth represent stations located further to the south in the more closed bay of Kallrigafjärden (stations 64, 65, and 84).

In the Laxemar-Simpevarp case we see the corresponding distinction between open-water stations and closed-bay stations, but with a more gradual increase towards greater penetration depths. By far the greatest penetration depths are found at station PSM002060.

The monthly values for each station were subsequently averaged to obtain yearly mean values as given in Tables 4-16 and 4-17. Note that Forsmark stations 82–84 were omitted at this stage due to their poor data coverage in time.

The yearly mean point values were converted into a grid by creating a regression between the point values and a parameter for which a grid was available.

Two parameters which could logically affect the penetration depth were tested: station depth (digital elevation model, DEM) and wave exposure. All stations for which penetration depth data were available (both in Forsmark and Laxemar-Simpevarp) were included. The penetration depth was more strongly correlated with wave exposure than with depth, $R^2 = 0.825$ (SWM-index) in comparison with $R^2 = 0.5608$(DEM), so the equation of this regression line was used to create the light penetration depth (L_p) grids for Forsmark and Laxemar-Simpevarp based on the wave exposure grid for each site, according to

$$L_p = 1.975\ \mathrm{LN(SWM)} – 13.686$$

Table 4-16. Forsmark light penetration depth. Yearly mean values for 2002–06 and standard deviation.

Station	Pen. Depth (m)	Std. Dev. (m)
PFM000062	3.73	0.3
PFM000063	3.53	0.8
PFM000064	1.49	0.2
PFM000065	1.13	0.2

Table 4-17. Laxemar-Simpevarp light penetration depth. Yearly mean values for 2002–06 and standard deviation.

Station	Pen. Depth (m)	Std. Dev. (m)
PSM002060	12.49	2.7
PSM002061	7.72	0.9
PSM002062	2.20	0.4
PSM002063	5.03	0.6
PSM002064	3.58	0.6

Light attenuation coefficients – both sites

A mean value of the light attenuation coefficient was calculated based on Photosynthetic Active Radiation (PAR) data, measured at the Forsmark sea stations PFM000062-65 during 2003 and 2004.

The PAR data were first normalized to the surface (maximum) value of each measured profile and then expressed as a function of depth by exponential trend curves according to the function

$$I = I_{surface} \cdot e^{-\kappa D},$$

where I is the normalized PAR at a given depth D (m), $I_{surface}$ is the PAR at the surface (normalized), and κ is the attenuation coefficient (m^{-1}). The PAR profiles and trend curves for each sample site are shown in Figure 4-17. The coefficients associated with each trend curve are summarized in Table 4-18.

The similar values of $I_{surface}$ at all stations indicate similar atmospheric conditions and reflectivity of the water during the PAR measurements. However, the fairly broad variation in κ reflects the different types of environment at the different stations.

In the ArcView script, $I_{surface}$ is the same as the constant N, and κ is equivalent to –M/s so that the constant M in the script is the same as $-\kappa \cdot s$.

The ArcView script asks for two values of N and M. However, our knowledge concerning the difference between the two values for each constant in these specific areas is limited, so for the subsequent modelling the overall mean values had to be used: N($I_{surface}$) = 0.77 and M($-\kappa \cdot s$) = –1.88.

Incoming light to bottom

The penetration depth grid and the light attenuation coefficient were then used with the ArcView script to calculate grids of percent of global irradiation reaching the bottom.

The number of days with more than 5 MJ m^{-2} reaching the bottom was derived by combining the global irradiation as measured at station PFM010700 in Forsmark with the respective grids of percent of global irradiation that reach the bottom, presented in the section above.

The half-hourly observations of incoming global irradiation were first integrated to daily values for the period between 1 July 2003 and 30 June 2006 in Forsmark, and between 1 January 2004 and 31 December 2006 at Laxemar-Simpevarp. All three years were then merged into one average curve, as shown in Figure 4-18.

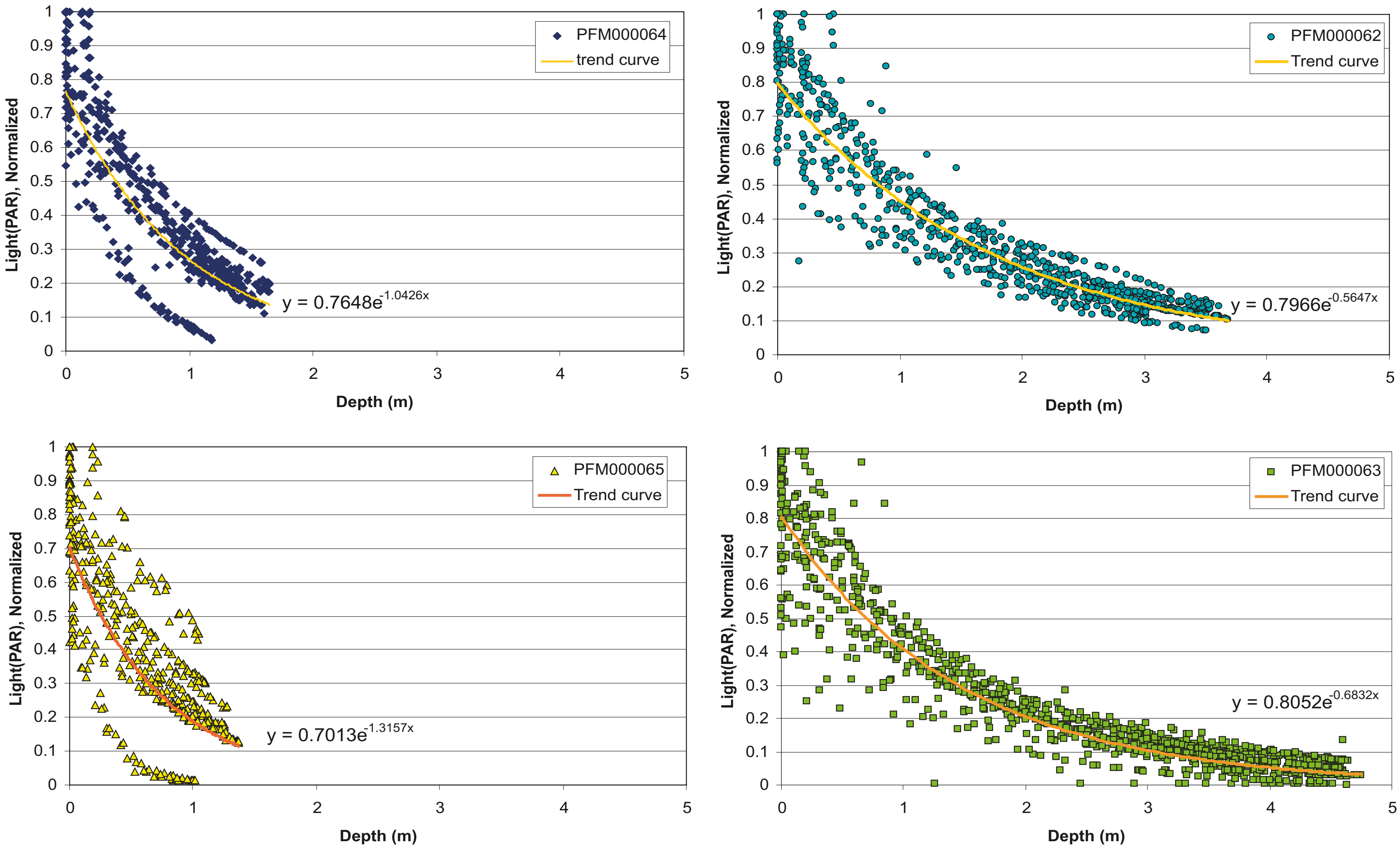


Figure 4-17. *Forsmark incoming radiation (PAR). Exponential trend curves superimposed on observations made during 2003–2004.*

Table 4-18. The normalized surface PAR value $I_{surface}$ and light attenuation coefficient κ for the Forsmark stations PFM000062-65.

Station	$I_{surface}$	κ (m^{-1})
PFM000062	0.797	0.565
PFM000063	0.805	0.683
PFM000064	0.765	1.043
PFM000065	0.701	1.316
Mean value	**0.77**	**0.90**

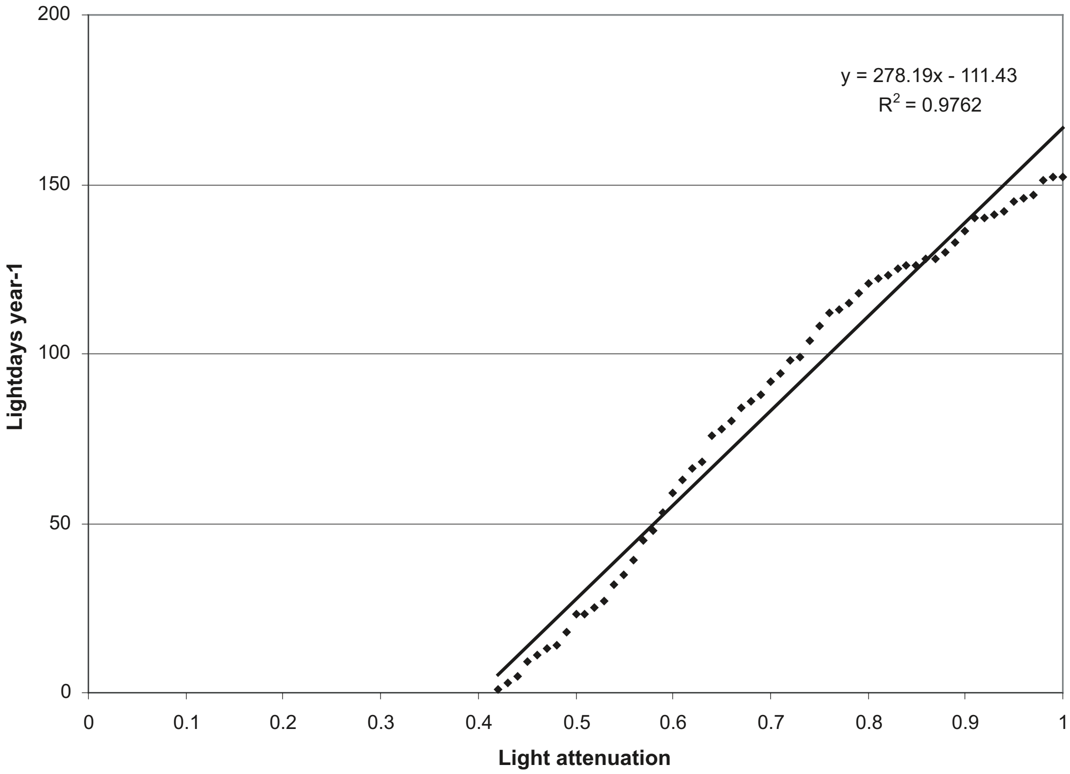


Figure 4-18. *Light days per year in areas with light attenuation between 0 to 1.*

By multiplying these average curves by a factor between 0 and 1 (i.e. 0–100%), number of days was plotted against incoming light to the bottom for which the incoming irradiation was greater than 5 MJ m^{-2}. A simple linear curve was fitted and used to extrapolate a light day grid. The results presenting days per year with incoming irradiation greater than 5 MJ are shown in Figures 4-19 and 4-20.

4.3.4 Temperature – both sites

Water temperature at both sites was generated in the modelling of advective flows in the 3D oceanographic modelling, see section 5 in this report. The mean temperature used here was generated by average temperatures saved every second week (n=25) in the modelling year. Mean pelagic temperature was calculated from data from all 3D grid cells and benthic temperature only from data from cells in contact with the sea floor.

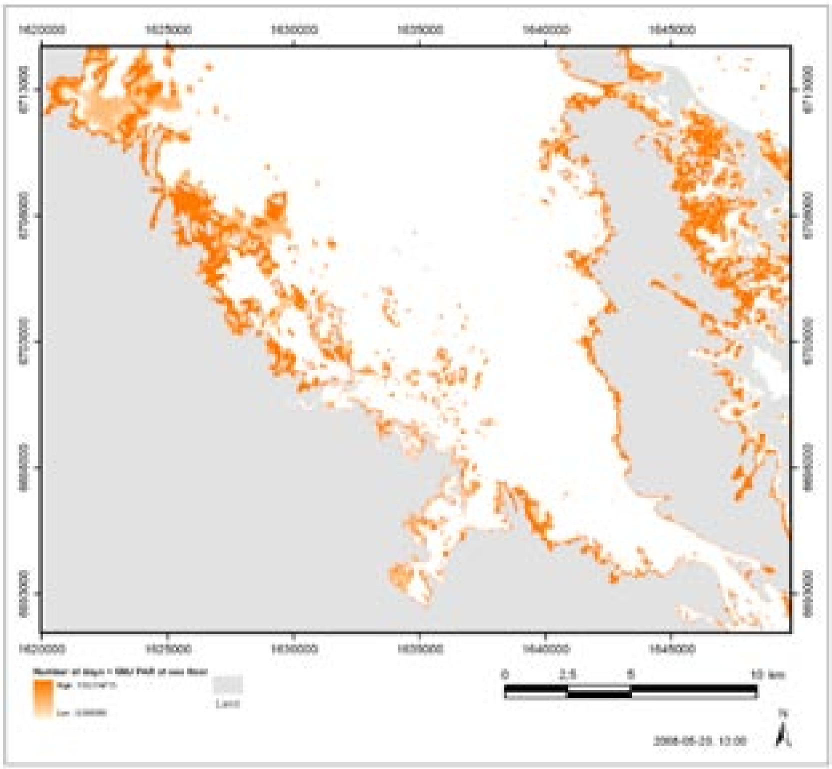


Figure 4-19. *Number of days per year on which irradiance exceeds 5 MJ (PAR) at the bottom in the Forsmark area.*

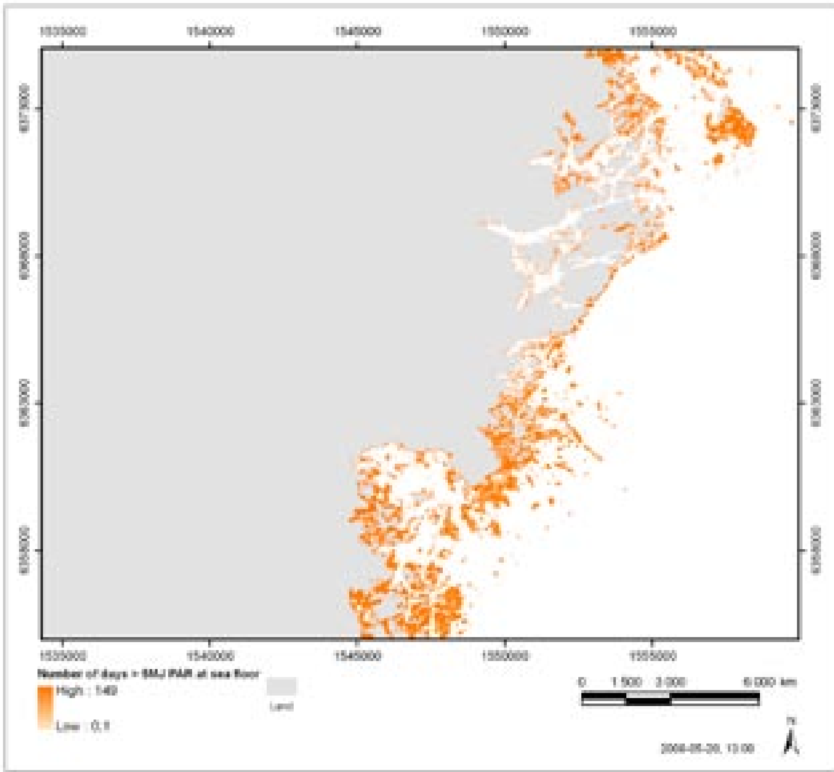


Figure 4-20. *Number of days per year on which irradiance exceeds 5 MJ (PAR) at the bottom in the Laxemar-Simpevarp area.*

Average annual temperature varied between 5.0 and 7.7 ºC in different areas in both bottom water and the pelagic water in the Forsmark area (Figure 4-21).

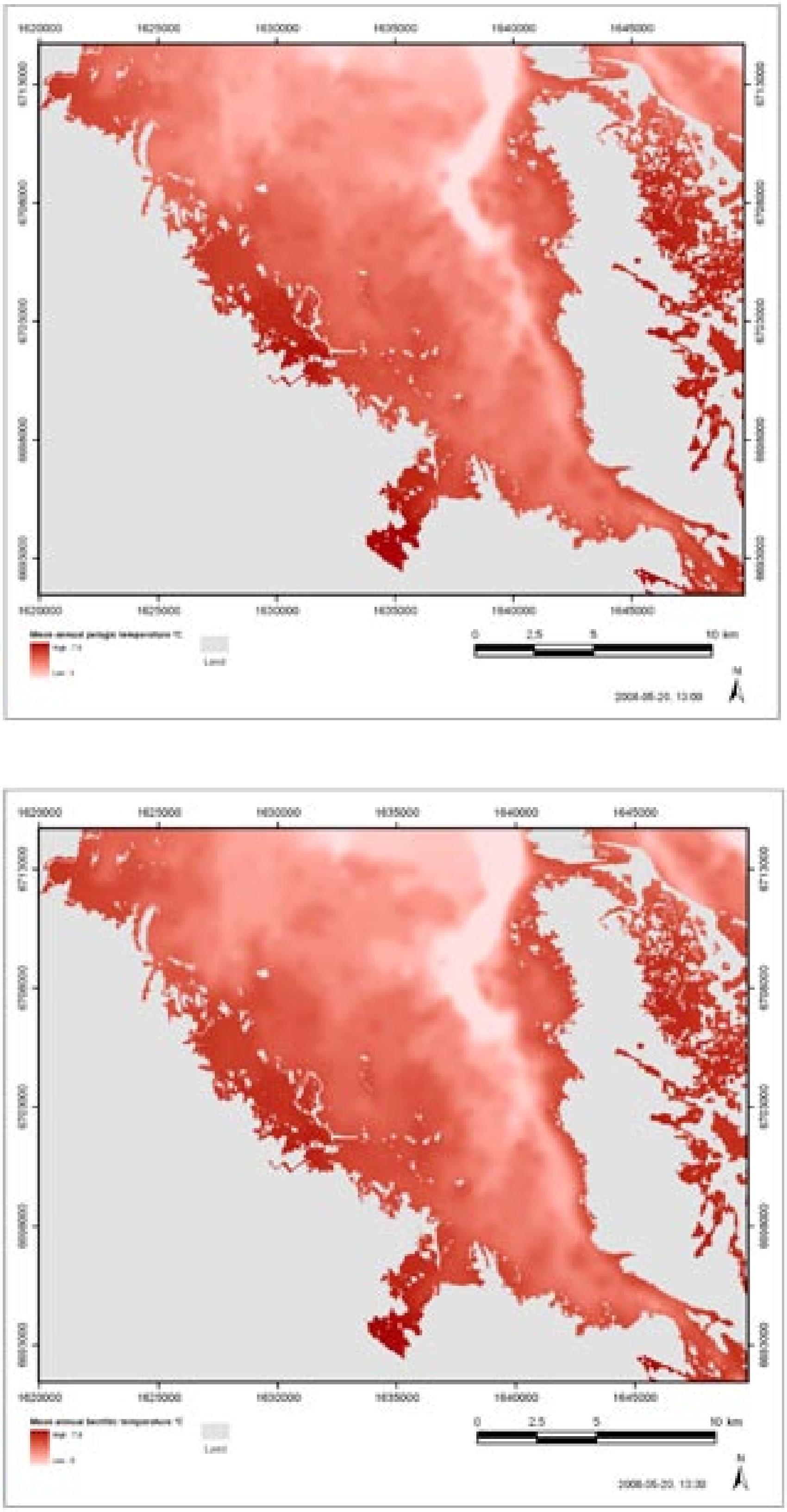
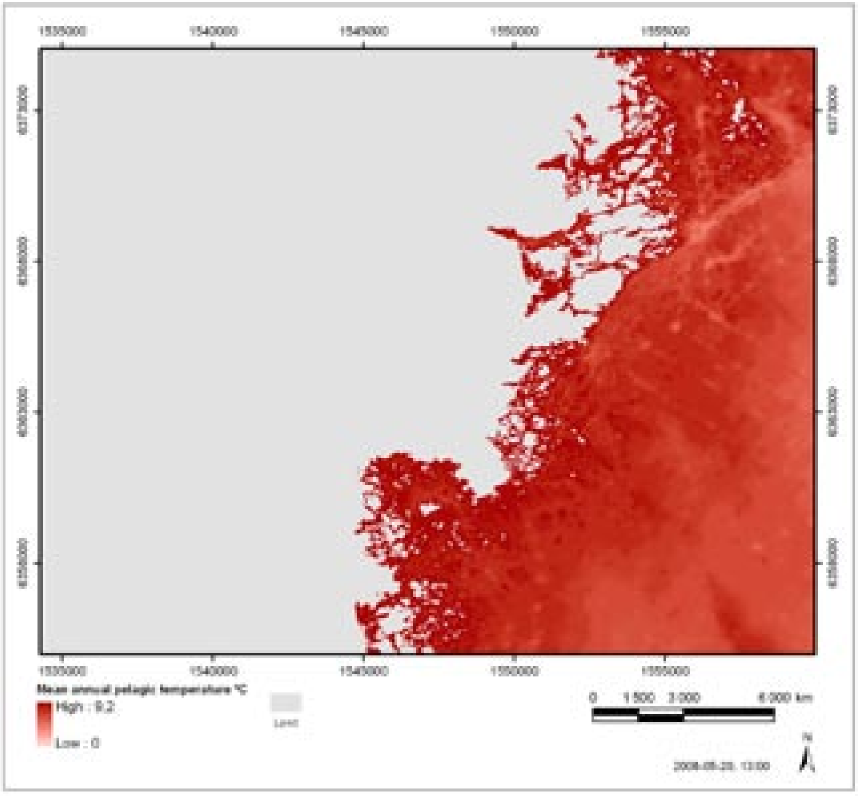


Figure 4-21. *Average annual pelagic (above) and benthic (below) temperature in Forsmark used for predictions of respiration.*

Average annual temperature varied between 6.1 and 8.8 ºC in different areas in bottom water and between 6.5 and 9.0 ºC in the pelagic water in the Laxemar-Simpevarp area (Figure 4-22).



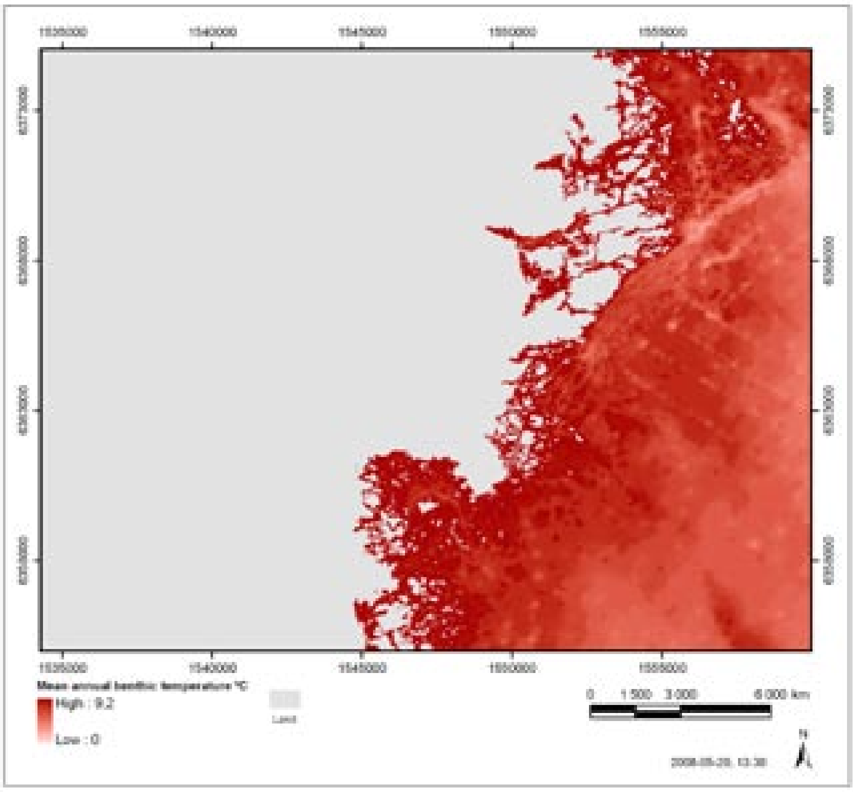


Figure 4-22. *Average annual pelagic (left) and benthic (right) temperature in Laxemar-Simpevarp used for predictions of respiration.*

4.3.5 Atmospheric deposistion – both sites

Data for mean elemental concentration in precipitation /Tröjbom and Söderbäck 2006ab, Karlsson et al. 2003, Phil Karlsson et al. 2008, Tyler and Olssson 2006/ along with data on precipitation amounts at the sites /Wern and Jones 2007, Werner et al. 2008/ were used to calculated the annual mean deposition of C, N, P and some other elements (see Table 4-19) in Forsmark and Laxemar-Simpevarp. Nitrogen in precipitation has not been measured in the site investigations performed by SKB, so data from the national monitoring performed by IVL /Phil Karlsson et al 2003, 2008/ were used (Table 4-19).

Table 4-19. Calculated atmospheric deposition via precipitation in Forsmark and Laxemar-Simpevarp.

Forsmark	(g m^{-2})	Reference
1.3	Carbon (C)	/Tröjbom and Söderbäck 2006a/
0.36	Nitrogen (N)	/Phil Karlsson et al. 2003/ (IVL)
0.012	Phosphorus (P)	/Tröjbom and Söderbäck 2006a/
2	Uranium (U) **(**ug m^{-2}**)**	/Tyler and Olsson 2006/
5	Thorium (Th) **(**ug m^{-2}**)**	/Tyler and Olsson 2006/
0.00028	Iodine (I)	Sicada, October 2007, site investigation
0.00002	Aluminium (al)	/Tröjbom and Söderbäck 2006a/
0.0014	Bromide (Br)	Sicada, October 2007, site investigation
0.17	Calcium (Ca)	/Tröjbom and Söderbäck 2006a/
0.51	Chloride (Cl)	/Tröjbom and Söderbäck 2006a/
0.018	Iron (Fe)	/Tröjbom and Söderbäck 2006a/
0.046	Magnesium (Mg)	/Tröjbom and Söderbäck 2006a/
0.098	Potassium (K)	/Tröjbom and Söderbäck 2006a/
0.0084	Silicon(Si)	/Tröjbom and Söderbäck 2006a/
0.30	Sodium (Na)	/Tröjbom and Söderbäck 2006a/
0.28	Sulfur (S)	/Tröjbom and Söderbäck 2006a/
0.013	Manganese(Mn)	/Tröjbom and Söderbäck 2006a/
0.0047	Strontium (Sr)	/Tröjbom and Söderbäck 2006a/
Laxemar-Simpevarp (g m^{-2})		
1.9	Carbon (C)	/Phil Karlsson et al. 2008/ (Rockneby Kalmar län medel 2000–20007) (IVL)
0.64	Nitrogen (N)	/Phil Karlsson et al. 2008/ (Rockneby Kalmar län medel 2000–20007) (IVL)
0.027	Phosphorus (P)	/Knape 2001/
2	Uranium (U) **(**ug m^{-2}**)**	/Tyler and Olsson 2006/
5	Thorium (Th) **(**ug m^{-2}**)**	/Tyler and Olsson 2006/
0.0003	Iodine (I)	Site investigation Forsmark
0.00002	Aluminium (al)	Site investigation Forsmark
0.08	Bromide (Br)	Sicada, October 2007, site investigation
0.42	Calcium (Ca)	Sicada, October 2007, site investigation
0.74	Chloride (Cl)	Sicada, October 2007, site investigation
0.038	Iron (Fe)	Sicada, October 2007, site investigation
0.13	Magnesium (Mg)	Sicada, October 2007, site investigation
0.36	Potassium (K)	Sicada, October 2007, site investigation
0.033	Silicon(Si)	Sicada, October 2007, site investigation
1.03	Sodium (Na)	Sicada, October 2007, site investigation
0.34	Sulfur (S)	Sicada, October 2007, site investigation
0.014	Manganese(Mn)	Sicada, October 2007, site investigation
0.0051	Strontium (Sr)	Sicada, October 2007, site investigation

4.3.6 Runoff – both sites

Water runoff from land and concentrations of carbon and other elements in runoff have been measured in several sampling stations in running waters representing a number of catchment areas in the Forsmark area during the period 2002 to 2007, see /Nilsson et al. 2003, Nilsson and Borgiel 2004, Nilsson and Borgiel 2005, Nilsson and Borgiel 2007/ and in the Laxemar-Simpevarp area /Ericsson and Engdahl 2004, Ericsson and Engdahl 2005 and Ericsson and Engdahl 2006/. Data from these years were compiled and analyzed by /Tröjbom et al. 2007/, who calculated specific runoff of water and Ca, Cl, HCO_3, K, Mg, Na, N, P, Si, SO_4, Sr and TOC (total organic carbon). Runoff was presented individually for sub-catchments where sampling stations were present and average runoff for the entire drainage area.

In the present report, specific runoff is used where possible and average runoff for catchment areas without sampling stations. To illustrate the various size of runoff in the different basins and for the different elements, runoff per basin is illustrated in, Figure 4-23 and Figure 4-24. Catchment areas for all basins are presented in table 4-1, and runoff in figures for the specific basins and elements is presented in Table 4-20.

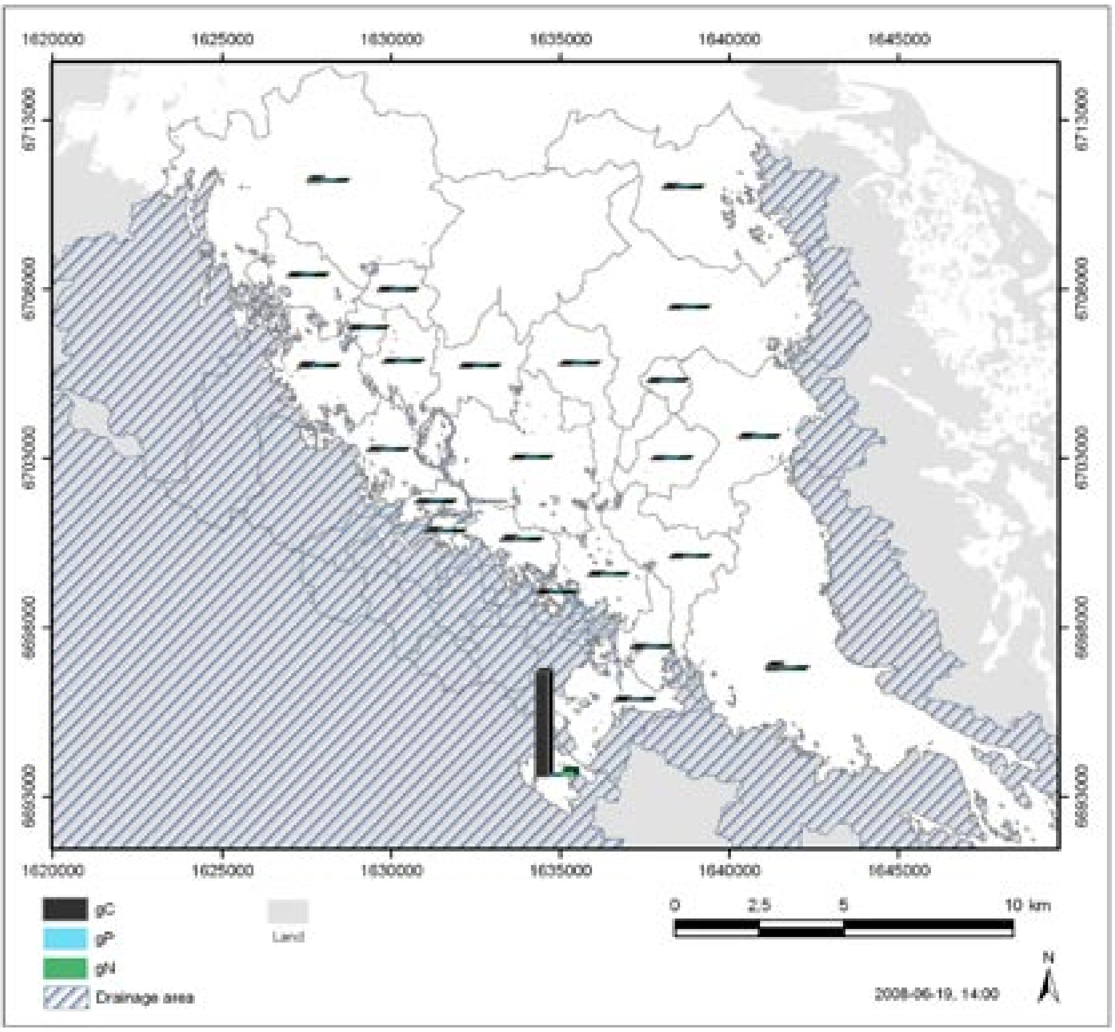


Figure 4-23. The marine basins, associated catchment areas and runoff (measured as tonnes of C , N and P year^{-1}) in Forsmark.

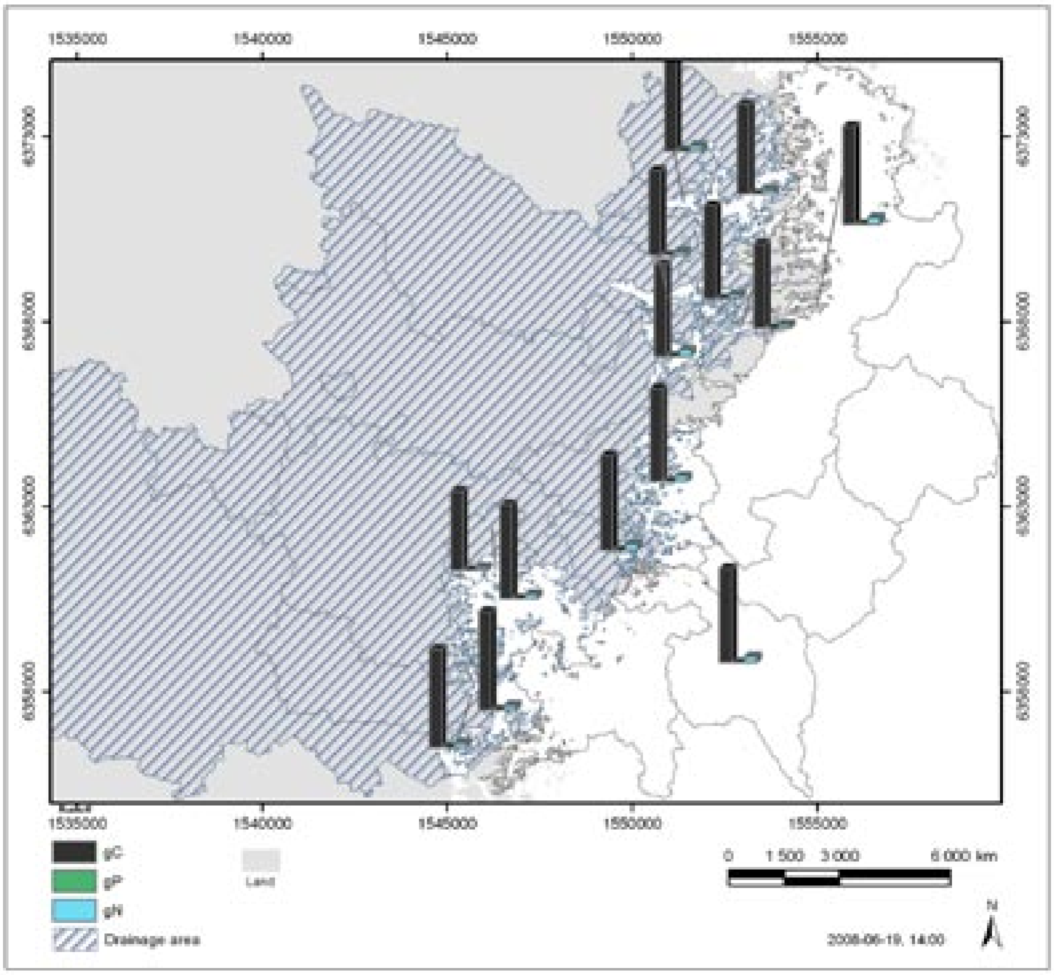


Figure 4-24. *The marine basins, associated catchment areas and runoff (measured as tonnes of C, N and P year^{-1}) in Laxemar-Simpevarp.*

4.3.7 Groundwater fluxes – both sites

Average annual vertical flows (recharge and discharge) at the sea floor surface were computed using CONNECTFLOW software and is presented for some basins in Forsmark in Figure 4-25. Modelling techniques were presented in /Follin et al. 2007/. Groundwater inflow was assumed to equal vertical flow. As the model only covers a few basins, groundwater flow was only presented where more than 50% of the basins areas were modelled. The results indicates a net discharge in most basins.

For Laxemar-Simpevarp the modelling results were not ready in time for the printing of this report.

4.3.8 Advective flux – both sites

Flux of water was one of the outputs computed in the oceanographic model (see section 5 in this report). Fluxes were presented both as gross fluxes to and from all basins and as net fluxes. To calculate potential transport of carbon and other elements we used concentrations in the basin multiplied by gross outflux and concentrations in the adjacent basins multiplied by gross influx.

These calculations was possible for dissolved and particulate carbon for all basins where concentrations were estimated in a grid. For all other elements, annual mean concentrations from the individual water sampling sites (see section 3.1) were used to represent the respective basins (Table 4-2). Due to a lack of data, most basins were not represented by a sampling site, and an average rate for all sites were used.

Table 4-20. Average yearly runoff to the marine basins in Forsmark and Laxemar-Simpevarp for C, N and P.

Forsmark	Carbon (C) tonnes $year^{-1}$	Nitrogen (N)	Phosphorus (P) kg $year^{-1}$
Basin 102	82	10	101
Basin 100	12	3.4	14
Basin 101			
Basin 105	13	4.2	16
Basin 103	1.7	0.9	2.0
Basin 104	0.1	0.4	0.2
Basin 108	1.1	1.1	1.3
Basin 106	0.1	0.2	0.1
Basin 111	32	2.8	39
Basin 107	0.6	0.7	0.7
Basin 110	0.3	1.1	0.3
Basin 114	13	2.9	16
Basin 109			
Basin 116	1.3	2.1	0.6
Basin 113			
Basin 117	27.5	2	34
Basin 112			
Basin 115	0.01	0.6	0.02
Basin 151	131	14	161
Basin 118	1.5	0.3	1.8
Basin 123	1.2	1.2	1.4
Basin 152	3,384	192	4,149
Basin 150	30	2.3	56
Basin 146	1.0	0.6	0.3
Basin 126	4.4	1.1	3.9
Basin 134	6.1	0.3	5.1
Basin 121	55	2.1	41
Basin 120	33	1.6	23
Laxemar-Simpevarp			
Basin 524	0.6	0.02	0.5
Basin 525			
Basin 522			
Basin 523			
Basin 521	5.5	0.24	5.6
Basin 501	0.1	0.003	0.09
Basin 500	0.1	0.003	0.09
Basin 504	8.2	0.37	9
Basin 502	162	10	295
Basin 506	4.4	0.21	6
Basin 508	213	14	391
Basin 513	34	2.1	57
Basin 514			
Basin 516	12.8	0.72	20
Basin 518			
Basin 515	53	3.5	99
Basin 517	104	7.6	220
Basin 520	0.1	0.003	0.09
Basin 519	0.6	0.04	1.0

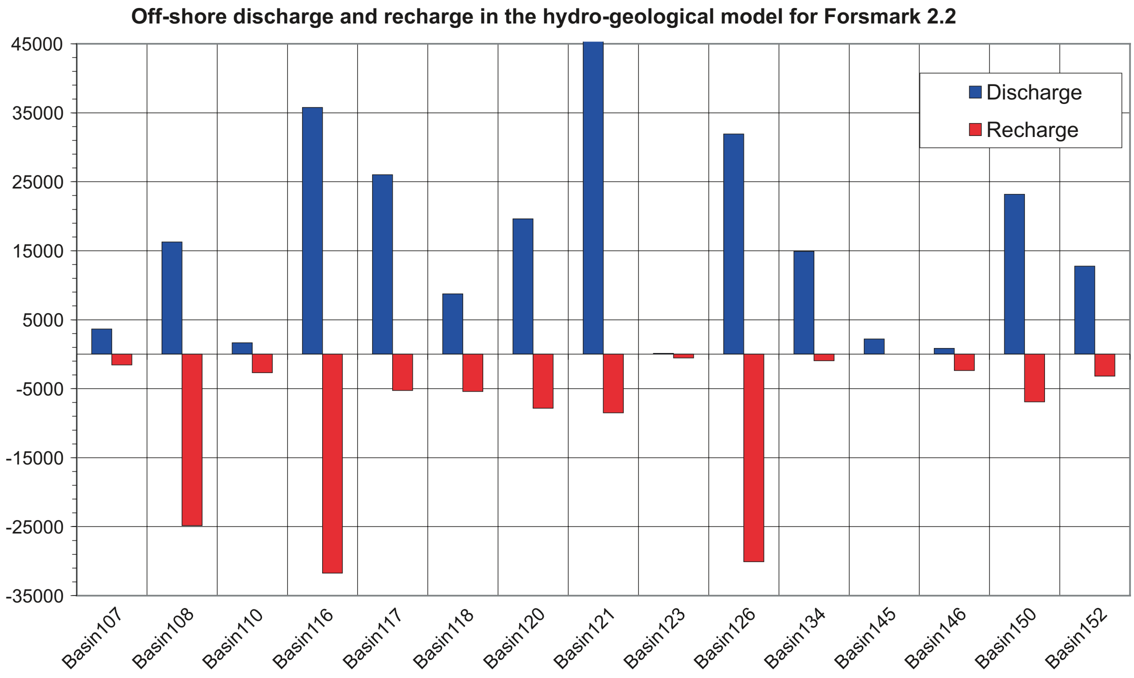


Figure 4-25. *Groundwater flow in marine basins in Forsmark computed using CONNECTFLOW software. From /Follin et al. 2007/.*

4.3.9 Regolith

Organic carbon concentration in sediment – both sites

The following analysis of sediment organic carbon concentrations (0–10 cm) is based on cores taken in the Forsmark area, and core-based maps for this area. In the Laxemar-Simpevarp area, only parameters for the top 0–10 cm of sediment were used.

Bulk sediment organic carbon densities were calculated from measured TOC concentrations and wet sediment bulk density (in ww gm^{-3}). The latter was calculated using /Håkanson and Jansson 1983/:

$$\rho_{bulk} = \frac{100\rho_s}{100 + (W + IG\,(1 - (\frac{W}{100}))(\rho_s - \rho_w)}$$

where W is water content (%), is loss-on-ignition, IG (% dry weight) and ρ_s and ρ_w are the densities of minerogenic solids in the sediment (2.6 g cm^{-3}) /Håkanson and Jansson 1983/ and of the pore water (in Forsmark, 1.005 g cm^{-3}), respectively. Where IG measurements were lacking, loss-on-ignition was assumed to be 2 x TOC, i.e. twice the content of total organic carbon in % dry weight /Jonsson 1992/.

The bulk sediment organic carbon density ρ_C (gC m^{-3}) was then derived from

$$\rho_C = \rho_{bulk}\frac{100 - W}{100}TOC$$

Data on sediment water and organic carbon content are available from the geological and lagoonal surveys (map in Figure 3-24, Chapter 3.3.2), including from /Wallström and Persson 1997/, and partly from deeper cores from lakes in the area /Hedenström 2003, Hedenström and Risberg 2004/. They are summarized in Figure 4-26.

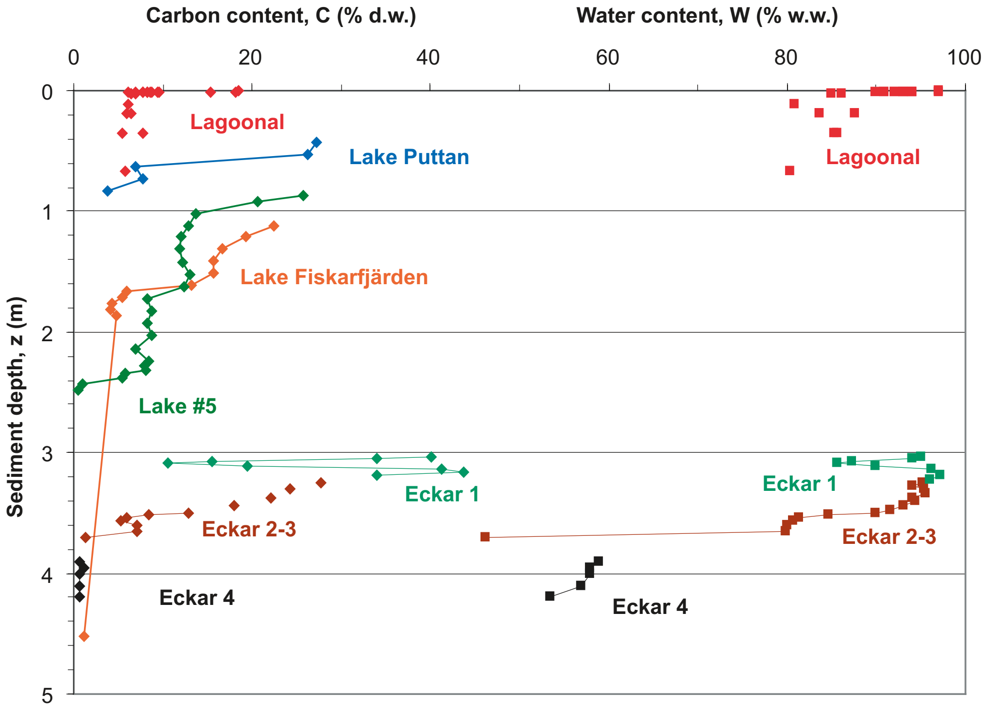


Figure 4-26. *Total organic carbon and water content as a function of sediment core depth, from lagoonal sampling /Wallström and Persson 1997, Sternbeck et al. 2006/, from the recently isolated gloe lakes Lake Puttan, Lake Fiskarfjärden and Lake #5 /Hedenström 2004/, and from Lake Eckarsfjärden, stages Eckar 1–4 /Hedenström and Risber 2003/.*

The lake cores illustrate the sequence from glacial and postglacial marine over lagoonal to lacustrine environments, which are fully represented from Lake Fiskarfjärden, Lake #5 and Lake Eckarfjärden (the latter divided into stages Eckar 1–4; for location of lakes see section 3.3.2, Figure 3-16). The total organic carbon content of postglacial marine deposits generally stays within a limited range of around 4–10% dw (lower part of Eckar 2 and upper part of Eckar 3). The much higher C concentrations are lacustrine and peat deposits (Eckar 1), while lower concentrations are from glacial or early postglacial deposition (e.g. Eckar 4).

For lagoonal data from the upper 68 cm (Figure 4-27) of core and grab samples /Wallström and Persson 1997; Sternbeck et al. 2006/ the following depth integral can be derived:

$$\rho_C = 13{,}896\ z^{0.1714} \qquad \text{for } z < 0.68$$

and $$\rho_C = 13{,}000 \qquad \text{for } z > 0.68$$

where z is sediment depth in m, Thus, ρ_C is set constant with depth for marine postglacial deposits in cores, based on the deeper marine lake-deposit data /Hedenström and Risberg 2003, Hedenström 2004/, except in the uppermost unconsolidated part. By means integration, these relationships permit carbon content in core samples to be estimated as a function of stratigraphy, their primitive functions being:

$$\int \rho_C dz = \frac{z^{1.1714}}{1.1714} \qquad \text{for } z < 0.68$$

and $$\int \rho_C dz = 13000z \qquad \text{for } z > 0.68$$

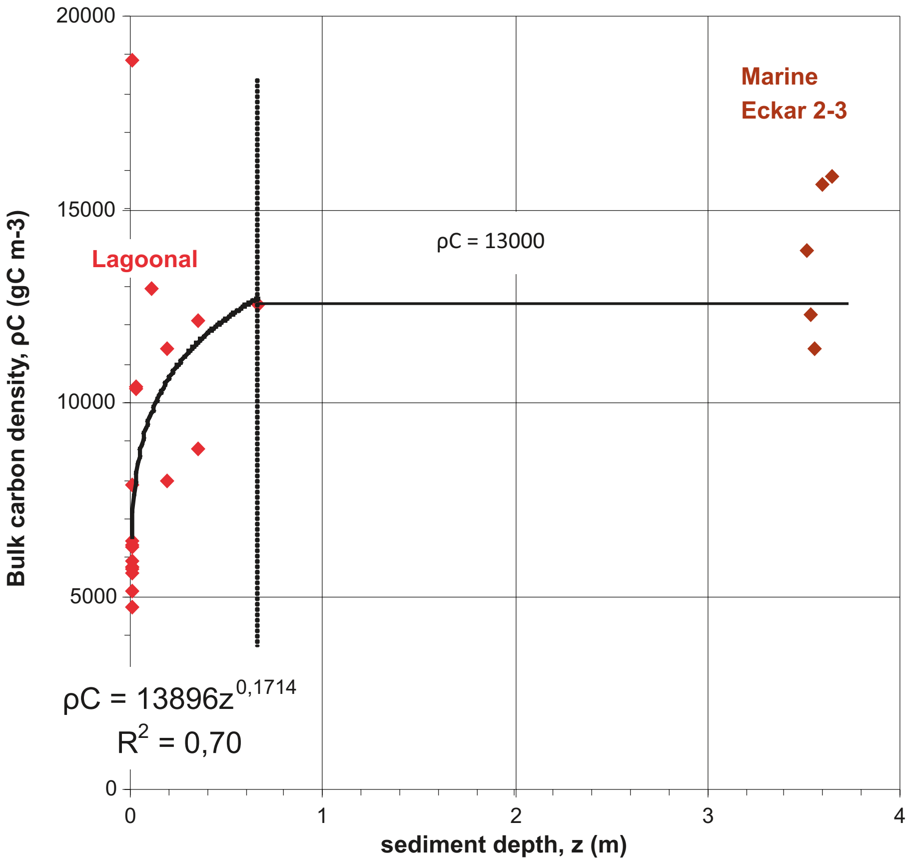


Figure 4-27. *The relationships used for depth integration of carbon content.*

and the ρ_C integral from z to 0 in cores:

$$\int_0^z \rho_C dz = \frac{13896 \cdot z^{1.1714}}{1.1714} \qquad \text{when } z < 0.68$$

and $$\int_0^z \rho_C dz = 7551 + 13000\,(z - 0.68) \qquad \text{when } z > 0.68$$

which was used to calculate the depth-integrated organic carbon content for available core stratigraphies (Figures 4-28 and 4-29). Glacial and early postglacial accumulations were then not depth-integrated, but set to 0 and 4,000 gC m^{-3}, respectively.

An additional set of W (watercontent) and IG (loss on ignition) data from Kattegat /Floderus and Håkanson 1985/ was used for estimating surficial ρ_C over wider areas, offering a rare wider range of characteristic carbon densities from coarser bottoms of erosion and transport. Figure 4-30 shows how such surficial sediments form a U-shaped ρ_C/W relationship from low to high water content, while the consolidated lake core deposits (Eckar 1–4, shown in green, brown and black) deviate from this pattern with the exception of the marine facies Eckar 2–3 (brown). Thus, once again, unlike the deep lacustrine (green) and early postglacial deposits (black), buried marine deposits show a similarity with recent marine ones.

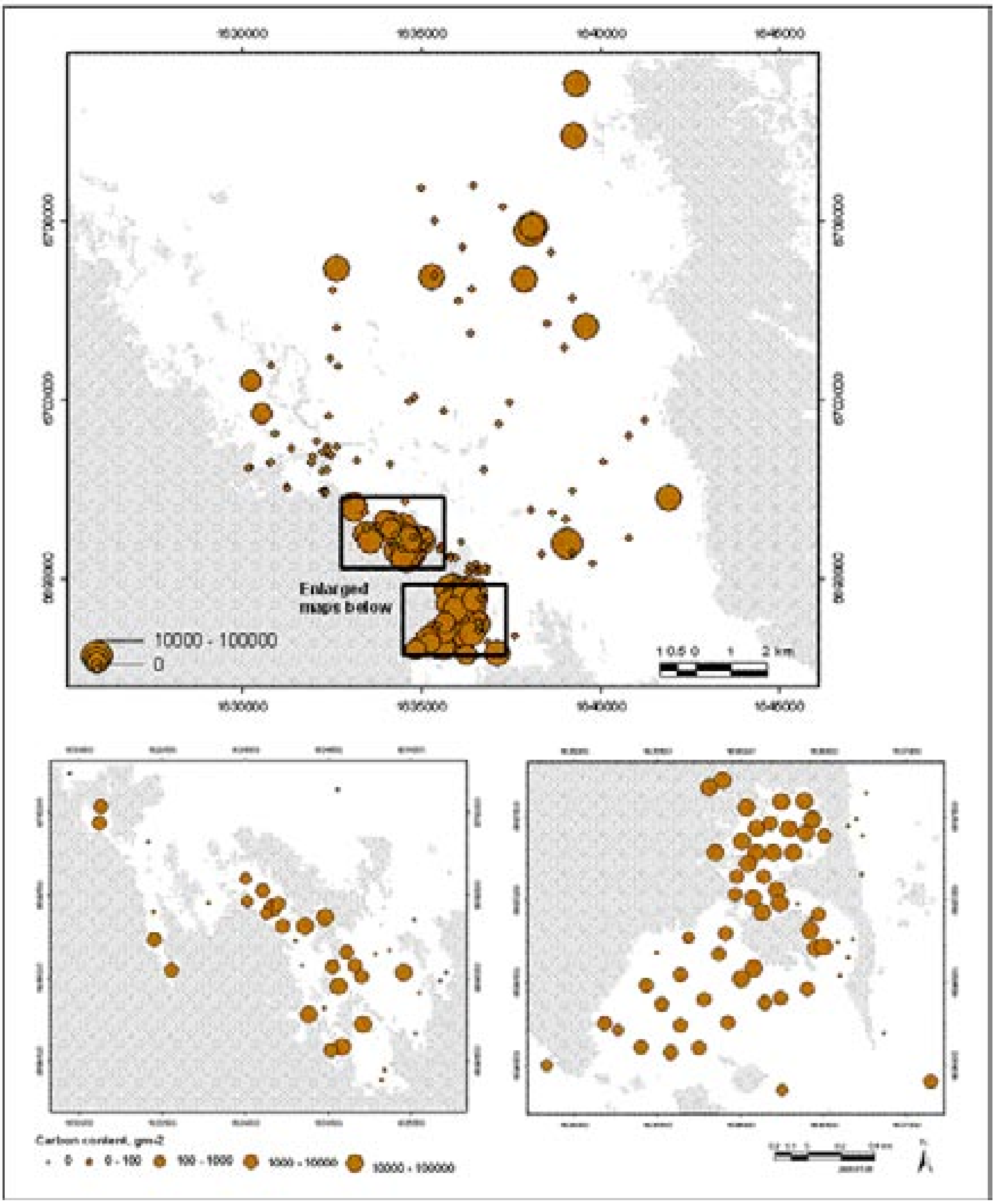


Figure 4-28. *The total carbon content (gC m⁻²) of subrecent parts of cored samples in Forsmark. The maximum sediment depth of such a deposit is 4.32 m, while the mean is 0.74 m and the median 0.53 m.*

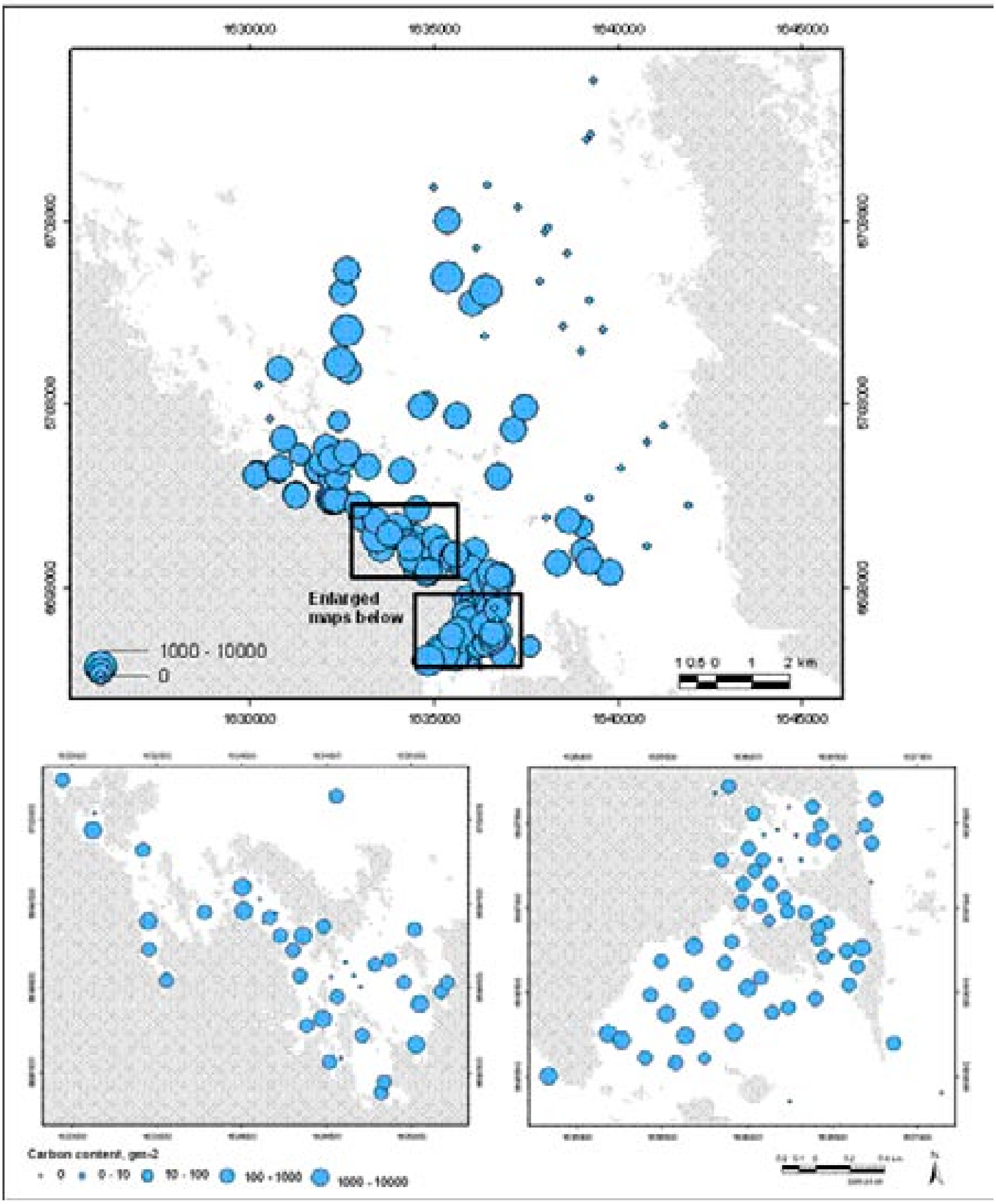


Figure 4-29. *The total organic carbon content (gC m^{-2}) of deeper glacial and early postglacial parts of cored samples, not including subrecent carbon in Forsmark.*

As indicated in Figure 4-30, the bulk organic carbon content in surficial sediments may be reasonably well approximated (R^2 = 0.54) from water content using the polynomial:

$\rho_{Csurf.} = 729\ W – 5.64\ W^2 – 12{,}676$

used as in Table 4-21 for classifying organic carbon densities for the top 10 cm of surficial sediment.

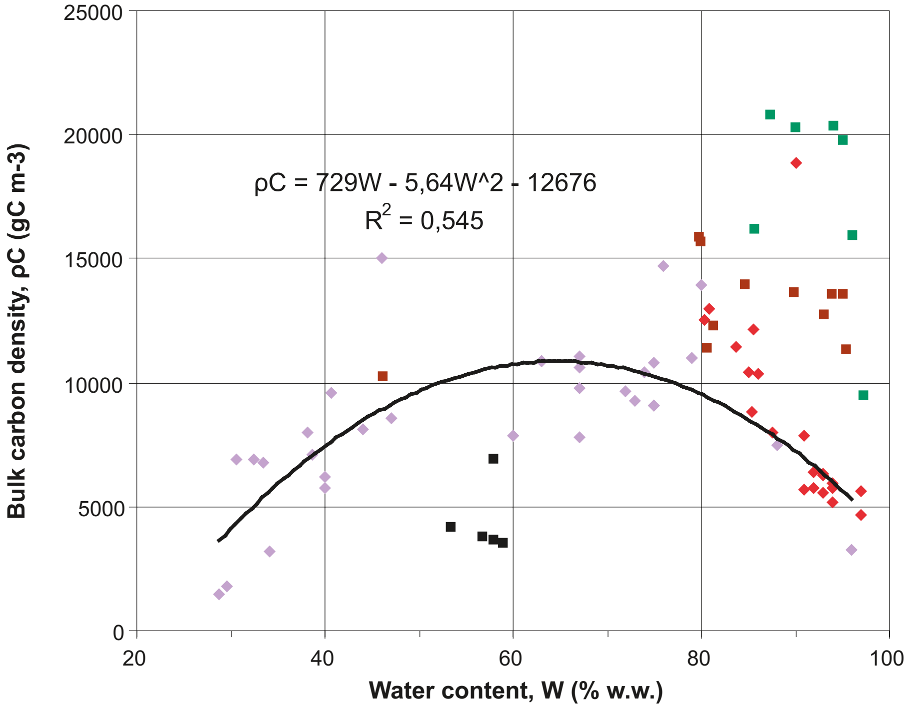


Figure 4-30. *Bulk organic carbon density as a function of water content in surficial sediments from bottoms of erosion and transport (purple) /Floderus and Håkanson 1985/. Also shown are data from surficial and near-surficial lagoonal sediments in the Forsmark area (red) /Wallström and Persson 1997, Sternbeck et al. 2006/ and from Lake Eckarfjärden /Hedenström and Risberg 2003/, stages Eckar 1 (green), 2–3 (brown) and 4 (black). The polynomial is a best-fit curve derived from the (purple) erosion- and transport-bottom samples only.*

As can be expected, the value for clay-gyttja is near the ρ_C depth-integral as derived above from lagoonal samples (Figure. 4-27) from z = 0.1 m to 0, which is 800 gC m^{-2}.

The resulting maps of carbon concentrations in the top 10 cm of sediment, thus based on the spatial distribution and classification used in the marine geological and soil survey (Chapter 3.3.2) are shown in Figures 4-31 and 4-32.

Top-10-cm organic carbon, a depth characteristic of the bioactive layer in the Baltic /Håkanson et al. 2004/ and elsewhere /Boudreau 1998/ was used in the budget calculations as the source of carbon for detritivores and benthic bacteria. Areas not covered by the marine geological investigations were then filled with data according to water depth, with average carbon content calculated for depth intervals 0–5 m, 5–20 m and > 20 m and distributed evenly according to these depth intervals.

4.3.10 Carbon burial (gC $m^{-2}y^{-1}$)

Marine sediment and organic carbon burial (not including the reed zone) was assumed to take place beneath two main types of accumulation bottoms (A-bottoms): shallow lagoonal (in the Forsmark area only) and deeper focusing-related A-bottoms.

Lagoonal burial – Forsmark

Areas mapped as covered by the periphytic yellow-green algae *Vaucheria* sp. were identified as representing burial of lagoonal-water algal mat deposits /Bergström 2001/. Such lagoonal burial takes place *in situ* below algal mats in the mostly shallow *flad* and *gloe* environments as described by /Munsterhjelm 2005/. Lagoonal burial was then set at 25 gC $m^{-2}y^{-1}$ in the *Vaucheria* zone, or 3/8ths of the *Vaucheria* production, and at 30 gC $m^{-2}y^{-1}$ in lagoonal areas without *Vaucheria* but still mapped as clay-gyttja /Sternbeck *et al.* 2006/.

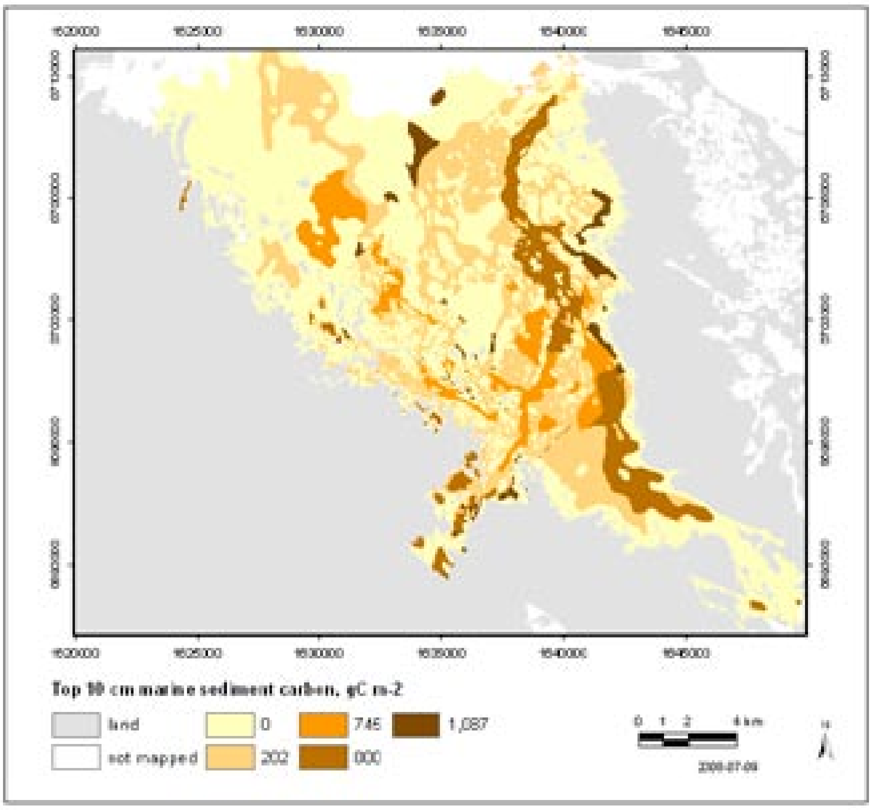


Figure 4-31. *The distribution of bulk total organic carbon content (gC m^{-2}) in the uppermost 10 cm of the sediment in Forsmark, based on classifications from the geological survey and relationships between sediment water content and organic carbon content.*

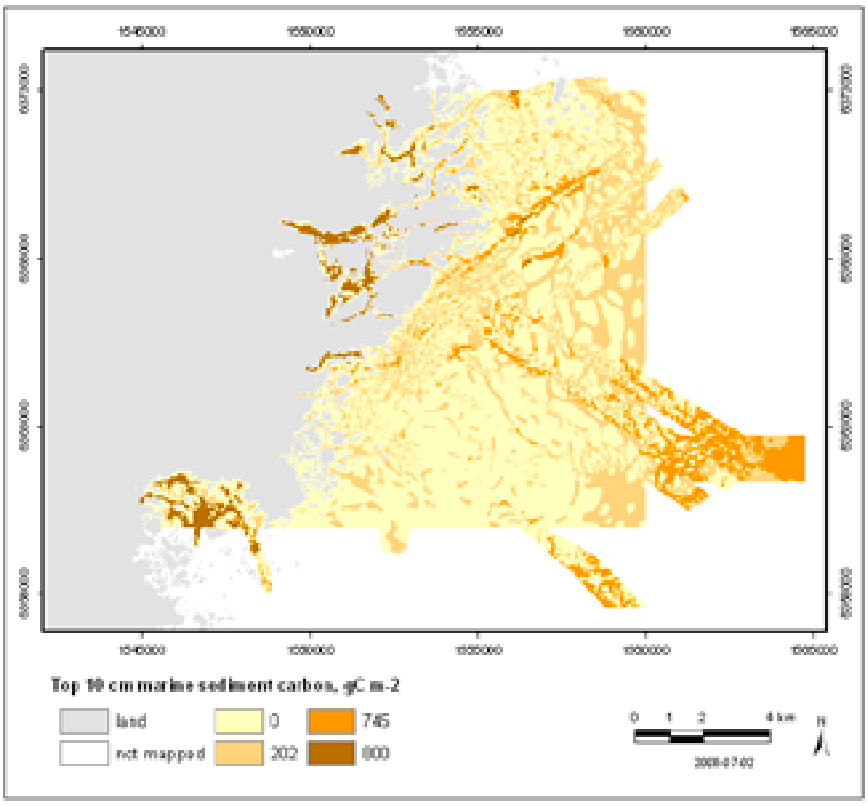


Figure 4-32. *The distribution of bulk total organic carbon content (gC m^{-2}) in the uppermost 10 cm of the sediment in Laxemar-Simpevarp, based on classifications from the geological survey and relationships between sediment water content and carbon content.*

Focusing-related burial

Focusing-related burial is the result of fine sediment transport along bottoms of erosion and transport towards topographical depressions, the process known as focusing. Water carrying the resuspended load passes over an A-bottom with bottom shear stress conditions insufficient for resuspension. Transported loads therefore accumulate and get buried following deposition.

A fraction of organic carbon and nutrients exported from the pelagic foodweb can be buried in A-bottoms. This fraction increases with the load received. Minerogenic particles also contribute to the load and in particular to burial efficiency. /Jonsson's 1992/ analyses of regional laminated deposits, formed under anoxic conditions in the Baltic proper and Stockholm archipelago, suggest that the bulk of Baltic Sea laminae are made up of the more inorganic material being resuspended and focused during storm events. Bioturbation and early diagenesis are then not efficient enough regenerative processes to fully control the concentration of organic matter regardless of its minerogenic content. Therefore, element concentrations will co-vary with minerogenic burial, and carbon burial rates in the Baltic Sea /Jonsson et al. 2000/, constituting the downward flux from the base of the mixed surficial zone of fine sediments, will be mainly controlled by sediment accumulation rates.

Total organic carbon burial was estimated as proportional to the ρ_C integral (see section 4.3.6) for buried non-sealed deposits (in gC m^{-2}):

$$\int_0^z \rho_C dz = \frac{13896 \cdot z^{1.1714}}{1.1714} \qquad \text{when } z < 0.68$$

and $$\int_0^z \rho_C dz = 7551 + 4000\,(z - 0.68) \qquad \text{when } z > 0.68$$

The relationship between burial and this ρ_C integral was then estimated empirically by comparing recent focusing-related carbon burial rates –30 gC $m^{-2}\,y^{-1}$ in the centre of focusing-related A-bottoms /Sternbeck et al. 2006/ – with ρ_C integrals derived using the above expressions on mapped mud deposit thicknesses. The resulting burial:ρ_C ratio is 0.006 y^{-1}. Thus, burial rate (in gC $m^{-2}\,y^{-1}$) could be mapped as a function of mud deposit thickness (in m).

Forsmark

Recent focusing-related burial in the Forsmark area took place in areas where bottoms were geologically mapped as fines, postglacial clay and/or gyttja, in the Gräsö trough. To represent the thickness of such deposits, horizontal straight-line distances from the outer edge of the deposit inward, SLD, were calculated, and total sediment thickness, z (in m, to be used in the expression above) was calculated as

z = 0.3 × ((log10 ([SLD])) –1)

which yields a logarithmic expression describing a depth distribution between the deposit center and the deposit edge, serving as depocentre morphology model. Thus, given an association of organic carbon burial with accumulation rate, burial was set in proportion to the thickness of the postglacial-fines deposit, using the ratio 0.006 y^{-1} resulting in a mean about 30 gC $m^{-2}y^{-1}$ in the Forsmark area /Jonsson et al. 2000, Sternbeck et al. 2006/.

Figure 4-33 maps both lagoonal and focusing-related organic carbon burial in the Forsmark area.

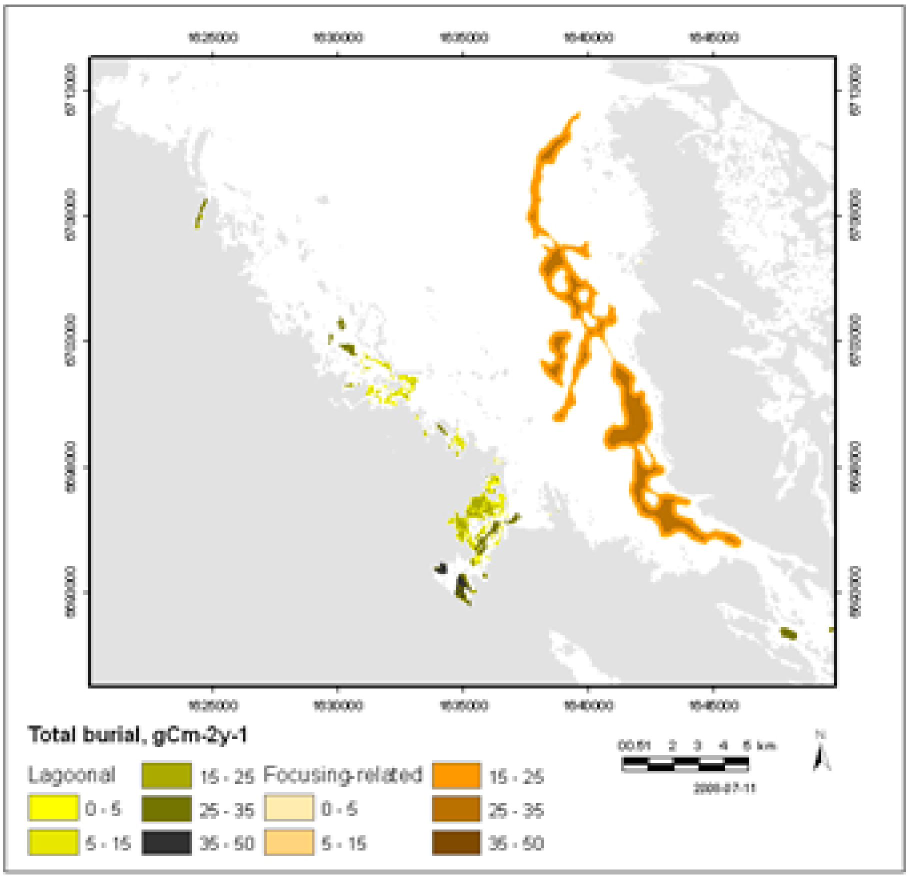


Figure 4-33. *The distribution of lagoonal and focusing-related organic carbon burial rates (gC $m^{-2}y^{-1}$) in the Forsmark subarea.*

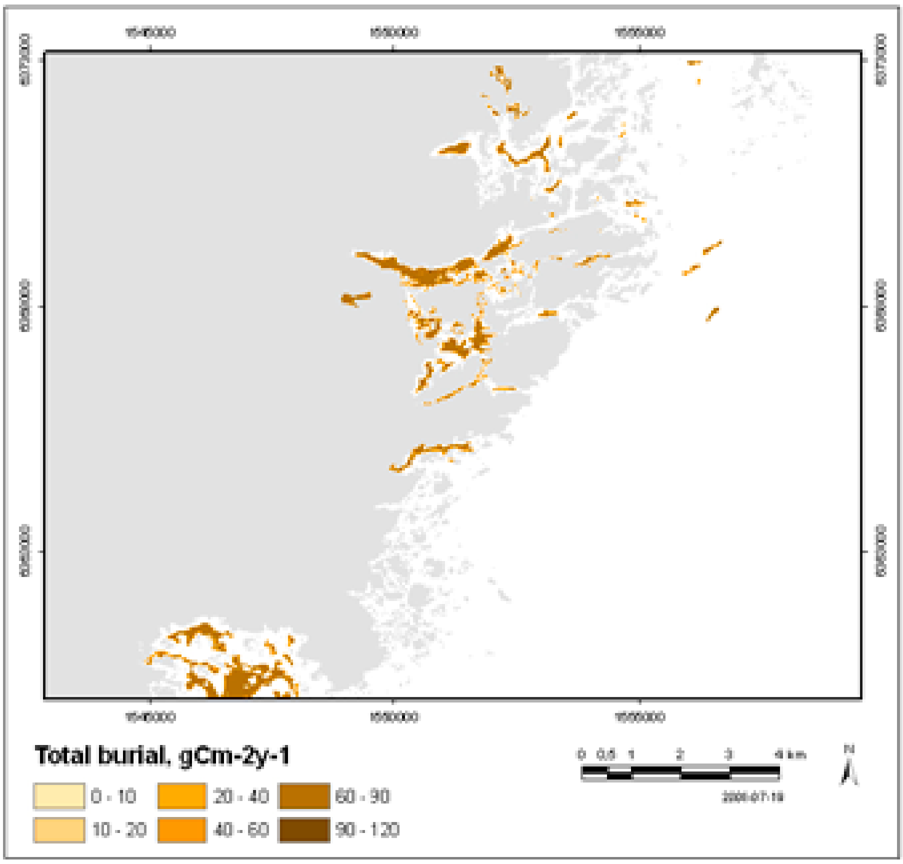


Figure 4-34. *The distribution of organic carbon burial rates (gC $m^{-2}y^{-1}$) in the Laxemar-Simpevarp subarea.*

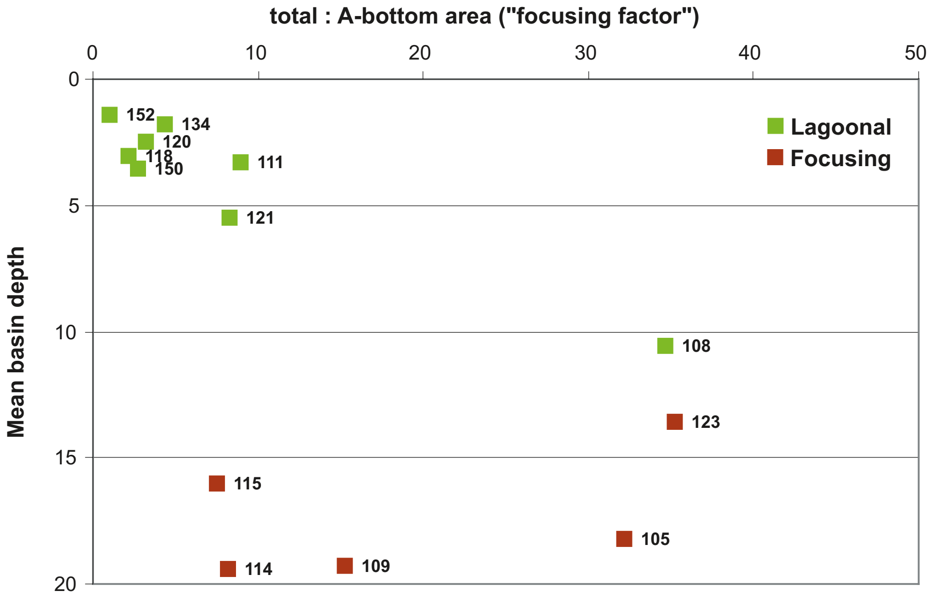


Figure 4-35. The relationship between mean basin depth (m) and the ratio total : A-bottom area, i.e., the "focusing factor" (FF) /Jonsson et al. 2000/, or equivalent total : A-bottom ratio in the case of lagoonal burial, in 13 basins in the Forsmark area with area-wise significant burial (FF < 50). The colour indicates the basin's dominant mode of burial. The otherwise deeper basin 108 includes the Vaucheria-dominated (shallow lagoonal) test lake.

Laxemar-Simpevarp

No distinction between lagoonal and focusing-related burial was made in Laxemar-Simpevarp. Instead, thicknesses of postglacial-fines deposits could be obtained directly from the soil depth model /Nyman et al. 2008/ in the areas where mapping /Sohlenius 2008/ classified the bulk of the bottom as consisting of clay-gyttja.

A realistic recent focusing-related carbon burial rate (in gC $m^{-2}y^{-1}$) was again estimated as being proportional to the ρ_C integral derived above using the ratio 0.006 y^{-1}, which given the thicker deposits, and in accordance with the higher rates observed /Sternbeck et al. 2006/ resulted in moderately higher rates in comparison with the Forsmark area.

Figure 4-34 maps total organic carbon burial in the Laxemar-Simpevarp area.

Focusing factors

For an assessment of the burial capacity of the overall marine ecosystem, the "focusing factor" presented and used by /Jonsson et al. 2000/ offers efficient parameterization of focusing as it affects burial. It uses a basin's ratio between total seabed area and A-bottom area, the focusing factor, in order to relate A-bottom deposition and burial to biogenic processes and transport in the pelagic system. The gross deposition rates on e.g. Erstafjärden A-bottoms and many similar bottoms, is 1,000–5,000 g dw $m^{-2}y^{-1}$. Deposition per pelagic system area decreases with the focusing factor, which in that case ranged between 1.8 and 4.2, the higher figures being from basins where A-bottom areas were comparatively smaller.

Forsmark

As seen in Figure 4-35, the ratio total:A-bottoms area ratio in the Forsmark subarea basins is close to the above low range (1.8–4.2) only in the five basins most dominated by lagoonal *Vaucheria*-type burial: basins 118, 120 (innermost Forsmarksfjärden and Asphällsfjärden), 134 (Tixelfjärden), 150 and 152 (the two Kallrigafjärden basins). In basins with focusing-related burial the focusing factor reaches only as low as ~ 8 in two of the basins in the Gräsö trough.

The latter figure would imply that focusing-related burial at approximately 30 gC m^{-2} y^{-1} represents a sink relative to the pelagic ecosystem locally in the order of 3–4 gC m^{-2} y^{-1} which is within previously published estimates of the carbon burial sink in the wider Baltic Sea, ranging between 1.5 and 9 gC m^{-2} y^{-1} as summarized by /Eilola 1998/. The focusing factor of the entire larger-scale Öregrundsgrepen may be as high as 75, however. So while element burial is significant locally, the latter figure is equivalent to no more than ~ 0.5 gC m^{-2} y^{-1} at the pelagic-system level. In other words, sediments in the Forsmark area itself carry only this more limited capacity for local, larger-scale sediment sequestration of the organic carbon and nutrients assimilated via primary production.

Laxemar-Simpevarp

The Laxemar-Simpevarp coast presents a widely different focusing regime, with significant burial in the inner bays, compared with very little burial along the open exposed coast (see chapter 6).

4.3.11 Substrate classification, soft and hard bottoms – both sites

To permit estimates of the distribution of benthic organisms, the marine geological map was classified into soft and hard bottoms. All sediment and substrate types were classified as soft, except the following: gravel, moraine/till and bedrock. All other size categories of sediment, i.e. sand to gyttja, were classified as soft based on the assumption that these substrates support burying and digging benthic fauna and provide a suitable habitat for rooted plants (at least in the photic zone). Differences in data availability led to a difference between Forsmark and Laxemar-Simpevarp which is described below.

Where the marine area was covered by the Quaternary deposit map /Sohlenius 2008/, this map was used. In the Forsmark area, a regional map (1:500,000) of Quaternary deposits was used for areas outside /SGU online database, Anna Hedenström, pers. comm./. The estimated distribution of soft and hard bottoms is presented in Figures 4-36 and 4-37.

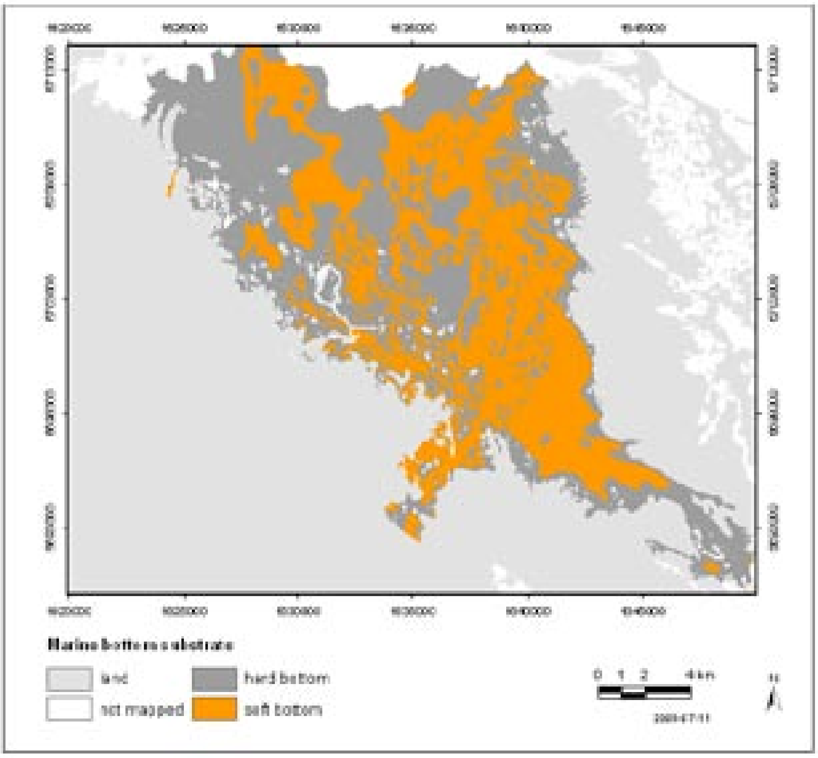


Figure 4-36. Distribution of hard and soft bottoms in the Forsmark area.

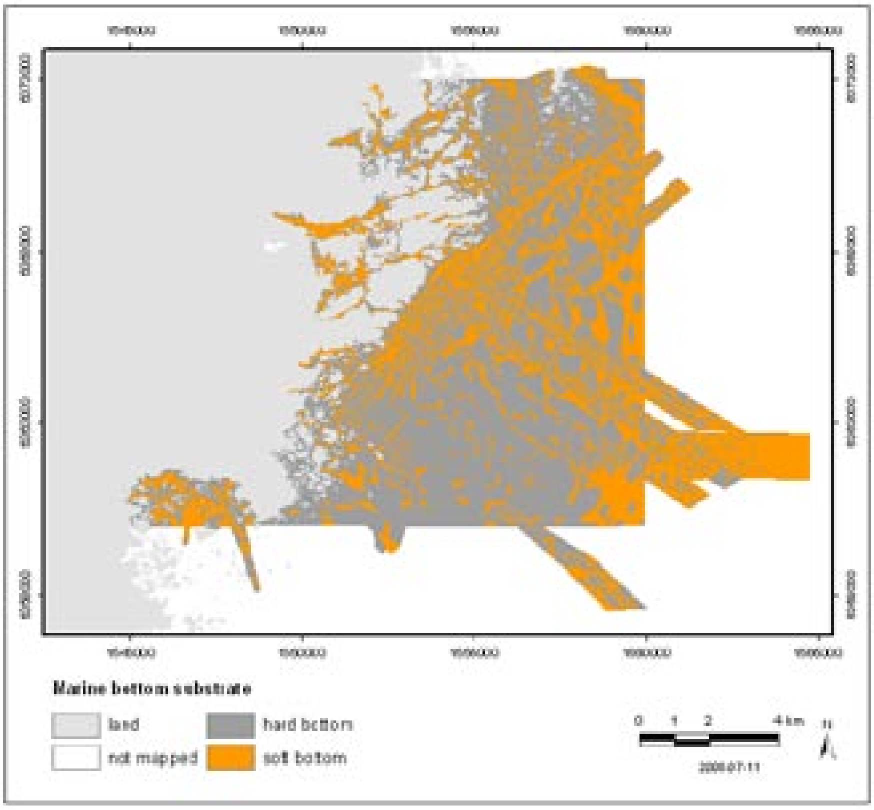


Figure 4-37. *Distribution of hard and soft bottoms in the Laxemar-Simpevarp area.*

It was furthermore observed in the Laxemar-Simpevarp area that within the mapped area, the proportions of soft bottom increased with depth. The proportions were estimated for depth categories, and the threshold between dominance of soft bottom over hard bottom in the offshore areas was found to be between 9.5 and 10 m depth. Therefore, all seafloor outside the mapped area below 10 m depth was designated as soft bottom and above 10 m depth as hard bottom.

The percentages of soft bottoms in all sub-basins fully covered by sediment mapping or substrate estimation are listed in Table 4-22.

Table 4-21. Derivation of top 10 cm organic carbon concentrations.

		surface ρC		
	W	**mean**	**per volume**	**W**
	%ww		gC m^{-3}	%ww
gyttja	95–100	97.5	4,770	477
clay gyttja	80–95	87.5	7,915	791
postglacial clay	50–80	65	10,866	1,087
coarse silt/fine sand	30–50	40	7,450	745
sand	20–30	25	2,017	202
sand/gravel, gravel	0–20	10	0	0

Table 4-22. The percentage of soft-bottoms in all sub-basins fully covered by sediment mapping or substrate estimation.

	Basin area, m2	Percent soft-bottoms		Basin area, m2	Percent soft-bottoms
Forsmark					
Basin 100	18,333,600	31.2	Forsmark (continued)		
Basin 101	21,796,800	43.2	Basin 123	72,63,600	73.4
Basin 102	33,822,000	24.9	Basin 126	5,402,800	51.2
Basin 103	5,616,400	0.0	Basin 134	576,400	57.3
Basin 104	2,699,200	70.5	Basin 137	3,600	0.0
Basin 105	22,646,000	54.2	Basin 145	75,600	0.0
Basin 106	1,382,400	37.1	Basin 146	3,358,000	55.5
Basin 107	4,495,600	38.9	Basin 150	5,745,200	71.5
Basin 108	6,924,400	31.5	Basin 151	41,230,000	55.6
Basin 109	1,521,200	65.2	Basin 152	2,084,800	36.0
Basin 110	7,067,600	37.4	**Laxemar-Simpevarp**		
Basin 111	6,575,200	24.6	Basin 501	338,400	44.1
Basin 112	696,800	41.7	Basin 502	1,122,000	62.9
Basin 113	1,596,800	36.4	Basin 504	607,200	40.3
Basin 114	14,058,400	74.1	Basin 506	340,400	47.0
Basin 115	4,211,200	61.1	Basin 508	1,382,000	50.7
Basin 116	13,382,800	37.6	Basin 513	4,044,800	21.7
Basin 117	5,590,400	15.5	Basin 514	956,000	23.6
Basin 118	1,347,200	23.9	Basin 515	869,600	44.9
Basin 120	666,000	28.3	Basin 516	471,200	0.0
Basin 121	3,615,600	61.3	Basin 518	758,800	30.1

4.4 Parameterization – mass balance, both sites

Estimates of abiotic and biotic pools and fluxes were used in the mass balances according to the parameterization presented above.

The functional groups in the biotic pools were added in primary producers (macro-, microphytes and phytoplankton) and consumers (benthic bacteria, benthic fauna, zooplankton, bacterioplankton, fish, birds and seal).

No fluxes or processes within the ecosystem were included only fluxes to and from the ecosystem: atmospheric deposition, runoff, advective flow, burial and total net primary production (NPP). NPP was included for C, N and P according to the presentation in section 4.2.1.

4.5 Parameterization – elemental composition

Elemental composition analyses were performed in Forsmark and Laxemar-Simpevarp for various abiotic pools and functional groups, see Table 4-23 (see also section 3.5 of this report). From these data, C:X ratios (where X represents the different elements) were derived for the various pools. Since not all organisms, abiotic pools or elements were analyzed at both sites, data for one pool or element at one site were sometimes used for the other site. Organisms from one functional group were sometimes used for another functional group when data were lacking. The C:X ratios used for each abiotic and biotic pool and element are presented in Appendix 6. For some of the elements (mainly trace elements), the results of the analyses were below the detection limit. In these cases, a value half of the detection limit was used (estimated mean) in the calculations. These elements are marked in the table in the Appendix 6.

Table 4-23. Analyzed abiotic pools and functional groups in Forsmark and Laxemar-Simpevarp. X, denotes analysed group and n=, denotes number of studies/replicates.

Pool/functional group	Analyzed in Forsmark	Analyzed in Laxemar-Simpevarp	Reference for Forsmark	Reference for Laxemar-Simpevarp	Comment
Particulate matter in water	X, n=3	X (POC) from SKB's site investigations	/Bradshaw and Kumblad 2008/	/Ericsson and Engdahl 2004, Ericsson and Engdahl 2005, Ericsson and Engdahl 2006/	Data on particulate organic carbon (POC) from 2003–2007 in marine water samples were used together with the C:X ratio found in Forsmark
Dissolved matter in water	X, n=3	X (DIC) from SKB's site investigations	/Bradshaw and Kumblad 2008/	/Ericsson and Engdahl 2004, Ericsson and Engdahl 2005, Ericsson and Engdahl 2006/	Data from SKB's database SICADA (dissolved inorganic carbon, DIC) from 2003–2007 were used
Sediment	X, n=2	X, n=2	/Engdahl 2008, Sterneck 2006/	/Nilsson 2004, Engdahl 2008/	N and P concentrations from /Sternbeck 2006/
Macrophytes	X, n=9	X, n=12	/Bradshaw and Kumblad 2008/	/Engdahl et al. 2006/	
Microphytes	X, n=2	–	/Bradshaw and Kumblad 2008/		Data for Forsmark were used in Laxemar-Simpevarp
Phytoplankton	X, n=3	–	/Bradshaw and Kumblad 2008/		Data for Forsmark were used in Laxemar-Simpevarp
Benthic bacteria	–	–		/Bertilsson et al. 2003, Heldal et al. 2003/	Literature data for concentrations of C, N, P and S were used
Benthic fauna – herbivores	X, n=4	–	/Bradshaw and Kumblad 2008/		Data for Forsmark were used in Laxemar-Simpevarp
Benthic fauna – detrivores	X, n=2	–	/Bradshaw and Kumblad 2008/		Data for Macoma baltica were used, could also be classified as a filter feeder
Benthic fauna – filter feeders	X, n=3	X, n=3	/Bradshaw and Kumblad 2008/	/Engdahl et al. 2006/	In Forsmark Cerastoderma glaucum, in Laxemar-Simpevarp Mytilus edulis
Benthic fauna – carnivores	–	–	/Bradshaw and Kumblad 2008/		Data for idothea in Forsmark were used, based on most likely to be similar as to benthic carnivores
Zooplankton	X, n=1	–	/Bradshaw and Kumblad 2008/		Data for Forsmark were used in Laxemar-Simpevarp
Bacterioplankton	–	–		/Vrede et al. 2002 Heldal et al. 2003/	C:N and C:P was taken from averages from cultures from exponential growth, C-, N- and P-limited growth studied by /Vrede et al. 2002/. Sulphur content in cyanobacteria was studied by /Heldal et al. 2003/ and the average molar ratio for six strains was used (C:S = 216).
Fish – benthivorous	X, n=3	X, n=3	/Bradshaw and Kumblad 2008/	/Engdahl et al. 2006/	
Fish – zooplanktivorous	X, n=3	X, n=3	/Bradshaw and Kumblad 2008/	/Engdahl et al. 2006/	
Fish – piscivorous	X, n=3	X, n=3	/Bradshaw and Kumblad 2008/	/Engdahl et al. 2006/	
Birds	–	–			No data
Mammals	–	–			No data

4.6 Confidence and uncertainties

4.6.1 Biota

Primary production

Primary production calculations are in this report dependant on annual average biomass (gC m^{-2}) and irradiance (MJ PAR d^{-1}, or days > 5 MJ PAR y^{-1}).

A comparison was made with the Photosynthesis – Irradiance (P-E) relationship proposed by /Binzer and Sand-Jensen 2006/. This study showed a hyperbolic relationship between photsythesis and Irradiance according to:

$$GP = GP_{max}\left[\frac{\alpha I}{GP_{max} + \alpha I}\right] \qquad \text{(Equation 4-3-1)}$$

where α is photosynthetic efficiency (mol mol $photons^{-1}$) and I is irradiance (µmol photons $m^{-2}s^{-1}$) and GP_{max} is maximum Gross Production (GP) (µmol O_2 $m^{-2}s^{-1}$). From 190 studies they calculated the average: $\alpha = 0.036$ and $GP_{max} = 14.2$. This equation was used to compare the calculations described in section 4.2, and so two years of irradiance ($I_{surface}$) measures (average every half hour) and spatial variation of light attenuation (LA) was used to integrate a two year average of annual primary production for the Forsmark area according to:

$$\frac{1}{2}\sum_{March2004}^{March2006} 14.2\left[\frac{0.036 \cdot I_{surface} \cdot LA}{14.2 + (0.036 \cdot I_{surface} \cdot LA)}\right] \qquad \text{(Equation 4-3-2)}$$

GP (mol O_2 $m^{-2}s^{-1}$) was recalculated to NP gC $m^{-2}y^{-1}$ to enable comparison using conversions factors. Calculations were performed in Matlab (Mathworks R2007a) and ArcMap (9.1). As the equation does not take biomass into account although is valid for macrophyte communities, a lower level of biomass was set to 1 gC m^{-2}.

Table 4-24. Benthic maximum and average Net Production (gC $m^{-2}y^{-1}$) and standard deviation (SD) in this study and earlier reported.

Study	Maximum	Average	SD[1]
Calc. according to /Binzer and Sand-Jensen 2006/	728	158	229
This study[2]	1,013 (948)	76 (53)	162 (148)

1. SD for calculations in this study is standard deviation from the grid dataset.

2. Benthic NP and (only macrophytes NP).

The resulting average annual NP (Table 4-24, Figure 4-38) was similar to the calculations, the maximum NP was lower, 728 gC m^{-2} $year^{-1}$ in the calculations according to /Binzer and Sand-Jensen 2006/ compared to a the NP predicted in this report; 948 gC $m^{-2}y^{-1}$ macrophyte community production or 1,014 gC $m^{-2}y^{-1}$ (including microphytes). Following the heterogeneous biomass distribution the the average was lower in this study than in calculations according to Binzer: Average benthic NP was approximately half that of predicted benthic primary production, 76 compared to 158 gC $m^{-2}y^{-1}$. However, the reported mean values for α and GP_{max} has a range approximately one order of magnitude (0.007–0.076 and 3.15– 25.2) and so the difference between our calculations and Equation 4-3-2 is well within the range reported in /Binzer and Sand-Jensen 2006/.

The estimates of primary production are based on biomass and irradiance and have been compared with an independent model (Equation 4-3-1). The quality of the biomass dataset is discussed earlier in this section and the method is evaluated for the Laxemar-Simpevarp area in /Wijnbladh and Plantman 2006/. Light measurements and light penetration are compiled from a large dataset from an investigation with high temporal density /Borgiel 2005/. Data from 11 independent *in situ* primary production studies were compiled in this report to calculate annual NP in the area. These calculations fit well in the range of reported NPs /Binzer and Sand-Jensen 2006/ and also take spatial variation of biomass into account.

Fish biomass

True biomass or density data on fish biomass are scarce. Most often biomass is reported as an index or at the best CPUE (catch per unit effort) or number of individuals /e.g. Axenrot and Hansson 2004, Horbowy 2003, Hansson and Rudstam 1995/. A few studies have attempted to estimate actual biomass data, however. In this study we have used site specific surveys in GRASP models to estimate biomass (in Forsmark /data from the Swedish Board of Fisheries, / Abrahamsson and Karås 2005, Heibo and Karås 2005/) and site specific data and literature data to estimate and distribute biomass spatially in Laxemar-Simpevarp /Jansson 2005, Enderlein 2005/.

In Laxemar-Simpevarp, one extensive study has been made in one of the basins (basin 508) using several methods to calculate biomass /Adill and Andersson 2006/. Only the proportions of the three functional groups of the catch found in this study were used to estimate total fish biomass. The biomass found in this study can therefore be used to validate calculations described in section 4.2.1.

The estimated total fish biomass was calculated (see section 4.2.1 in this report) to be 0.79 (SD = 0.24) g C m^{-2}, varying between 0.42 and 0.85 g C m^{-2} for the other inner basins.

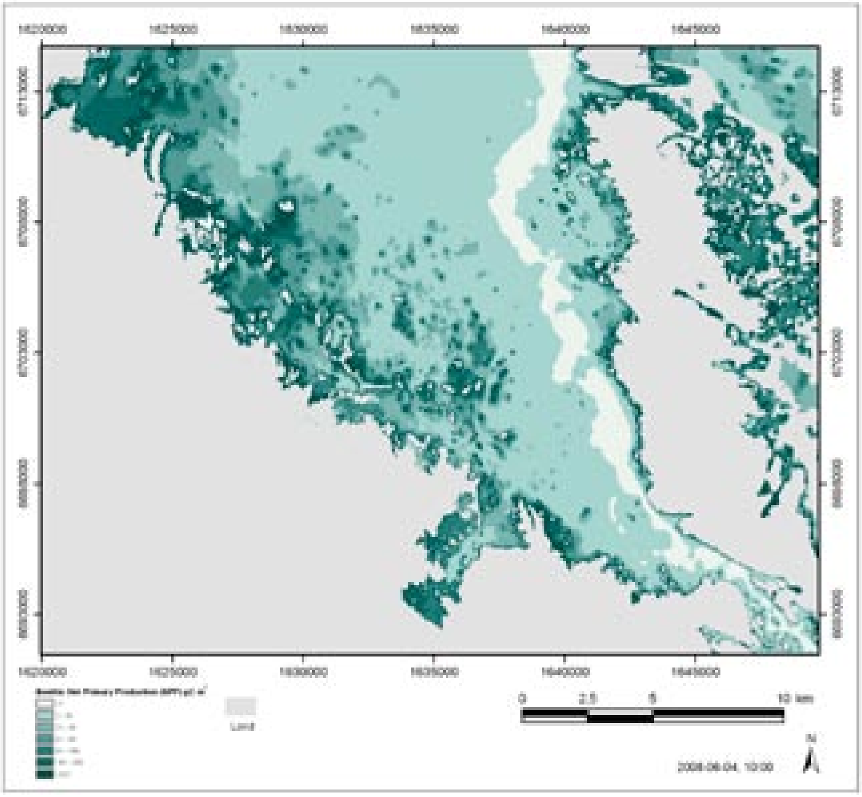
The biomass estimates in /Adill and Andersson 2006/ varied between 81.2 and 71 kg ww ha-1 for May and September respectively, equivalent to 0.812 and 0.71 g C m^{-2}, with an average of 76.1 kg ww ha^{-1}.

The deviation between biomass in the model (0.79, calculated from literature data) and biomass observed in field (0.76) is therefore only 4% which must be considered surprisingly small but definitely acceptable.

4.6.2 Regolith

Substrate

Substrate from the geological mapping was used to classify bottom substrate as hard or soft. This is a simplification of real conditions as hard substrate, e.g. bedrock, often contains patches of soft substrate within its area. Further, classifications in the deeper outer parts are subject to error due to the fact that classifications do not concern top sediment. Less than 50 cm sediment has been ignored in the classification in these areas /Hedenström personal communication/.



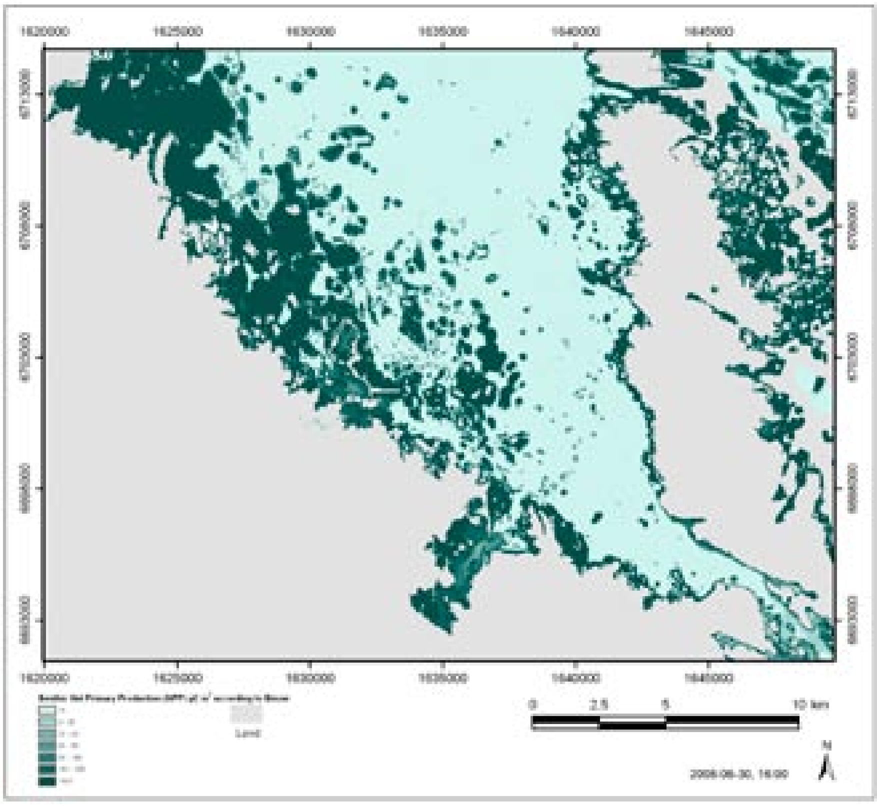


Figure 4-38. *Benthic primary production calculated according to section 4.2 in this report (above) and according to /Binzer and Sand-Jensen 2006/ (below).*

5 Oceanographic model

5.1 Water exchange

The Baltic coastal waters serve as an intermediary link whereby waterborne material released from the geosphere may eventually be transported via advective and diffusive processes to the world oceans (Figure 5-1). The primary connection with the geosphere may be direct via leakage through the sea floor of the coastal zone or via water runoff (discharged diffusely by groundwater flows, or discretely by localized watersheds such as streams or rivers) which enters the surface layers of the coastal zone. The coastal waters also comprise aquatic ecosystems in which inflowing material can be transformed via food chains. For aquatic ecosystems the rate of water exchange is an indisputable basic parameter that sets the externally forced pace of material turnover. The overall objective is to quantify the water exchange of the coastal area in the vicinity of the planned repositories in such terms that projection into the distant future is made possible. Various water circulation models driven by reasonably simplified but adequate forcing are employed for this purpose, and the large amounts of oceanographic data generated over the cycle of a typical year are condensed into a conceptual form that can serve as a basis for communication with other concerned disciplines. The year 1988 was chosen as the most representative year for the Forsmark coastal area /Larsson-McCann et al. 2002a/, while 1981 was recommended and for the Laxemar area /Larsson-McCann et al. 2002b/.

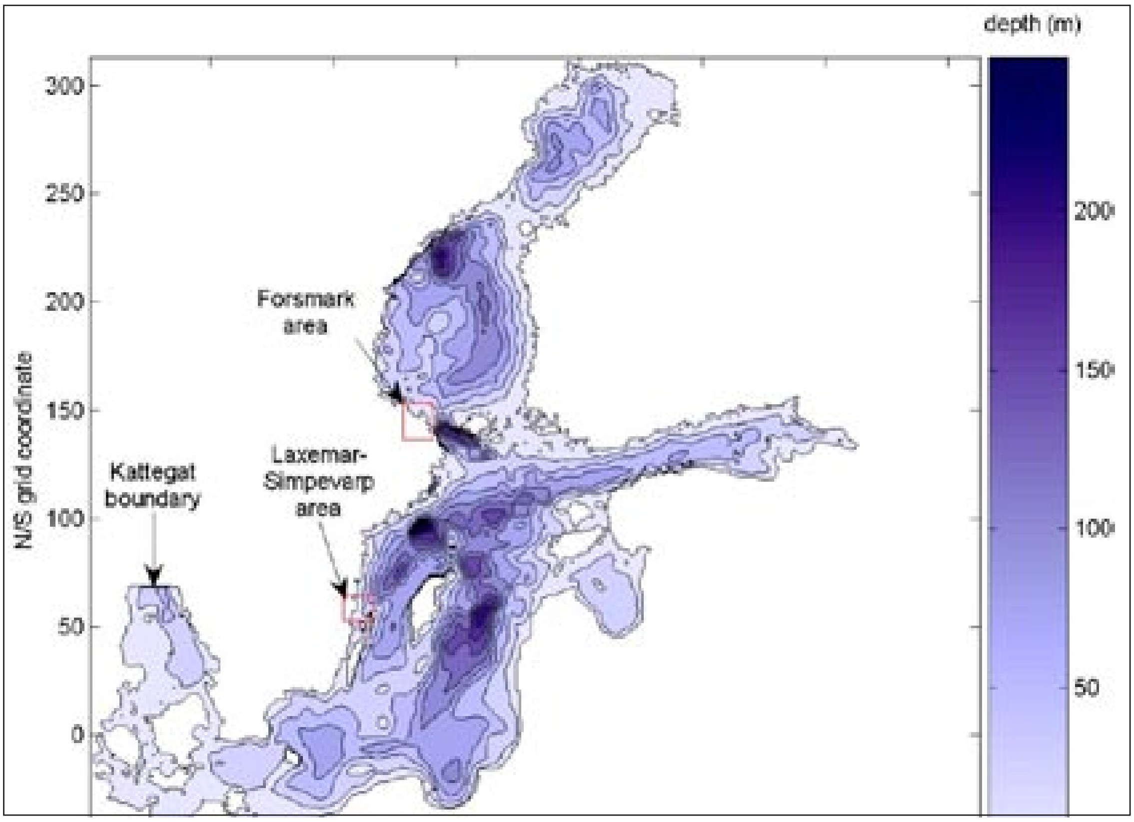


Figure 5-1. *The Baltic model grid displaying the Warnemünde bathymetric data. The approximate locations of the Forsmark and the Laxemar model domains are indicated, as is the boundary of the Kattegat model with Skagerrak.*

In describing the water exchange processes of the coastal zone, those of the deeper open coast and those of the normally shallower and possibly land-locked waters near the mainland should be distinguished. In the open coastal zone, the water circulation is mainly determined by barotropic (sea level-related) surface waves or baroclinic (density difference-related) internal waves. The local wind exerts shear friction on the surface that induces vertical mixing leading to deepening of the surface layer /Stigebrandt 1985/. Horizontal surface currents are also set in motion. Large-scale events such as up- and down-welling generated by Ekman dynamics in adjacent coastal areas normally affect the circulation in a particular section of the coast to a greater extent /Engqvist and Andrejev 1999/. Such events manifest themselves by entering into a particular coastal section through its boundaries. This external influence may be imposed on the interior of the model domains as appropriately varying sea level and density profiles along the boundaries.

5.2 Methodology

To obtain quantitative time-based estimates of particle turnover in general reservoirs, Bolin and /Bohlin and Rodhe 1973/ formulated a strict foundation in statistical terms. One of these well-defined concepts was independently adapted to water circulation models by introducing its volume-specific counterpart /England 1995, Engqvist 1996/. The naming of this concept has been somewhat variable and vague in subsequent years. A clarifying nomenclature fully compatible with the volume-specific concepts has recently been suggested by /Delhez et al. 2004/ and has been adopted. Looking at a particular water parcel present in a reservoir at a given moment and following it individually while measuring the time it takes until it leaves yields its residence time. The ensemble average over all parcels present at a given instant in the specified reservoir gives the *average residence* (*AvR*) time. Analogously, backtracking the same parcel chronologically in reverse until the point in time it entered the reservoir gives the 'age' of that water parcel, and the average age over the water parcel ensemble gives the ***average age*** or *AvA*. The sum of *AvA* and *AvR* gives the ***average transit time*** or *ATR* time, which is sometimes referred to as the (hydraulic) turnover time, since these were proven equal for stationary distribution cases by /Bolin and Rodhe 1973/. *AvA* thus denotes the length of time a particular water parcel of originally exogeneous water (or parts thereof) has on the average spent within a defined connected body of water. This could be discharged freshwater and/or water entering from any other connecting water body with a boundary across which water is exchanged. The relationship between two of those measures and the comparative advantages and disadvantages of other compacting methods to describe water exchange in a transdisciplinary communicative manner are discussed in /Engqvist et al. 2006/.

What is regarded as interior and exogeneous water must thus be specified. Once this has been determined, then the development of *AvA* for the entire defined volume partitioned into subbasins can readily be computed, each of these possibly further subdivided into vertical layers. Each subbasin can then be treated as surrounded by exogeneous water, and this case will be referred to as ***individually*** computed *AvA* values with regard to a particular subbasin. Alternatively, a number of neighbouring subbasins are treated as conjoined, which case is called ***collective*** *AvA* since the subbasins have a delimiting boundary with the exogeneous water in common that may or may not coincide with the borders of any of the individual subbasins.

Given information on the mixing time scales in relation to the advective time scales, it is possible to use the *AvA* concept to obtain an overview estimate of the water exchange over long-term periods, typically one year, by computing its average, maximum and minimum values. These values, together with an estimate of the variance, e.g. the standard deviation (S.D.), can be computed from instantaneous *AvA* values. These *AvA* snapshots should be sampled over a shorter time period than the timescales set by the temporal variation of the imposed forcing. The advantage is that diffusive processes are included, all sources of exogeneous water can be accounted for simultaneously and no post-processing is needed /Döös and Engqvist 2007/.

The *AvA* concept must, however, be used with due caution when the associated flows are to be inferred from it, in particular if the *AvA* values reach parity with the designated one-year cycle time scale that is derived from ecological modelling considerations. The highest *a priori* likelihood for this eventuality to occur concerns the decisively landlocked areas, which will therefore consistently be modelled separately. When water exchange estimates are used in integrated ecological models, the fluxes are computed directly from the actual model without recourse to the *AvA* measure.

5.3 Description of models

A common trait of the Forsmark and the Laxemar-Simpevarp coastal areas is that the coastal waters close to a possible nuclide leakage point near the mainland coast are delimited by a land barrier to the east (Gräsö and Öland respectively) forming a funnel-like primary receiving offshore area with its wide end to the north and the narrow end southwards. The horizontal resolution of the corresponding grids of the respective areas are presented in Figure 5-2 (Forsmark) and Figure 5-3 (Laxemar), both with a grid side length of 0.1' (nautical mile). In addition to a coarser morphometric horizontal scale, the Laxemar area also displays a more rugged coastline with considerably more semi-enclosed, landlocked basins.

The bottom along the Laxemar coast gradually slopes in the offshore direction; there are few topographic features that naturally indicate a well-defined delimitation line. The model areas of both Forsmark and Laxemar-Simpevarp are further partitioned into a number of non-overlapping subbasins (SBs) based on the consideration of present underwater structures that, due to future land uplift, will potentially accentuate the confinement of the water movements to a progressively shallower bathymetry until lakes are eventually formed. These areas are

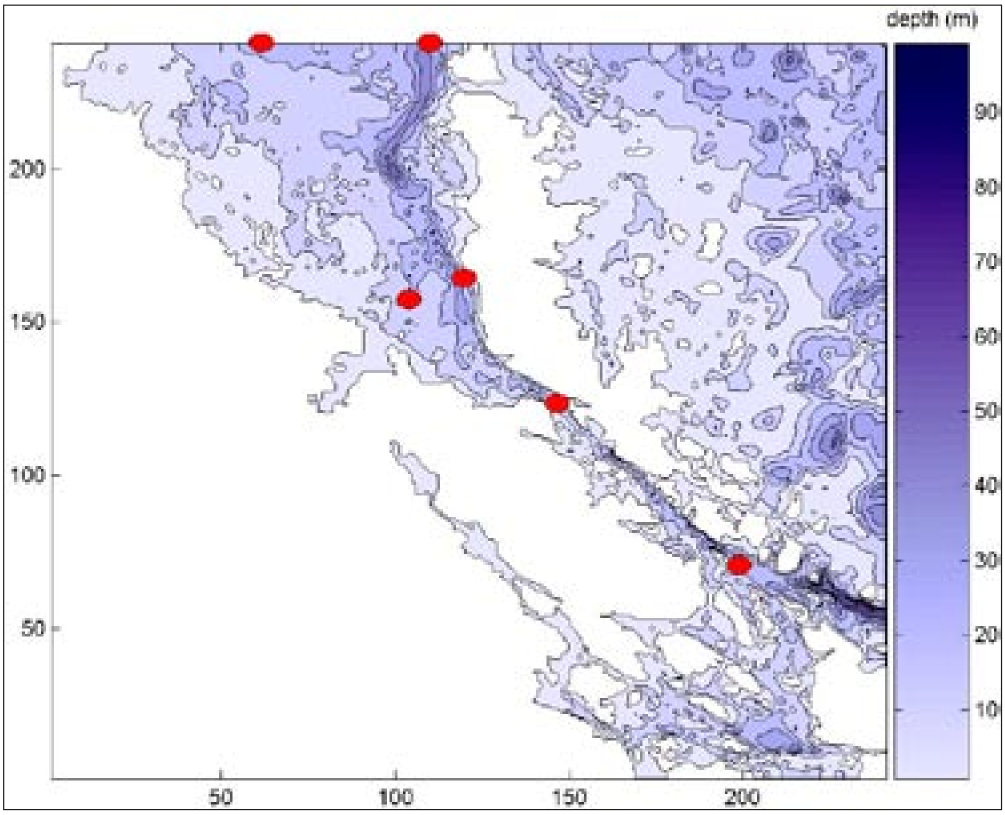


Figure 5-2. *The chosen model domain of the Forsmark area with some of the grid cells manipulated manually. In particular, the narrow channels that connect the fjord branches with the southern basins have been made sufficiently wide in a few sections to permit through-flow. The six red spots mark the sites of deployed oceanographic instruments during the validation year 2004.*

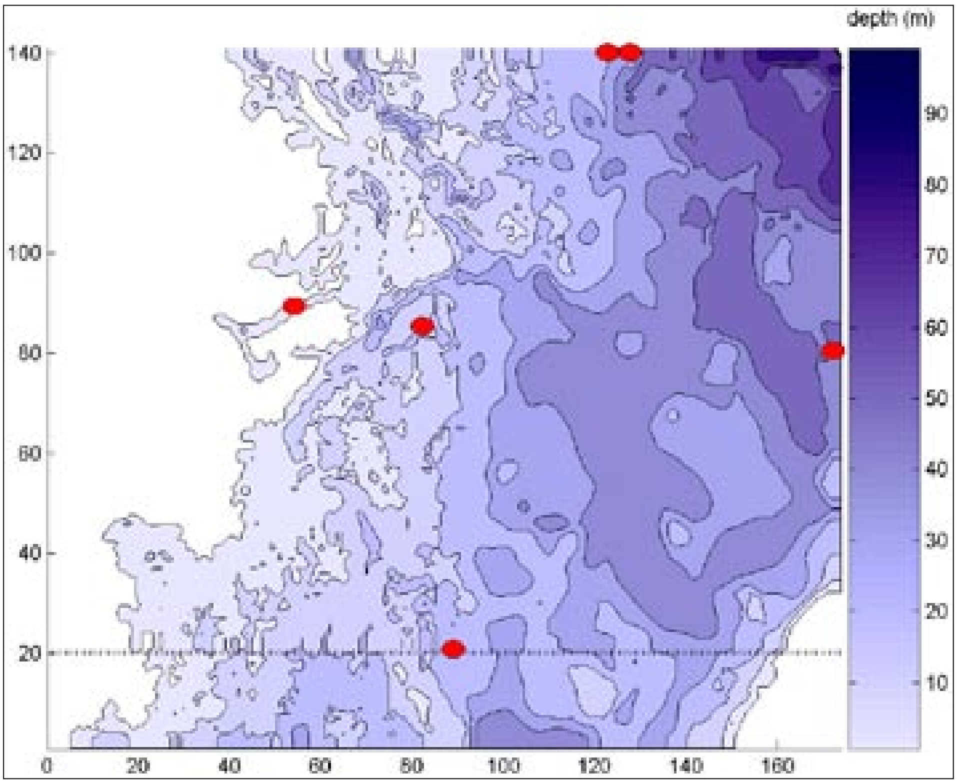


Figure 5-3. *The Laxemar-Simpevarp model area. A bit of the island of Öland can be seen in the southeast corner. The broken black line delineates the original grid prior to its extension southward. The sites of the six measurement stations where oceanographic instruments were deployed for the 2004 validation programme are indicated as red spots.*

shown in Figures 5-4 and 5-5. The location of some of these SBs also coincides with anticipated leakage points connecting to the geosphere. The water exchange of a particular SB is broken down into the yearly volume fluxes across its boundary interfaces with other SBs or the Baltic. These consist typically of flows going in opposite directions, separated in time or in space, both horizontally and vertically. These are accounted for by the sign convention that a positive flow goes from a basin with a higher order number to one with a lower. The sum of these flows (with sign) gives the net flow. The sum of the annually averaged net fluxes along the boundary of each SB should thus be close to zero, within the allowance of an equivalent flow producing the volume of a differing sea level at the beginning and the end of the year-long period.

Concerning both the Forsmark and the Laxemar-Simpevarp areas, two versions of the same generic 3D model have been employed: one for the entire Baltic Sea circulation and the other for a local section of the near-shore coastal area. These models are nested so that the Baltic oceanographic properties (currents, salinity, and temperature fluctuations) along the border are propagated into the local models. In order to account for the forcing data unequivocally, the Baltic model will be referred to as **B3D** and the two local models as **F3D** and **L3D**. In the Laxemar-Simpevarp area there is an additional model that resolves the coastal embayments that are not deemed appropriate for 3D-modelling. This semi-enclosed area is modelled with hydraulically coupled discrete basins which will be referred to as the **CDB** model.

The baroclinic 3D model, AS3D, /Andrejev and Sokolov 1990/ has been set up for the entire Baltic and the two offshore areas and run for a specified time period comprising a one-year cycle. Since sufficient oceanographic measured data are not available along the border of the two offshore areas, these are provided by the **B3D** model /Engqvist and Andrejev 1999/. The large-scale Baltic model is thus interfaced to the local models along a geometrically simple delineation line where the grids coincide. All three 3D models comprise 40 vertical levels with monotonically increasing layer thickness towards the bottom. A comprehensive description of the numerical scheme has been given in /Andrejev and Sokolov 1997/ and a succinct summary of the main numerical features can be found in /Engqvist and Andrejev 2003/.

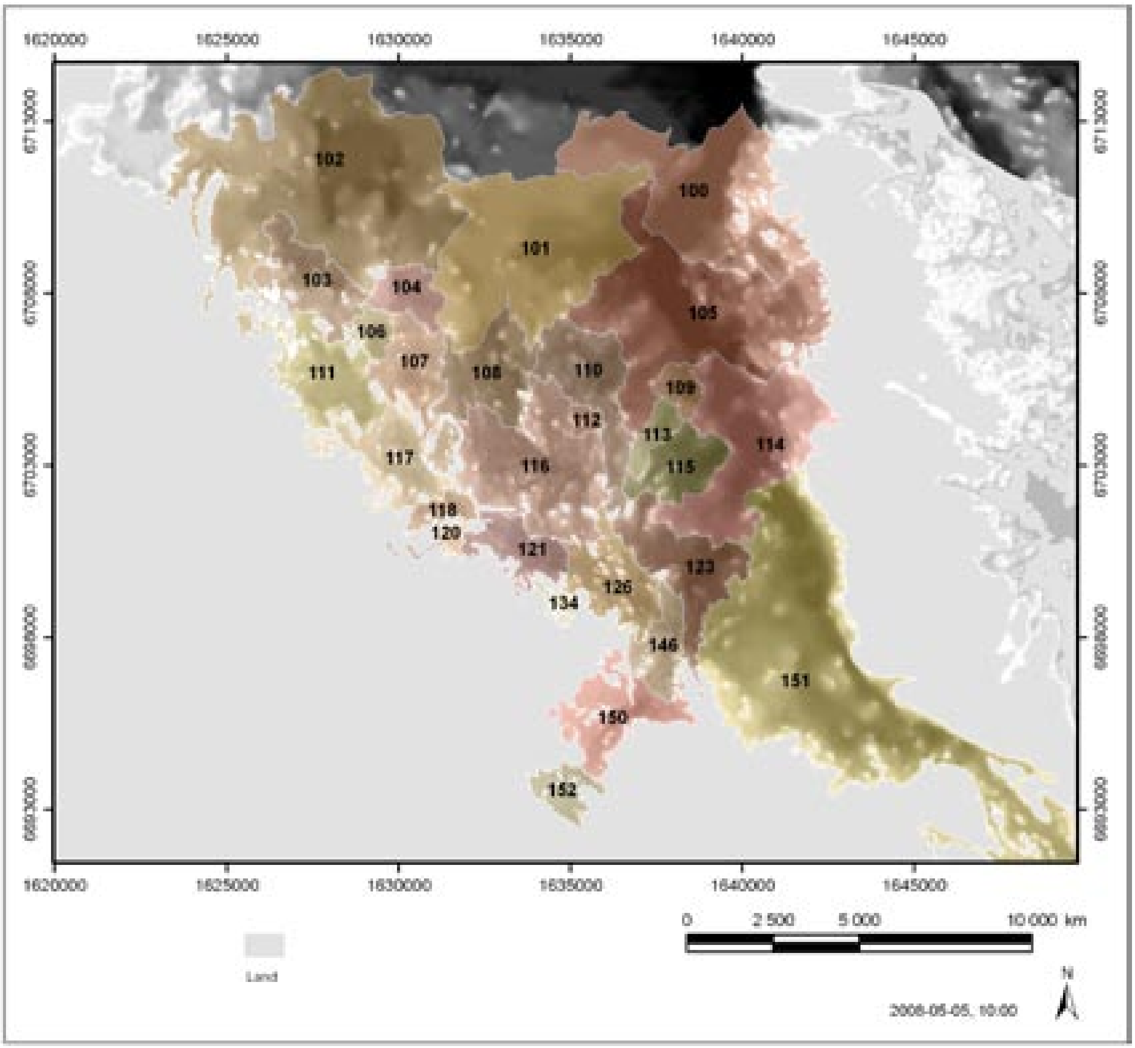


Figure 5-4. The partitioning of the Forsmark coastal area into subbasins (SBs) with labelling of the major basins.

For the more shallow landlocked basins of the Laxemar area adequate resolution of narrow straits may demand a more sophisticated (non-hydrostatic) 3D model approach. In this case a more attractive method is, however, to parameterize the strait exchange /Stigebrandt 1990/ and use CDB models to resolve the area /Engqvist 1997/. This method limits the temporal scale that is possible to resolve, since the basins must be considered horizontally well-mixed. The straits interconnecting such a partition into discrete subbasins may have various geometrical characteristics: lengths and depths and the existence/absence of a sill which will influence the exchange /Engqvist and Stenström 2004/. Straits connected to basins that receive discharged freshwater consequently often display a pronounced estuarine circulation mode. Even with an established estuarine circulation flow regime, the varying density stratification in the offshore waters is often the dominant cause of ventilation of coastal basins /Engqvist and Omstedt 1992/. The choice of appropriate models to simulate the water exchange depends on both the hypsography and how separate model areas are connected.

Due to the existence of narrow internal straits within the primary partitioning, however, an additional split of three of these SBs into a pair of directly connected basins is recommended based on oceanographic considerations. Altogether, this analysis thus involves 19 SBs, ten of which are located along the open coast and will be referred to as *outer* SBs while the other group will be called *inner* SBs, see Figure 5-6.

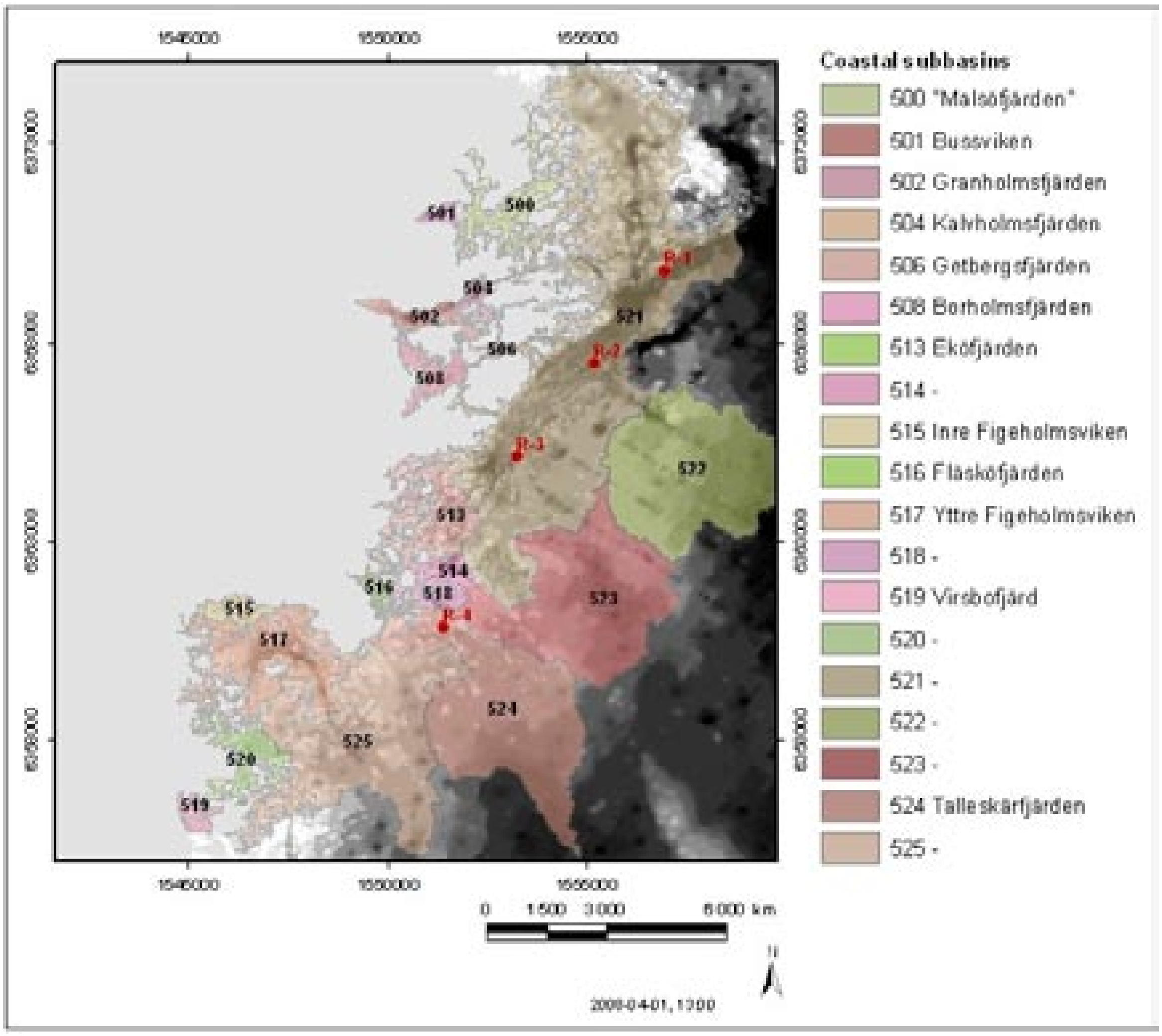


__Figure 5-5.__ The partitioning of the Laxemar coastal area into subbasins (SBs) together with their numbering and naming when trivial names exist. The red spots denote the locations along the coast for which the forcing (salinity, temperature and sea level) of the __CDB__ model has been computed by the __L3D__ model. These profiles are used for the modelling of the interior basins, see Figure 5-6.

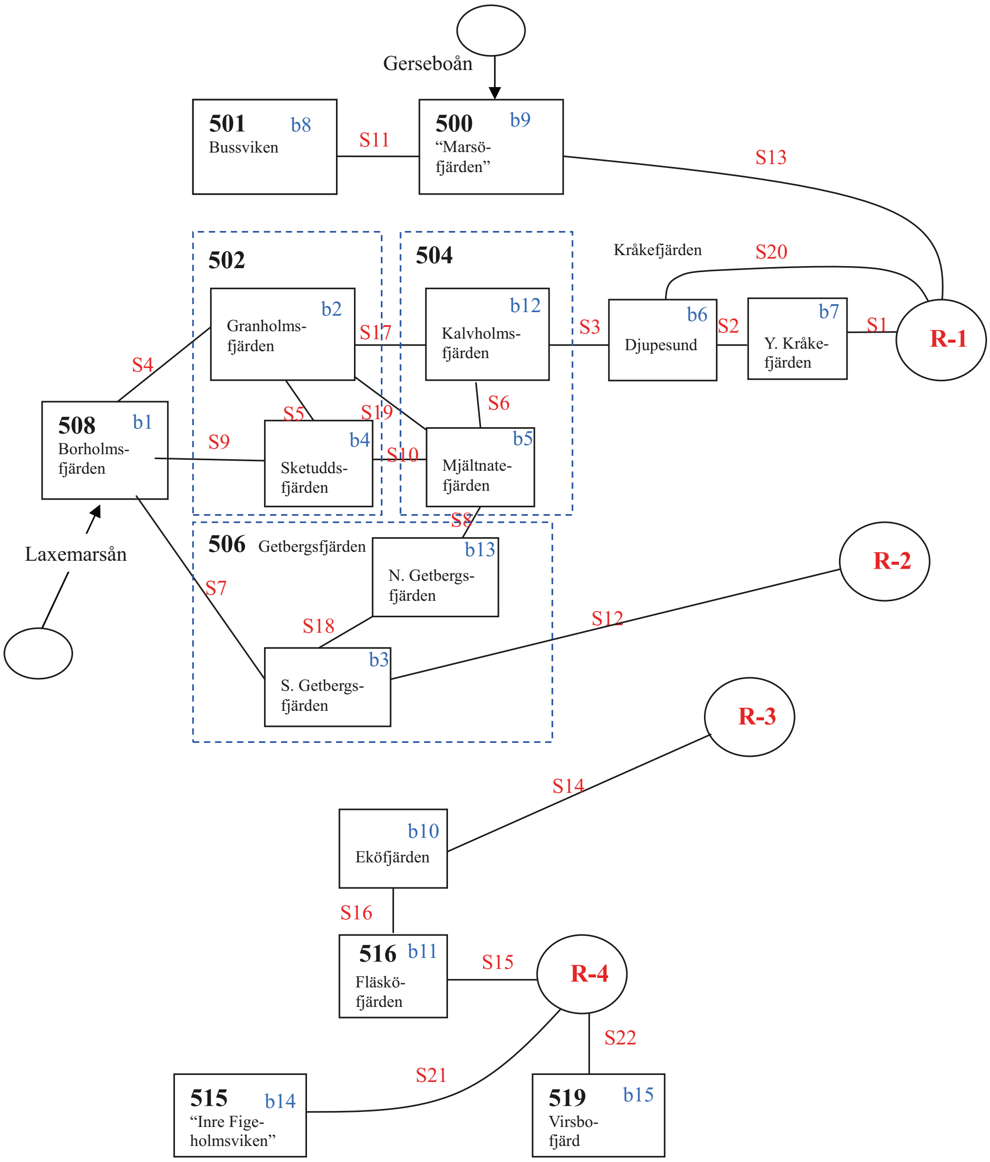


Figure 5-6. *Basin and strait configuration for the computation of AvA times for the semi-enclosed basins of the Laxemar-Simpevarp area. The basins denoted with bold capital ID labels (e.g.* **508***, Borholmsfjärden) refer to the SKB partitioning and are chosen with regard to their topographic features /Brydsten and Strömgren 2005/. Three of these basins also possess narrow internal passages that constrain water exchange, warranting a further subdivision based on oceanographic considerations; this is indicated by the blue broken lines. The lower-case basin blue ID labels (e.g. b10, Eköfjärden) in the upper right corner are the systematic consecutive labelling used in the model computations. The corresponding labels of the straits are given in red letters. The connections with the coastal basins are labelled R-1 to R-4, Figure 3-5. The sea level, together with the salinity and temperature profiles at these locations, has been computed with the Laxemar coast fine-resolution 3D model.*

5.4 Input data

The input data come from many disparate sources with the common denominator that they are judged to represent the available source with the highest degree of adequacy.

Kattegat boundary data needed for the Baltic model are the sea level, salinity and temperature of the Kattegat model boundary. These sea level data are gauged both on the Swedish side (Göteborg) and on the Danish side (Fredrikshavn). The difference between those levels is an important model parameter and provides the geostrophically adjusted flow. The absolute vertical position of these gauges is not possible to reconstruct reliably from available data; instead the long-term average has been used to obtain this information. The salinity and temperature profiles are mainly determined by North Sea dynamics and display a repeating pattern from year to year /Gustafsson 2000/; these averages have been used.

Bottom bathymetric data for the **B3D** model come from the Warnemünde Oceanographic Institute (http://www.io-warnemuende.de/research/en_iowtopo.html) covering the entire Baltic Sea from 9°00' to 15°10' East and from 53°30' to 56°30' North. The resolution is 2 (spherical) minutes with respect to latitude, and about 4 minutes with respect to longitude. This corresponds to a grid with a side length of approximately 1 nautical mile. For the **F3D** and the **L3D** models, the grid has been computed from a DEM based on national digitized charts and supplemented by shoreline information from economical maps, resolving the shoreline better. The grid was specified in spherical coordinates WGS84 (SWEREF 99 long lat ellh) with the constraint that to be considered as a wet grid cell, at least 50% of the covered area should consist of water. This necessitates some manual adjustments of channels connecting interior embayments.

The gridding has been performed by the National Land Survey of Sweden. The hypsographic data (area as a function of depth for the discrete basins and width as a function of depth for the straits) of the **CDB** model have been extracted from the 10 m resolution DEM /Brydsten and Strömgren 2005/ using GIS methods, supplemented by field assays performed in August 2005.

Ice formation and melting data pertaining to the **F3D** model stem from systematic data compiled by SMHI and the Swedish Maritime Administration, Figure 5-7a. This is not applicable for the **L3D** model since ice formation rarely occurs. The **B3D** model computes the formation and melting of the ice cover by means of a simple but straightforward mechanism. These data needed as forcing to the CDB model are mainly based on SICADA data but also in a few instances on local observations made by the Swedish Board of Fisheries.

Atmospheric forcing data pertain to all the involved models. The meteorological forcing data of the 3D models comprise wind velocity, at standard 10 m, air pressure, and air temperature sampled every third hour. The primary data used, known as the Mueller data set, has a horizontal resolution of (1° × 1°) and consists of synoptic geostrophic wind that needs to be discounted to the standard 10 m level. In addition to the required variables it also includes data pertaining to humidity, cloudiness, precipitation and insolation. These data sets have been used in earlier modelling studies /Engqvist and Andrejev 1999, 2000/ and are made available by the Oceanographic Institute, Göteborg University. SMHI announced that this data set was to be discontinued after 2001. To make up for this loss, so-called Mesan data were offered as a substitute. The wind speed in 1981 for the centre of the Laxemar area is depicted together with a wind rose in Figure 5-7b.

The geographical coverage of both these grids spans the entire Baltic, Figure 5-8. For projected estimates of distant future coastal water exchange, more refined and explicit atmospheric thermal forcing (e.g. humidity, insolation and nebulosity) cannot be assumed to be readily available.

Initialization data for the local models have been produced by tentatively starting from climate average salinity and temperature profiles and then running the model for the month that precedes the starting date a number of times. Reiterated runs of the model are then performed with resulting salinity and temperature states at the end of month as initial data until the boundary properties have to a sufficient degree permeated into the central parts of model area through the boundaries. For the Baltic model, however, all consecutive intervening years have been run.

Freshwater discharge data for the **B3D** model are based for the type-years (1981 for Laxemar and 1988 for Forsmark) on 10-year averages of runoff data comprising the watershed of the entire Baltic, subdivided into 29 major river discharge locations, all with monthly resolution. For the recent year simulations involving the validation years 2004 and early 2005, the freshwater discharge data were computed from HBV model data /Graham 1999/ with monthly resolution made available by Phil Graham of the Swedish Meteorological and Hydrological Institute (SMHI). The computation has been able to redistribute in proportion the estimated discharge of the HBV model's 15 areas into the 29 discharge points of the **B3D** model. For the **F3D** and **L3D** models the local freshwater discharge has been directly based on HBV model estimates obtained from the SICADA data base with weekly temporal resolution, Figures 5-7c and 5-7d.

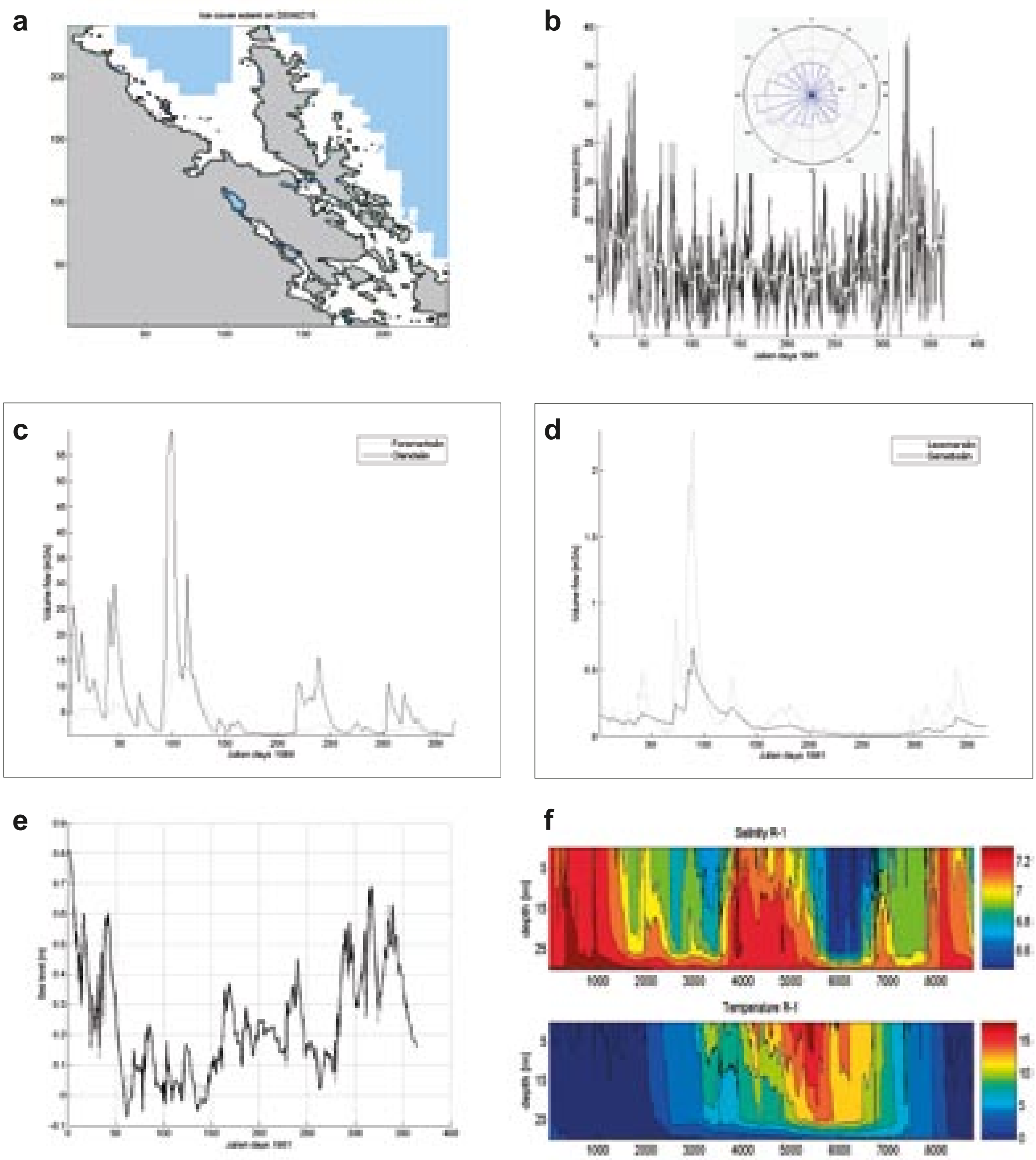


Figure 5-7a. *Example of ice statistics concerning the Forsmark area with ice cover in white and land in gray, as presented by the Finnish Institute of Marine Research.* ***7b*** *Wind forcing with 3-h resolution as measured at Ölands Norra Udde 1981 near the eastern border of the Laxemar grid. A running average of approximately 3 weeks is shown as a white broken line. A wind rose, showing that the predominant wind direction is from the WSW, is inset at the top.* ***7c*** *Water discharge of the two major streams Forsmarksån and Olandsån 1988.* ***7d*** *Discharge of the two major streams Laxemarån and Gerseboån 1981. Only Laxemarån discharges into the discrete basin model area.* ***7e*** *Sea level forcing of the coastal stations R-1(solid) and R-4 (broken). Only in a few periods (e.g. around day 60 and day 130) is there a noticeable difference between these curves. The computed sea levels of R-2 and R-3 fall within these limits.* ***7f*** *Computed salinity and temperature profiles during the type-year 1981 at a location corresponding to the location R-1 in Figure 4. The incidences of up- and downwelling occasions are clearly seen, as is the stabilizing thermal stratification during the summer period. The other three boundary stations R-2 through R-4 display similar profile dynamics with small variations.*

Sea level and density fluctuations at the peripheral boundaries of the respective model areas (i.e. the external border to other adjacent water bodies) concern the **B3D** model derived from (SMHI) sea level measurements at Göteborg harbour and the Danish Meteorological Institute's (DMI) corresponding records from Fredrikshavn. The sea level forcing of the **F3D** and **L3D** models is provided by the Baltic model and the corresponding forcing of the **CDB** model is in turn computed by means of the **L3D** model, Figures 5-7e and 5-7f. These data have hourly temporal resolution in common.

5.5 Results

Employed 3D models have the capacity to generate a massive output of data. For the purpose of effective communication of results concerning the water exchange across transdisciplinary boundaries, these data are condensed into the preferred *AvA* measure. The yearly averages of these values are graphically presented with regard to their depth variation in Figures 5-9 through 11 for the **F3D**, **L3D** and **CDB** models and as yearly basin volume averages in Table 5-1 for the **F3D** model and Table 5-2 for the combined **L3D** and **CDB** models**.** All these AvA times are an order of magnitude smaller than the one-year cycle over which they are averaged. The intra-annual variations seem to be greater than the short-term inter-annual variations.

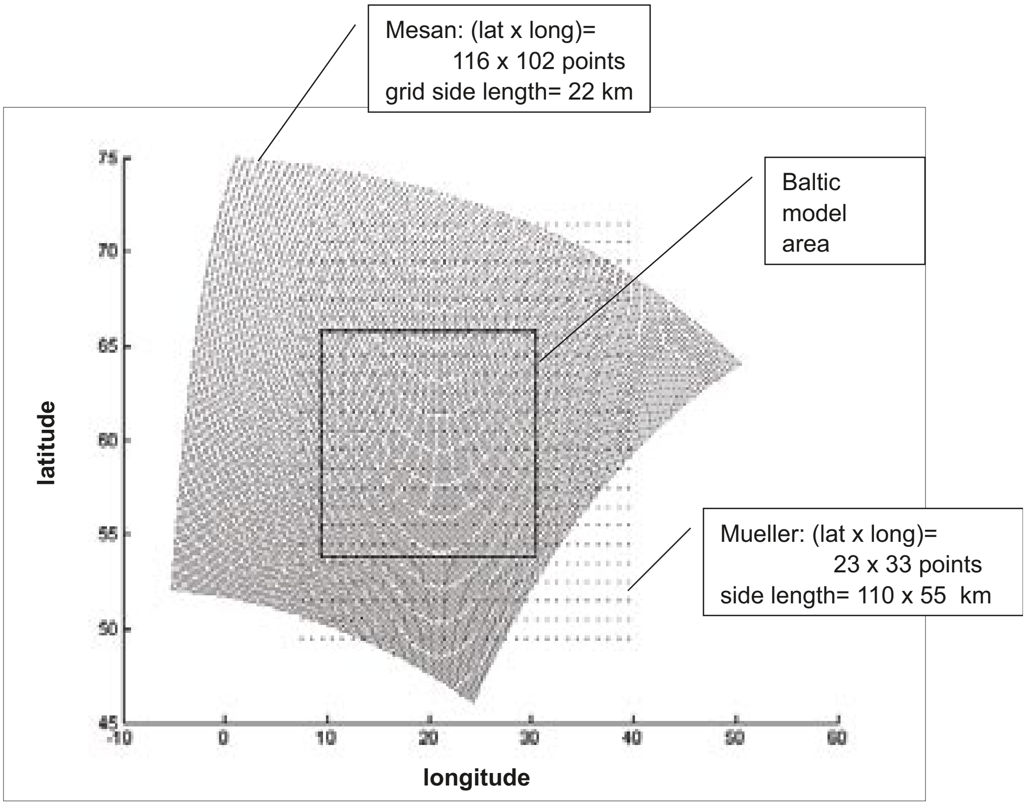
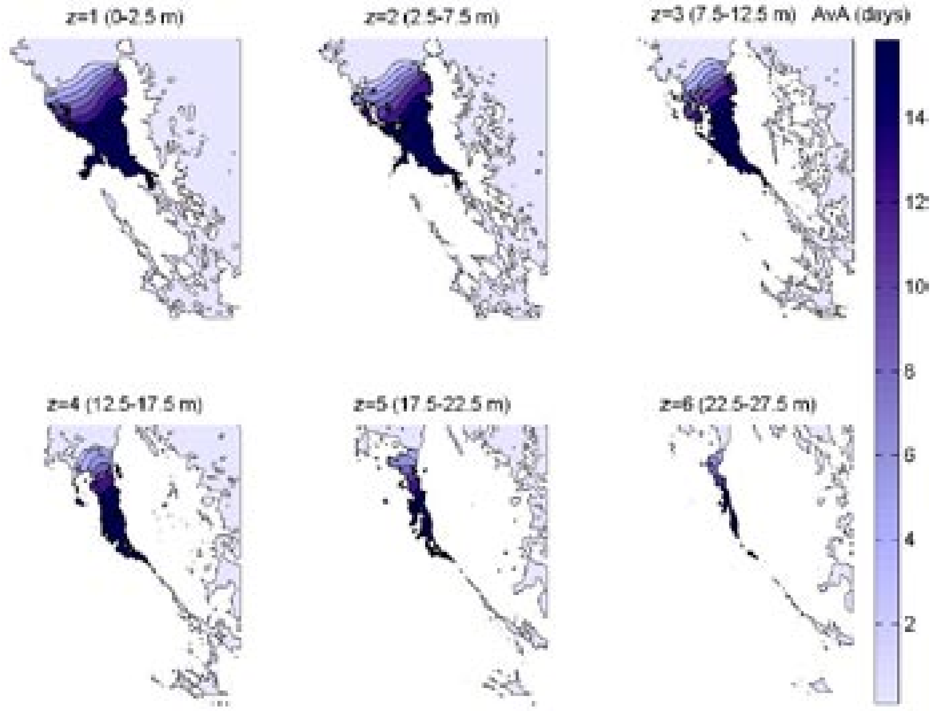
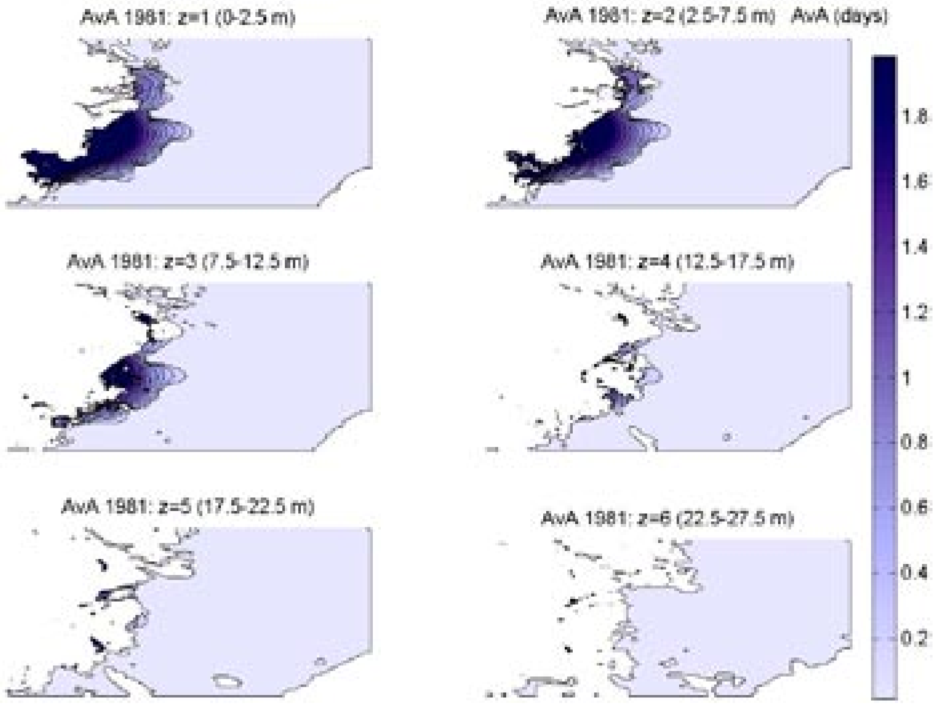


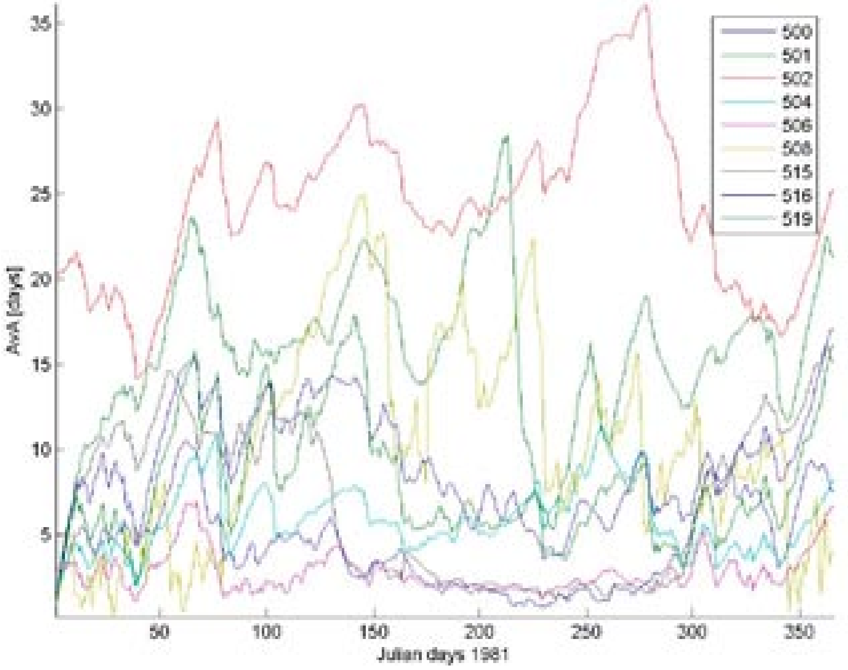
Figure 5-8. Illustration of the transformation relationship between the two mutually rotated coordinate systems for the Mueller and the Mesan data sets. Both these data sets cover the Baltic model area domain completely.



Figures 5-9. *AvA times calculated as a yearly average for the type-year 1988 considering the union of all SBs* ***collectively*** *ventilated relative to the adjacent sea. Exogeneous water enters from outside the boundaries of this union, and as the discharge of the two streams, Figures 5-4-7c. The calculation was based on bi-monthly samples of the AvA times for the different strata down to a depth of 27.5 m. Even for the innermost part of the major coastal subbasin (Öregrundsgrepen) the average AvA times are less than one year.*



Figures 5-10. *AvA times calculated as a yearly average for the type-year 1981 considering all the off-shore SBs conjoined to a union as to obtain an appreciation of the general water renewal of this coastal section. Exogenous water is thus considered entering from the adjacent sea and also as discharge from the two streams, Figures 5-4-7d. The calculation is based on bi-monthly samples of the AvA times for the different strata down to a depth (27.5 m). Even for the innermost of the offshore SBs the average AvA times are less than one year and about one order of magnitude smaller than for the corresponding union of the SBs of the Forsmark area.*



Figures 5-11. *Calculations of the **individual** basin AvA times in 1981 for the inner Laxemar-Simpevarp SBs with each of the adjacent basins counted as exogenous water. These volume-averaged data form the basis of the statistics presented in Table 5-2. The spin-up time is about one month.*

Table 5-1. Individual AvA time [days] estimates for the 28 SBs of the Forsmark area in Fig.4 which means that these data are computed with all water outside an individual SB considered as exogeneous.

Basin	Min [days]	Mean S.D.[days]	Mean [days]	Mean S.D. [days]	Max [days]
100	0.045	0.253	0.345	0.437	1.718
101	0.063	0.289	0.391	0.492	1.626
102	0.038	0.47	0.676	0.883	1.004
103	0.031	0.104	0.127	0.151	0.161
104	0.015	0.054	0.067	0.08	0.411
105	0.062	0.343	0.487	0.631	4.261
106	0.026	0.083	0.137	0.192	0.86
107	0.031	0.132	0.217	0.302	1.535
108	0.051	0.141	0.189	0.238	1.001
109	0.013	0.022	0.045	0.068	1.882
110	0.024	0.086	0.124	0.162	1.545
111	0.308	0.619	0.994	1.369	2.843
112	0.008	0.02	0.023	0.026	0.044
113	0.01	0.021	0.031	0.041	0.854
114	0.07	0.301	0.444	0.587	4.063
115	0.025	0.078	0.119	0.16	2.261
116	0.114	0.489	0.74	0.991	1.347
117	0.551	0.576	1.411	2.245	4.227
118	0.276	0.309	0.666	1.022	1.703
120	0.087	0.293	0.329	0.366	0.439
121	0.083	0.219	0.27	0.322	0.354
123	0.029	0.091	0.125	0.158	1.721
126	0.033	0.167	0.245	0.322	0.395
134	0.016	0.022	0.024	0.027	0.039
146	0.025	0.073	0.091	0.108	0.696
150	0.392	0.612	0.686	0.761	0.884
151	1.059	3.281	4.52	5.759	6.897
152	0.188	0.419	0.524	0.628	0.763

Table 5-2 Individual basin AvA time estimates for the 19 SBs in the Laxemar-Simpevarp area, in the form of vertically integrated volume averages. The inner subbasins are computed with the CDB model, while for the offshore SBs these volume averages are calculated directly from L3D model results, which have a temporal resolution of one hour.

	min	mean S.D.	mean	mean+S.D.	max	model type
500	0.73	1.77	4.26	6.75	10.5	CDB
501	0.94	11.2	15.8	20.4	28.5	CDB
502	14.1	19.6	24.4	29.1	36.2	CDB
504	0.82	3.90	5.88	7.86	11.4	CDB
506	1.08	1.62	2.78	3.93	6.99	CDB
508	0.20	4.14	10.3	16.4	25.0	CDB
513	0.09	0.24	0.29	0.35	0.43	3D
514	0.03	0.04	0.31	0.57	1.78	3D
515	0.95	2.28	6.86	11.4	16.0	CDB
516	0.88	6.07	9.25	12.4	17.1	CDB
517	0.29	0.67	1.03	1.38	2.13	3D
518	0.02	0.05	0.40	0.75	1.10	3D
519	0.80	4.41	7.98	11.6	17.9	CDB
520	0.19	0.34	0.40	0.46	0.52	3D
521	0.24	0.57	0.81	1.04	1.53	3D
522	0.04	0.13	0.19	0.26	0.35	3D
523	0.03	0.15	0.27	0.38	0.62	3D
524	0.01	0.08	0.14	0.19	0.25	3D
525	0.08	0.22	0.31	0.40	0.56	3D

When the model results are needed for the water exchange of the associated ecological (integrated) models, however, the flow rates are explicitly computed with an hourly temporal resolution, which can subsequently be averaged into the chosen resolved timescale of the these models. The intra-annual variations may then be represented by an S.D. measure. Since the results are given with regard to the subbasins into which the whole model area has been subdivided, a direct comparison between these areas will to some degree also reflect various sizes, Tables 5-3 and 5-4.

Table 5-3. Average flow between basins of the Forsmark area. The positive flows go in the direction indicated by 'from' → 'to' and the negative flows in the opposite direction. The sum of these fluxes (with sign) renders the net flow with the sign giving its direction. These estimates have been passed on to the ecological (integrated) model.

Basin ID from	to	Pos. flow [m^3/s]	Neg. flow [m^3/s]	Net flow [m^3/s]
Basin102	The Baltic	2,188.5	–3,006.5	–818.0
Basin100	The Baltic	6,101.0	–4,640.6	1,460.4
Basin101	The Baltic	556.0	–1,268.9	–712.9
Basin101	Basin102	691.4	–1,183.7	–492.2
Basin101	Basin100	1,099.0	–1,112.7	–13.7
Basin103	Basin102	816.0	–918.1	–102.1
Basin104	Basin102	118.2	–346.7	–228.5
Basin104	Basin101	294.7	–173.0	121.7
Basin104	Basin103	13.3	–47.9	–34.6
Basin105	Basin100	2,940.9	–1,469.5	1,471.4

Basin ID from	to	Pos. flow [m³/s]	Neg. flow [m³/s]	Net flow [m³/s]
Basin105	Basin101	1,611.2	–2,405.1	–793.9
Basin107	Basin101	8.3	–23.3	–15.0
Basin107	Basin104	130.3	–252.2	–121.9
Basin110	Basin101	139.5	–359.3	–219.8
Basin110	Basin105	1,334.8	–1,081.4	253.4
Basin108	Basin101	715.4	–1,030.4	–315.1
Basin108	Basin107	187.2	–414.9	–227.7
Basin108	Basin110	297.2	–100.1	197.1
Basin112	Basin110	177.9	–184.9	–7.0
Basin116	Basin110	694.8	–517.0	177.8
Basin116	Basin108	360.9	–707.6	–346.6
Basin116	Basin112	230.4	–237.5	–7.1
Basin117	Basin107	31.3	–21.0	10.3
Basin117	Basin108	2.2	–2.2	0.0
Basin118	Basin117	7.2	–7.0	0.2
Basin121	Basin116	106.5	–175.2	–68.7
Basin121	Basin120	0.8	–0.8	0.0
Basin123	Basin110	21.8	–40.0	–18.2
Basin134	Basin121	0.03	–0.03	0.00
Basin126	Basin110	15.4	–15.7	–0.3
Basin126	Basin116	81.8	–190.9	–109.1
Basin126	Basin121	79.3	–148.6	–69.3
Basin126	Basin123	239.8	–180.9	58.9
Basin146	Basin123	474.7	–342.8	131.9
Basin146	Basin126	167.3	–287.8	–120.6
Basin151	The Baltic	169.9	–55.7	114.2
Basin151	Basin123	959.3	–1,199.3	–239.9
Basin150	Basin146	103.4	–92.6	10.8
Basin152	Basin150	12.8	–2.7	10.1
Basin106	Basin103	39.6	–86.4	–46.7
Basin106	Basin104	50.5	–70.4	–19.9
Basin106	Basin107	162.7	–94.2	68.5
Basin109	Basin105	617.2	–549.2	68.0
Basin111	Basin103	24.9	–46.4	–21.5
Basin111	Basin107	34.0	–22.7	11.4
Basin111	Basin117	24.9	–15.6	9.3
Basin111	Basin106	23.1	–21.5	1.6
Basin113	Basin105	183.4	–467.8	–284.4
Basin113	Basin110	75.6	–289.9	–214.2
Basin113	Basin109	321.9	–230.9	91.0
Basin115	Basin110	51.9	–154.3	–102.5
Basin115	Basin123	229.7	–154.9	74.7
Basin115	Basin109	46.0	–35.9	10.0
Basin115	Basin113	393.8	–801.6	–407.8
Basin114	Basin105	1,435.5	–798.2	637.3
Basin114	Basin123	697.5	–742.2	–44.8
Basin114	Basin151	1,055.4	–1,186.6	–131.1
Basin114	Basin109	504.1	–537.4	–33.3
Basin114	Basin115	1,198.2	–1,624.3	–426.1

Table 5-4 Yearly average volume flow between the subbasins of the Laxemar area. A positive flow goes consistently from an SB with a higher ID number to one with a lower such number. The sum of these fluxes (with sign) renders the net flow with the sign giving its direction. Estimates to two decimals pertain to the DB model. Flow estimates have been passed on to be used in the ecological (integrated) model.

From basin	To basin	Pos. flow [m^3/s]	Neg. flow [m^3/s]	Net. flow [m^3/s]
501	500	0.88	–0.88	0.00
504	502	2.20	–2.19	0.01
506	504	0.18	–0.20	–0.02
508	506	1.27	–1.09	0.18
508	502	0.66	–0.66	0.00
514	513	64.5	–57.1	7.37
517	515	13.3	–13.3	–0.02
517	515	9.39	–9.39	0.00
518	514	112	–87.2	24.3
518	516	81.0	–81.0	0.00
520	517	2.17	–1.31	0.86
520	519	0.39	–0.39	0.00
521	500	3.59	–3.76	–0.16
521	504	2.53	–2.49	0.04
521	506	4.10	–4.30	–0.20
521	513	202	–210	–7.43
521	514	55.9	–75.5	–19.6
521	500	24.4	–24.5	–0.10
521	504	2.37	–2.35	0.02
521	506	4.02	–4.23	–0.21
522	521	900	–961	–61.0
523	514	44.3	–41.8	2.58
523	518	40.6	–59.0	–18.4
523	521	1,855	–1,820	34.9
523	522	1,145	–1,001	143
524	518	150	–107	42.8
524	523	1,478	–1,122	356
525	517	167.2	–168.2	–0.98
525	520	32.6	–31.8	0.83
525	524	1,569	–1,277	292
Baltic	521	4,085	–4,087	–2.34
Baltic	522	6,387	–6,591	–204
Baltic	523	3,144	–3,337	–194
Baltic	524	11,959	–11,852	106
Baltic	525	4,175	–3,883	291

5.6 Confidence and uncertanties

5.6.1 Sensitivity analysis

Sensitivity analysis with regard to variations of the forcing has been performed for the **F3D** model /Engqvist and Andrejev 2000/. The greatest sensitivity occurred when the wind speed was reduced by 10% in both the **F3D** and the **B3D** models, which resulted in a 9% increase of the *AvA* measure. The two sensitive forcing parameters for the **CDB** model were additional precipitation and higher frequencies of sea level forcing. The former affects all basins and enhances the estuarine circulation, while the latter increases the net water exchange, above all in the comparatively shallow inner basins. Artificially decreasing the hypsographic surface areas of the basins proportionally has a much greater impact on the *AvA* times than increasing them.

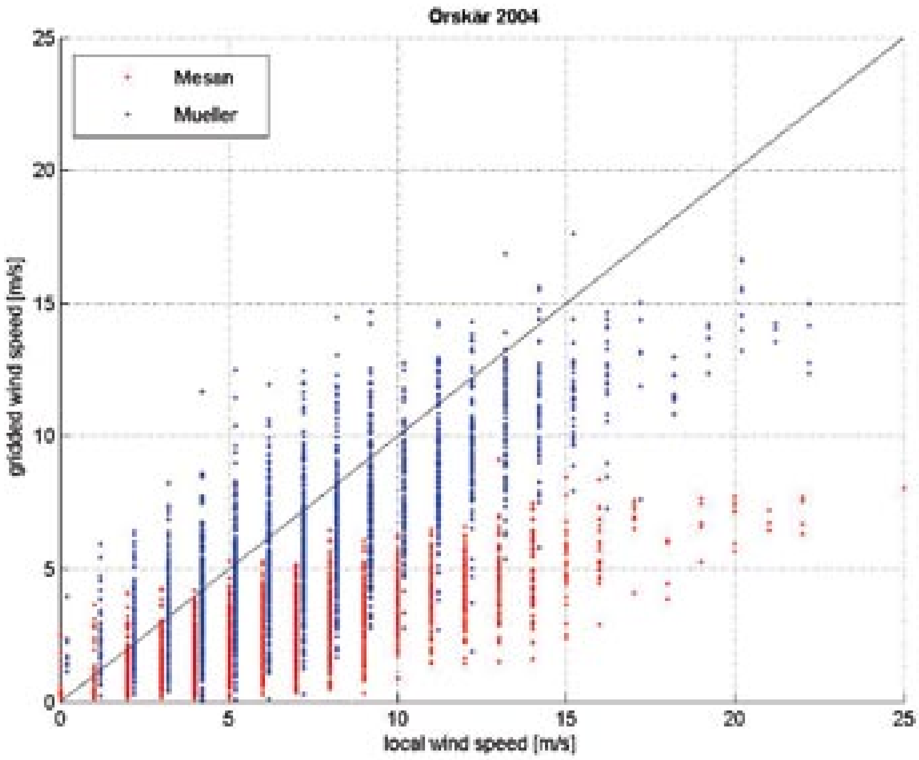
5.6.2 Validation analysis

The most pertinent studies of the uncertainties are the two validation programmes that were launched in order to collect oceanographic data and compare them with corresponding model data. This work has been concluded for the Forsmark area /Engqvist and Andrejev 2008/ but is still going on for the Laxemar-Simpevarp area. Thus only the findings for the first investigated **F3D** model area can be related. Preliminary analysis makes it highly likely that the findings concerning the **L3D** area give improved correlation coefficients on comparison of measured and simulated data.

The major shortcoming of this modelling approach is the inability of the B3D model to maintain the salinity concentration gradients over the extended modelling period, in the case in question consisting of 16 consecutive months /Engqvist and Andrejev 2008/. At least this applies to the transition zone between the Gulf of Bothnia and the Baltic Proper offshore of the Forsmark coastal area. As for the prospect of using these models for estimates projected into the distant future, this does not constitute an unsolvable difficulty since the density structure of the Baltic will, for such projections, probably only be available in general terms that are suitable for data assimilation /Westman et al. 1999/ so that the mean stratification can be upheld. With its present horizontal resolution, the Baltic model does not resolve all the relevant oceanographic features offshore of the Forsmark area. The nested coupling between the **B3D** and **F3D** models yields an acceptably good correlation of salinity between measured and simulated data of an inner station near the centre of the **F3D** area. These arguments seem to permit the conclusion that both the model approach and the design of the validation scheme may be continued to be invested with confidence.

When the Mueller and the Mesan wind data for the same year, 2004, are compared for corresponding closest points in space and time for the entire set of the Mueller grid /Engqvist and Andrejev 2007/, an overall correlation coefficient of typically 50% results. Limiting the analysis to include only one wind station location in the **F3D** domain greatly improves the correlation coefficients, revealing that the Mueller data are systematically higher and closer to the logged wind speed than the Mesan data, Figure 5-12a. The corresponding comparison of a wind station in the immediate vicinity of the **L3D** area yields no such systematic deviation, but an improved correlation for the Mesan data set. Together with the sensitivity analysis of the wind forcing of the **F3D** model, this suggests that it is important to estimate this forcing factor as correctly as possible when the models are used to estimate the circulation of a distant future state of the Baltic Sea.

a



b

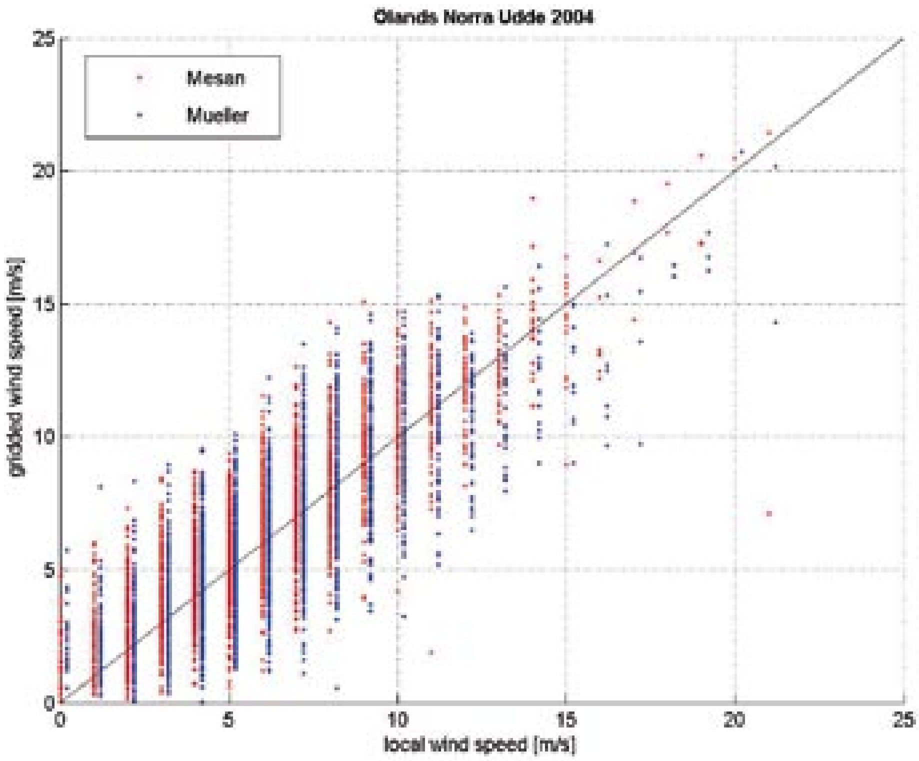


Figure 5-12 a and b. *(a, left panel) Comparison of wind speed for 2004 measurements at Örskär vs. the Mesan and the Mueller data sets. The Mueller data have been adjusted to match the 10m level of the Mesan data and yield a considerably better match with the black diagonal line, indicating ideal agreement. The correlation coefficient is also slightly improved:* ρ*=0.73 compared with 0.71 for the Mesan data.*

(b, right panel) A corresponding scatter diagram for the meteorological station at Ölands Norra Udde gives a correlation coefficient of 0.84 for the Mesan data and 0.77 for the Mueller data. In both panels, the Mueller data set has been graphically shifted to the right in order to prevent the two sets blocking each other.

6 Marine ecosystem – ecosystemodels, mass balances and elemental composition

Marine ecosystem models have been developed for marine basins in Forsmark and Laxemar-Simpevarp to describe the transfer of energy between functional groups and abiotic pools in the ecosystem. Ecosystems models can be developed for any element. In this case carbon has been used as a proxy for energy transfer. Carbon constitutes the major part of the biomass in ecosystems, and besides reflecting the biomass it also represents the maximum accumulation of any element in biota except water. Mass balances can be useful to develop in connection with ecosystem models to strengthen the conclusions from the ecosystem models and to illustrate large-scale characteristics of pools and fluxes in the ecosystem. Elements and/or groups of elements in the marine environment will accumulate/dissolve to a varying degree in various media/pools and be transferred to a varying degree between media, and to illustrate possible major sources and sinks of elements in the marine area, a general elemental composition of marine abiotic and biotic pools has been described.

The results of the marine ecosystem models for carbon (C), nitrogen (N), phosphorus (P) and mass balances for C, N, P, iodine (I), thorium (Th) and uranium (U) are presented in this chapter, along with the elemental composition (49 elements) of abiotic and biotic pools in the marine basins in Forsmark and Laxemar-Simpevarp. C, N and P have been chosen since they are the most important elements in biota in terms of mass. Moreover carbon may be used to describe the flux of C-14, one of the radioactive elements of interest for the safety assessment. I and the actinides (Th and U) since they are elements which represent a large span of particle affinity (K_d) and they are therefore of importance with regard to the safety analysis as they can be used as representatives of radionuclides with different sorption properties /SKB 2006a /. Data presented in Chapters 3 and 4 of this report have been used as quantitative input to the marine ecosystem model, the mass balances and the presentation of elemental compositions in marine pools.

The results of the marine ecosystem model, describing the spatial distribution of carbon in the whole marine model area and in separate basins (Appendix 7), are presented initially (sections 6.1.1–6.1.2) for each site (marine basins described in Chapter 4 and shown in Figure 4-1 and 4-2). Mass balances for C, N, P, I, Th and U in the whole marine model area are then presented (section 6.1.3). This section is followed by a third section describing the elemental composition of the marine pools in Forsmark and Laxemar-Simpevarp (section 6.1.4). The final section (6.1.5) presents marine ecosystem models for C, N and P and mass balances for C, N, P, I, Th and U for 5 specifically chosen basins at each site. These basin are specifically presented since they fulfil two criteria: (i) they are basins were the density of site-specific in data is high and (ii) they are located where exit points for radionuclides were located in a preliminary safety assessment, see /SKB 2006c/. In Appendix 8 the results from the marine ecosystem model calculations for carbon from is presented. In Appendix 9 pools and fluxes from massbalance calculations, for carbon, nitrogen, phosphorus, thorium, uranium and iodine is presented.

6.1 Marine ecosystem model – Forsmark

The results of the marine ecosystem modelling of carbon (C) are presented below on a model area scale for the Forsmark model area, i.e. the marine area divided into basins (described in Chapter 4 and displayed in Figure 4-1). The results presented below for the Forsmark area pertain to that model area. The food webs of the marine ecosystem are also presented for C, nitrogen (N) and phosphorus (P).

6.1.1 Biomass distribution

Total biomass varies from just over 5 gC m^{-2} to 160 gC m^{-2} in the whole area and is distributed unevenly, focused mainly along the coast and in shallow areas. Mean biomass is 18 gC m^{-2} in the whole area, resulting in an estimated total of 4,400 tonnes of carbon fixed in biota in all basins. The mean biomass in separate basins ranges between 7 and 106 gC m^{-2}. In 14 out of 29 basins the mean biomass is higher than the mean biomass for the whole area. The lowest biomass values are found in the deep areas offshore, with biomasses of 5.5 to 8 gC m^{-2} comprising bacteria and plankton and to some extent benthic fauna.

Biomass in most basins is dominated by macrophytes, 4 to 87% of the biomass in separate basins (the latter figure in basin 152). Macrophytes are especially dominating in basins along the western coastline. In the east, Öregrundsgrepen is steeper and the depths in the basins deeper and therefore not as suitable for macrophytes. Here, the consumer part of the biomass is larger and detrivores dominate the total biomass (5–38% of the biomass in separate basins). Apart from these two macroscopic organism groups, the third and fourth largest biomass in the area belongs to microphytes and benthic bacteria up to 19%, of the biomass in separate basins. Other organisms contribute less than 10% of the total biomass, see Figure 6-1. Basin-specific biomass data in gC m^{-2} are found in Appendix 8. Primary producers (dominated by macrophytes) are the most abundant group in most of the basins, especially in the coastal zone. In offshore basins benthic fauna tend to dominate. Pelagic fauna is the smallest group in all basins.

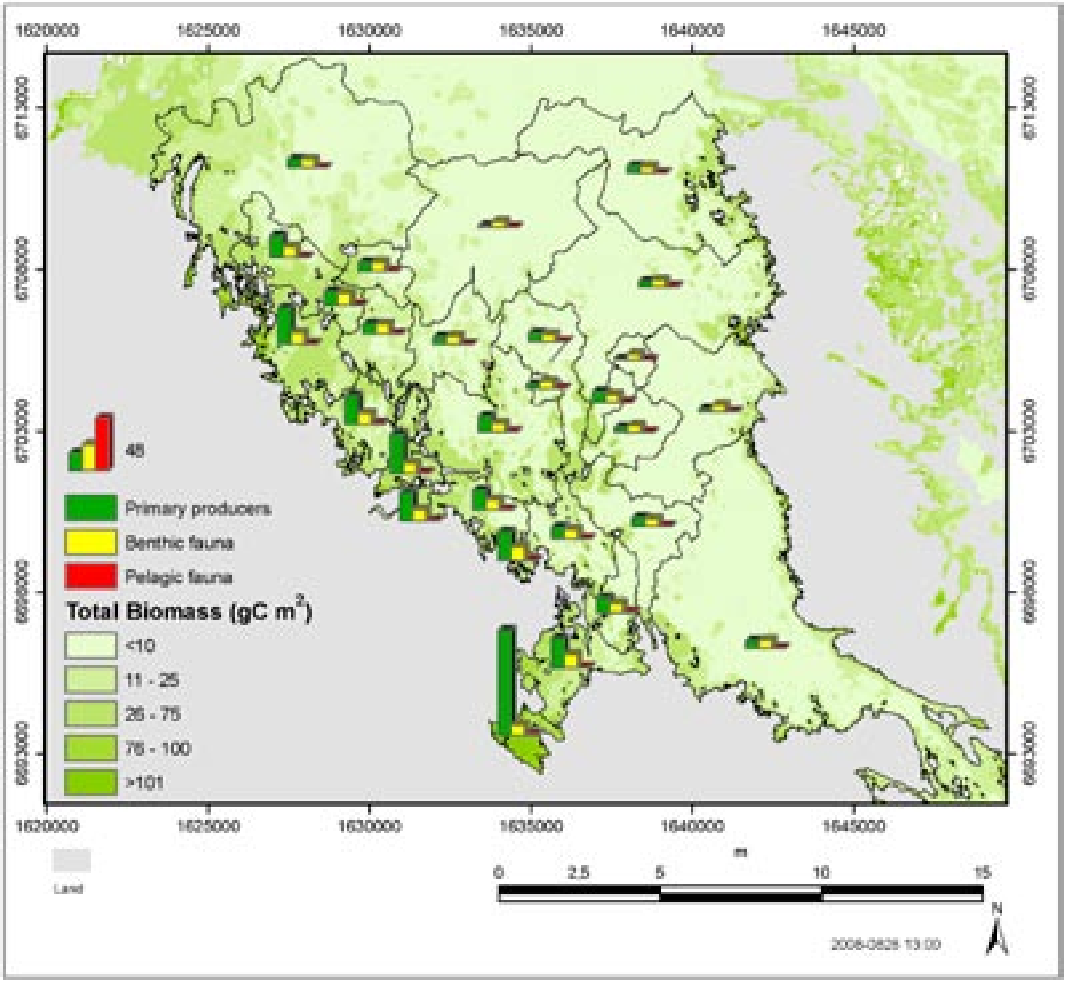


Figure 6-1. Proportional biomass distribution of the functional groups in the various basins: primary producers, benthic fauna and pelagic fauna, and total biomass (shaded in background) (g C m^{-2}) for all basins in the Forsmark area. For biomasses in figures per basin, see Appendix 8.

The annual average biomasses for functional groups in the whole marine area are presented in Figure 6-2. In comparison with biomass data from other studies (described in section 3), the modelled average biomass values for the whole area are somewhat lower, probably due to the fact that that the modelled values are interpolations over the whole area with various abiotic characteristics such as suitability of substrate etc while other studies have been focused on specific habitats. However, the biomass ranges are in the same size order as others reported.

The biomass is dominated by benthic organisms. The benthic component of the total biomass is shown in Figure 6-3. Altogether, 70–100% (average 91%) of the biomass in all basins consists of benthic organisms.

As Figure 6-1 indicates, the biomass decreases with depth and distance from land. This is clearly illustrated in Figure 6-4, where the mean depth of the basins is plotted against the mean annual biomass in each basin.

6.1.2 Primary Production

Like biomass, net primary production (NPP) is concentrated at the shoreline, where the highest values are found, but also in the offshore areas where depth, higher water transparency and availability of nutrients permit high phytoplankton production. The mean annual NPP in the whole marine area in Forsmark is 100 gC m^{-2}. The mean NPP in separate basins ranges from 43 to 287 gC m^{-2}. The mean NPP is above the mean for the whole marine area in 12 out of 28 basins. The maximum values in individual basins (over 250 gC m^{-2}) are found along the shoreline in densely vegetated areas, e.g. in Kallrigafjärden (basin 150 and 152), but high values are also found in small areas of the deeper exposed coastal basins, see Figure 6-5. The NPP values are in the same range as reported in other studies /Gazeau et al. 2004, Pergent-Martini et al. 1994/ in the Baltic.

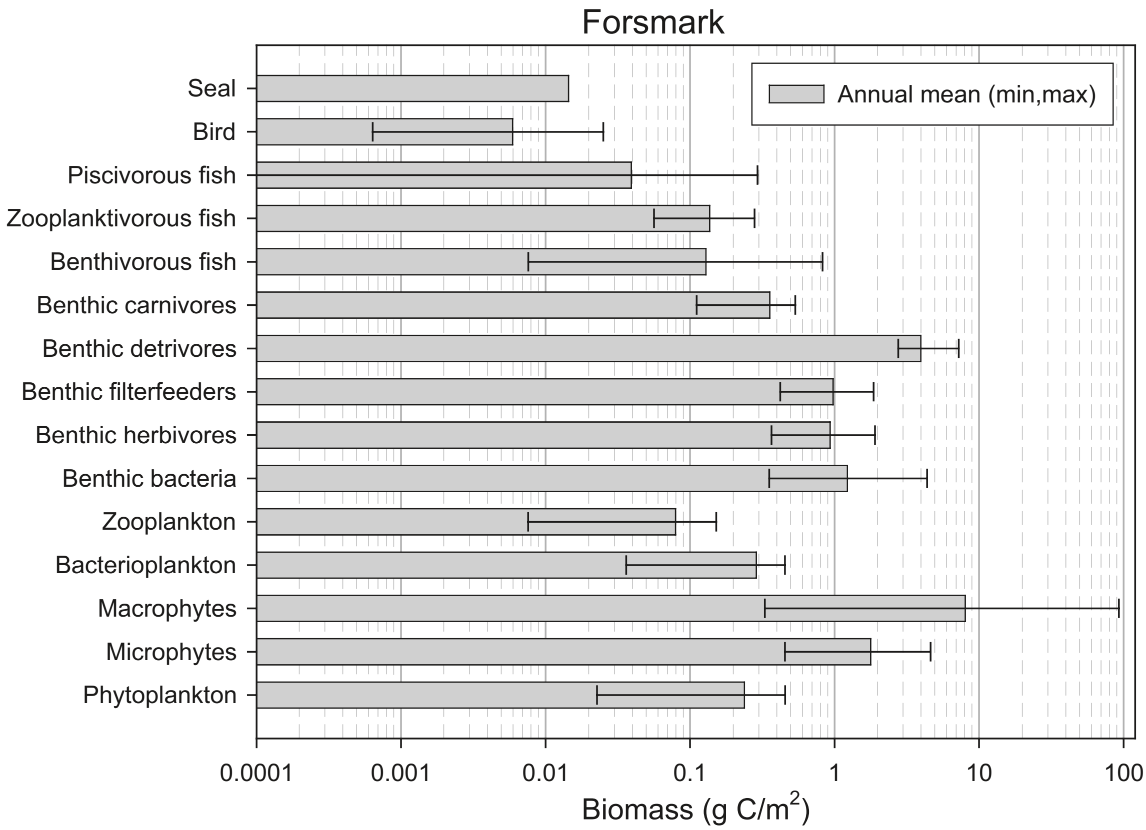


***Figure 6-2.** Annual average biomass (gC m^{-2}) for functional groups of marine biota in the whole marine model area in Forsmark (average for all basins in Forsmark).*

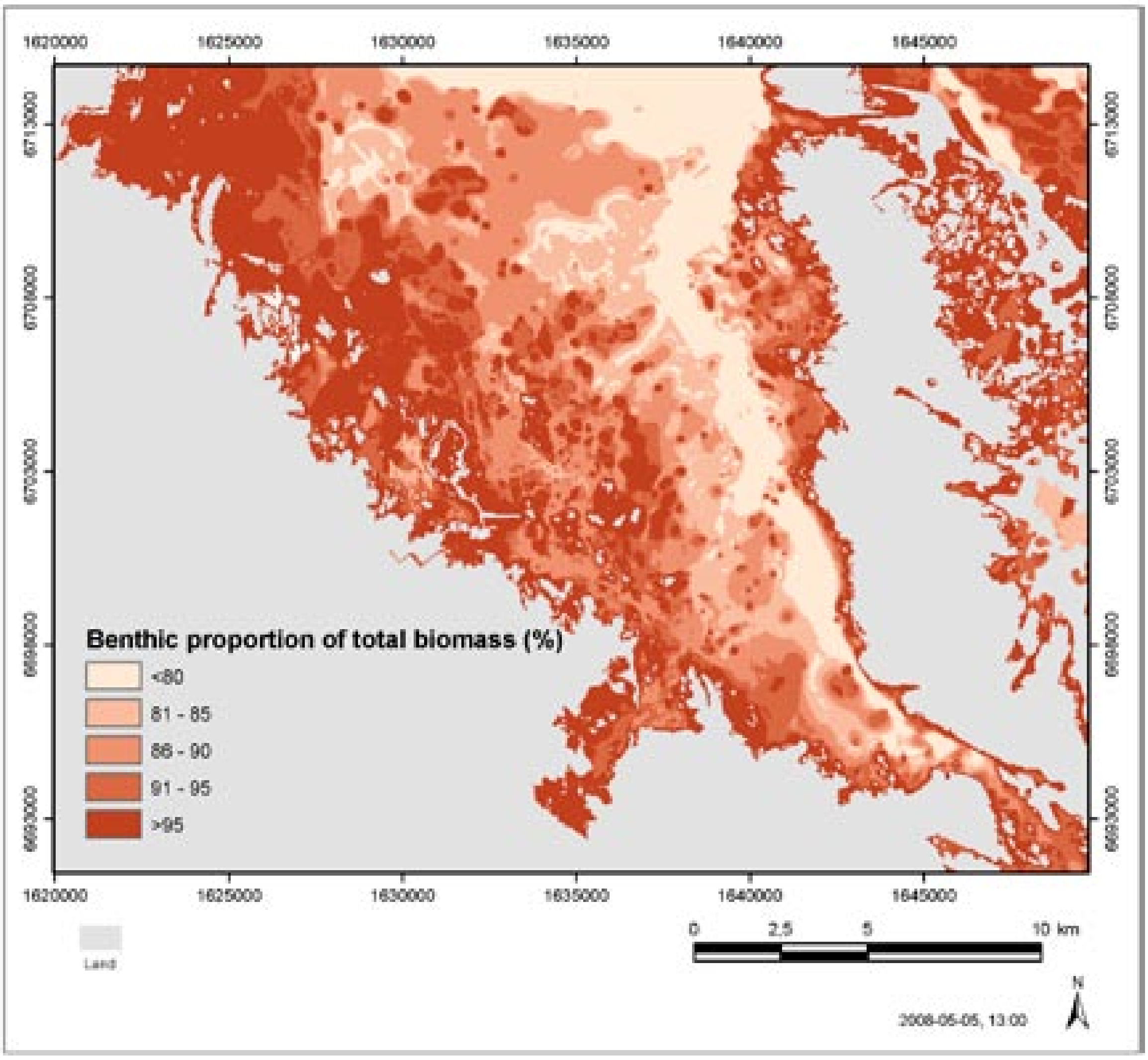


Figure 6-3. Proportion of the benthic component of total biomass in the Forsmark area.

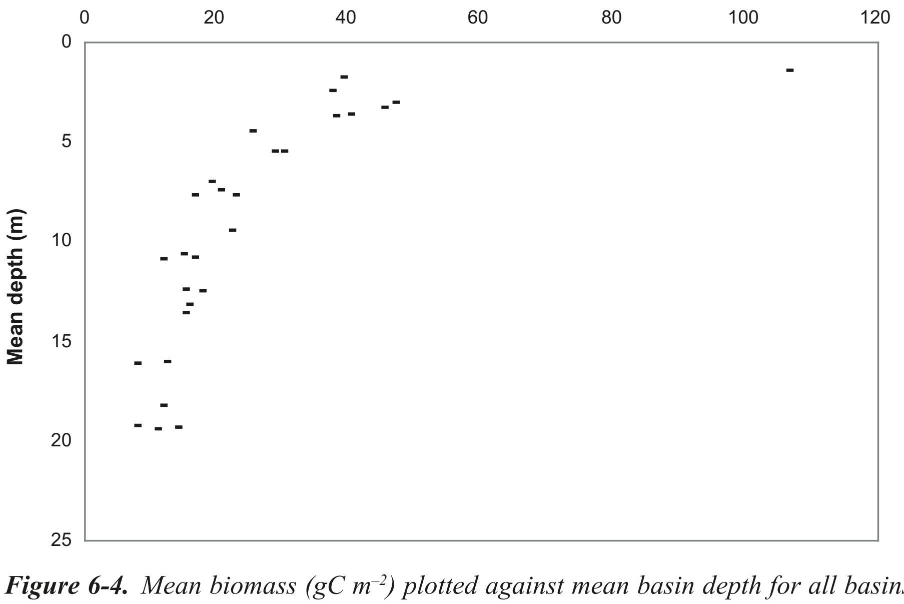


Figure 6-4. Mean biomass (gC m⁻²) plotted against mean basin depth for all basins in the Forsmark model area.

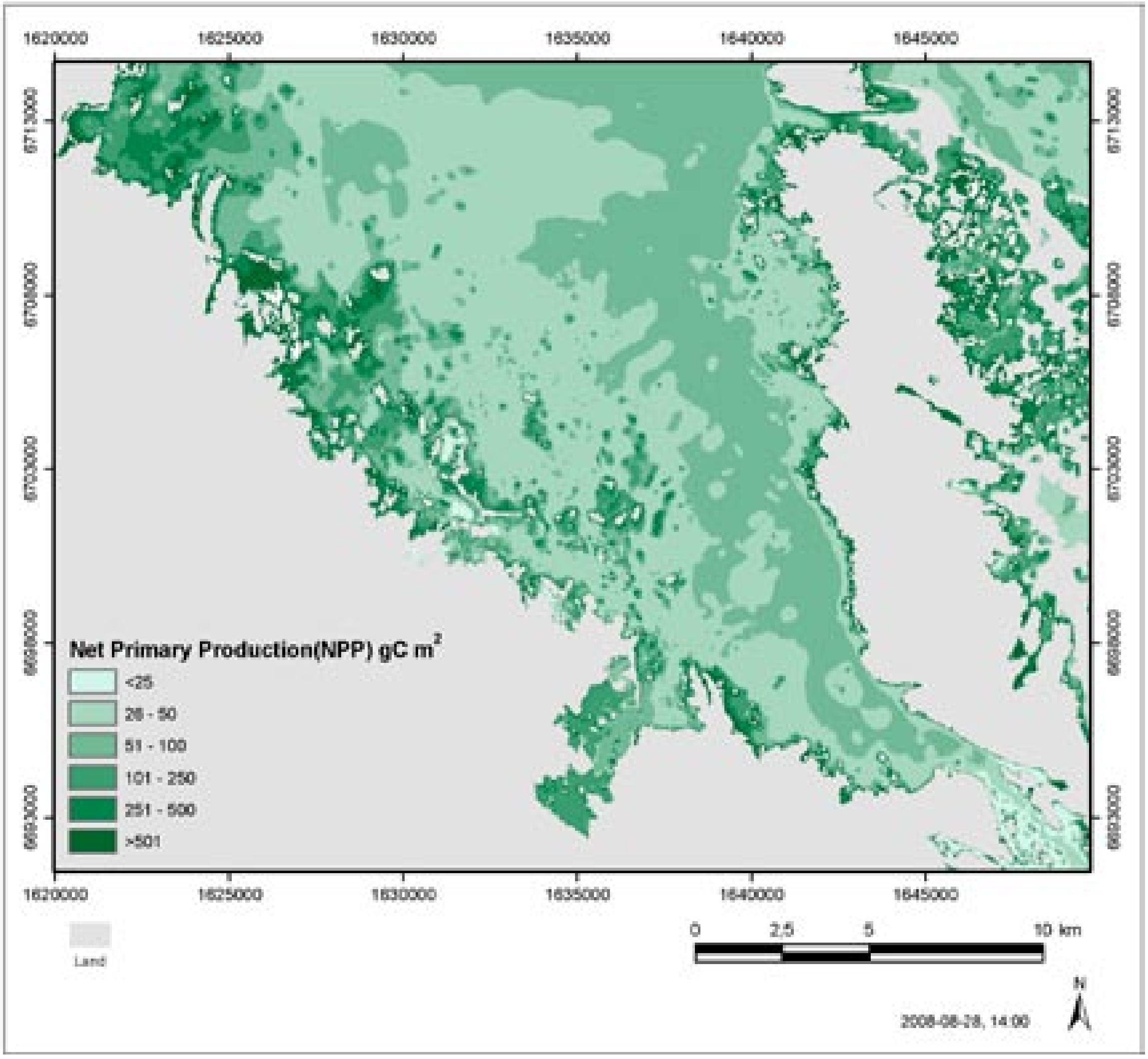
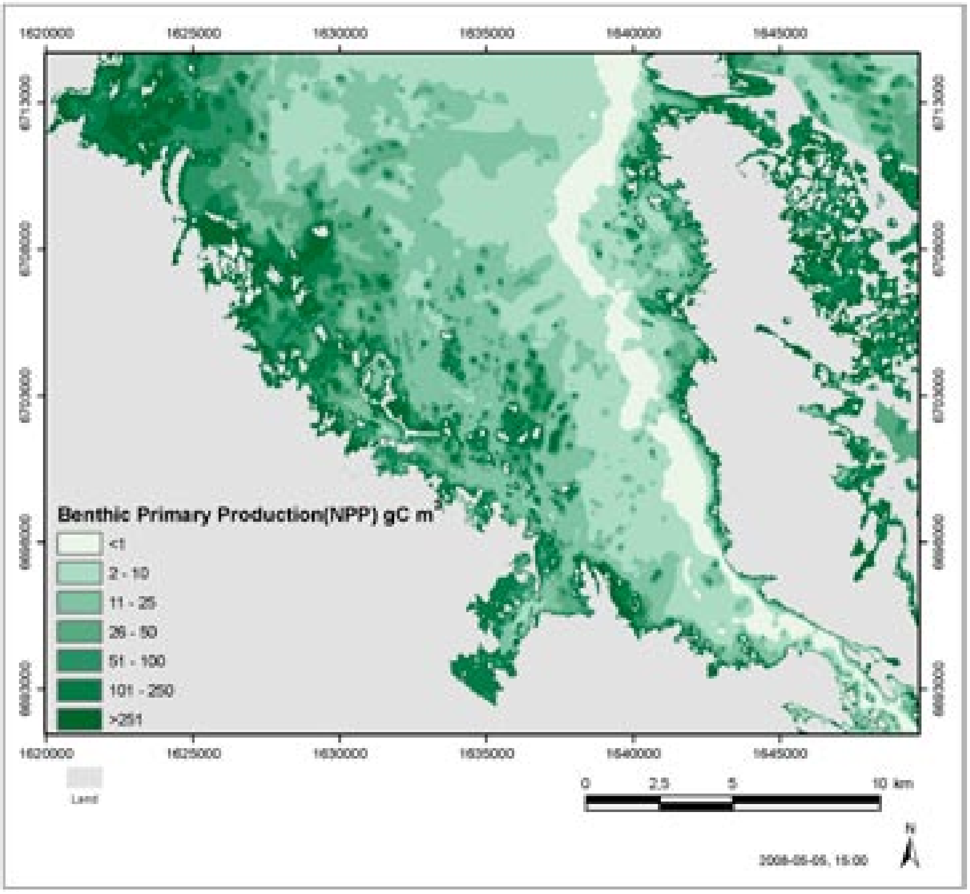


Figure 6-5. Net Primary Production (gC m^{-2} y^{-1}) in the Forsmark area. Higher NPP is indicated by increasingly dark green colour.

The benthic and pelagic components of the NPP display roughly the opposite pattern (Figure 6-6); pelagic increases and benthic decreases with depth. This is probably due to the fact that the benthic primary producers are restricted by the depth of the sea floor while increasing depth increases the volume where phytoplankton can photosynthesize and the deeper areas occur in the more outer areas where also the water transparency is greater than in the coastal zone of the area. In the whole marine model area the benthic community contributes 77% of the total NPP, which decreases with increasing depth, Figure 6-7.

6.1.3 Consumption

The most consumed component of the marine ecosystem in Forsmark is the abiotic pool of carbon, dissolved organic carbon (DOC), which is consumed mainly by bacterioplankton, followed by consumption of sediment and consumption of particulate organic carbon (POC), Figure 6-8.



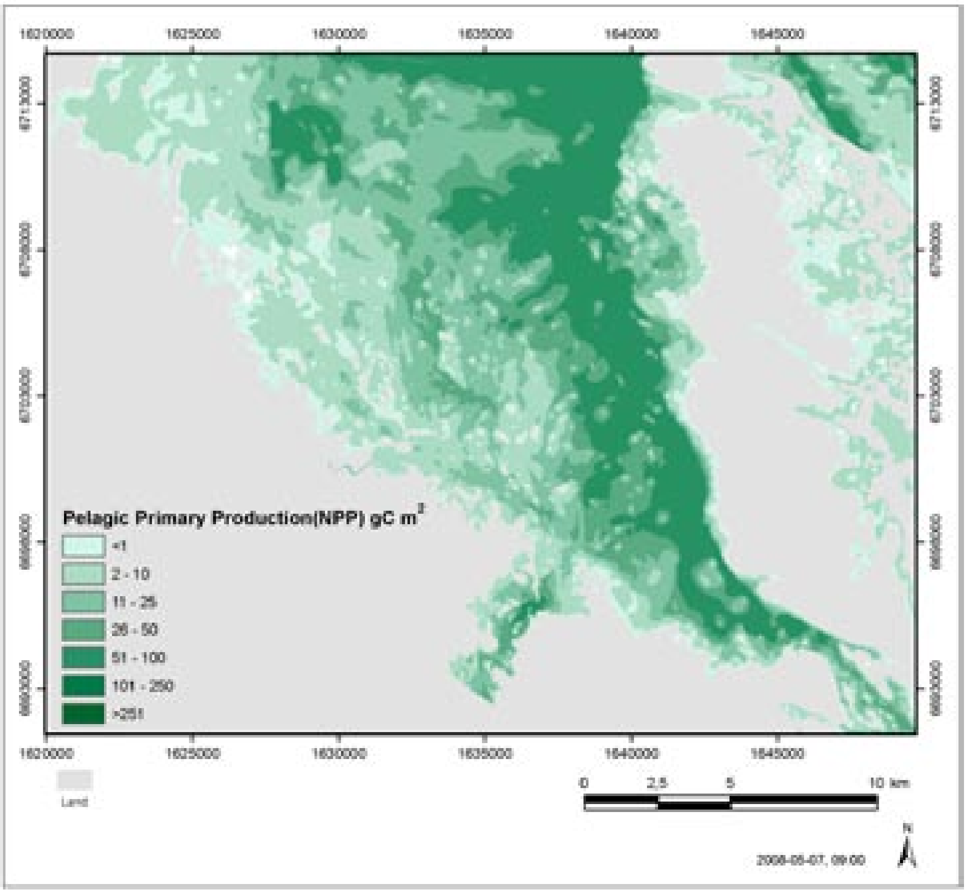


Figure 6-6. *Benthic (above) and pelagic (below) Net Primary Production (gC m^{-2} year^{-1}) in the Forsmark area. Higher NPP is indicated by increasingly dark green colour.*

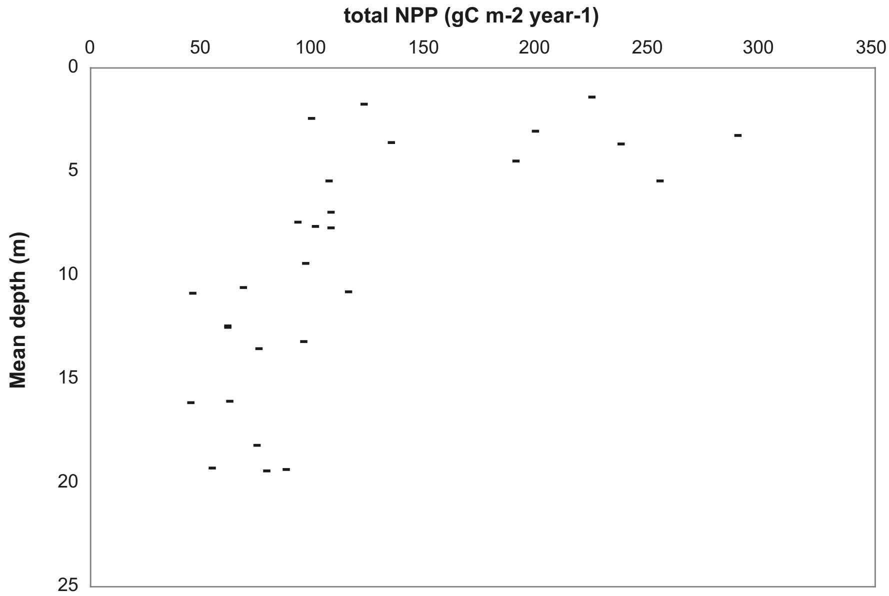


__Figure 6-7.__ Mean NPP (gC m² year⁻¹) plotted against mean basin depth for all basins in the model area.

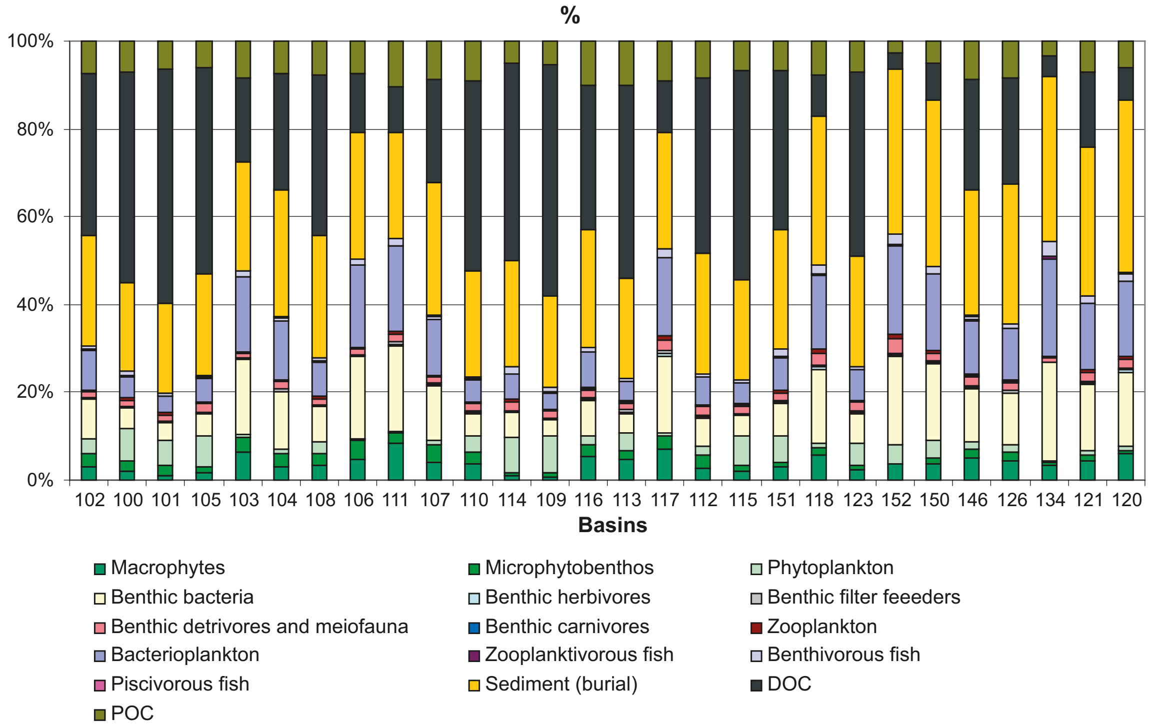


__Figure 6-8.__ Percentage annual consumption of the biotic and abiotic pools in the ecosystem, in separate basins, in the marine area in Forsmark.

The functional group that consumes the largest amount of carbon per year is bacterioplankton, followed by benthic detrivores and meiofauna, Figure 6-9. This is somewhat surprising since the bacterioplankton have a smaller biomass than the benthic bacteria. This is an indication of uncertainties in the calculations as it suggests either an overestimation of consumption by bacterioplankton or an underestimation of consumption by benthic bacteria because they are calculated in different ways (see section 4). A modelled factor for the consumption/biomass ration was used for bacterioplankton /Sandberg et al. 2000/, while consumption by benthic bacteria was calculated using a consumption/respiration factor of 2 from /Kumblad et al. 2003/.

6.1.4 Heterotrophic respiration

The distribution of total benthic and pelagic respiration is presented in Figure 6-10. Total respiration includes only respiration by heterotrophs (consumers) as respiration by primary producers is included in the NPP presented above. Values range from 31 to 162 gC m^{-2}, with an average of 76 gC m^{-2}, in the whole marine area, which is in accordance with other reported values for respiration in the Baltic (74 gC m^{-2}) /Gazeau et al. 2004/. Respiration is not as clearly differentiated between the deep offshore areas and the coastal zone as biomass and NPP, although on a basin level, as illustrated by Figure 6-10, respiration generally increases with depth. 10 out of 28 basins have an annual mean respiration above the mean respiration for the whole area, and of these all but two are offshore basins. The two exceptions (Basin 152 and 134) are basins with high bacterial and benthic fauna biomass.

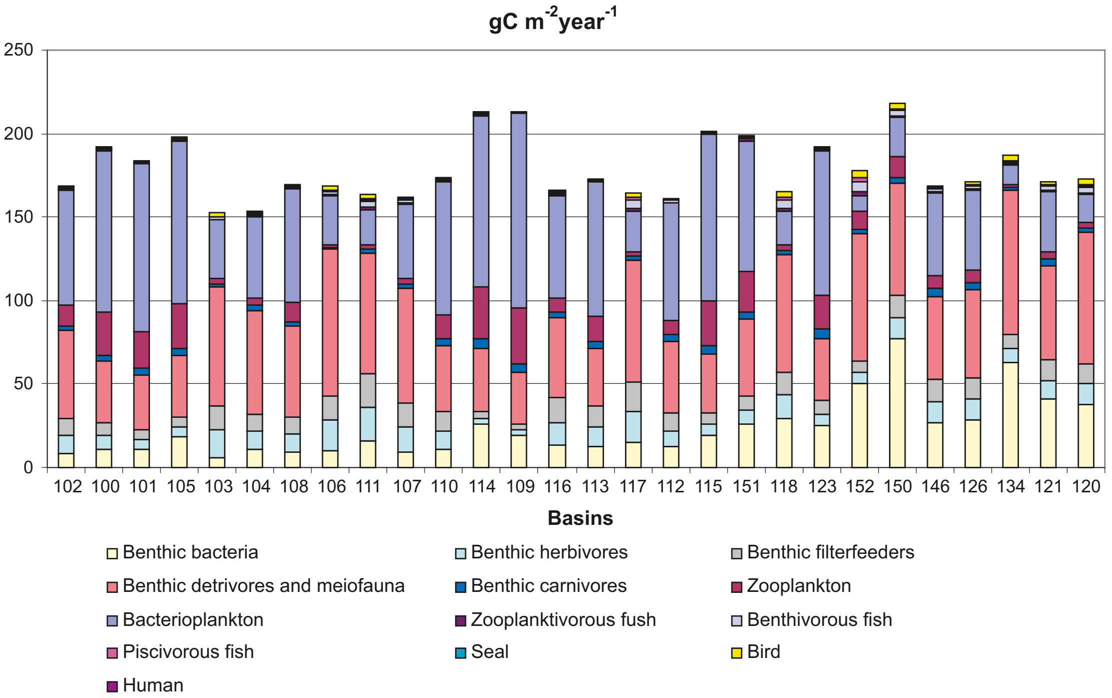


Figure 6-9. *The annual mean consumption, in gC m^{-2} $year^{-1}$in separate basins, by different consumers in the ecosystem in Forsmark.*

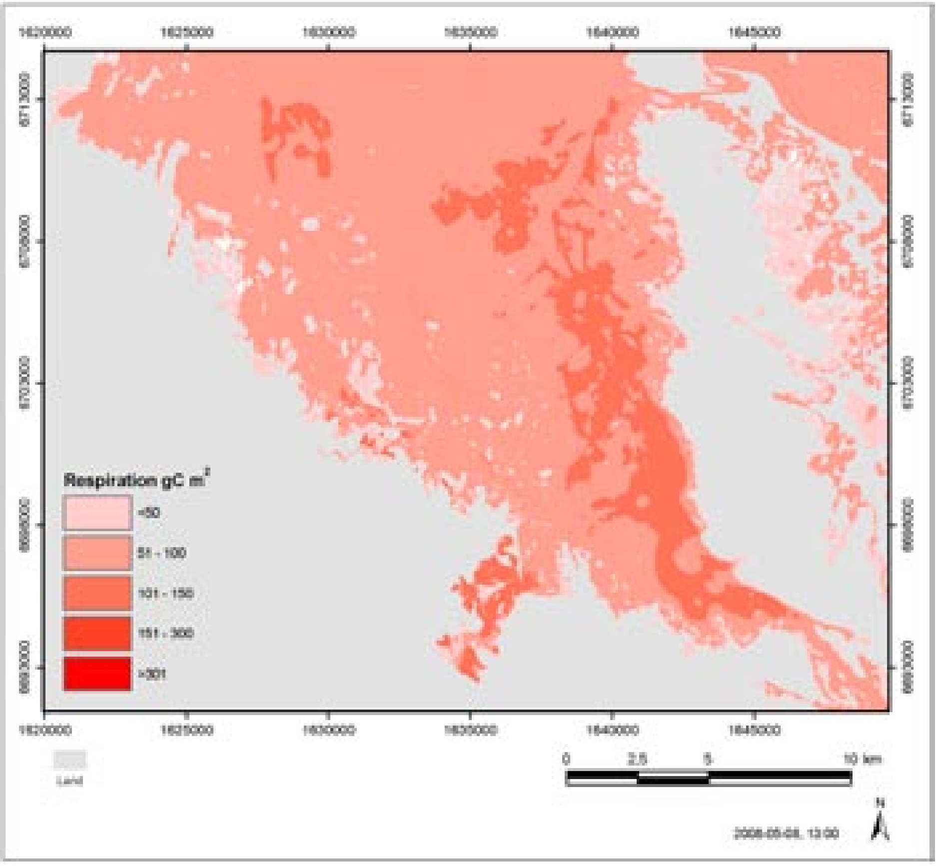
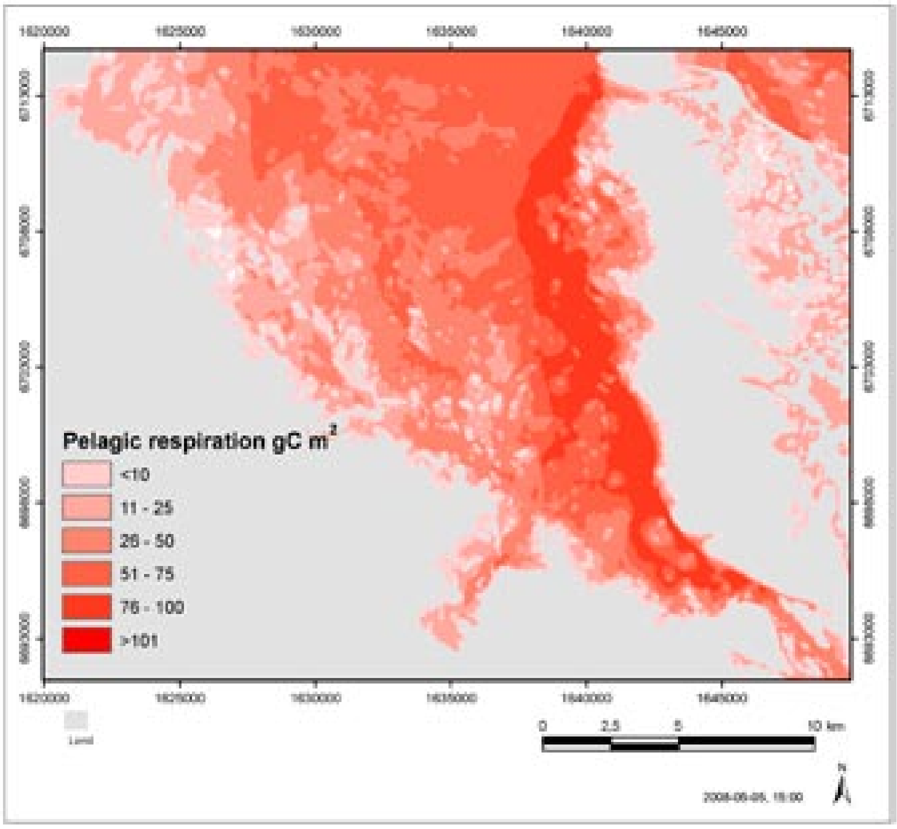


Figure 6-10. *The sum of heterotrophic respiration (gC m^{-2} year^{-1}), both benthic and pelagic, in the Forsmark area. Higher respiration is indicated by increasingly dark red colour.*

The largest component of the respiration in most basins is respiration by bacterioplankton, which on average constitutes 35% of the total annual respiration and ranges from 6 to 58% in separate basins. The second largest component of the respiration is benthic detritivores, followed by benthic bacteria with an annual average per basin of 28 and 16% of the total respiration, respectively, Figure 6-11. The same argument as in the section above (section 6.1.3) regarding consumption by bacterioplankton and benthic bacteria can be applied here, since they are not calculated the same way and indicate an uncertainty in the calculations.

When benthic and pelagic respiration are examined separately (Figure 6-11), they display, like NPP, roughly the opposite pattern. Pelagic respiration increases and benthic respiration decreases with depth. The increase of pelagic respiration is primarily a result of higher biomass due to increasing depth. The decrease in benthic respiration is due to two factors: a smaller biomass and a decrease in temperature in the benthic habitat. The mean pelagic temperature also decreases with depth, but this is compensated for by the biomass increase. The correlation between respiration and depth is presented in Figure 6-12.



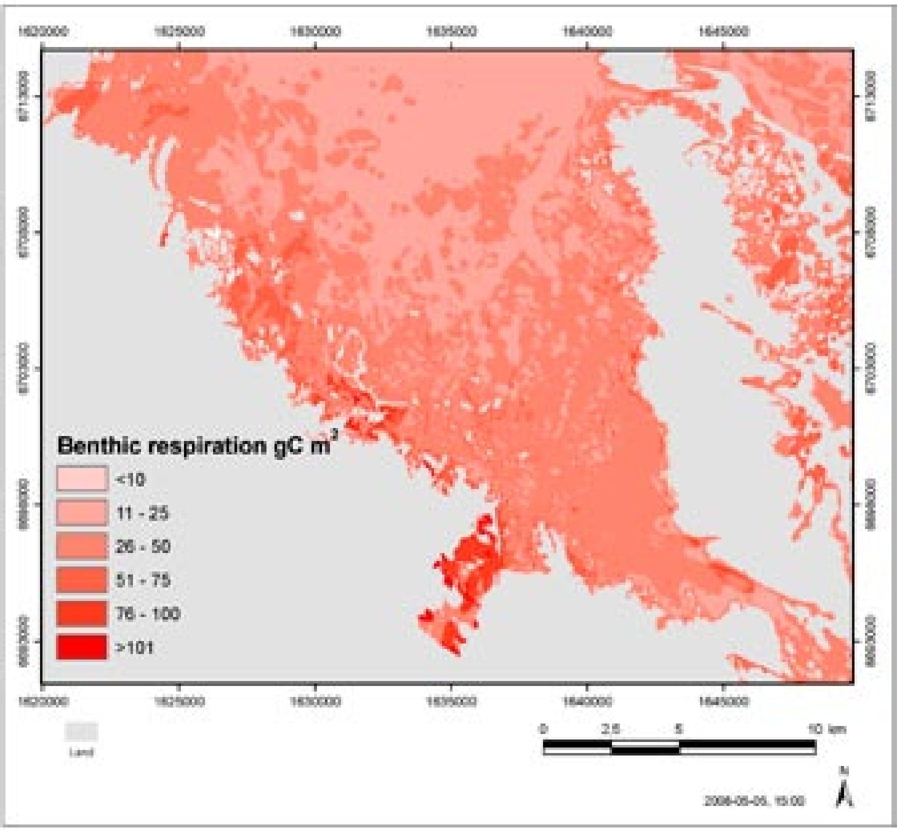


Figure 6-11. *Pelagic (above) and Benthic (below) respiration (gC m^{-2} year^{-1}) in the Forsmark area. The same scale is used (range: > 10 to < 150 gC m^{-2}).*

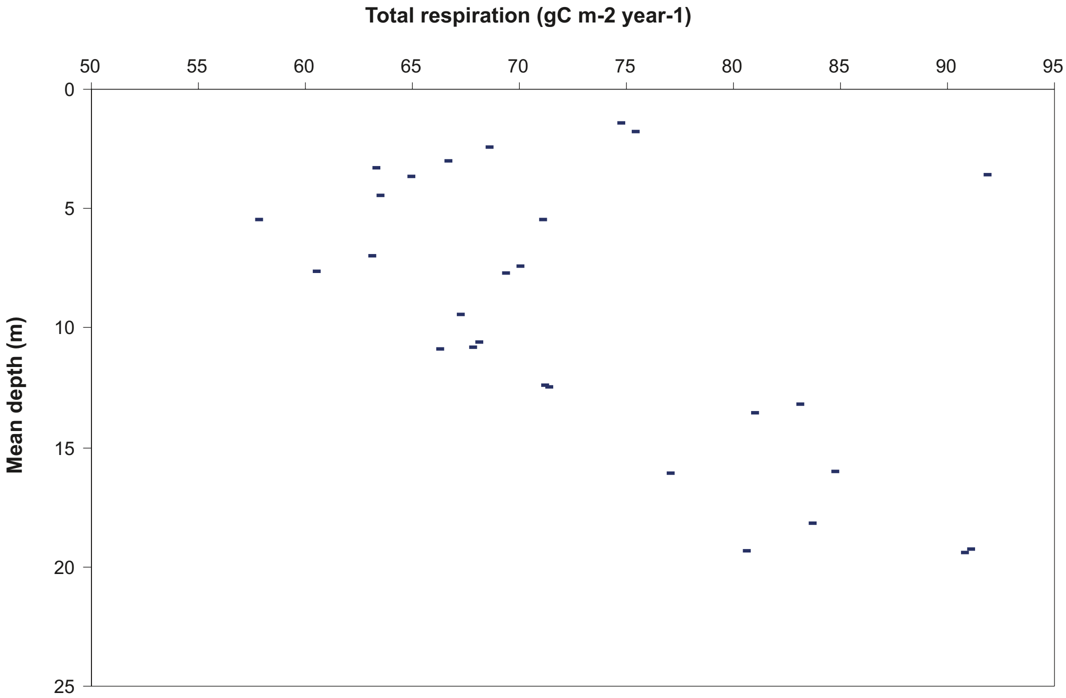


Figure 6-12. *Total heterotroph respiration (gC m^{-2} year^{-1}) plotted against mean depth for every basin in the Forsmark model area.*

6.1.5 Net Ecosystem Production

Net Ecosystem Production (NEP = NPP-R) for the marine area in Forsmark is presented in Figure 6-13. The results show that although most of the studied area is heterotrophic, the mean for the whole area is autotrophic, i.e. more carbon is fixed in biomass by primary producers than is released by all organisms (NEP> 1). The mean NEP in the whole model area is 24 gC m^{-2} year^{-1}. The annual mean in separate basins ranges between –33 and 224 gC m^{-2} year^{-1}. In comparison the NEP according to /Witek et al. 2003/ in the Gulf of Gdansk were 82 g Cm^{-2} year^{-2}. All basins on the western coast of the whole marine area are autotrophic and have an annual mean NEP above the mean NEP for the whole area. Ten out of 28 basins are heterotrophic, and they are all offshore or located on the deeper eastern coast. Thus, as Figure 6-13 suggests, the shallow coastal basins tend to be generally autotrophic, while the offshore areas are heterotrophic.

The pelagic component of the ecosystem is mainly heterotrophic, while a larger share of the benthic community along the shores is autotrophic (Figure 6-14 and 15). Both the benthic and pelagic components are heterotrophic in the deeper areas, however. This results in a lower NEP the deeper the mean depth of the basins is, as illustrated by Figure 6-16, which shows a breakeven point for NEP, where NPP equals R at a mean depth of 10–15 m. The autotrophic basins in the area serve as possible carbon sources for the more heterotrophic basins, which are sinks of carbon.

The net heterotrophy in deeper areas is supported by studies made in the Bothnian Bay suggesting that the Bothnian Bay (mean depth of 62 m) is as a whole net heterotrophic and is supplied by organic carbon from the Baltic Sea and from rivers discharging into the Bothnian Bay /Algesten et al. 2004/. Other studies in the Baltic suggest that the NEP of the whole Bothnian Sea is 0 /Gazeau et al. 2004/, i.e. all of the NPP is remineralized by the heterotrophs over an annual cycle and no net production of organic carbon takes place in the ecosystem.

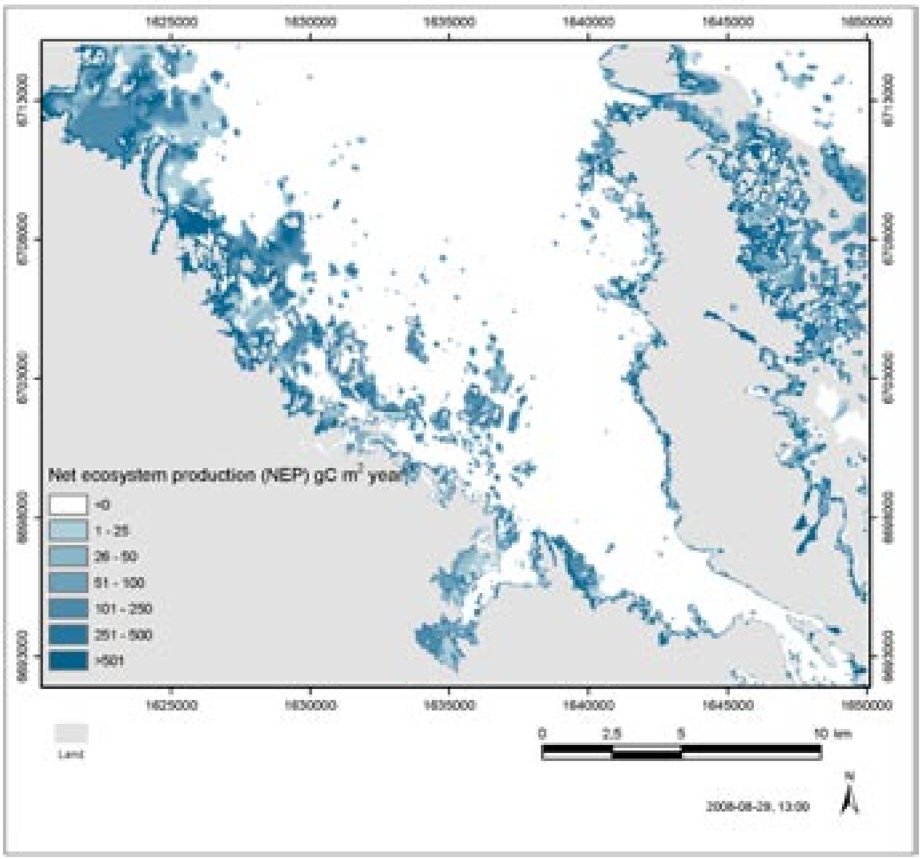


Figure 6-13. Net ecosystem production (NEP) (gC m^{-2} y^{-1}) in the marine basins in the Forsmark area. Higher respiration is indicated by increasingly dark blue green colour.

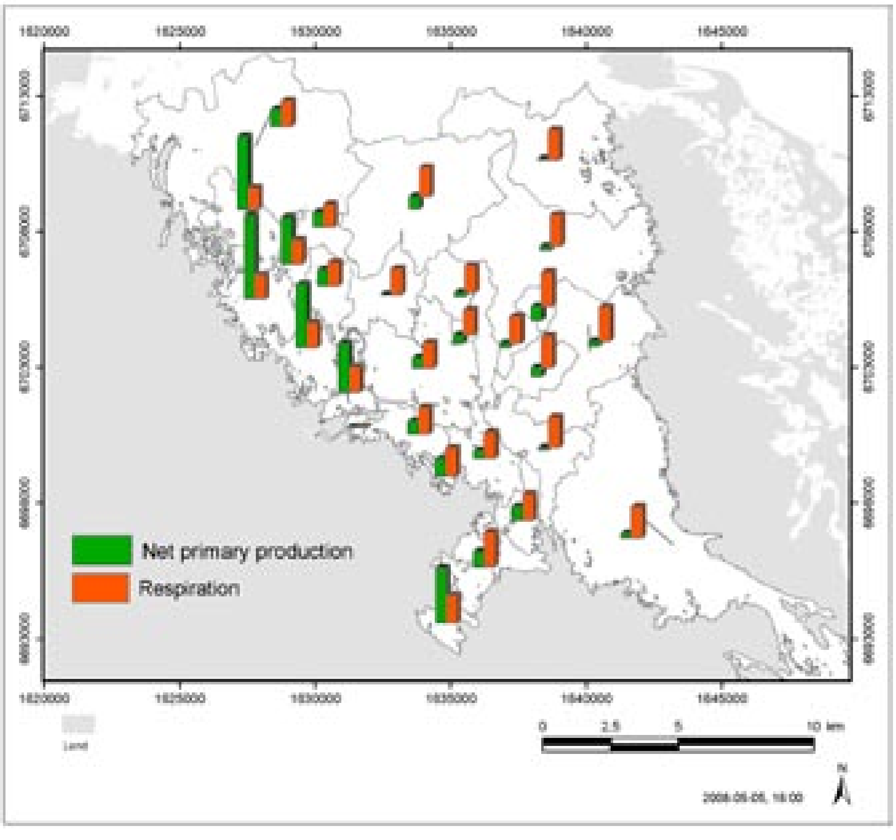


Figure 6-14. Relative amount of Net Primary Production (NPP = green bars) and Respiration (R = red bars) (gC m^{-2} year^{-1}) for the marine basins in the Forsmark area.

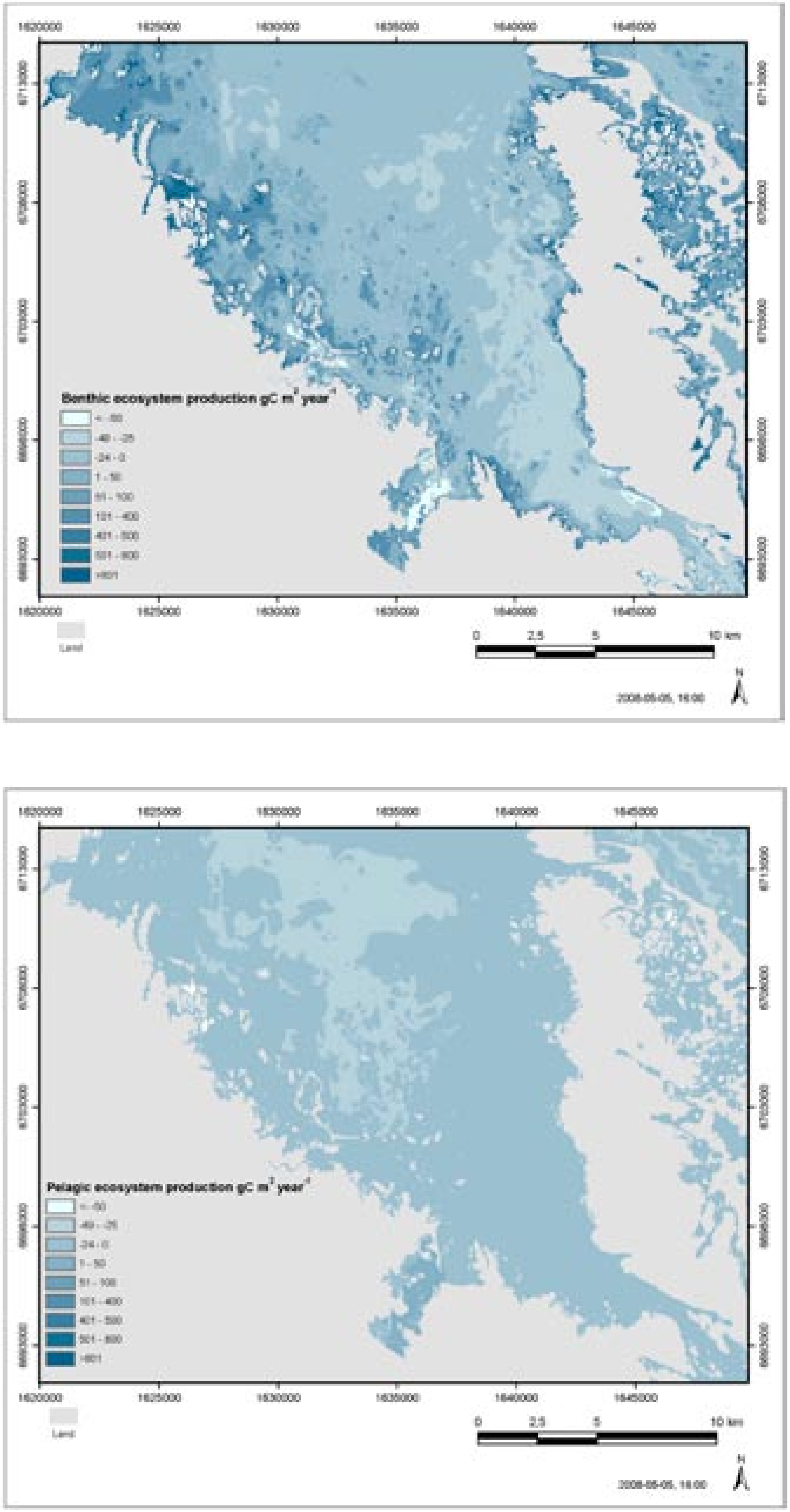


Figure 6-15. *Benthic (above) and pelagic (below) net ecosystem production (gC m^{-2} year^{-1}) in the Forsmark area.*

6.1.6 Marine ecosystem food webs

The marine ecosystem model can be summarized and illustrated in a food web representing various biotic and abiotic pools and fluxes within the ecosystem and between the ecosystem and the surroundings. Food webs illustrating average pools and fluxes for all marine basins in the functional groups of the marine ecosystem in Forsmark are presented for C, N and P. For N and P, fluxes during net primary production have been estimated with the Redfield ratio (se section 4) to give a rough estimate of the magnitude of these processes for these elements. The figures in the food webs represent relative (square root transformed) values of pools and fluxes, the figures are presented in Appendix 7.

The largest pools of carbon in all basins in the marine area in Forsmark are the abiotic pools: sediment, DIC and DOC, followed by the largest biotic pool, the macrophytes. The largest biotic carbon flux is the fixation of carbon by primary producers, while the second largest is the consumption of DOC by bacterioplankton. The biotic fluxes are still small in comparison with advective flux, Figure 6-17.

On average in the marine area in Forsmark, 20% of the carbon fixed by the primary producers is transferred to the next trophic level, the herbivorous pathway in the food web. The other pathway in the food web for carbon is via consumption of POC dissolved in water or in the surface sediment, the sediment and POC pathway. The size of primary consumption by heterotrophs in this pathway is on average 4 (in separate basins) times higher than primary consumption in the herbivorous pathway. Of the total initially consumed carbon in the whole food web, around 4% is transferred all the way up to the top predators (piscivorous fish, seal bird and humans).

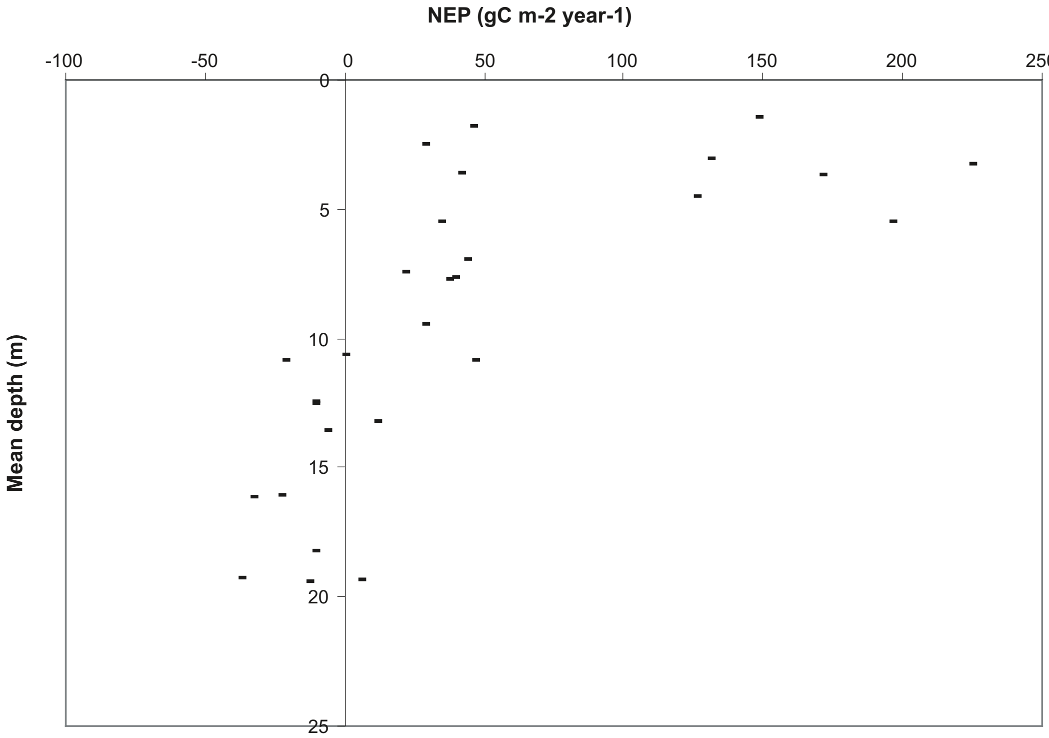


Figure 6-16. Net Ecosystem Production (NEP) in gC m^{-2} $year^{-1}$ correlated to depth in the marine area in Forsmark.

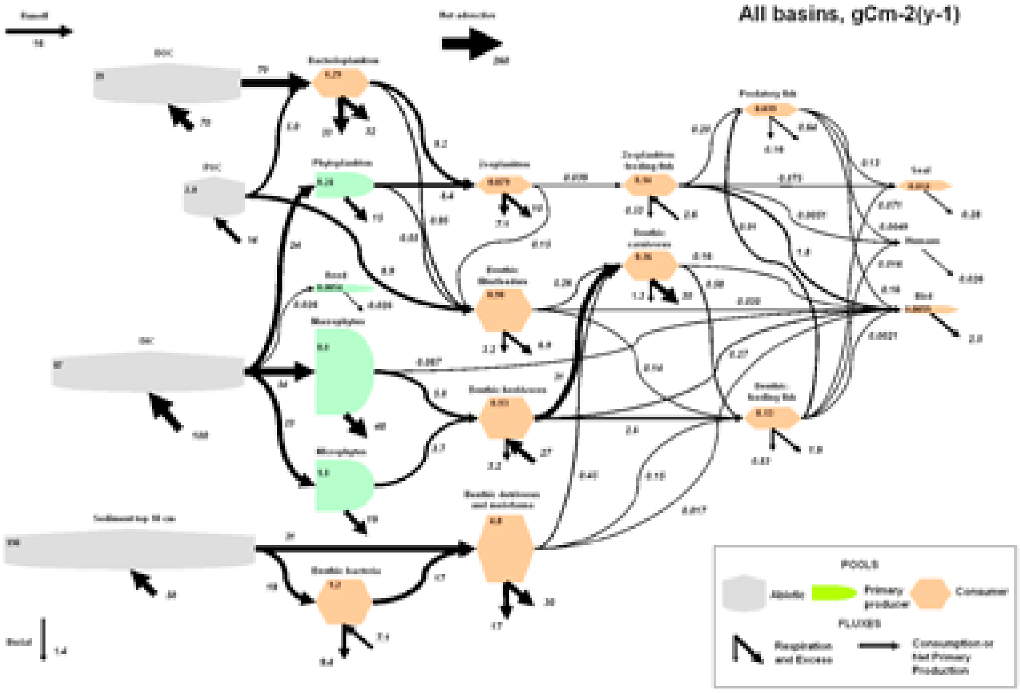


Figure 6-17. *Food web based on pools and fluxes of carbon in the whole marine model area in Forsmark. Boxes and arrows denote relative (square root transformed) size of pools and fluxes.*

The excess (the remainder including secondary production, excretion, faeces and dead material from all functional groups and mortality) in the whole marine basin is positive. The positive excess for most of the functional groups can either result in an accumulation of biomass or, as we assume in this steady-state model, formation of POC. However, most of the excess carbon in the marine ecosystem is probably recycled internally and is not transferred to the sediments via burial. The probable fates of POC are consumption, sedimentation, resuspension or export to other basins via water movement. The excess for benthic bacteria, zooplanktivorous fish and benthic herbivores is negative in the whole basin and in most separate basins as well, which could be due to underestimations of biomasses, overestimations of consumption or respiration, that they are transferred from adjacent areas or that these pools are decreasing.

Most nitrogen (N) is also distributed in the abiotic pools: sediment, dissolved inorganic nitrogen DIN and particulate nitrogen PON. Large biotic fluxes of nitrogen are the consumption of sediment by benthic detrivores and benthic bacteria, consumption of benthic herbivores by benthic carnivores and bacterioplankton consumption of particulate nitrogen in water, but they are all still very small compared to the advective flux, Figure 6-18.

The transfer of N between trophic levels in the food web is similar to that of carbon.

The nitrogen excess (the remainder including secondary production, excretion and faeces and mortality) in the whole marine basin is positive. The nitrogen excess for the functional groups bacterioplankton, benthic bacteria, benthivorous- and zooplanktivorous fish is negative.

The major pool for phosphorus is sediment, although the other abiotic pools – dissolved inorganic phosphorus (DIP) and particulate phosphorus (POP) – are not so large compared to the biotic pools as for C and N. Large biotic fluxes of phosphorus are the consumption of sediment by benthic detrivores and benthic bacteria and consumption of benthic herbivores by benthic carnivores, but they are still very small compared with the advective flux, Figure 6-19.

The transfer between trophic levels in the food webs of P is similar to that of C and N, and the phosphorus excess (the remainder including secondary production, excretion and faeces and mortality) in the whole marine basin is very small but still positive.

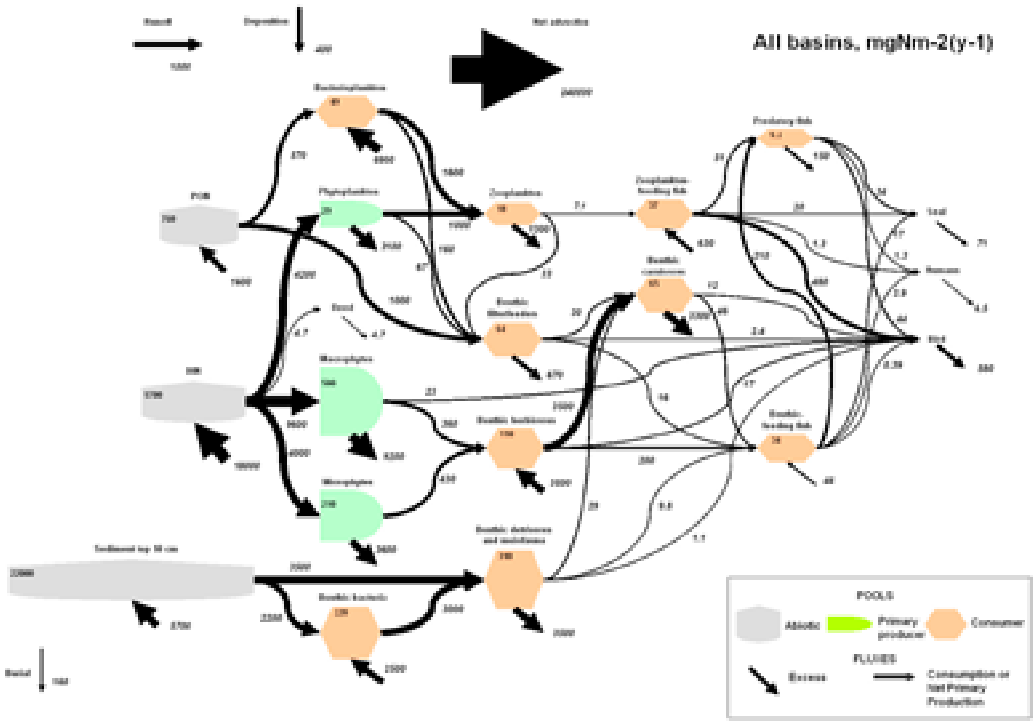


Figure 6-18. *Food web based on pools and fluxes of nitrogen in the whole marine model area in Forsmark. Boxes and arrows denote relative size of pools and fluxes.*

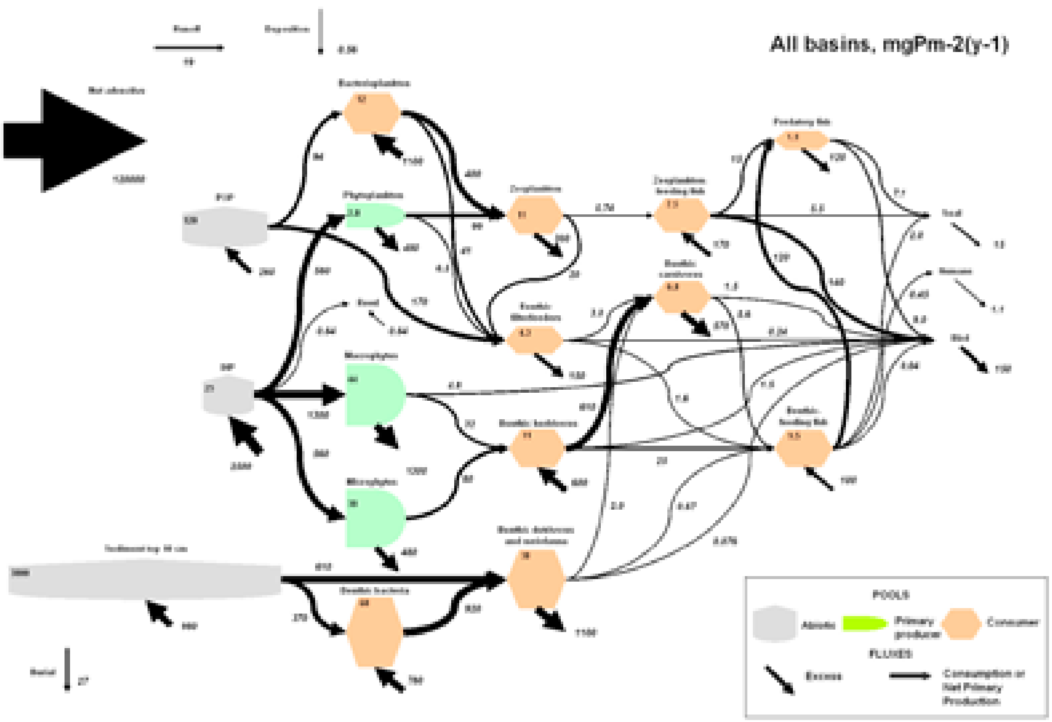


Figure 6-19. *Food web based on pools and fluxes of phosphorus in the whole marine model area in Forsmark. Boxes and arrows denote relative size of pools and fluxes.*

6.2 Marine ecosystem model – Laxemar-Simpevarp

The results of modelling are presented below on a model area scale for the Laxemar-Simpevarp model area, i.e. the marine area divided into basins (described in Chapter 4 and displayed in Figure 4-2). The results presented below for the Laxemar-Simpevarp area pertain to that model area. The food web of the marine ecosystem is presented for carbon (C), nitrogen (N) and phosphorus (P).

6.2.1 Biomass distribution

Total biomass varies from just below 2 gC m^{-2} to over 450 gC m^{-2} in the area, see Figure 6-20. Mean biomass is 91 g C m^{-2} in the whole area, resulting in an estimated total of 10,430 tonnes of carbon fixed in biota in all basins in the Laxemar-Simpevarp marine model area. In 6 (Basin 513, 514, 518, 523, 524 and 525) out of 19 basins the annual mean biomasses are above the mean biomass for the whole area, and these basins are all situated offshore in more exposed areas with high densities of *M. edulis.* The highest average biomass in the area is found among the filter feeders, which, when the substrate is suitable, form very dense colonies with high biomasses (up to above 100 gC m^{-2}).

The biomass in 8 (Basin 501, 500, 504, 502, 506, 508, 516 and 519) out of 19 basins is dominated by macrophytes, and they are all secluded bays. The average macrophyte fraction of the total biomass in all separate basins varies between 26 and 80%. In some of the more exposed basins (Basin 521, 522, 523, 524 and 525), filter feeders constitute a large portion (50–60%) of the total biomass, but for the whole marine area the filter feeders only constitute on average 28% of the total biomass. Other organisms contribute on average to less than 10% of the total biomass, see Figure 6-20 and 6-21. Basin-specific biomass data in gC m^{-2} are found in Appendix 7.

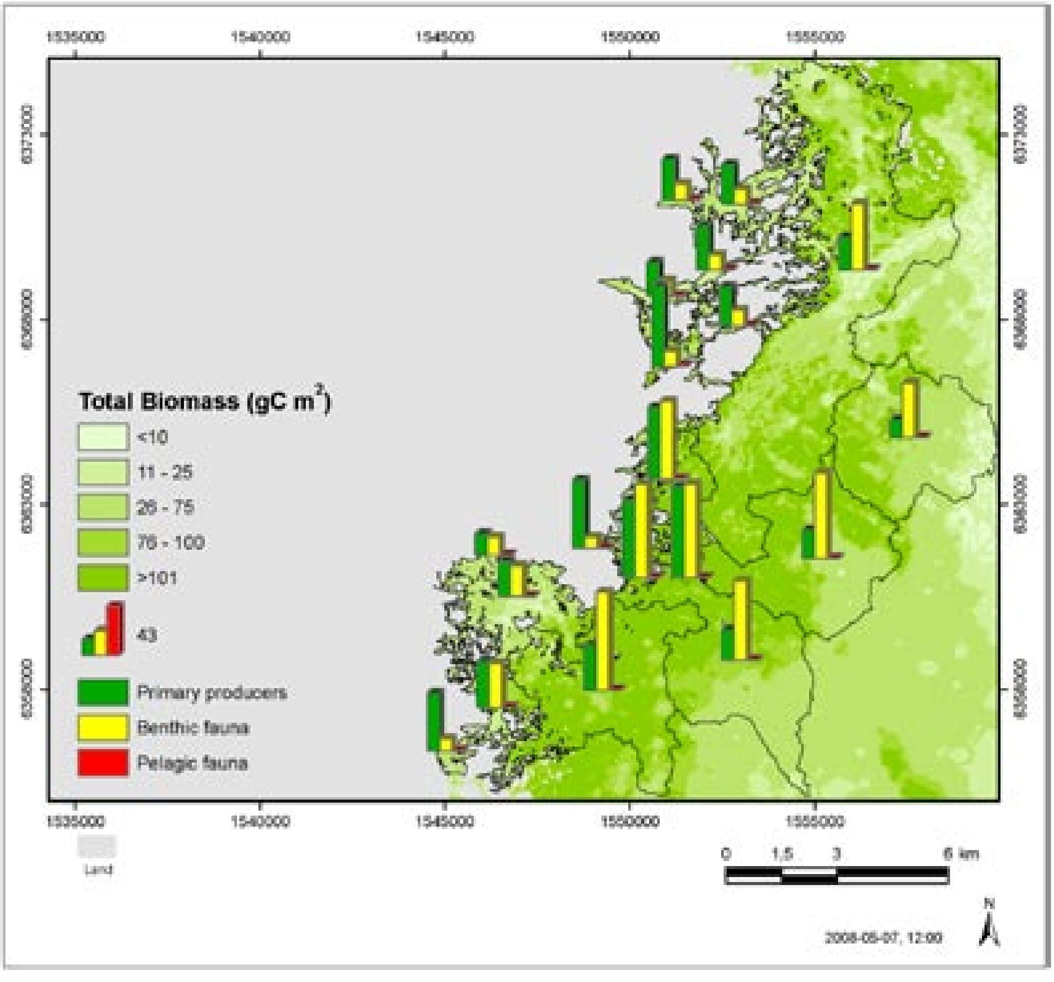


Figure 6-20. Annual average biomass of the functional groups in the ecosystem model and total biomass (shaded in background) (g C m^{-2}) for all basins in the Laxemar-Simpevarp area.

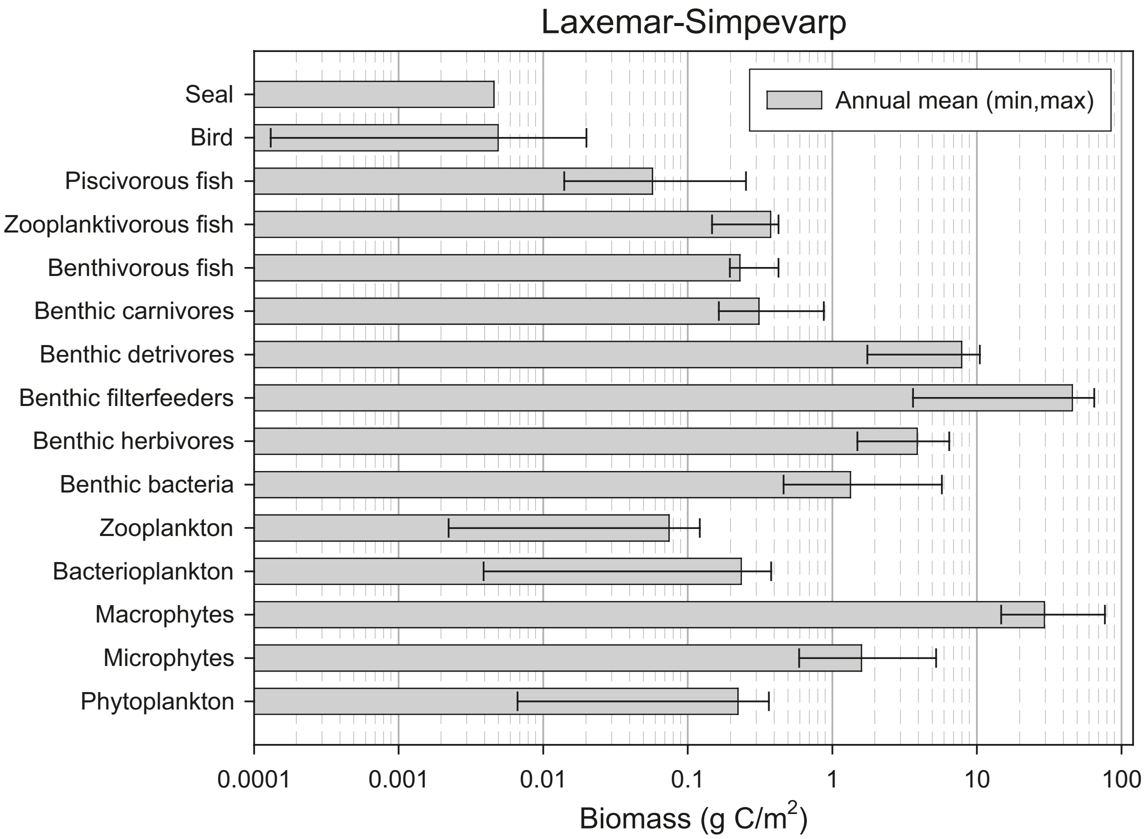


Figure 6-21. *Annual average biomass (gC m⁻²) for functional groups of marine biota in the Laxemar-Simpevarp area.*

The annual mean biomasses for the various functional groups are in good agreement with other reported values (se section 3) from the Baltic, although the biomasses for phytoplankton and the microphytobenthos might be a bit lower /Feuerfil et al. 2004/.

Figure 6-22 shows the percentage which benthic organisms comprise of the total biomass, which varies from 95 to close to 99% for separate basins.

In Figure 6-23, biomass is plotted against mean depth in each basin. There is no evident correlation with depth, however, in areas with depth > 4 m a correlation with depth can be seen. The highest mean biomasses are found in basins with intermediate depth, 4–8 m.

6.2.2 Primary Production

Net primary production (NPP) is presented in Figure 6-24. Like biomass, NPP is concentrated at the shoreline, where the highest values are found, but also in the offshore areas where depth and higher water transparency permit high phytoplankton production. In 10 out of 19 basins, most of them located near shore (except for Basin 523, 524 and 525), the annual mean NPP exceeds the annual mean NPP for the whole marine model area. The average value for the whole marine area in Laxemar-Simpevarp is 170 gC m^{-2}. This agrees well with other reported average values of primary production in the Baltic, 160 gC m^{-2} /Feuerfil et al. 2004/. Some of the southern coastal basins have very high NPP values, although the data density in these basins is lower than in the more extensively examined northern basins and these values have a higher uncertainty.

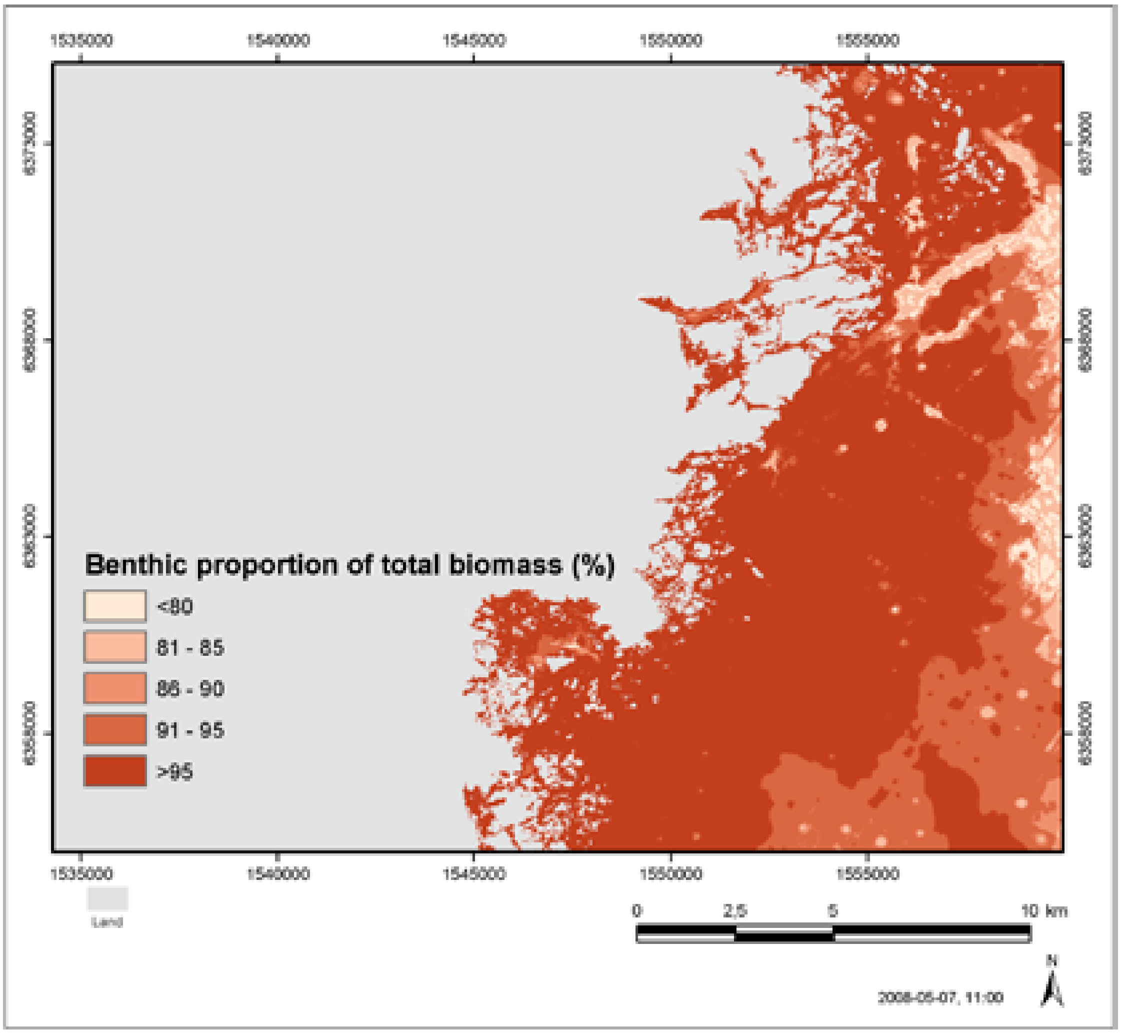


Figure 6-22. *Percentage which benthic component comprises of biomass in the Laxemar-Simpevarp area.*

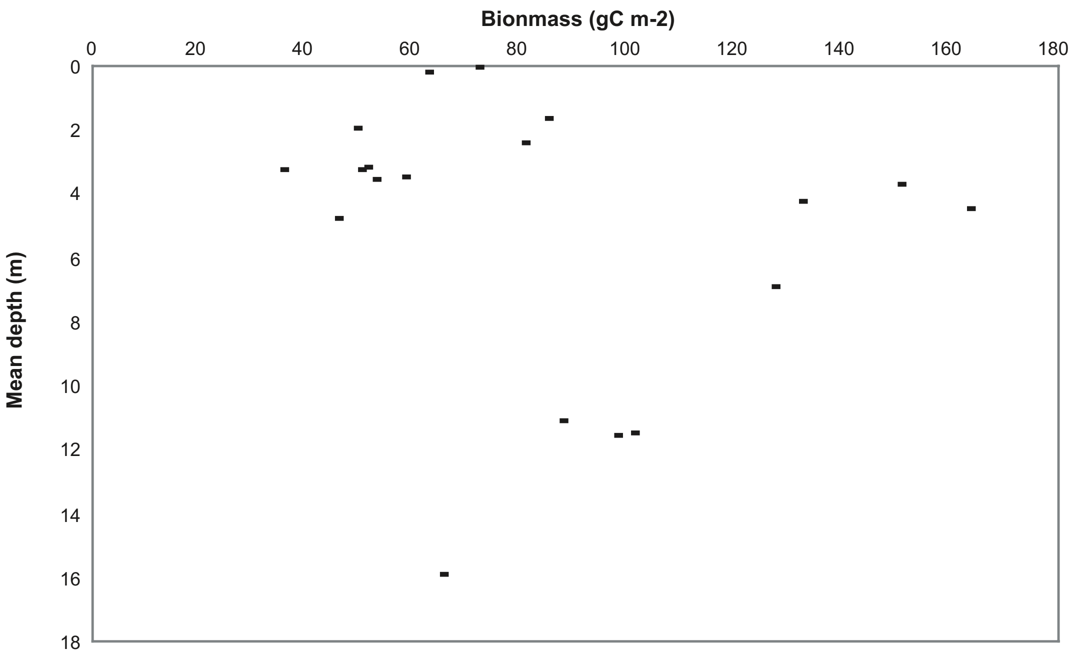


Figure 6-23. *Mean biomass (gC m^{-2}) plotted against mean basin depth for all basins in the model area.*

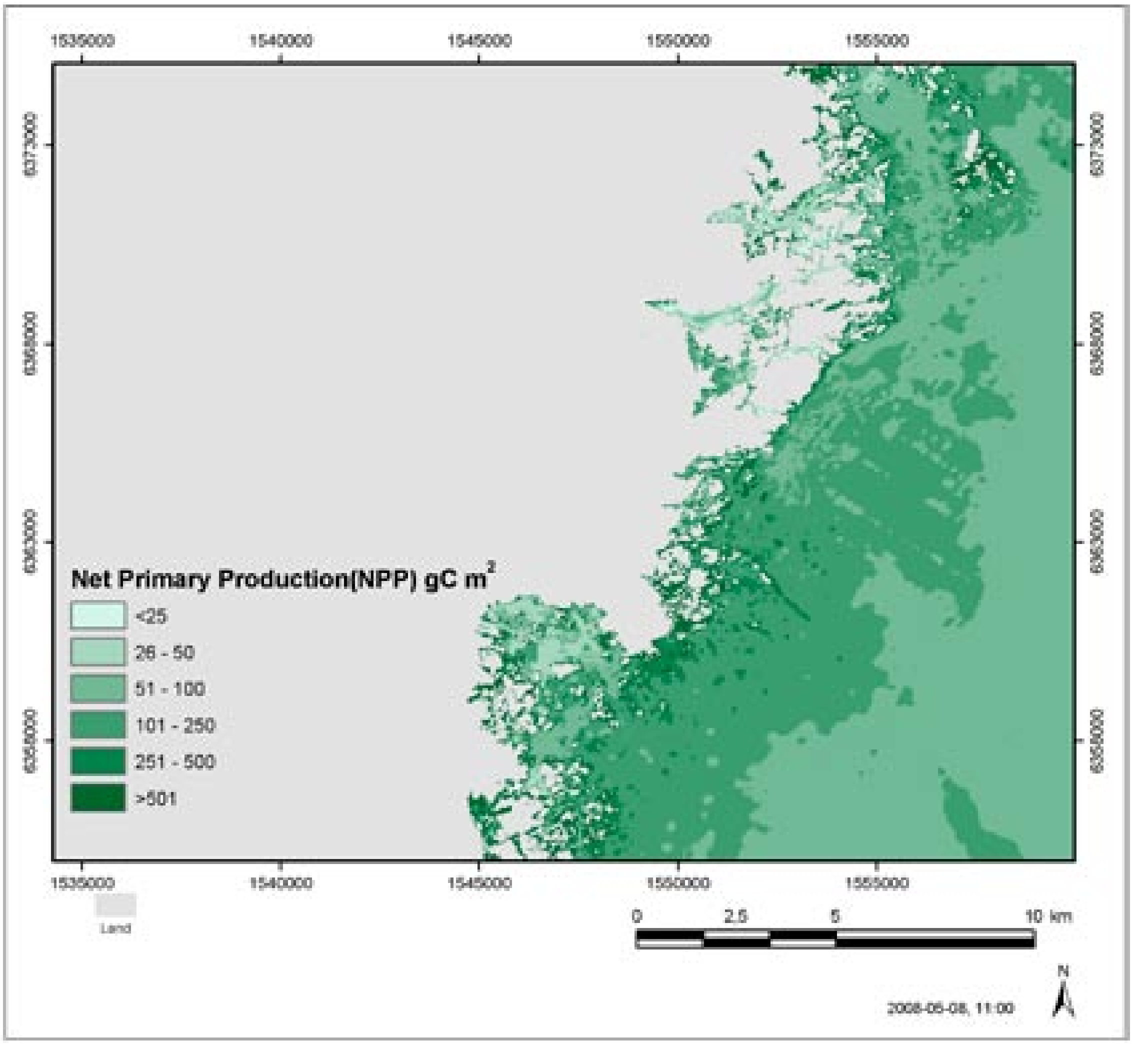


Figure 6-24. *Net Primary Production (gC m^{-2} $year^{-1}$) in the Laxemar-Simpevarp area. Higher NPP is indicated by increasingly dark green colour.*

The benthic and pelagic components of NPP are shown in Figure 6-25. The benthic and pelagic components display roughly the opposite patterns: pelagic increases with depth and benthic decreases with depth. In the whole marine model area the benthic community contributes 90% to the total NPP, which decreases with increasing depth along with macrophyte biomass and light penetration (Figure 6-26). In separate basins the benthic NPP varies from 64 to 100%.

6.2.3 Consumption

The most consumed component of the marine ecosystem in Laxemar-Simpevarp is POC (Figure 6-27). In the bays with a higher degree of soft bottoms, consumption of sediment and DOC is higher than consumption of POC.

The overall dominant consumer in Laxemar-Simpevarp is the filter feeders (dominated by *M. edulis*). In average they consume from 69 to 97% of all consumed carbon in the area, Figure 6-28.

Figure 6-25. *Pelagic (above) and benthic (below) Net Primary Production (gC m^{-2} year^{-1}) in the Laxemar-Simpevarp area. Higher NPP is indicated by increasingly dark green colour.*

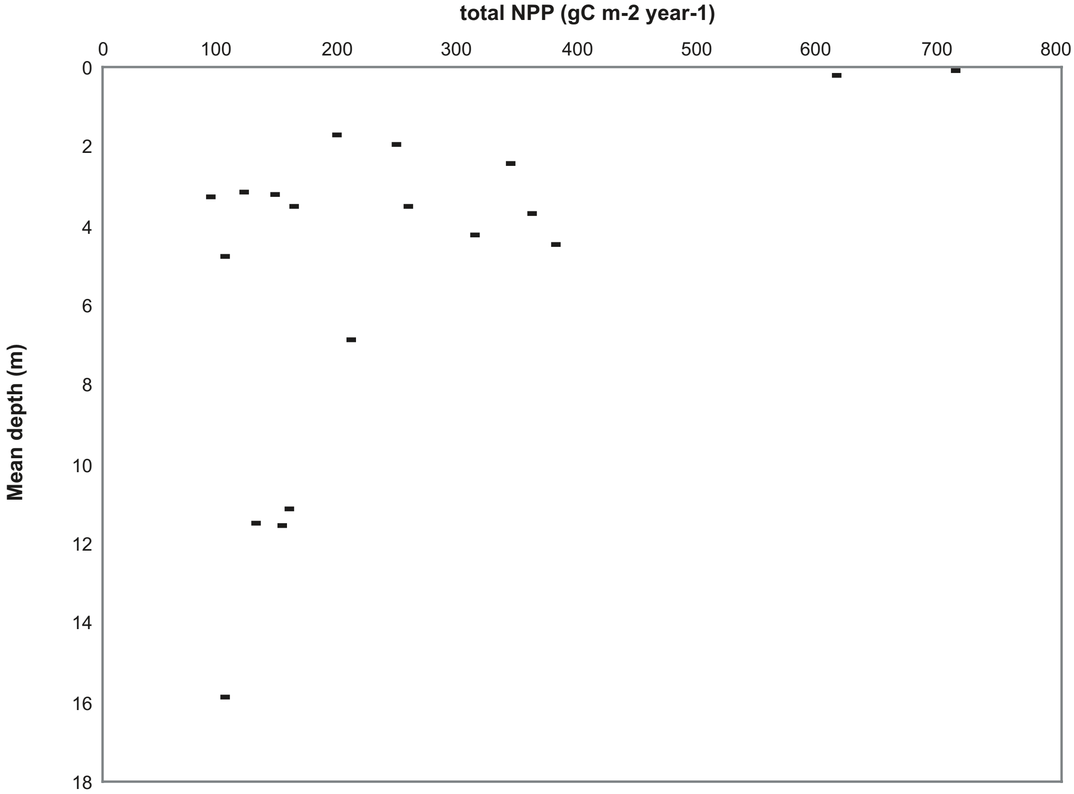


Figure 6-26. Mean NPP (gC m² year⁻¹) plotted against mean basin depth for all basins in the model area.

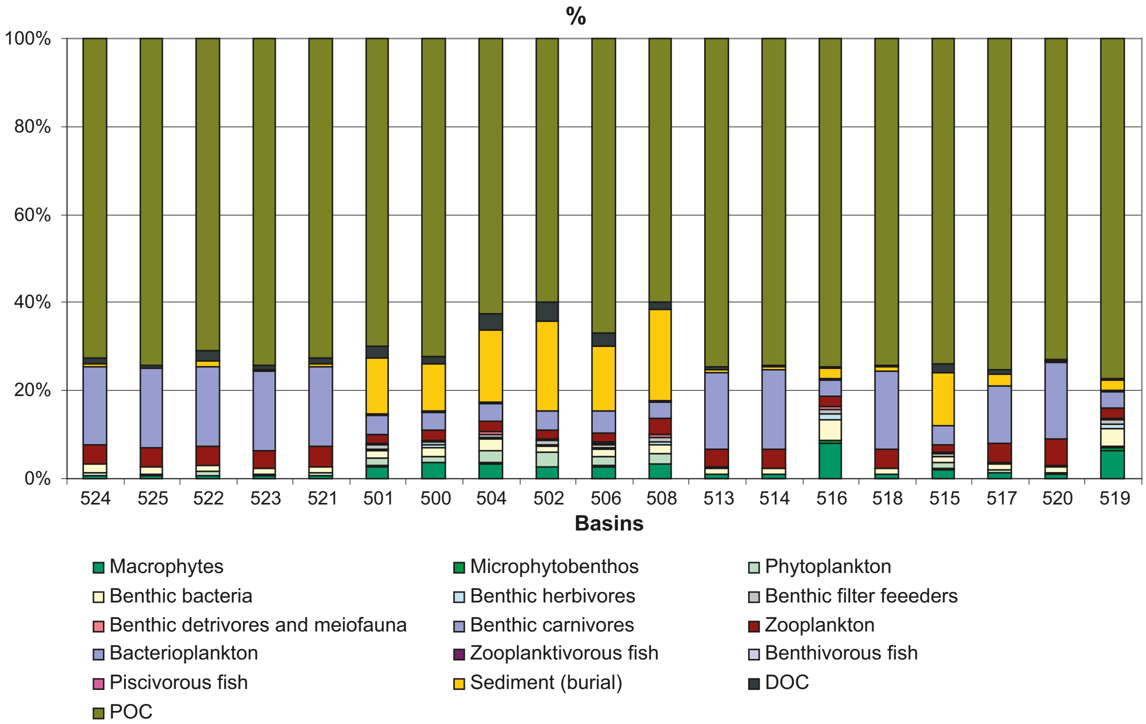


Figure 6-27. Percentage consumption of the biotic and abiotic pools in the ecosystem, in the separate basins, in the marine area in Laxemar-Simpevarp.

6.2.4 Heterotrophic respiration

The distribution of total respiration benthic and pelagic is presented in Figure 6-29. Total respiration includes only respiration by heterotrophs (consumers) as respiration by primary producers is included in the NPP presented above.

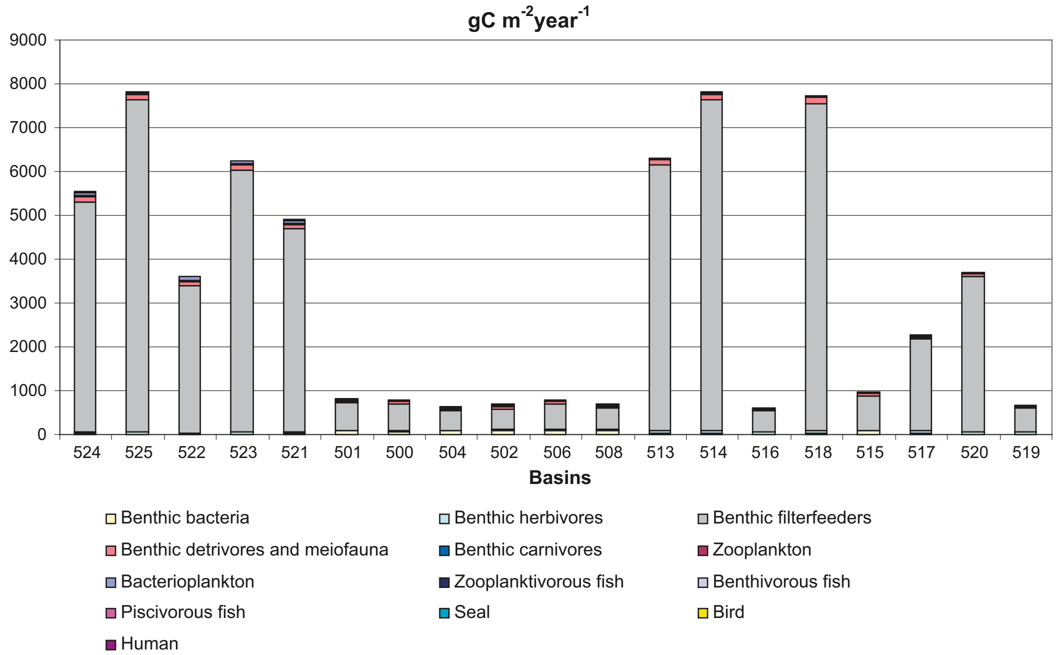


Figure 6-28. The annual mean consumption, in gC m^{-2} $year^{-1}$ in separate basins, by the consumers in the ecosystem in Laxemar-Simpevarp.

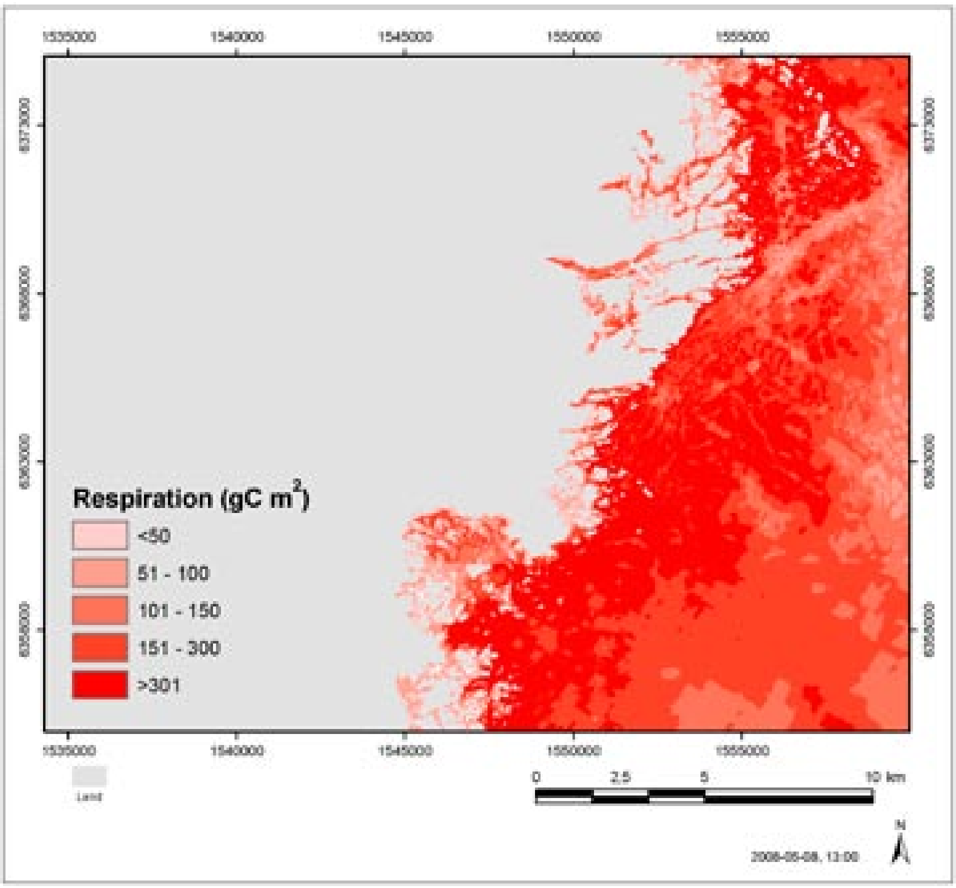


Figure 6-29. The sum of heterotrophic respiration (gC m^{-2} $year^{-1}$) in the Laxemar-Simpevarp area.

In the whole area the annual average respiration is 332 gC m^{-2}, while the annual average value in separate basins ranges from 56 to 486 gC m^{-2}. Compared with other reported values of respiration in the Baltic, 74 gC m^{-2} /Gazeau et al. 2004/ it is high. The largest component of the respiration in most basins is respiration by filter feeders, which on an annual average constitutes 48% of the total respiration and ranges from 13 to 80% in separate basins. One cause of the high respiration is the large amounts of *M. edulis* in some of the basins in the area. The second largest component of the respiration is benthic bacteria, which are a major constituent in the inner basins in particular.

When the benthic and pelagic components of the respiration are examined separately (Figure 6-30), they display, like NPP, roughly the opposite pattern. Pelagic respiration increases and benthic decreases with depth. The increase of pelagic respiration is primarily a result of higher biomass due to increasing depth, Figure 6-31. The decrease in benthic respiration is due to two factors: a smaller biomass and a decrease in temperature in the benthic community. The mean pelagic temperature also decreases with depth, but this is compensated for by the biomass.

6.2.5 Net Ecosystem Production

Net ecosystem production (NEP = NPP-R) for the area is presented in Figure 6-32. The annual average NEP in the Laxemar-Simpevarp model area is –161 gC m^{-2} $year^{-1}$. In separate basins the annual mean ranges between –282 to 651 gC m^{-2} $year^{-1}$. The marine area as a whole is heterotrophic, i.e. more carbon is released to the atmosphere than is fixed in biomass. 9 (501, 500, 504, 508, 516, 515, 517, 520 and 519) out of 19 basins are autotrophic, all of them coastal basins with macrophyte biomass constituting more than 50% of the total biomass. The rest of the basins are heterotrophic. Thus, bays in the area tend to be autotrophic while the more offshore basins are heterotrophic.

NPP in comparison with total respiration is displayed in Figure 6-33.

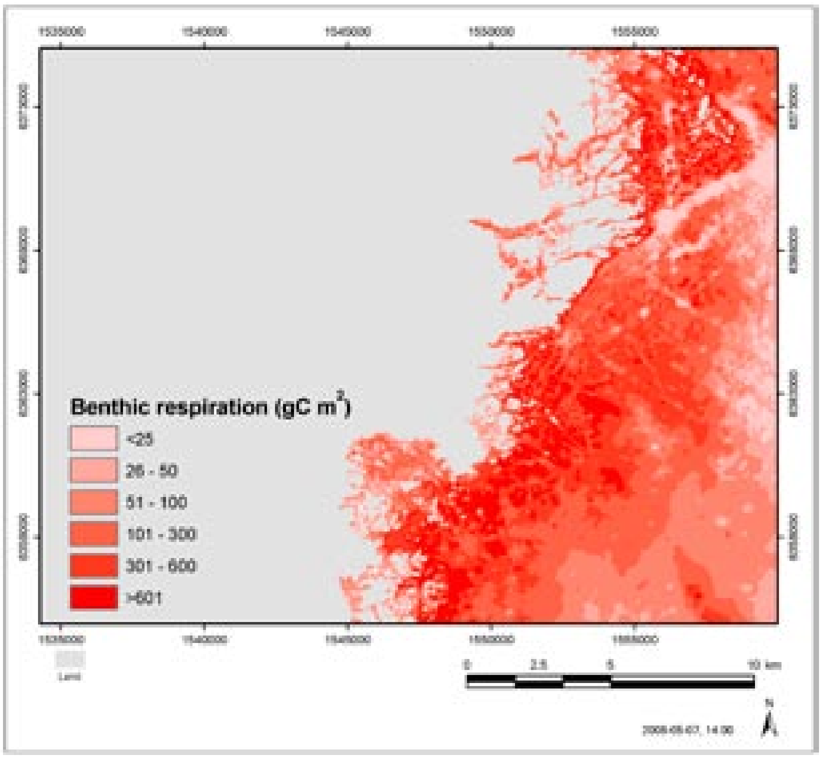
There is in a lower NEP the deeper the mean depth of the basins, as illustrated by Figure 6-34, which indicate a breakeven point for NEP, where NPP equals R at a mean depth of 3 m, Figure 6-35.

6.2.6 Marine ecosystem food webs

The marine ecosystem model can be summarized and illustrated in a food web representing various biotic and abiotic pools and fluxes in the ecosystem and between the ecosystem and the surroundings. Food webs illustrating average pools and fluxes for all marine basins in the functional groups of the marine ecosystem in Laxemar-Simpevarp are presented for C, N and P. For N and P, fluxes during net primary production have been estimated with the Redfield ratio to give a rough estimate of the magnitude of these processes for these elements.

The largest pools of carbon in the whole area in Laxemar–Simpevarp are the DIC pool, the sediment and the benthic filter feeders. The DOC pool and the macrophytes are also major contributors to the total carbon inventory in the area. Advective flux is the largest flux. The largest biotic carbon flux is the consumption of POC, phytoplankton and bacterioplankton by the filter feeders. NPP is only about 4% of the consumption by filter feeders. Runoff, diffusion, burial and precipitation are very small in comparison with the other fluxes, Figure 6-36.

The marine ecosystem food web description of consumption of primary producers in Laxemar-Simpevarp, especially the consumption of phytoplankton, is greater than production and biomass in most basins, indicating that the transfer of carbon from primary production to the first trophic level is greater than what is produced in several basins. This suggests that there are uncertainties in these calculations and is an indication that the model calculations have underestimated the primary production of phytoplankton, or the secondary production. It can also be due to an overestimation of consumption by the filter feeders. However, the consumption of filter feeders does in reality include resuspended material (some of the excess) to a higher degree than described in the model. In the model the filter feeders only consume directly from the functional groups. It may also indicate that there is a large transfer of pelagic organisms and POC from adjacent areas.



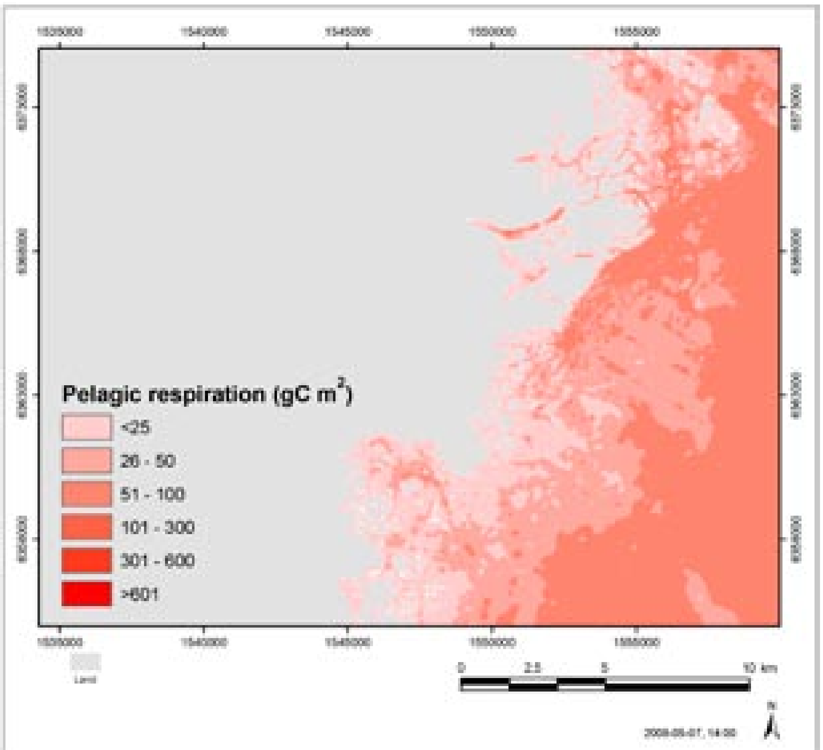


Figure 6-30. *Benthic (above) and pelagic (below) respiration (gC m^{-2} $year^{-1}$) in the Laxemar-Simpevarp area. The same scale is used in both figures.*

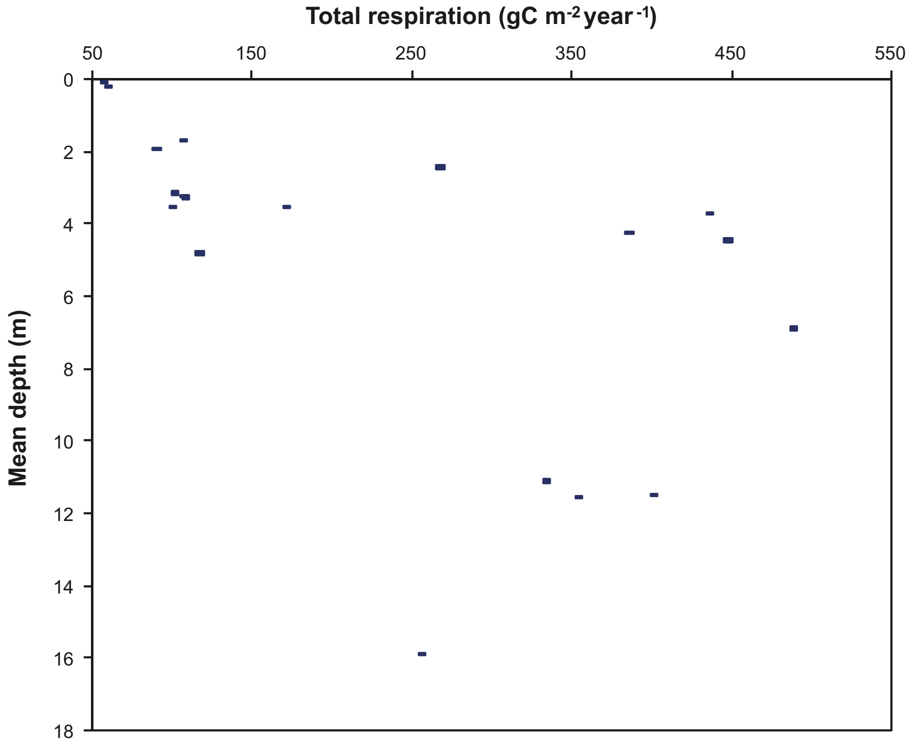


Figure 6-31. Respiration (gC m^{-2} year^{-1}) plotted against mean depth for every basin in the model area.

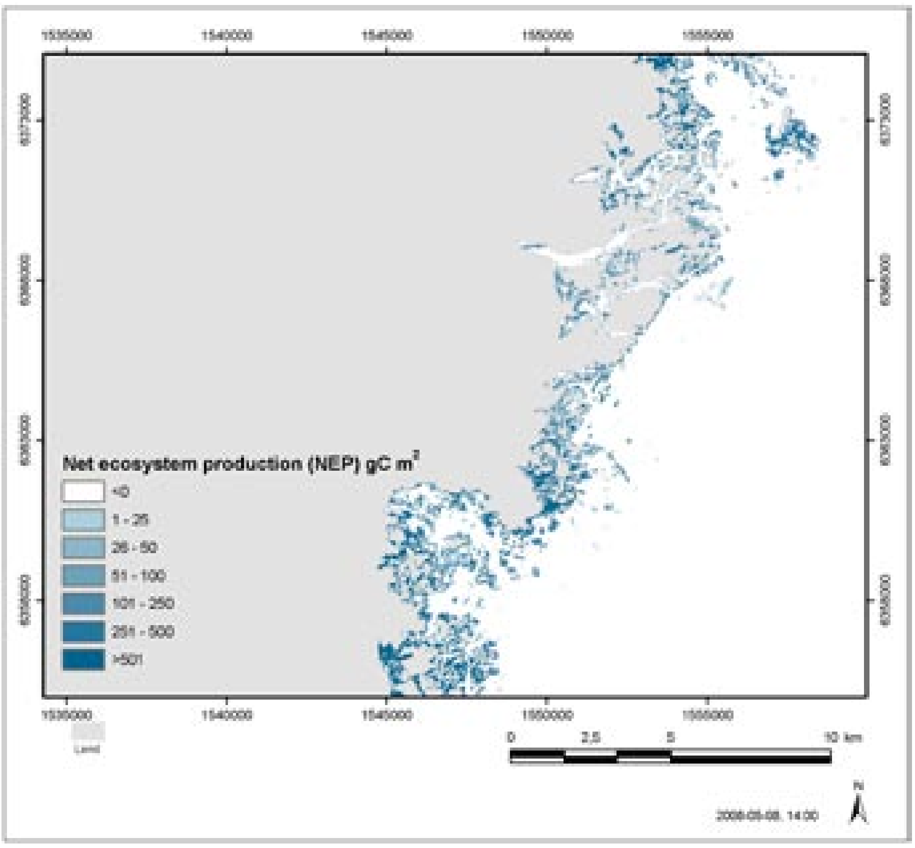


Figure 6-32. Net Ecosystem Production (NEP = NPP-R) for the Laxemar-Simpevarp area. White colour indicates a net negative NEP.

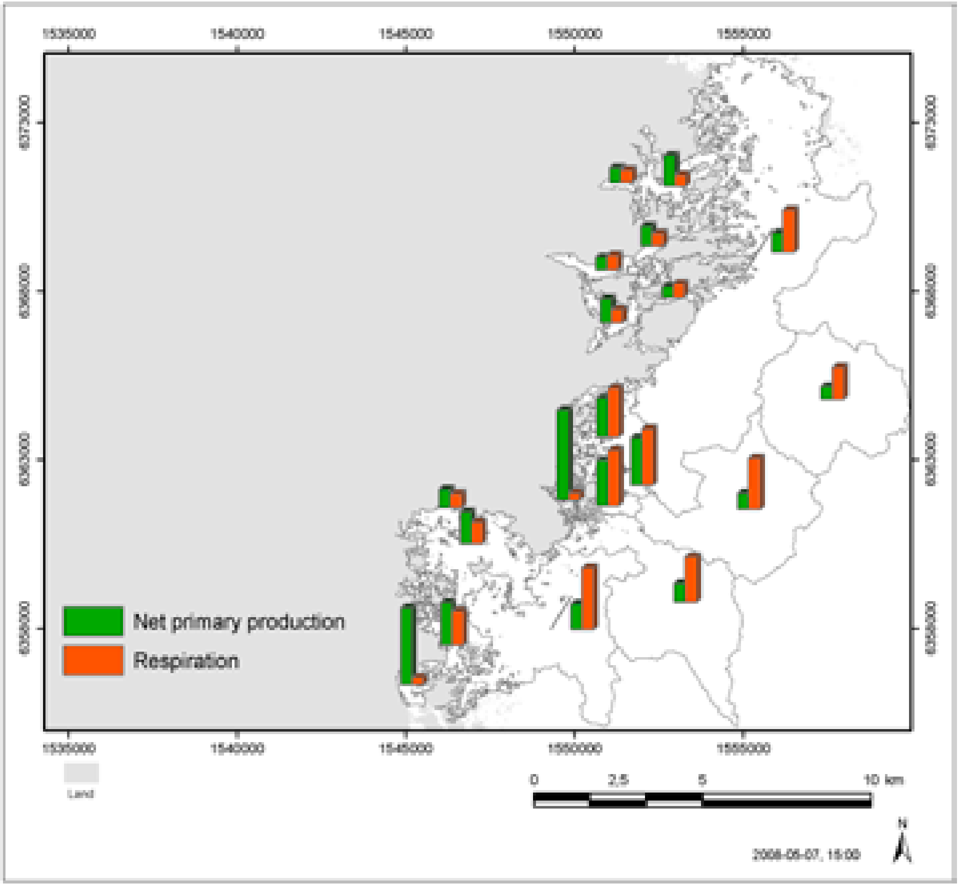


Figure 6-33. *Relative amount of Net Primary Production (NPP) and Respiration (R) (gC m^{-2} year^{-1}) for the marine basins in the Forsmark area. Green and red bars designate NPP and R, respectively.*

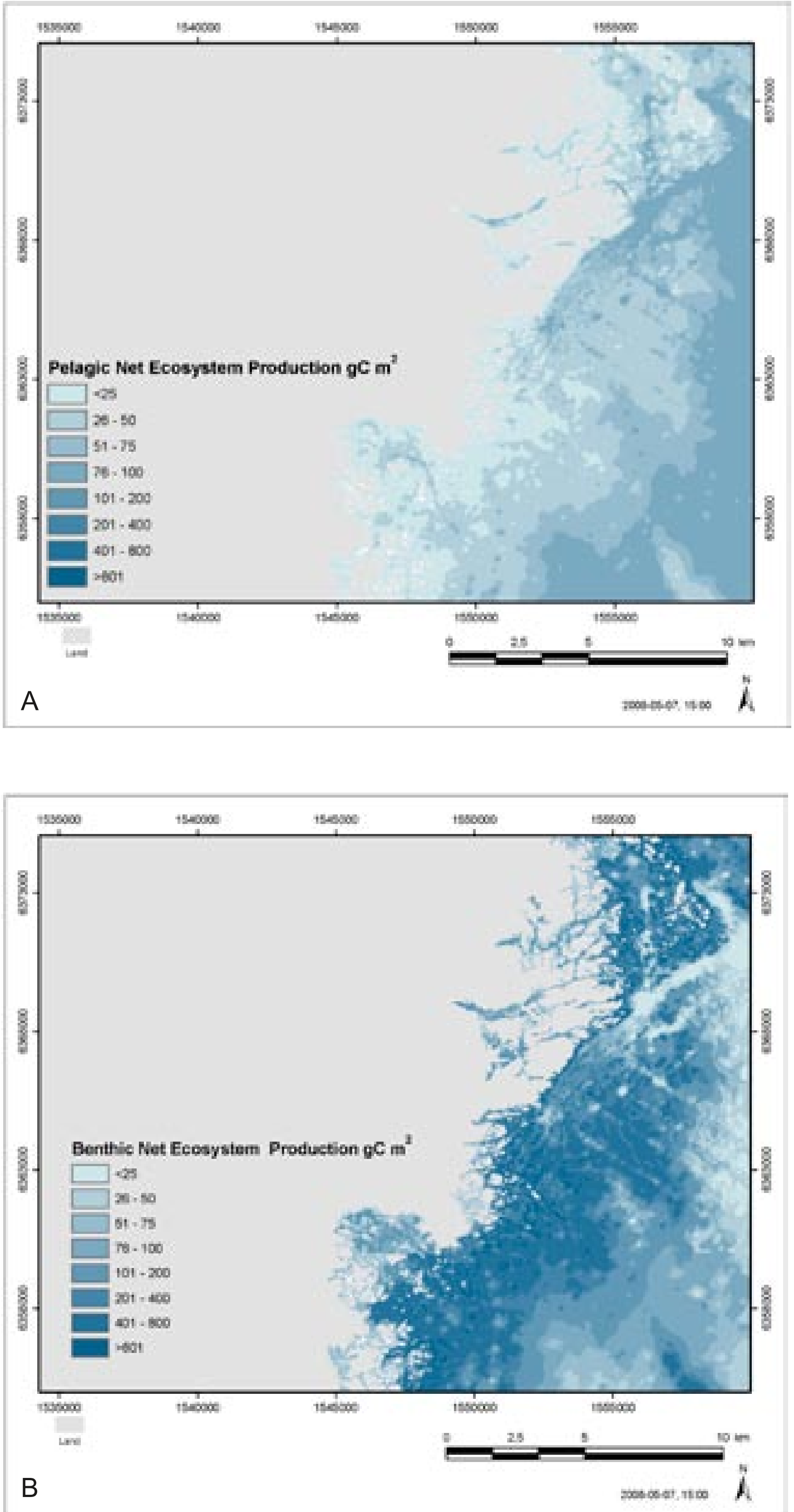


Figure 6-34. *Pelagic (above) and benthic (below) net ecosystem production (gC m^{-2} $year^{-1}$) in the Forsmark area.*

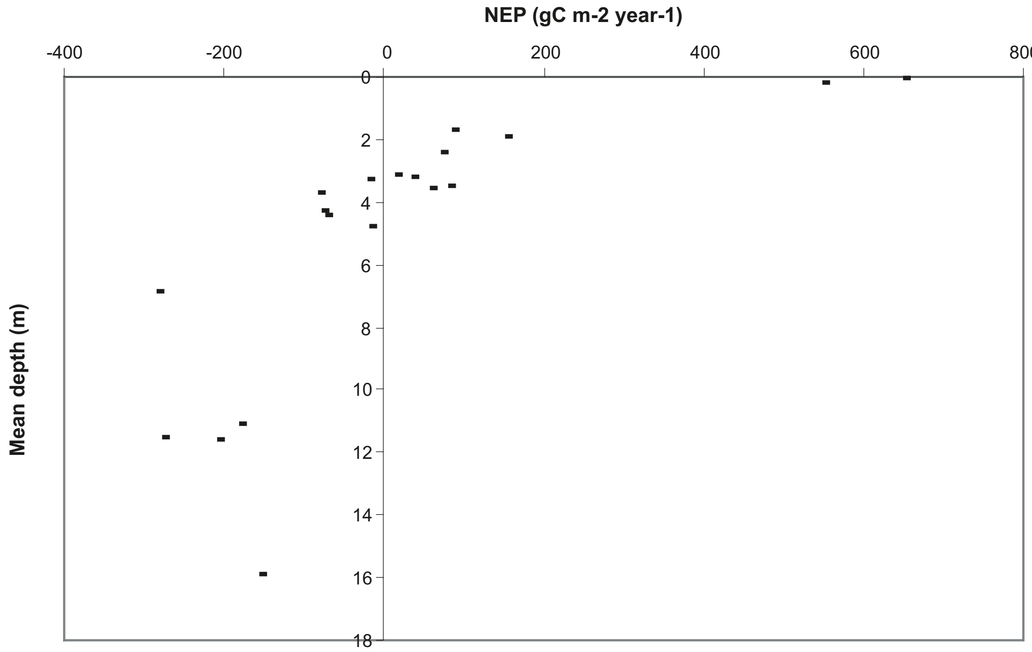


Figure 6-35. *NEP (gC m^{-2} year^{-1}) plotted against mean depth for all basins in the model area.*

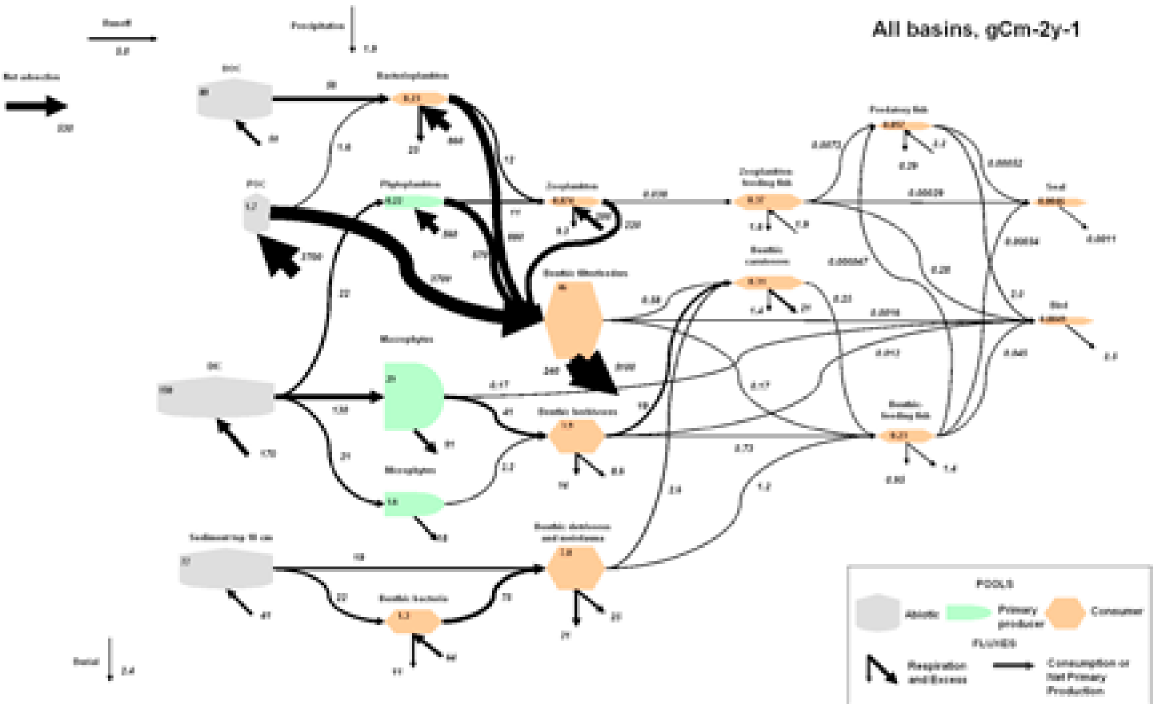


Figure 6-36. *Food web based on pools and fluxes of carbon in the whole marine model area in Laxemar-Simpevarp. Boxes and arrows denote relative size of pools and fluxes respectively.*

The excess (the remainder including secondary production, excretion faeces and dead material from all functional groups and mortality) in the whole marine basin is positive mainly due to the filter feeders.

Of the carbon initially consumed from primary producers, POC and sediment, only 0.8% reaches the top predators (piscivorous fish, birds, seals and humans) in this food web.

The largest pools for nitrogen are the sediment and the filter feeders and they are similar in order of size. The fluxes are similar to the fluxes of carbon. The largest biotic nitrogen flux is consumption of PON, phytoplankton and bacterioplankton by filter feeders. Accumulation of N during primary production is very small in comparison with consumption by filter feeders, Figure 6-37.

The excess in the whole marine basin post is positive mainly due to the filter feeders, but a majority of the biotic functional groups have a negative excess. Since the incorporation of nitrogen during photosynthesis is represented roughly by the Redfield ratio (see section 4), the negative excess term may indicate that this process is underestimated by this method. It can also be an uncertainty in the calculations of the pools since this is done using the ratios between carbon and nitrogen in (number of analyzed samples from 1 and 9) samples from the area (see section 4), which might not have been representative.

For phosphorus as for nitrogen and carbon, the largest pools are the sediment and the filter feeders. The fluxes are also similar to the nitrogen food web. The largest biotic phosphorus flux is the consumption of particular organic phosphorus (POP), phytoplankton and bacterioplankton by the filter feeders. Incorporation of P during NPP is very small in comparison with consumption by filter feeders, Figure 6-38. The same reasoning considering the negative excess for many pools of nitrogen can be valid for phosphorus as well.

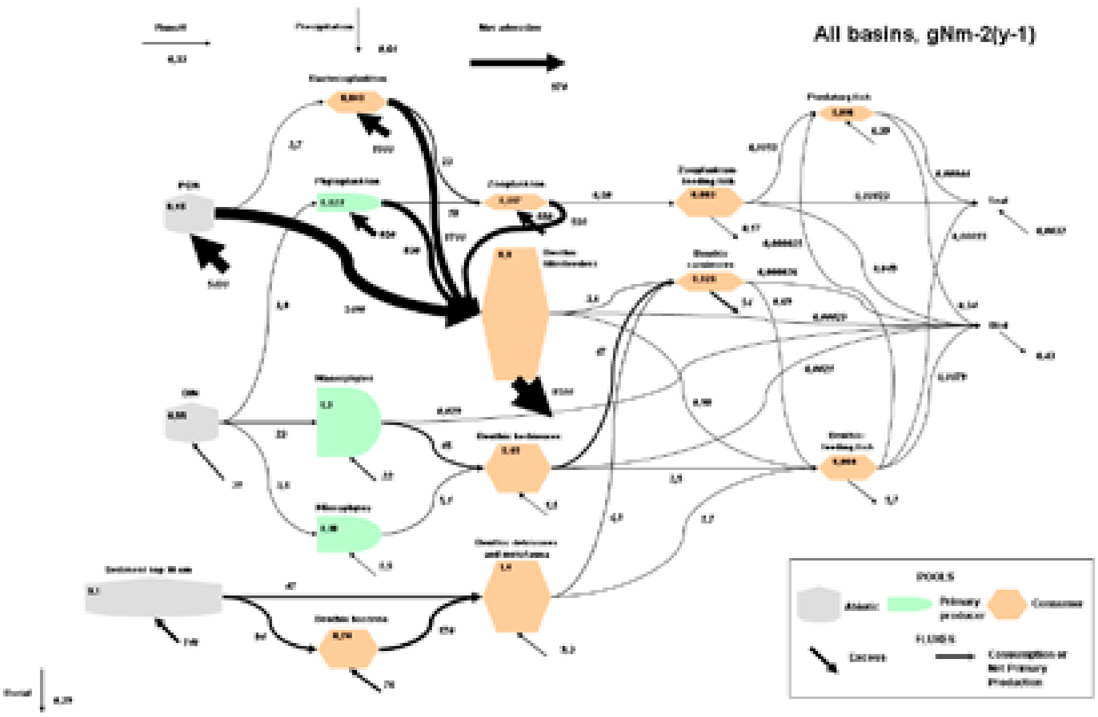


Figure 6- 37. *Food web based on pools and fluxes of nitrogen in the whole marine model area in Laxemar-Simpevarp. Boxes and arrows denote relative size of pools and fluxes.*

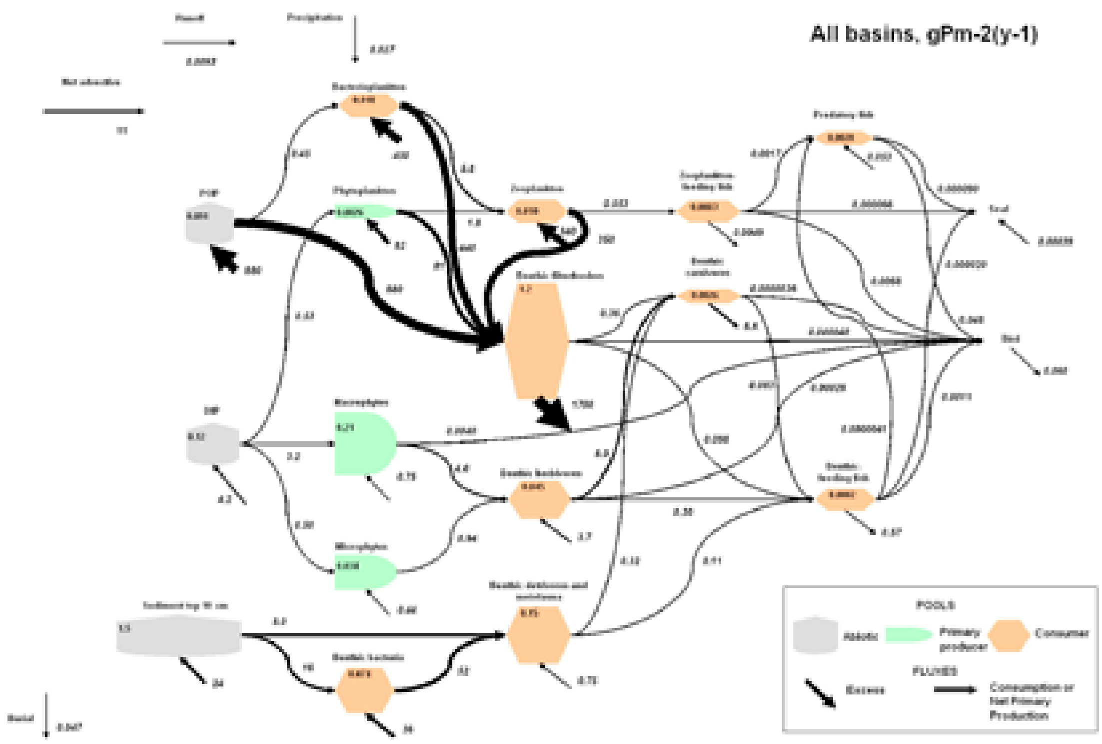


Figure 6-38. *Food web based on pools and fluxes of phosphorus in the whole marine model area in Laxemar-Simpevarp. Boxes and arrows denote relative size of pools and fluxes.*

6.3 Mass balances for carbon and other elements – both sites

Mass balances for carbon (C), nitrogen (N), phosphorus (P), iodine (I), thorium (Th) and uranium (U) are presented in detail for the whole marine area in Forsmark and Laxemar-Simpevarp. Mass balances for the five selected basins at each site and additional elements are described in the following section (6.5). Mass balance data for the rest of the basins are presented in Appendix 8. Biotic and abiotic pools in the marine ecosystem were calculated in the mass balance calculations (see also section 4) for the following biotic and abiotic pools:

- Producers (phytoplankton, microphytobenthos and macrophytes).
- Consumers (bacterioplankton, zooplankton, benthic bacteria, benthic detrivores and meio-fauna, benthic herbivores, benthic filter feeders, benthic carnivores, benthic feeding fish, zooplankton feeding fish, piscivorous fish birds and seals (only for C).
- Abiotic pools (top 10 cm of the sediment, dissolved elements (for carbon DIC and DOC are counted together) and elements in the particulate phase.

The following fluxes of elements in the ecosystem were also included in the mass balance calculations where data were available:

- Net primary production (for C, N and P, see section 4 of this report).
- Respiration (for C, see section 4 of this report).
- Advective flow (section 5 of this report).
- Runoff /Tröjbom 2007 and 2008/.
- Accumulation in the sediments (burial) (see section 4 of this report).
- Precipitation /Tröjbom and Söderbäck 2006ab, Phil Karlsson et al. 2003, 2008, Knape 2003 and Tyler and Olsson 2006/.
- Exchange with atmosphere via diffusion for C /Kumblad et al. 2003/.

Other flux processes such as evaporation, denitrification, volatilization etc were not considered in the mass balance due to a lack of data on these processes in a marine ecosystem. Site-specific ground-water fluxes from land to the marine basin were not ready in time to be included in the calculations.

6.3.1 Carbon, nitrogen and phosporus – Forsmark

A schematic overview of pools and fluxes of carbon, nitrogen and phosphorus in the whole marine model area is shown in Figure 6-39, 6-40, 6-41(per m^{-2} $year^{-1}$) and summarized in Table 6-1 (in total amount in the whole area).

Carbon

The major pool of carbon in the whole marine area is sediment, followed by the dissolved water phase of carbon and the primary producers. Sediment comprises 76% of the carbon pool in the whole basin, followed by dissolved carbon (15%), macrophytes (3%), benthic detrivores and meiofauna (1.5%), and particulate carbon (1%). All other pools contain less than 1% of the total carbon inventory in the marine model area in Forsmark (see also Appendix 8). In this study the top 10 cm of sediment is assumed to be the biologically active part of the ecosystem. Although organic-rich sediment is not present in large amounts, low concentrations of carbon are found in till and other Quaternary deposits, and the great total volume of sediment make the sediment pool of carbon very large.

The major flux of carbon is the advective flux. There is a net advective outflux of carbon in the whole marine area in Forsmark (65,065 tonnes $year^{1}$). NPP and respiration are second and third in magnitude, while runoff, diffusion, precipitation and burial are very small in comparison with other fluxes.

The total fluxes of carbon in the whole marine area, considering both influxes (runoff, advection, deposition, diffusion and net primary production) and outfluxes (advection, respiration and burial), is negative, i.e. there is a net outflux of carbon from the whole marine area of about 36,000 tonnes per year. This is equivalent to around 50 gC m^{-2} $year^{-1}$. Although not all of the basins show a net outflux (only Basins 100, 105, 103, 108, 151, 118, 150 126 and 121, most of them in smaller volumes), some of them, like Basin 151, show a large net outflux of carbon in the mass balance calculations.

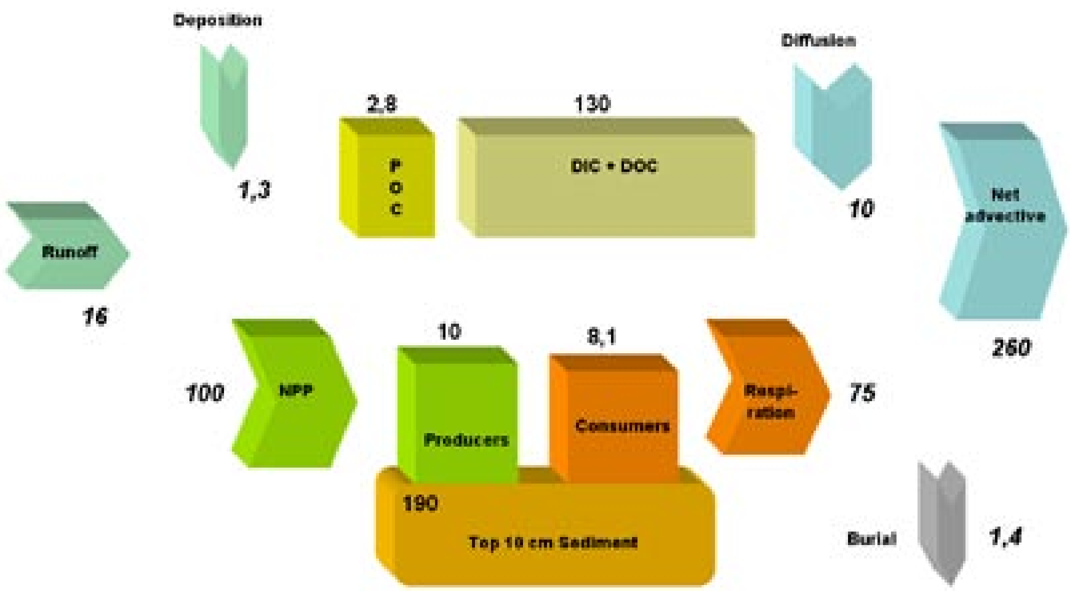


Figure 6-39. Schematic overview of pools and fluxes of carbon in the whole marine model area in Forsmark, in g C m^{-2} $year^{-1}$.

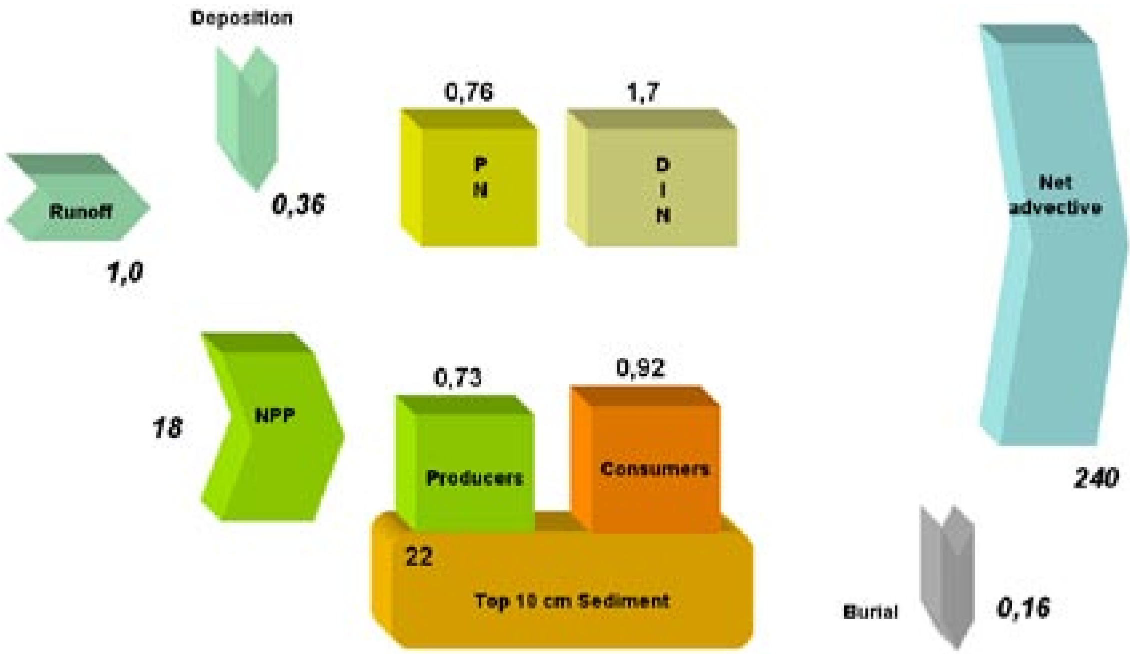


Figure 6-40. *Schematic overview of pools and fluxes of nitrogen in the whole marine model area in Forsmark, in g C m^{-2} year^{-1}.*

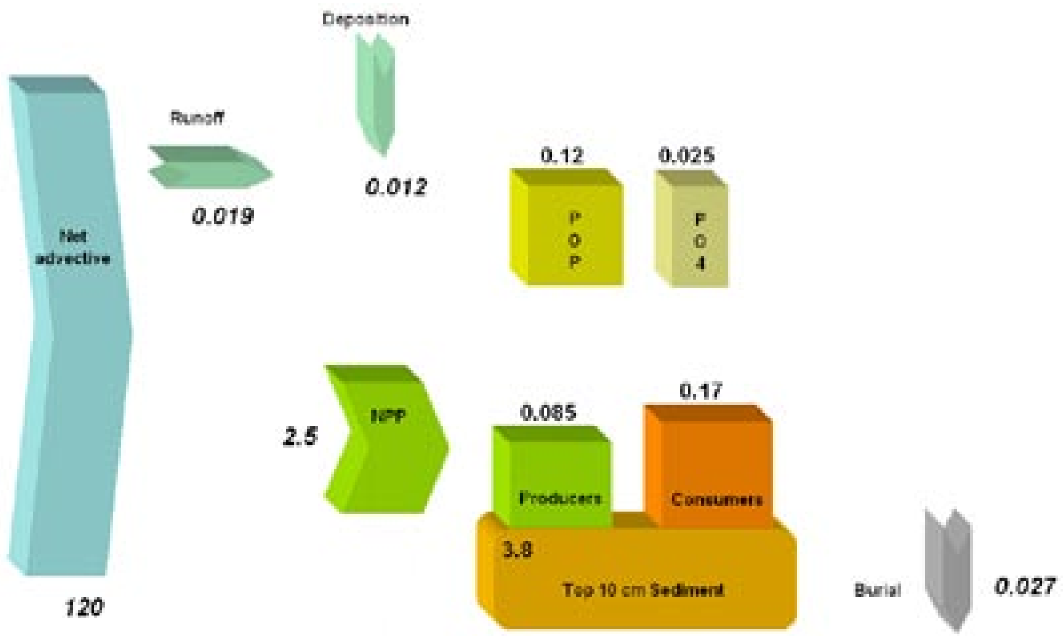


Figure 6-41. *Schematic overview of pools and fluxes of phosphorus in the whole marine model area in Forsmark, in g C m^{-2} year^{-1}.*

Table 6-1. Pools and fluxes of carbon, nitrogen and phosphorus, in tonnes per year for the whole marine model area in Forsmark.

Area: 246 km², volume: 3,088 ×10⁶ m³, mean depth: 12.6 m Fluxes	C	N	P
Runoff	3,830	248	5
Advective influx	5,390,000	736,000	59,200
Net Primary Production	25,000	4,460	608
In by precipitation	310	89	30
Advective outflux	5,460,000	794,000	28,900
Out to air, respiration	18,700	Not applicable	Not applicable
Accumulation by burial	333	38	7
Diffusion (exchange with atmosphere)	2,562	No data	No data
Net advective flux	**–65,065**	**–58,066**	**30,218**
Pools			
Phytoplankton	59	7	1
Microphytes	438	51	9
Macrophytes	1,972	123	11
Total pool producers	**2,470**	**181**	**21**
Bacterioplankton	71	12	3
Zooplankton	20	4	3
Benthic bacteria	302	54	17
Benthic herbivores	229	27	3
Benthic filter feeders	240	16	1
Benthic detrivores	974	77	9
Benthic carnivores	88	16	2
Benthivorous fish	32	8	2
Zooplanktivorous fish	34	9	2
Piscivorous fish	10	2	0
Birds	1	no data	no data
Seals	4	no data	no data
Total pool consumers	**2,000**	**226**	**42**
Top 10 cm regolith pool	47,800	5,480	938
Particulate pool	696	187	31
Dissolved pool (inorganic and organic)	31,000	410	6

According to /Broecker and Peng 1982/, the exchange between atmosphere and sea water can be very large depending on the net outflux from the system, and the carbon needed to exhibit equilibrium between the sea water and the atmosphere is generally supplied by the atmosphere. The estimate of diffusion used is a reported mean value for the Baltic and may be an underestimate. The carbon concentrations and fluxes of water used in the mass balance calculations greatly affect the results of mass balance calculations, since a small concentration difference may cause large changes in the carbon moved by water. However, the carbon concentrations are based on a large amount of data (see section 3) with high confidence, Figure 6-39.

Nitrogen

The sediment is the overall dominant pool for nitrogen. Sediment comprises 85% of the nitrogen pool in the whole basin, followed by dissolved nitrogen (6%), particulate nitrogen (3%), macrophytes (2%), and microphytes (1%), while all other pools contain less than 1% of the total nitrogen inventory in the marine model area in Forsmark (see also Appendix 9).

The major flux of nitrogen is the advective flux, with a net outflux in the basin (58,000 tonnes year^{-1}). The incorporation of nitrogen during NPP and runoff is the second and third fluxes in magnitude, while precipitation and burial are very small in comparison to the other fluxes. Processes like denitrification and exchange with atmosphere are not included. Although most of the basins show a net influx of nitrogen and are almost balanced, 7 out of 28 show a net outflux (Basins 102 and 100, see Appendix 8). The large advective flows in some of these basins contributes so much to the total result for the whole marine area that the total resulting flux is negative. Denitrification probably contributes somewhat to the release of nitrogen from sediment and PON to the dissolved phase, Figure 6-40. /Witek et al.2003/ have reported denitrification rates in The Baltic of 18 gN m^{-2} year^{-1}, which is in the same size as nitrogen incorporated during photosynthesis.

Phosphorus

Phosphorus is less abundant than C and N in the marine ecosystem in Forsmark, but sediment is once again the overall dominant pool for phosphorus. Sediment comprises 90% of the pool in the whole basin, followed by particulate phosphorus (3%), dissolved phosphorus (1%), macrophytes (1%), and microphytes (1%), while all other pools contain less than 1% of the total phosphorus inventory in the marine model area in Forsmark (see also Appendix 9).

As for C and N the major flux of phosphorus is the conrective flux. The incorporation of phosphorus during NPP is the second flux in magnitude. Runoff, precipitation and burial are very small in comparison with the other fluxes, Figure 6-41.There is a net influx in the whole marine area, considering all flux processes (abiotic and biotic), of around 30,000 tonnes year^{-1}. But in most basins the net flux of phosphorus is very small, i.e. the fluxes are almost in balance, and in some basins the influx is very large. This could indicate that these marine basins in Forsmark in some way serve as a sink and accumulate P, although, since burial is still very small, this is probably due to uncertainties in the calculations. But as for all other elements, the advective flux is a large term and will affect the results of the mass balance calculations greatly at even small changes in concentration and/or water volume.

6.3.2 Actinides and Iodine – Forsmark

The fluxes considered are advective flux, precipitation and burial. Other fluxes were not included due to a lack of data. For some functional groups (benthic bacteria, bacterioplankton, benthic filter feeders, benthic carnivores, birds and seals), no analysis data were available and they are not included in the mass balances, which underestimates the consumer pool. Concentrations of some elements in some biota were below the detection limit, and estimated means based on half the detection limit were used to give a rough estimate. For uranium concentrations in biota have not been measured in Forsmark and data from Laxemar-Simpevarp have been used to give rough estimate. The biotic pools for which estimated means of concentrations were used are marked in Table 6-2. Data for all basins are presented in Appendix 9.

The distribution coefficients (K_d) for these elements cover a wide range: 3,200 ml/g (Th), 35 ml/g (U) and 0.6 ml/g (I) /SKB 2006a/, which is also reflected in the distribution of the elements in the marine pools. Th has the smallest pools in the water compared to the sediments and I the largest (Figures 6-42, 6-43, 6-44 and Table 6-2). The mass balances for Th, U and I indicate that there is a net outflux of these elements from the marine area in Forsmark, although processes such as runoff, incorporation during growth of biota and release during decomposition of organic material are not included and will contribute to the uncertainty of the mass balance calculations.

Thorium

For thorium the major pool is the sediment. The sediment comprises 89% of the pool in the whole basin, followed by dissolved thorium (7%), particulate thorium (2%) and the primary producers, microphytes (1%). All other pools contain less than 1% of the total thorium inventory in the marine model area in Forsmark.

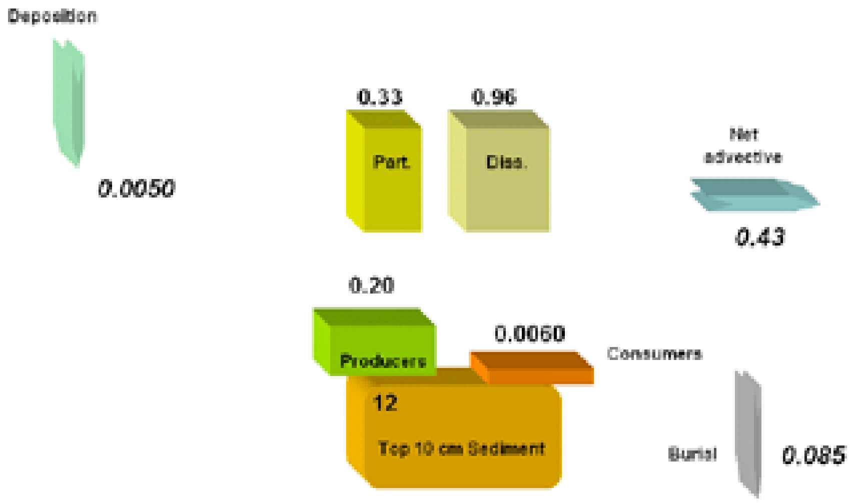


Figure 6-42. *Schematic overview of pools and fluxes of thorium in the whole marine model area in Forsmark, in mg Th m*$^{-2}$ *year*$^{-1}$.

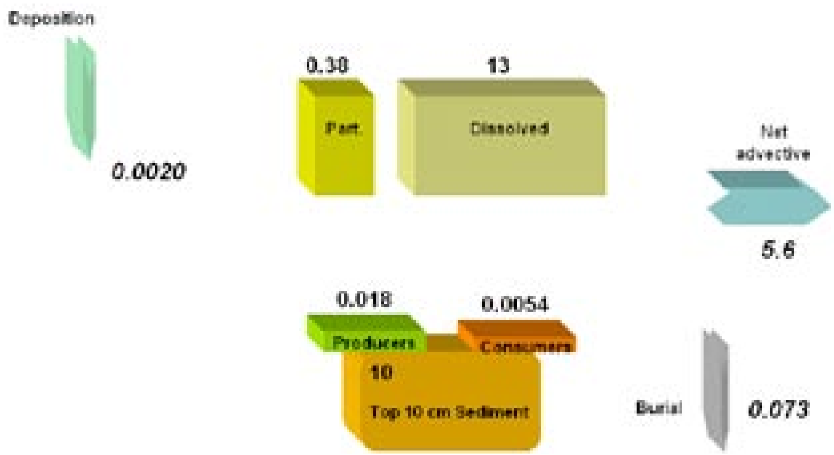


Figure 6-43. *Schematic overview of pools and fluxes of uranium in the whole marine model area in Forsmark, in mg U m*$^{-2}$ *year*$^{-1}$.

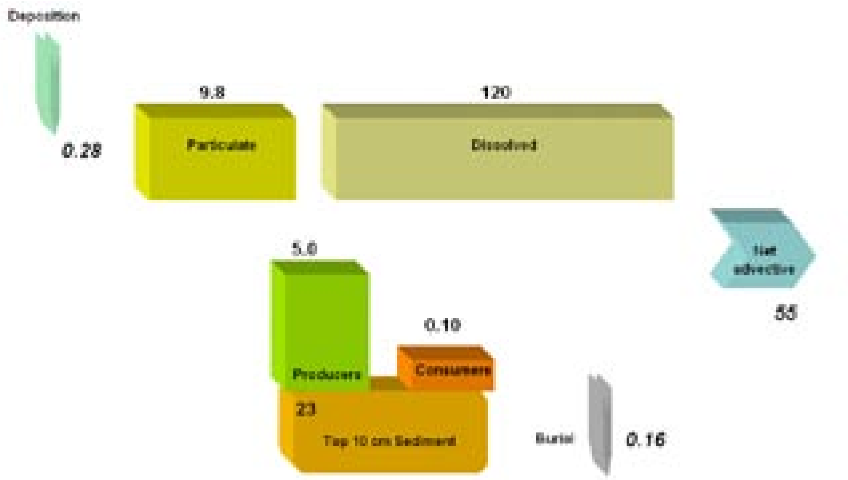


Figure 6-44. *Schematic overview of pools and fluxes of iodine in the whole marine model area in Forsmark, in mg I m^{-2} year^{-1}.*

Table 6-2. Pools and fluxes of iodine, thorium and uranium in tonnes per year for the whole marine model area in Forsmark. Values marked with * denotes reported values below detection limit were reported value have been divided by 2 in calculations. Values marked with ** denotes data from analyses in Laxemar-Simpevarp. Values marked with * denotes that concentrations measured in macrophytes in Laxemar-Simpevarp have been used for all primary producers and that concentrations for benthic filter feeders in Laxemar-Simpevarp have been used for zooplankton and benthic fauna.**

Area: 246 km², volume: 3 088 ×10⁶ m³, mean depth: 12.6 m			
Fluxes	**I**	**Th**	**U**
Runoff	no data	no data	no data
Advective influx	16,489	130	1,706
Net Primary Production	no data	No data	no data
In by precipitation	0.07	0.00121	0.0005
Advective outflux	16,503	130	1,708
Out to air, respiration	No data	no data	no data
Accumulation by burial	0.04	0.02	0.02
Net advective flux	–14	–0.1	–2
Pools			
Phytoplankton	0.01	0.0005	0.0001**
Microphytes	1	0.05	0.001**
Macrophytes	0.4	0.002	0.004**
Total pool producers	**1**	**0.05**	**0.004**
Bacterioplankton	no data	no data	no data
Zooplankton	0.003	0.00002	no data
Benthic bacteria	no data	no data	no data
Benthic herbivores	0.01	0.0002	0.0002***
Benthic filter feeders	no data	0.0001	0.0002
Benthic detrivores	0.01	0.001	0.0008***
benthic carnivores	no data	0.0001	0.0001***
Benthivorous fish	0.0001	0.0000004*	0.0000001**
Zooplanktivorous fish	0.0001	0.0000003*	0.0000001**
Piscivorous fish	0.00004	0.0000001	0.00000002*
Bird	no data	no data	no data
Seal	no data	no data	no data
Total pool consumers	**0.02**	**0.001**	**0.001**
Top 10 cm regolith pool	6*	3	3
Particulate pool	2	0.1	4
Dissolved pool	30	0.2	3

The major flux of thorium is the advective flux; the model shows a net outflux in the basin (125 kg year^{-1}). Deposition and burial are very small in comparison with the advective fluxes, Figure 6-42.

Uranium

For uranium the dissolved pool in the water is the overall dominant pool, although the sediment pool is almost as large. The biotic pools are very small and the largest pool is the macrophytes, which constitute 0.004% of the total uranium pool in the marine model area in Forsmark.

The major flux of uranium is the advective flux. Burial and deposition are very small in comparison with the advective fluxes, see Figure 6-43. According to the model there is a net outflux of U from the marine model area in Forsmark of around 1,400 kg year^{-1}.

Iodine

For iodine the dissolved pool in the water is the overall dominant pool. Dissolved iodine comprises 76% of the pool in the whole basin, followed by sediment (14%), particulate iodine (6%), macrophytes (2%) and microphytes (1%). All other pools contain less than 1% of the total iodine inventory in the marine model area in Forsmark.

The major flux of iodine is the advective flux, and as in the case of Th and U, burial is very small in comparison with the advective fluxes. The model indicates a net outflux of I from the marine area in Forsmark, see Figure 6-44. The calculations of fluxes resulted in a net outflux of around 14 tonnes year^{-1}.

6.3.3 Carbon, nitrogen and phosphorus – Laxemar-Simpevarp

A schematic overview of pools and fluxes of carbon, nitrogen and phosphorus in the whole marine model area is shown in Figures 6-45, 6-46, 6-47 and Table 6-3.

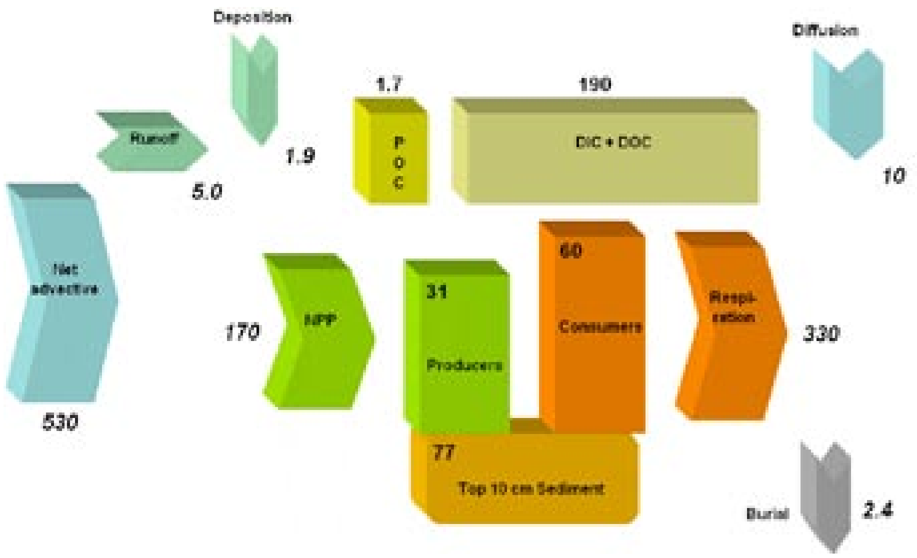


Figure 6-45. Schematic overview of pools and fluxes of carbon in the whole marine model area in Laxemar-Simpevarp, in g C m^{-2} year^{-1}.

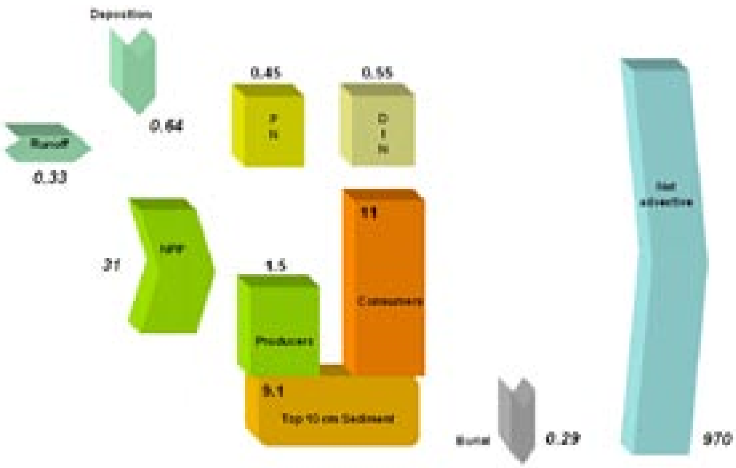


***Figure 6-46.** Schematic overview of pools and fluxes of nitrogen in the whole marine model area in Laxemar-Simpevarp, in g N m^{-2} year^{-1}.*

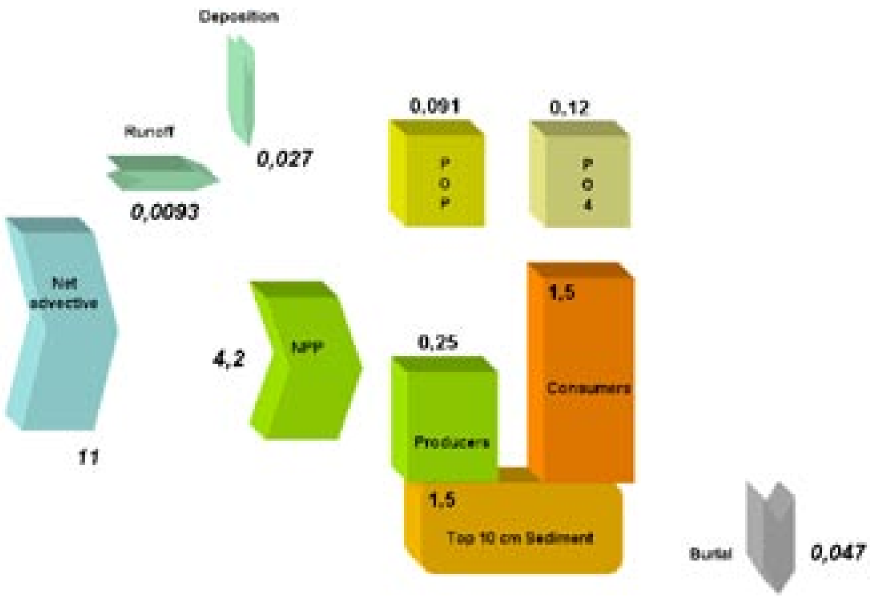


***Figure 6-47.** Schematic overview of pools and fluxes of phosphorus in the whole marine model area in Laxemar-Simpevarp, in g P m^{-2} year^{-1}.*

Table 6-3. Pools and fluxes of carbon, nitrogen and phosphorus, in tonnes per year for the whole marine model area in Laxemar-Simpevarp.

Area: 119 km², volume: 1,154 ×10⁶ m³, mean depth: 9.9 m **Fluxes**	**C**	**N**	**P**
Runoff	598	39	1
Advective inflow	5,123,978	448,090	36,893
Net Primary Production	20,565	3,621	501
In by precipitation (deposition)	223	760	3
Advective outflow	5,060,767	563,256	35,575
Out to air, respiration	39,331	6,890	954
Accumulation by burial	287	34	6
Diffusion (exchange with atmosphere)	1,235	no data	No data
Pools			
Phytoplankton	26	3	0.3
Microphytes	189	22	4
Macrophytes	3,481	151	25
Emerging macrophytes	incl in macrphytes	incl in macrphytes	incl in macrphytes
Total pool producers	**3,696**	**176**	**29**
Bacterioplankton	28	5	1
Zooplankton	9	2	1
Benthic bacteria	158	29	9
Benthic herbivores	459	53	5
Benthic filter feeders	5,425	1,053	146
Benthic detrivores	930	170	18
Benthic carnivores	37	3	0,3
Benthic feeding fish	27	8	1
Zooplankton-feeding fish	44	10	1
Piscivorous fish	7	2	0
Birds	1	no data	no data
Seals	1	no data	no data
Total pool consumers	**7,125**	**1,334**	**183**
Top 10 cm regolith pool	9,090	1,077	178
Particulate pool	201	53	11
Dissolved pool (inorganic and organic)	4,934	66	14

Carbon

In the separate basins (the inner bays) the sediment pool can be the major carbon pool but in an average for the whole marine area, the dominant carbon pool is the dissolved phase. DIC and DOC, constitute in total 54% of the whole carbon pool in the area, followed by the sediment pool (21%), the consumer pool (16%, dominated by the filter feeders) and the producer pool (8.5%). Among the producers it is the macrophytes that constitute the main pool, while the other producers contribute less than 1% to the producer pool.

Considering all fluxes in the mass balance calculations (advective flux, deposition, diffusion, runoff primary production, respiration and burial), there is a net influx of carbon to the whole marine area in Laxemar-Simpevarp, equivalent to around 9 gC m^{-2} $year^{-1}$. But not all basins show this net influx, and some have a net outflux of carbon instead (11 out of 19 basins, see Appendix 8). Burial is very low, although the net influx indicates there are uncertainties in the mass balance calculations. The major flux of carbon is the advective flux This estimate is based on very large volumes of water transferred between the basins (se section 5) and on concentrations of C in the water from sampling during the site investigation in the area (see sections 3 and 4), and since the water volumes are so large even small uncertainties in these estimates will have great consequences for the mass balance. All other fluxes including burial are very small in comparison with the advective flux, and since there is less uncertainty in the burial term than in the advective term, the large net influx does not indicate that the area is a sink for carbon, Figure 6-45.

Nitrogen

Looking at the total inventory of nitrogen in the whole marine basin in Laxemar-Simpevarp, consumers constitute the major pool (49%), Table 6-3, followed by sediment (40%) and macrophytes (6%). The consumer pool is totally dominated by filter feeders. This is also true of nitrogen pools per m^2 (Figure 6-46).

The mass balance calculations show an annual net advective outflux of nitrogen in the whole marine area (around 111,000 tonnes $year^{-1}$) and in 7 out of 19 basins (Appendix 8). The major flux of nitrogen is the advective flux, in comparison all other fluxes are very small. Since advection is such a large term it will have great influence on the results and even minor uncertainties will greatly affect the result. Denitrification is not included in the mass balance and could contribute to an even larger outflux in the basins.

Phosphorus

Phosphorus is quite evenly distributed between the sediment and consumer pools, which are of the same order of magnitude (43% and 44%, respectively). The third largest pool, although much smaller than the former two, is primary producers (7%). (Figure 6-47, Table 6-3).

The major flux of phosphorus is the advective flux. Runoff, burial and precipitation are very small in comparison with the other fluxes (Figure 6-47). The mass balance calculation shows a net influx of phosphorus in the whole marine area of 2,600 tonnes $year^{-1}$, mainly due to a large net influx in Basins 523 and 521. In most basins the net flux of phosphorus is quite low. Release of phosphorus during decomposition of organic material is not included. This could indicate that the marine basins in Laxemar-Simpevarp in some way serve as a sink and accumulate P, although since the burial is still very low this probably indicates uncertainties in the calculations. But as for all other elements, the advective flux is a large term and will affect the results of the mass balance calculations greatly at even small changes in concentration and/or water volume.

6.3.4 Actinides and Iodine – Laxemar-Simpevarp

Considered fluxes are advective flow, deposition and burial. The other fluxes NPP, respiration and diffusion were not included due to a lack of data. For some functional groups (benthic bacteria, bacterioplankton, benthic filter feeders, benthic carnivores, birds and seals), no analysis data were available and they are not included in the mass balances, entailing an underestimation of the consumer pool. Data on uranium concentrations in some of the biotic functional groups were not available for Laxemar-Simpevarp, so data from Forsmark were used for them to give a rough estimate of these pools relative to other pools. Since mainly salinity but also other chemical characteristics will affect uranium distribution, these estimates of uranium concentrations are to be regarded as very rough. Some analyses of biota were below the detection limit, and estimated means based on half the detection limit were used to give a rough estimate. Uranium analyses did not include all functional groups, and to give a rough estimate of pools, reported concentrations for macrophytes have been used for all primary producers and reported values for benthic filters have been used for all benthic fauna. These data are marked in Table 6-4 and in Appendix 9.

The varying distribution coefficients (Kd) for the elements, thorium, uranium and iodine, are reflected in the distribution in the marine pools in Laxemar-Simpevarp as well (Figures 6-48, 6-49 and 6-50). The mass balances for Th, U and I entail that there is a net outflux of these elements from the marine area in Laxemar-Simpevarp, although processes such as runoff, incorporation during growth of biota, and release during decomposition of organic material are not included and will contribute to the uncertainty of the mass balance calculations.

Table 6-4. Pools and fluxes of iodine, thorium and uranium in tonnes per year for the whole marine model area in Laxemar-Simpevarp. Values marked with an * denotes reported concentrations below detection limit, were half the reported value have been used in the calculations.

Area: 119 km^2, volume: 1 154 ×10^6 m^3, mean depth: 9.9 m Fluxes	I	Th	U
Runoff	no data	no data	no data
Advective inflow	14,958	3	987
In by precipitation	0.04	0.001	0.0002
Advective outflow	18,291	8	959
Accumulation by burial	0.02	0.01	0.01
Pools			
Phytoplankton	0.002	0.0002	0.0001
Microphytes	0.4	0.02	0.0004
Macrophytes	1	0.002*	0.008
Emerging macrophytes	incl in macrphytes	incl in macrphytes	incl in macrphytes
Total pool producers	**1**	**0.02**	**0.01**
Bacterioplankton	no data	no data	no data
Zooplankton	0.001	0.00001	no data
Benthic bacteria	no data	no data	no data
Benthic herbivores	0.02	0.0005	0.000
Benthic filter feeders	0.3	0.0004*	0.005
Benthic detrivores	0.05	0.001	0.001
Benthic carnivores	0.002	0.00007	0.00003
Benthic feeding fish	0.00006*	0.000001*	0.00000001
Zooplankton-feeding fish	0.00002*	0.0000002*	0.00000005
Piscivorous fish	0.00001	0.0000002	0.000000001*
Birds	no data	no data	no data
Seals	no data	no data	no data
Total pool consumers	**0.3**	**0.002**	**0.01**
Top 10 cm regolith pool	1	0.5	0.4
Particulate pool	1	0.02	0.01
Dissolved pool	16	0.01	1

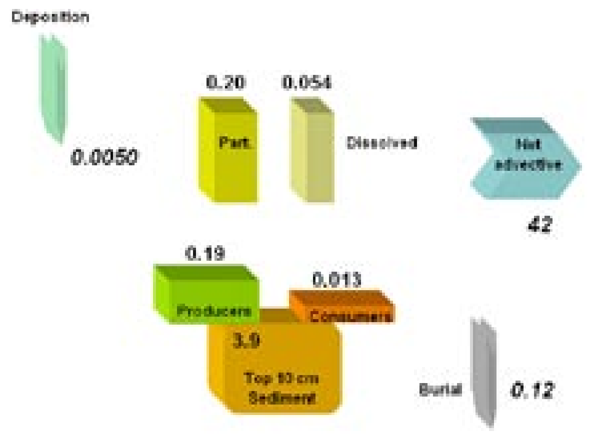


Figure 6-48. *Schematic overview of pools and fluxes of thorium in the whole marine model area in Laxemar-Simpevarp, in mg Th m*$^{-2}$ *year*$^{-1.}$

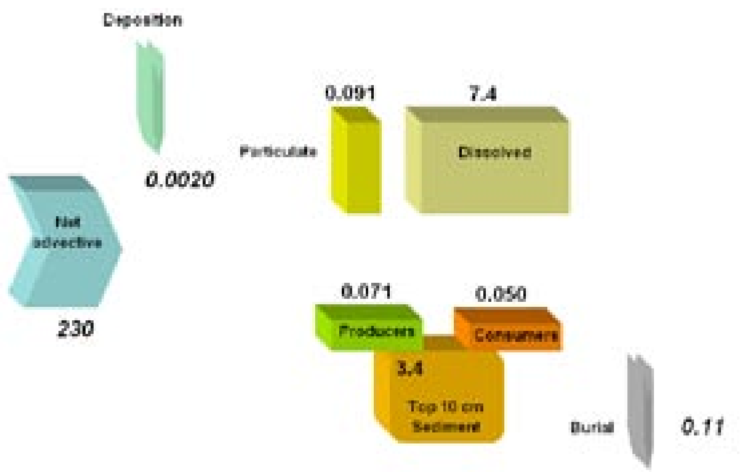


Figure 6-49. *Schematic overview of pools and fluxes of uranium in the whole marine model area in Laxemar-Simpevarp, in mg U m*$^{-2}$ *year*$^{-1.}$

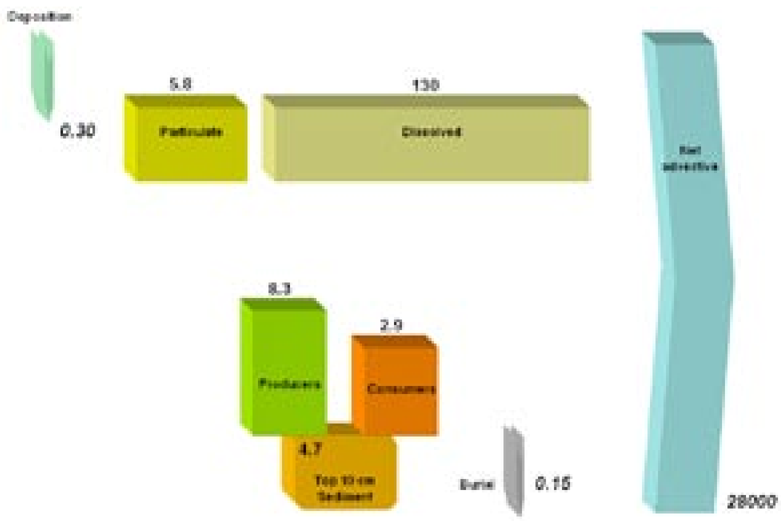


Figure 6-50. *Schematic overview of pools and fluxes of iodine in the whole marine model area in Laxemar-Simpevarp, in mg I m*$^{-2}$ *year*$^{-1.}$

Thorium

For thorium the major pool is the sediment. The sediment comprises 90% of the pool in the whole basin, followed by particulate matter (4%), microphytobenthos (4%) and the dissolved pool (1%). All other pools contain less than 1% of the total thorium inventory in the marine model area in Laxemar-Simpevarp.

The major flux of thorium is the advective flux; the model indicates a net advective outflux in the basin (5 tonnes year^{-1}). Burial is very small in comparison with the advective fluxes, see Figure 6-48.

Uranium

For uranium the dissolved pool in the water is the dominant pool (67%). The particulate pool comprises 31% of the pool in the whole basin, followed by sediment (1%). All other pools contain less than 1% of the total thorium inventory in the marine model area in Laxemar-Simpevarp.

The major flux of uranium is the advective flux; the model indicates large net advective in flux in the basin (28 tonnes year^{-1}). The size of the net in flux is due to small concentration differences at the various sampling sites in the marine area. It will be of great importance to the calculation results since it is connected to the large advective flows in the area. Burial is very small in comparison with the advective fluxes, see Figure 6-49.

Iodine

For iodine the dissolved pool is dominant (86% of total iodine). The producer pool constitutes only around 5%, of the total iodine in the ecosystem. That is the same order of magnitude as the sediment and particulate pools. The consumer pool constitutes 2%, while all other pools contain less than 1% of the total iodine inventory in the marine model area in Laxemar-Simpevarp.

The major flux of iodine is the advective flux; the model indicates a net advective outflux in the basin (3,333 tonnes year-^{1}). Burial is very small in comparison with the advective fluxes, see Figure 6-50.

6.4 Abundance and distribution of carbon and other elements – both sites

This chapter discusses the abundance and distribution of 49 elements in the marine ecosystem in Forsmark and Laxemar-Simpevarp.

The annual average concentrations in all model pools (biotic and abiotic) are presented for the following elements (metalloids: Si, As, Se, metals: Ti, Fe, Zr, V, Co, Al, Hg, Cs, Pb, Cu, Cr, Ni, Mn, Cd, Rb, Mo, Li, Ba, K, Zn, Ca, Na, Mg, lanthanides: Dy, Ce, Pr, Gd, Sm, Yb, Ho, Eu, Er, Lu, Tm, Nd, Tb, non-metals: P, N, C, I, S, F, Br, Cl and the actinides: Th, U). C, N, P and I, Th and U will be specifically presented.

The data presented for Forsmark are based on analyses made in 2005 for the biotic pools /Kumblad and Bradshaw 2008/, sediment /Engdahl 2008/ and data from the site investigations in Forsmark 2002–2006 extracted from SKB's database SICADA (dissolved and particulate phase).

The data presented for Laxemar-Simpevarp are based on analyses in /Engdahl et al. 2006 (deposits and biota), Nilsson 2004, Engdahl 2008 (sediment) and data from the site investigations in 2003–2008, extracted from SKB's database SICADA (dissolved and particulate phase)/.

6.4.1 Distribution of elements in all model pools – Forsmark

The elemental composition of all pools (biota, dissolved in water, particulate and sediment (top 10 cm), for the whole marine area is presented in Figure 6-51. Table 6-5 shows the elemental composition in figures for the whole marine area and for one separate basin, Basin 134. The most abundant elements are carbon and the major constituents such as Cl, Na, Mg, S. The major constituents are present to a large extent in the dissolved phase and will therefore be very abundant due to the large water volume. Cl is the most abundant element in the marine ecosystem. On average the total Cl content in all pools constitutes 31 kg m^{-2}. The rest of the elements are minor constituents contributing less than 1% of the total weight.

The whole model area in Forsmark is compared with one separate basin, Basin 134. Basin 134 is rather small and shallow which implies rather large differences in abundance of the major sea water constituents per square metre between the whole area and the basin. The elemental pools in Basin 134 are therefore presented together with the pools of the whole area in Table 6-5. There was a lot more carbon per m^2 in Basin 134, although the nitrogen and phosphorus pools are of the same size per m^2.

Only the elements Mn, P, N, C, I, Co, Ni, Th, Cu, Fe and Ca have biotic pools larger than 1% (by weight), while 99% of all other elements are distributed in the abiotic pools considered (sediment, particulate matter and dissolved), Figure 6-52. However, some analyses of some elements are missing for some biotic pools. Seals and birds are not included, only data for C, N and P were available for benthic bacteria and bacterioplankton, data for elemental composition of C, F and Br are missing for macrophytes and benthic detrivores, and since no biotic pools in Forsmark were analyzed with regard to uranium (U) data for biota in Laxemar-Simpevarp were used.

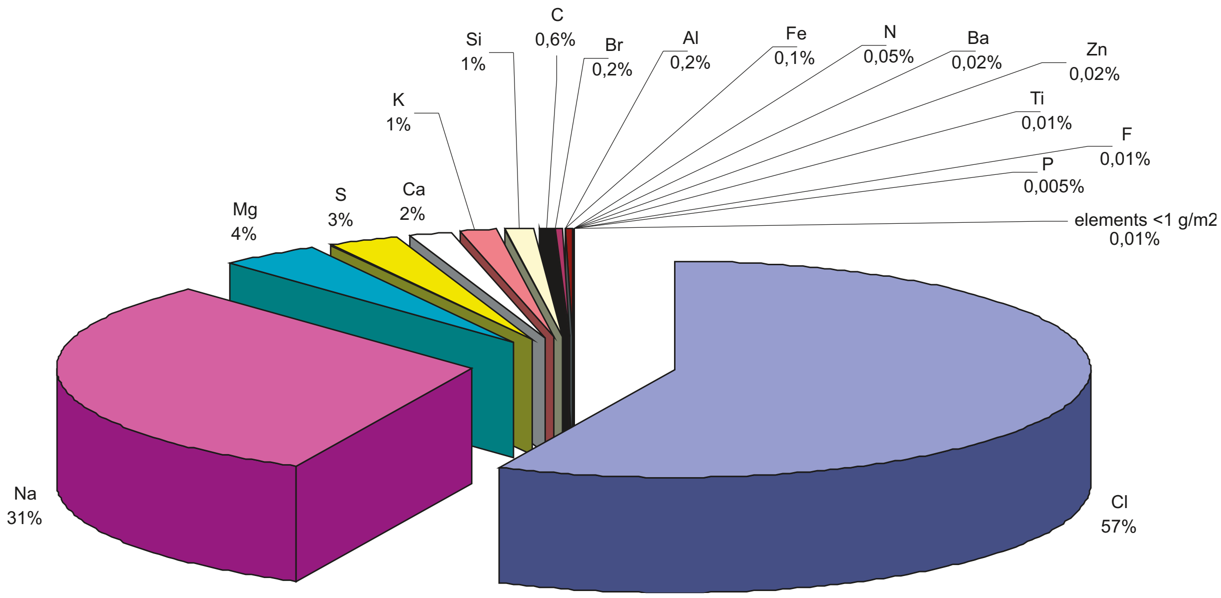


Figure 6-51. *Elemental abundance in all pools the marine model area in Forsmark, in weight percent of investigated elements and in order of magnitude. Note that the elements of water (hydrogen and oxgen) is not included.*

Table 6-5. Elemental abundance in total mass (g) and per m² in all pools in the whole marine model area considered in Forsmark and specifically for Basin 134. C, N, P are presented first, followed by the rest of the elements, in order of magnitude in the whole marine area in Forsmark (all basins). Elements described in further detail below are highlighted in bold text.

Element	All basins g m^{-2}	tonnes	Basin 134 g m^{-2}	tonnes
C	**341**	**83,966**	**6,135**	**3,598**
N	**25**	**6,128**	**32**	**19**
P	**2**	**477**	**3**	**2**
Cl	30,806	7,589,019	4,424	2,594
Na	16,809	4,140,988	2,431	1,425
Mg	2,041	502,880	293	172
S	1,461	359,825	246	144
Ca	945	232,793	164	96
K	657	161,795	132	78
Si	410	101,037	582	341
Br	103	25,396	15	9
Al	70	17,306	99	58
Fe	44	10,763	69	40
Ba	11	2,809	1	0
Zn	9	2,100	1	0
F	4	1,097	0.7	0.4
Ti	3	795	5	3
Mn	1	193	1	1
Rb	0	87	0.2	0.1
Zr	0	74	0.4	0.3
Li	0	83	0	0.1
I	**0.2**	**39**	**0.1**	**0.0**
As	0.2	46	0.0	0.0
Pb	0.1	22	0.1	0.1
V	0.1	21	0.1	0.1
Cr	0.1	25	0.1	0.1
Cu	0.1	23	0.1	0.1
Ni	0.1	15	0.1	0.04
Ce	0.09	23	0.1	0.08
Nd	0.05	13	0.1	0.04
Mo	0.03	8	0.01	0.01
U	**0.02**	**6**	**0.02**	**0.01**
Co	0.01	3	0.02	0.01
Cs	0.01	2	0.01	0.01
Th	**0.01**	**3**	**0.0**	**0.01**
Cd	0.01	2	0.01	0.00
Pr	0.01	3	0.02	0.01
Sm	0.01	2	0.01	0.007
Gd	0.01	2	0.01	0.01
Dy	0.005	1	0.01	0.00
Er	0.004	1	0.005	0.003
Yb	0.003	0.8	0.005	0.003
Se	0.003	1	0.002	0.001
Tb	0.002	0.4	0.002	0.001
Hg	0.001	0.1	0.001	0.0004
Ho	0.001	0.3	0.002	0.001
Lu	0.0006	0.1	0.001	0.0005
Tm	0.0006	0.1	0.001	0.0004
Eu	0.002	0.4	0.002	0.001

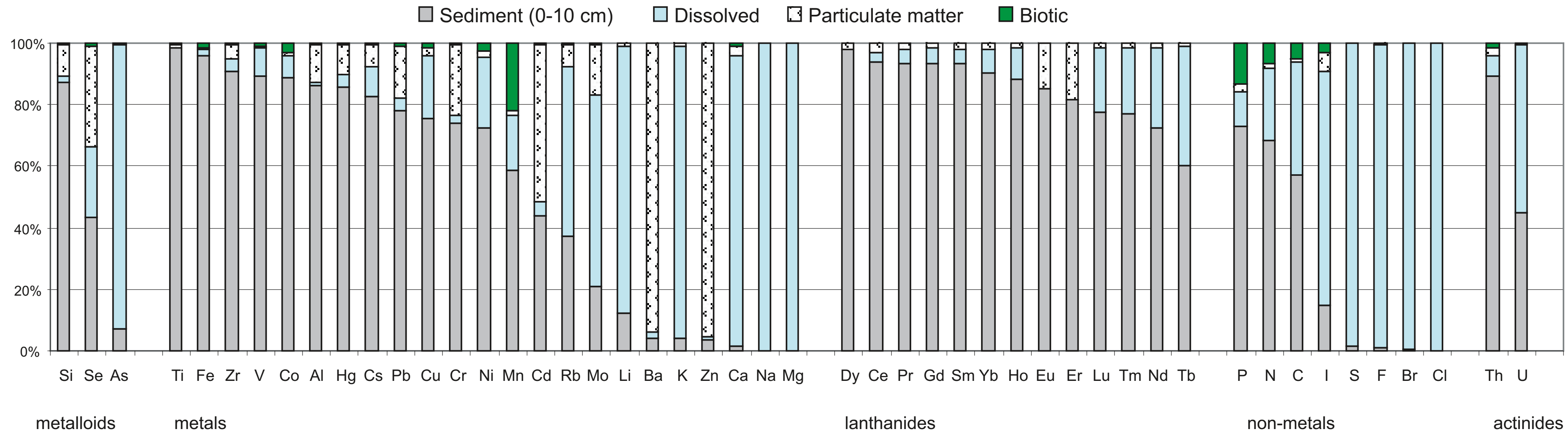


Figure 6-52. *Elemental distribution in percent of total abundance, in biotic and abiotic ecosystem pools in Forsmark model area.*

6.4.2 Distribution of elements in abiotic pools – Forsmark

In general the abundance of various elements in abiotic pools will reflect the composition of the geology at the site, and the expected abundance in order of size in this region of the Baltic is in fairly good agreement with the results from Forsmark /Pettersson and Strömberg 2007/. The ten most abundant elements in sediment in Forsmark in order of size in the three abiotic pools are: Si > C > Al > Fe > K > S > N > Ca > Cl > Ti > P; in the particulate pool: Si > Ca > Na > Al > Zn > K > C > Mg > S > N; and in the dissolved pool: Cl > Na > Mg > S > Ca > K > C > Br > Si > N.

Cd, Ba and Zn are the only elements distributed to the greatest extent in the particulate pool (> 50% of total abundance). More than 50% of the metals Rb, Mo, Li, Ba, K, Zn, Ca, Na, and Mg and the non-metals I, S, F, Br, Cl and As occur in the dissolved pool. For the rest of the elements the sediments are the major abiotic pool, Figure 6-53.

6.4.3 Distribution of elements in biotic pools – Forsmark

The principal chemical constituents that make up the soft tissues of all organisms are: oxygen, hydrogen, carbon, nitrogen and phosphorus (oxygen and hydrogen have not been analyzed in this study).

In the biotic pools, the dominant pool for the majority of elements is producers and especially microphytes. This distribution pattern within the producers could be attributable to some overestimation of microphyte biomass, since the sampling technique does not allow a distinction between microphytes and benthic bacteria, and there may also have been contamination of theses samples by sediment. All lanthanides have a similar distribution pattern, and benthic fauna is the dominant pool. Se, Ca, N and P are distributed to the greatest extent in consumers, see Figure 6-54. Organisms that use elements more specifically for certain purposes, such as Ca for skeletons, comprise a large pool in consumers. Data on birds and seals were only available for carbon, so other pools are underestimated.

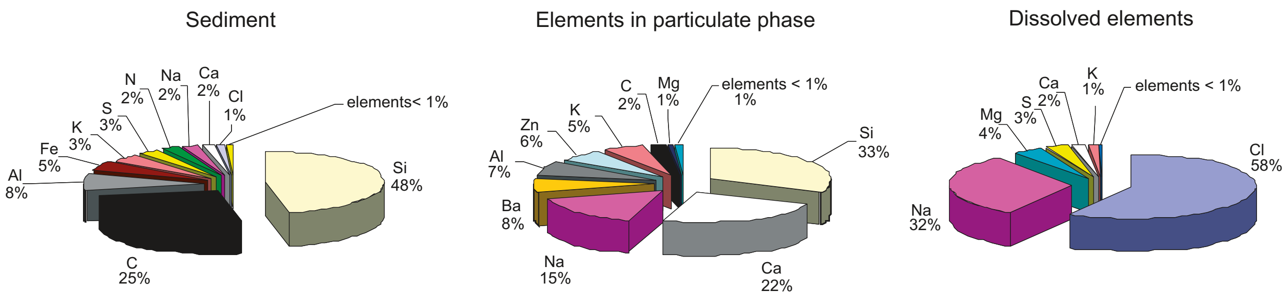


__Figure 6-53.__ Elemental distribution in percent of total abundance in the abiotic pools of the marine ecosystem in the Forsmark marine model area. Note that the elements of water (hydrogen and oxygen) is not included.

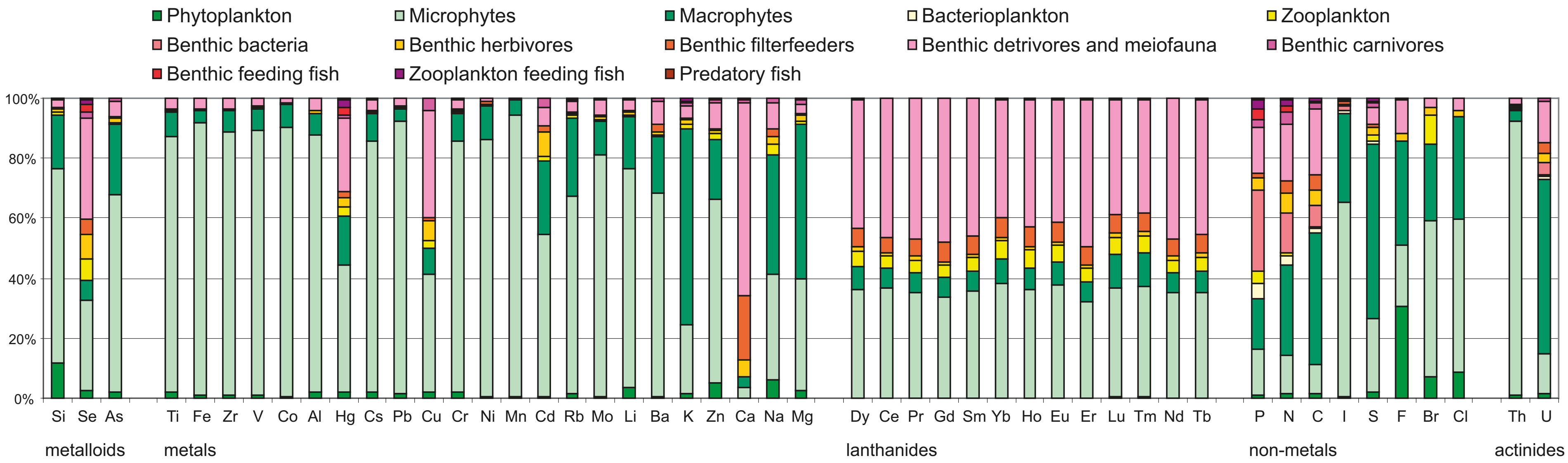


Figure 6-54. *Elemental distribution in percent of total abundance in biotic pools in the marine ecosystem in the model area in Forsmark.*

6.4.4 Distribution of elements in all model pools – Laxemar-Simpevarp

The elemental composition of all pools (biota, dissolved in water, particulate and sediment (top 10 cm)), for the whole marine area is presented in Figure 6-55. Table 6-6 shows the elemental composition in figures for the whole marine area and for one separate basin, Basin 508. Basin 508 is compared with the whole marine basin in Laxemar-Simpevarp, since data from this basin are abundant and to illustrate the variation within the whole marine area. The major constituents such as Cl, Na, Mg, S etc are present to a great extent in the dissolved phase and will therefore be very abundant due to the large water volume. Cl is the most abundant element in the marine ecosystem. On average, the total Cl content in all pools is 32 kg m^{-2}. In general, minor constituents are those contributing less than 1% of the total mass.

The distribution pattern of all elements in the biotic pools – sediment, dissolved phase and particulate matter – is shown in Figure 6-56. Just over 50% of the analyzed elements have a distribution with more than 50% in the sediments. The metalloids and the non-metals are more heterogeneously distributed in the pools.

6.4.5 Distribution of elements in abiotic pools – Laxemar-Simpevarp

The ten most abundant elements in Laxemar-Simpevarp in order of size in the three abiotic pools are in sediment: Si > C > Cl > S > Fe > Al > Na > N > K > Ca; in the particulate pool: Si < Ca > Na > Ba > Al > Zn > K > C > Mg > S; and in the dissolved pool: Cl > Na > Mg > Ca > K > C > Br > Si > N > F.

In the abiotic pools, Si dominates the particulate and sediment pools and Cl the dissolved pool, see Figure 6-57.

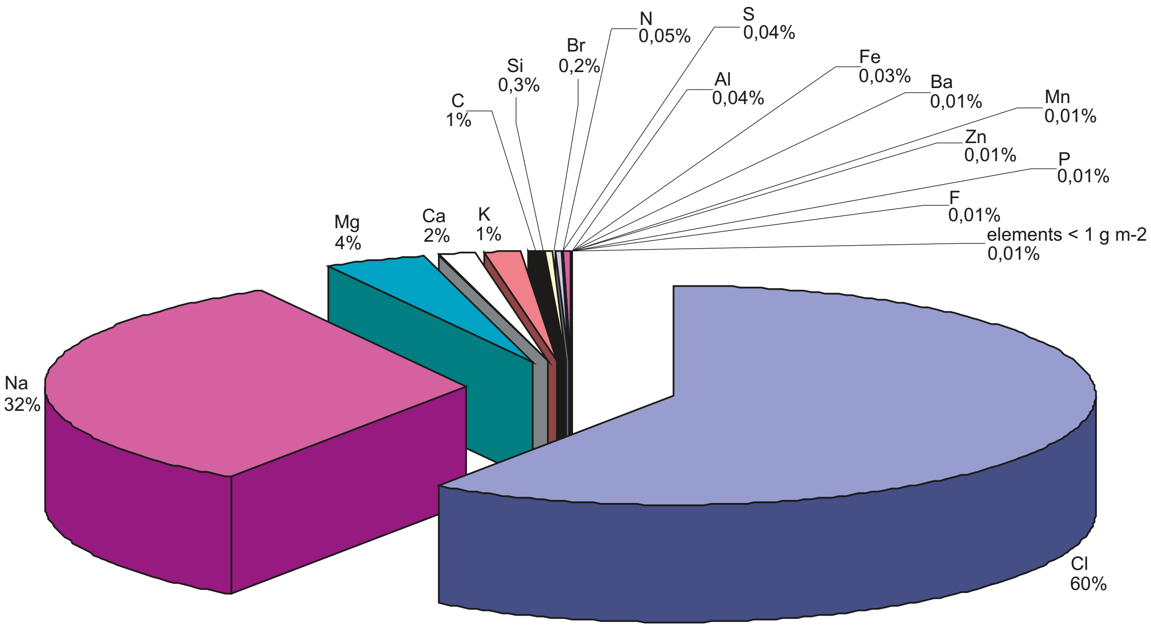


Figure 6-55. Elemental abundance in all pools the marine model area in Laxemar-Simpevarp, in weight-percent per m² and in order of magnitude. Note that the elements of water (hydrogen and oxygen) is not included.

Table 6-6. Elemental abundance in total mass (tonnes) and per m² (g m^{-2}) in all pools in the marine model area considered in Laxemar-Simpevarp area and specifically for Basin 508. C, N, P are presented first. The other elements are presented in order of magnitude in the whole marine area in Forsmark (all basins). Elements presented specifically are highlighted with bold text.

Element	All basins g m^{-2}	tonnes	Basin 508 g m^{-2}	tonnes
C	**31,845**	**43,256**	**1**	**118**
N	**27**	**3,172**	**1**	**72**
P	**4**	**428**	**0.1**	**12**
Cl	31,845	3,782,910	1	177
Na	17,262	2,050,584	1	110
Mg	2,074	246,345	0.04	4
Ca	883	104,939	1	62
K	671	79,666	0.4	44
Si	146	17,361	7	799
Br	121	14,374	0.0	1
S	22	2,595	1	128
Al	20	2,382	1	106
Fe	17	1,974	1	104
Ba	7	792	0.05	6
Zn	5	595	0.04	5
F	4	518	0.0001	0.0
Mn	4	517	0.01	1
Er	0.6	71	0.0001	0.02
Ti	0.6	66	0.03	4
Ho	0.6	66	0.00005	0.006
Dy	0.5	65	0.0002	0.03
Li	0.3	36	0.001	0.1
Rb	0.2	29	0.001	0.1
I	**0.2**	**20**	**0.001**	**0.1**
Ce	0.08	9	0.004	0.5
Nd	0.05	6	0.002	0.3
Cu	0.05	5	0.002	0.2
Zr	0.04	5	0.002	0.2
Cr	0.03	4	0.001	0.1
Ni	0.03	4	0.001	0.1
Yb	0.03	4	0.002	0.2
Pb	0.03	3	0.001	0.1
V	0.02	3	0.001	0.1
Mo	0.02	2	0.00003	0.003
As	0.01	2	0.0002	0.03
Pr	0.01	1	0.0006	0.07
Co	0.008	1	0.0003	0.04
Sm	0.006	1	0.0004	0.04
U	**0.006**	**1**	**0.0003**	**0.04**
Gd	0.005	1	0.0003	0.04
Th	**0.005**	**1**	**0.0002**	**0.03**
Cd	0.004	0	0.0001	0.01
Cs	0.002	0.3	0.0001	0.01
Se	0.002	0.2	0.00004	0.005
Tb	0.001	0.2	0.00004	0.005
Eu	0.001	0.2	0.0001	0.007
Lu	0.0005	0.1	0.00002	0.003
Tm	0.0005	0.1	0.00002	0.003
Hg	0.00009	0.01	0.000002	0.0003

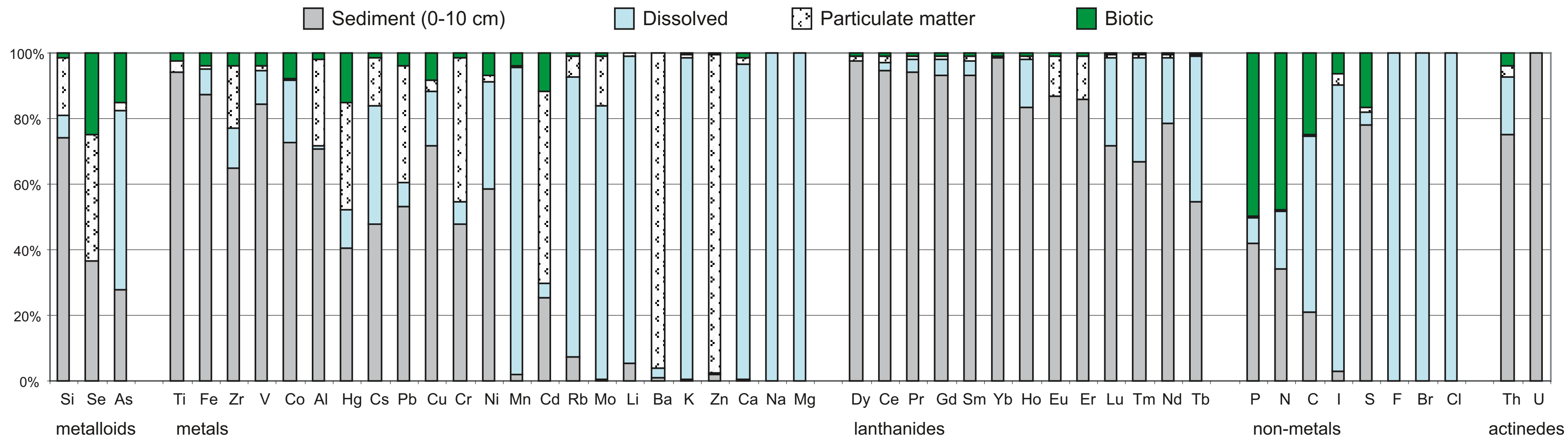


Figure 6-56. *Elemental distribution in percent of total abundance, in biotic and abiotic ecosystem pools in Laxemar-Simpevarp marine model area.*

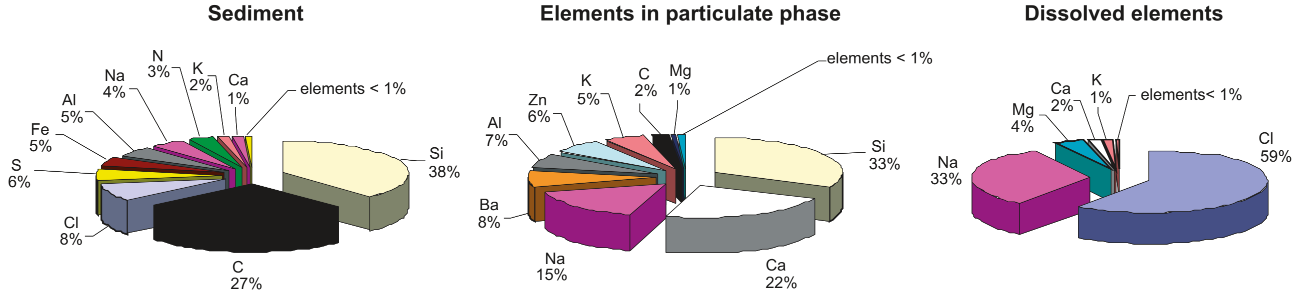


Figure 6-57. *Elemental distribution in percent of total abundance in the abiotic pools in the marine ecosystem in the Laxemar-Simpevarp marine model area.*

6.4.6 Distribution of elements in biotic pools – Laxemar-Simpevarp

In the biotic pools, the dominant pool for the majority of elements is producers and especially microphytes. This distribution pattern within the producers could be attributable to some overestimation of microphyte biomass, since the sampling technique did not allow distinction between microphytes and benthic bacteria. The lanthanides exhibit a very similar distribution pattern in Laxemar-Simpevarp. Se, Ca, N and P are mainly distributed in consumers, see Figure 6-58. Data on birds and seals were only available for carbon, so other pools are underestimated.

6.5 Marine basins – both sites

In this section, ecosystem food webs, mass balances with pools and fluxes are specifically presented for separate basins in Forsmark and Laxemar-Simpevarp. In Forsmark, Basin 134 is presented graphically and numerically together with four additional basins (116, 120, 121 and 126) in Table 6-7. In Laxemar-Simpevarp, Basin 508 is presented graphically and numerically together with four additional basins (520, 502, 504 and 506) in Table 6-8. Detailed data tables are presented for all basins in Appendix 8 and 9. The basins are selected because they fulfil two criteria: (i) the density of site-specific in data is high and (ii) they are located where exit points for radionuclides were located in a preliminary safety assessment, see /SKB 2006c/.

Food webs for C, N and P and mass balances, pools and fluxes for C, N ,P , I, Th and U and will be presented for the basins. Pools and fluxes will also be presented for some other elements representing general elemental groups in the periodic table.

6.5.1 Basins – Forsmark

In Figure 6-59, the selected basins are marked and the adjacent catchment areas are shown.

In Table 6-7, basic physical characteristics for basins 116, 120, 121, 126 and 134 are presented.

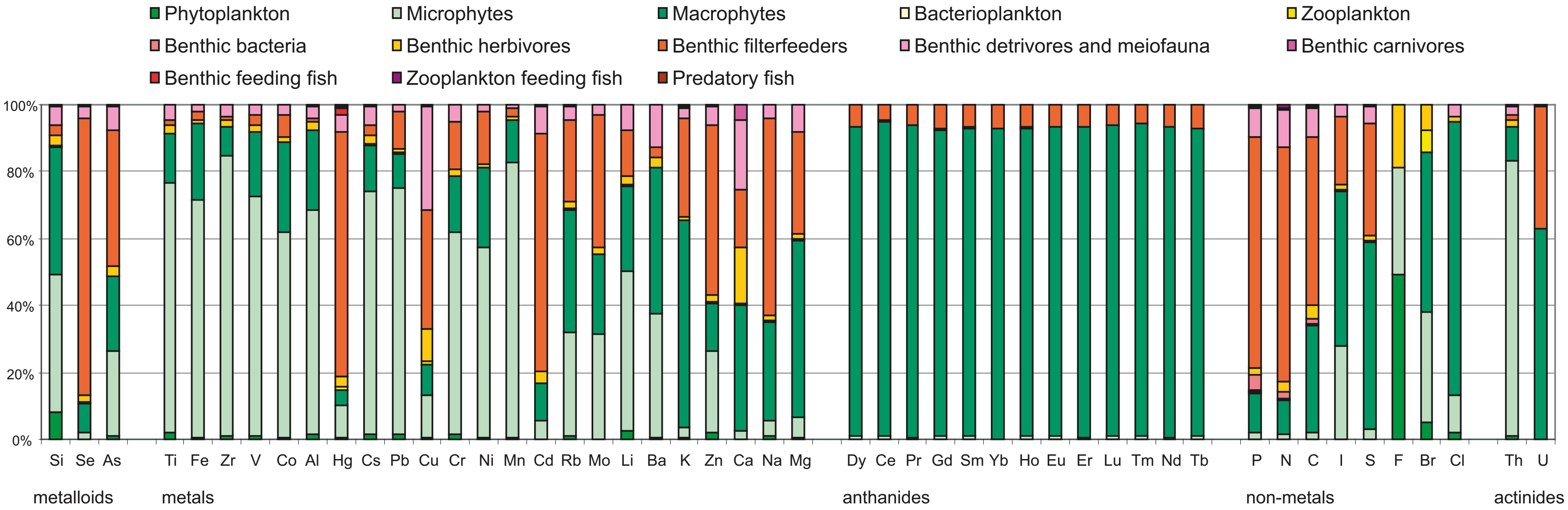


Figure 6-58. Elemental distribution in biotic ecosystem pools in the marine model area in the Laxemar-Simpevarp area.

Table 6-7. Basic characteristics for five basins in Forsmark marine model area.

	Basin 116	Basin 126	Basin 134	Basin 121	Basin 120
Marine basin area (m^2)	13,534,000	5,440,400	586,400	3,692,400	729,200
Mean depth (m)	9	7	2	6	2
Max. depth (m)	19	16	6	13	12
Volume (m^3)	128,153,311	40,604,153	1,052,611	20,313,960	1,815,453
Total catchment area (m^2)	14,101,600	7,232,000	1,957,600	13,983,600	10,336,400
Runoff (m^3 $year^{-1}$)	19,222,997	6,090,623	157,892	3,047,094	272,318
Advective outflow (m^3)	52,142,360,552	22,217,768,523	1,017,417	8,073,976,047	26,125,590
Advective inflow (m^3)	52,082,246,480	22,194,479,015	862,217	8,058,725,774	24,685,617

Table 6-8. Pools and fluxes of carbon, mass balances, in total tonnes per year and basin for five basins in the Forsmark marine model area.

	Tonnes C $basin^{-1}y^{-1}$ Basin 116	Basin 126	Basin 134	Basin 121	Basin 120
Fluxes					
Runoff	1	4	6	55	33
Advective influx	165,877	75,385	3	27,095	89
Net Primary Production	1,286	494	71	388	71
In by deposition	17	7	1	5	1
Advective outflux	166,951	82,509	4	29,265	95
Out to air, respiration	908	380	44	262	50
Accumulation by burial	1	1	4	12	6
Pools					
Phytoplankton	2	1	0.02	0.2	0.03
Microphytes	32	14	2	11	2
Macrophytes	150	45	13	56	17
Total pool producers	**183**	**59**	**15**	**67**	**19**
Bacterioplankton	3	1	0.03	1	0.05
Zooplankton	1	0.2	0.01	0.1	0.01
Benthic bacteria	11	9	2	9	2
Benthic herbivores	18	6	0.5	4	1
Benthic filter feeders	20	7	0.4	4	1
Benthic detrivores	52	23	4	16	4
Benthic carnivores	4	2	0.1	1	0.1
Benthic feeding fish	3	1	0.1	1	0.4
Zooplankton feeding fish	1	1	0.1	1	0.1
Piscivorous fish	1	0.4	0.02	0.4	0.1
Birds	0.1	0.04	0.01	0.05	0.02
Seals	0.2	0.1	0.01	0.1	0.01
Total pool consumers	114	51	7	37	8
Top 10 cm regolith pool	1,718	1,012	184	609	38
Particulate pool	27	11	1	6	1
Dissolved pool	1,134	140	6	74	23

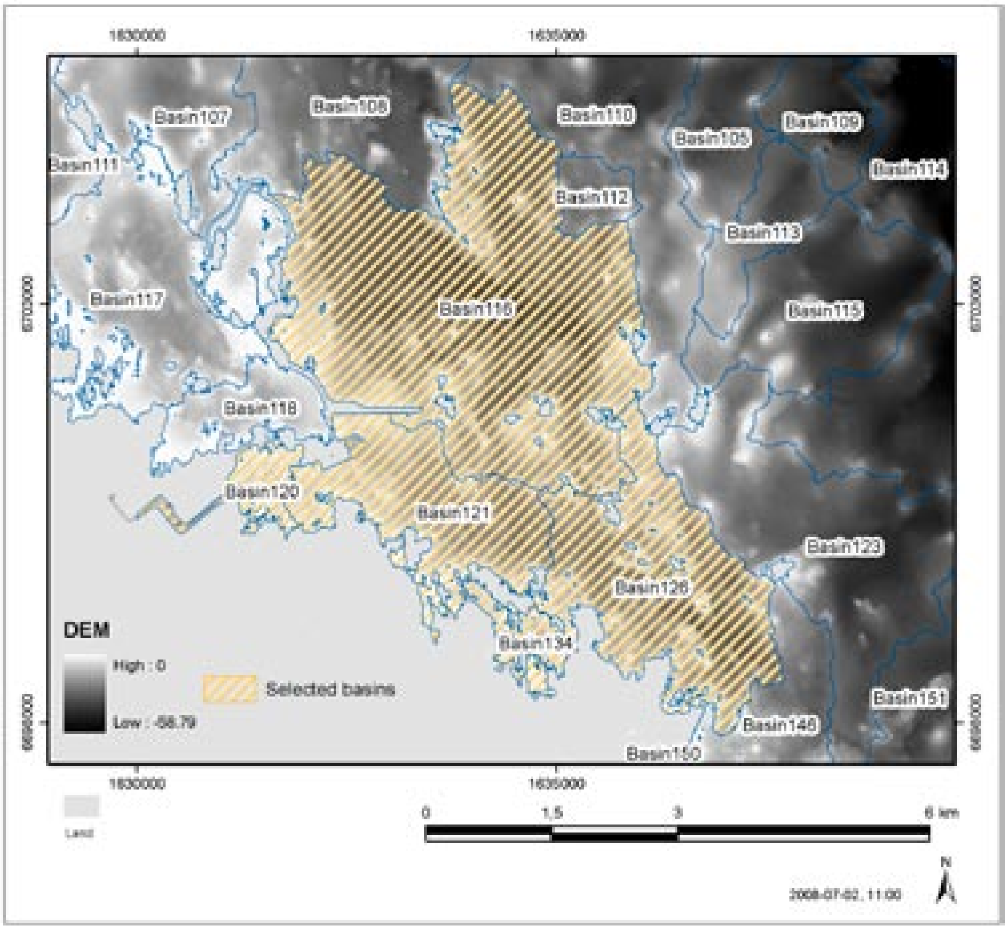


Figure 6-59. Basins 116,120,121, 126 and 134 presented in this chapter.

Basin specific food webs – Carbon, nitrogen and phosphorus

Food webs illustrating the C, N, P pools and fluxes in the marine ecosystem in Basin 134 are presented in Figure 6-60, 6-61 and 6-62. Food webs for the four other basins are presented in Appendix 8.

The pools and fluxes of carbon in the marine ecosystem food web in Basin 134 are is similar to those for the average food web for the whole area, although there are some differences. The largest fluxes are the biotic fluxes, with NPP being the largest followed by consumption by benthic bacteria and of herbivores by benthic carnivores. The abiotic fluxes are generally smaller than the biotic fluxes in Basin 134. Burial is larger than the small net advective outflux and larger than burial on average for the whole marine area. In comparison with the whole marine area, macrophytes account for a larger portion of the NPP flux, consumption by birds is larger and consumption by herbivores and zooplankton is smaller.

The pools and fluxes of nitrogen in the marine ecosystem food web in Basin 134 are somewhat different than the average nitrogen pools and fluxes in the whole marine area in Forsmark. In comparison with the other pools in Basin 134, macrophytes, DIN and PON are larger than they are on average in the whole marine area. There is a positive net advective influx of nitrogen into the basin, in contrast to the average net outflux in the whole marine area. Burial is the largest abiotic flux, although it is much smaller than the accumulation of nitrogen in primary producers during photosynthesis, which is the largest flux of nitrogen. The excess term is also large for nitrogen in Basin 134, especially from benthic fauna such as carnivores and detrivores. This is also true of the average food web for the whole basin. As for fluxes of carbon, the flux of nitrogen due to consumption by birds is larger in this basin.

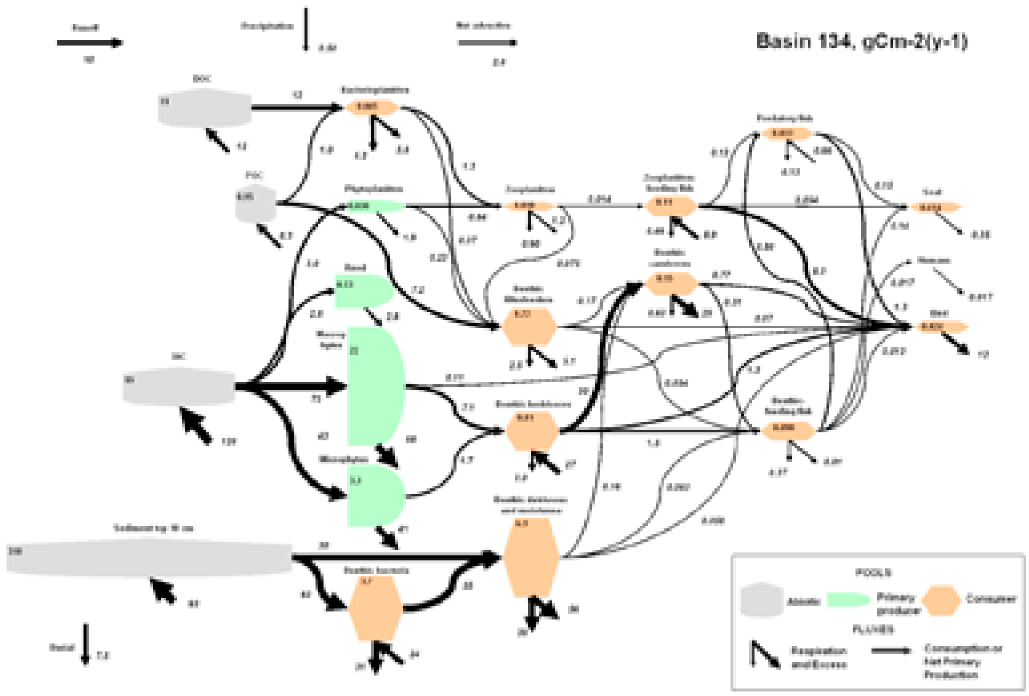


Figure 6-60. *Food web based on pools and fluxes of carbon in Basin 134. Boxes and arrows designate relative size of pools and fluxes.*

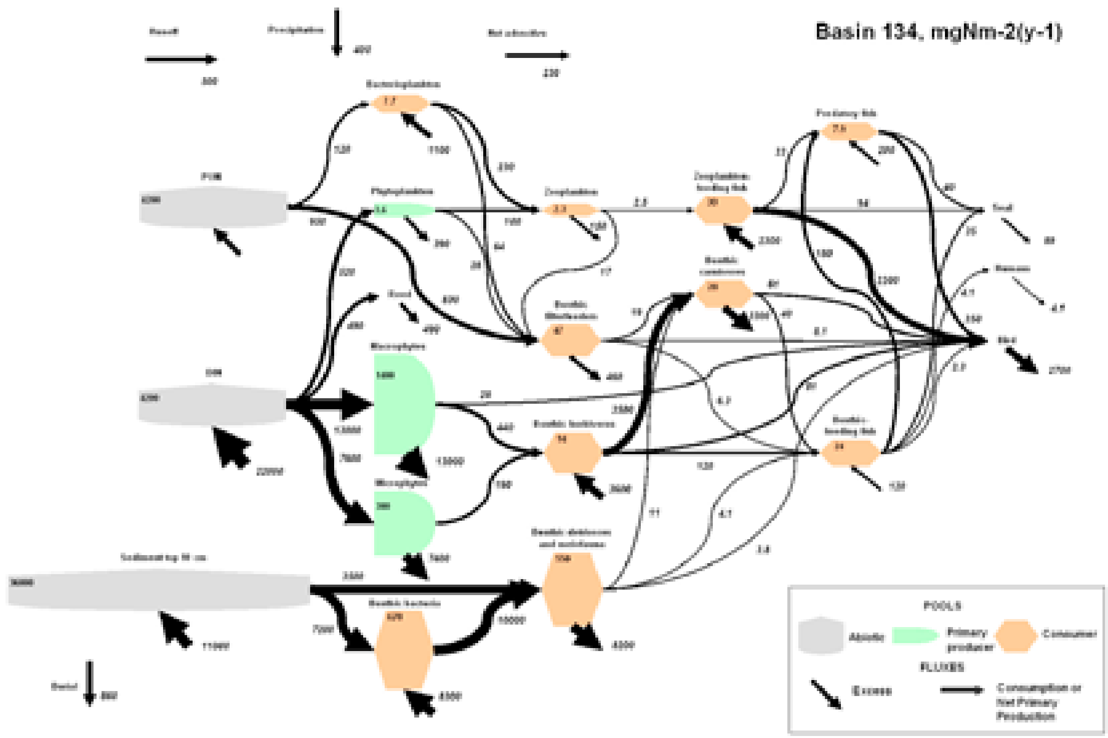


Figure 6-61. *Pools and fluxes of nitrogen in Basin 134. Boxes and arrows denote relative size of pools and fluxes.*

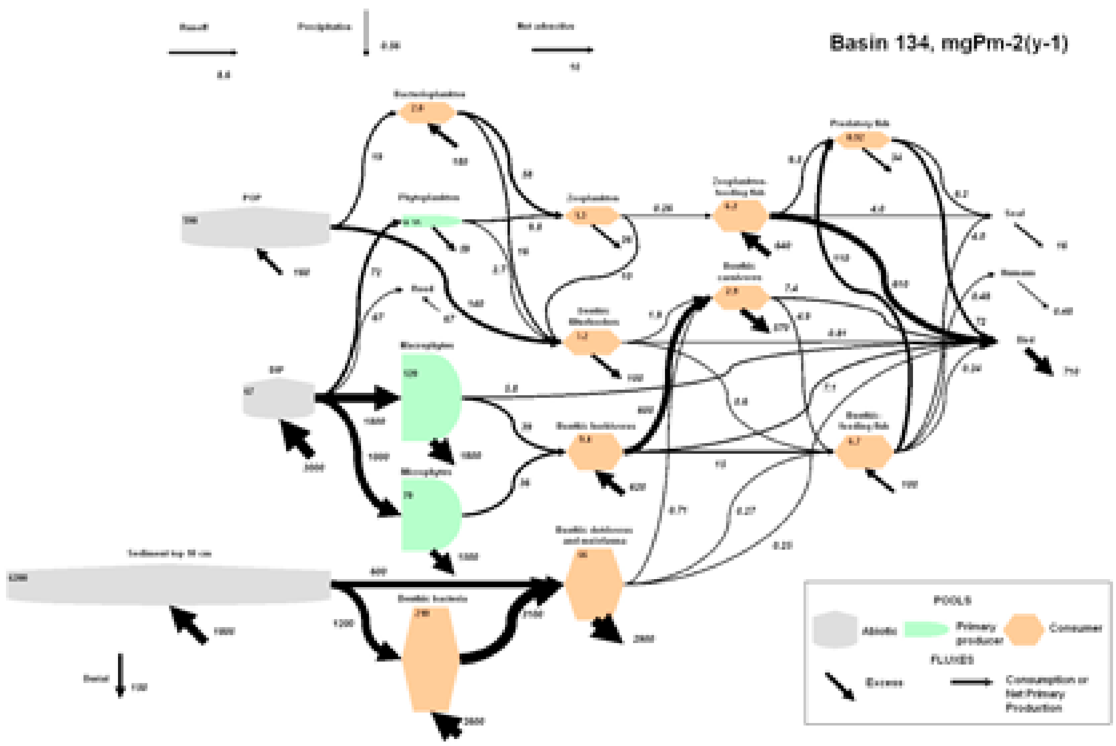


Figure 6-62. *Pools and fluxes of phosphorous in Basin 134. Boxes and arrows denote relative size of pools and fluxes.*

The pools and fluxes of phosphorus in the marine ecosystem food web in Basin 134 are similar to those in the food web of nitrogen in Basin 134, but with some differences. In Basin 134, the DIP and sediment pools are the largest, larger in relation to the other pools in this basin than in the whole marine area. The phosphorus pools in macrophytes, microphytes and benthic bacteria are much larger than on average in the whole basin, and the phytoplankton, bacterioplankton and zooplankton pools in the pelagic organisms are much smaller. As for nitrogen and carbon, the flux due to consumption by birds is larger than on average in the marine area.

Basin-specific mass balances – Carbon, nitrogen and phosphorus

Pools and fluxes of carbon, nitrogen and phosphorus in Basin 134 are shown in Figures 6-63, 6-64 and 6-65 and Tables 6-8, 6-9 and 6-10.

Carbon

The carbon pools in the fives basins are dominated by sediment in three of five basins (126, 134 and 121), as in the whole marine basin. In Basins 116 and 120 the DIC and DOC pools are larger in relation to the sediment; see Table 6-8 and Appendix 8. The sediment pool is followed by the DIC pool (5–32%), the macrophyte pool (3–17%) , the DOC pool (3–12%), benthic detrivores and meiofauna (2–6%) and microphytes (1–2%). All other pools contain less than 1% of the total carbon inventory in the five basins.

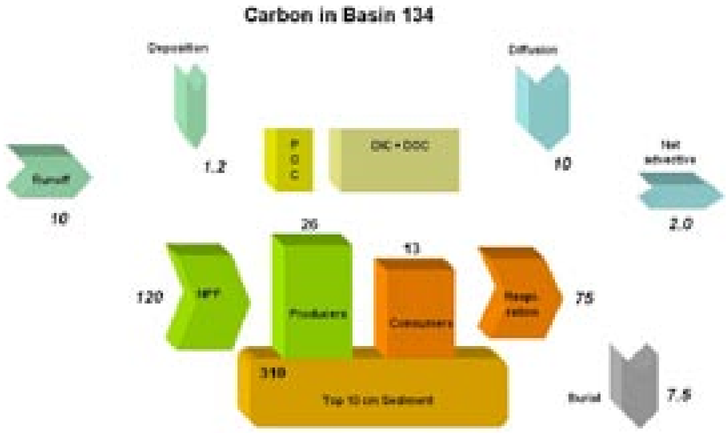


Figure 6-63. *Schematic overview of pools and fluxes, mass balances, of carbon on average per m*^{2} *in basin 134.*

Figure 6-64. *Schematic overview of pools and fluxes of nitrogen on average per m*$^{-2}$ *in Basin 134.*

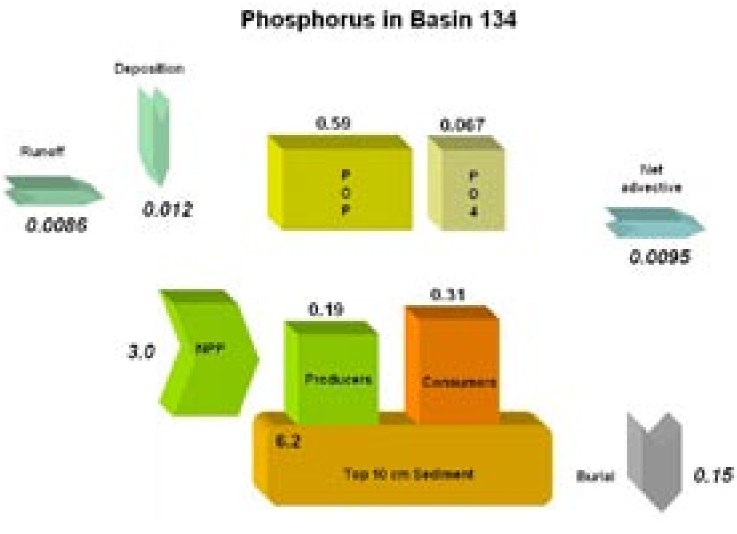


Figure 6-65. *Schematic overview of pools and fluxes of phosphorus on average per m*^{2} *in Basin 134.*

Table 6-9. Pools and fluxes of nitrogen (total for the whole basin in kg) for five basins in the Forsmark marine model area.

	Kg N basin^{-1}y^{-1} Basin 116	Basin 126	Basin 134	Basin 121	Basin 120
Fluxes					
Runoff	0.0	574	2,348	13,742	191,951
Advective influx	23,579,843	9,525,289	233	3,497,284	6,665
Net Primary Production	226,501	87,042	12,453	68,324	74,610
In by deposition	4,872	1,959	211	1,329	263
Advective outflux	24,600,649	7,776,219	366	2,179,974	12,326
Accumulation by burial	100	86	503	1,324	662
Pools					
Phytoplankton	190	65	2	29	4
Microphytes	3,727	1,617	224	1,250	212
Macrophytes	9,312	2,777	812	3,491	1,064
Total pool producers	**13,229**	**4,459**	**1,038**	**4,770**	**1,280**
Bacterioplankton	545	173	5	86	8
Zooplankton	119	41	1	18	3
Benthic bacteria	1,988	1,705	395	1,614	275
benthic herbivores	2,059	720	55	429	92
Benthic filter feeders	1,298	451	28	282	50
Benthic detrivores	4,123	1,836	320	1,280	343
Benthic carnivores	810	339	16	222	23
Benthic feeding fish	667	299	14	299	94
Zooplankton feeding fish	347	211	18	162	27
Piscivorous fish	199	99	5	100	23
Birds	no,data	no data	no data	no data	no data
Seals	no data	no data	no data	no data	no data
Total pool consumers	12,157	5,875	857	4,492	936
Top 10 cm regolith pool	197,108	116,124	21,124	69,919	4,408
Particulate pool	1,760	1,592	2,480	59	832
Dissolved pool	3,907	3,535	2,480	71	416

Table 6-10. Pools and fluxes of phosphorus (total for the whole basin in kg) for five basins in the Forsmark marine model area.

	Kg P basin^{-1}y^{-1}				
	Basin 116	**Basin 126**	**Basin 134**	**Basin 121**	**Basin 120**
Fluxes					
Runoff	1	4	5	41	23
Advective influx	864,928	351,836	9	129,872	269
Net Primary Production	31,346	12,046	1,723	9,456	1,722
In by deposition	164	66	7	45	9
Advective outflux	896,032	305,336	15	87,833	449
Accumulation by burial	17	15	86	227	113
Pools					
Phytoplankton	18	6	0	3	0
Microphytes	687	298	41	230	39
Macrophytes	818	244	71	307	94
Emerg macrophytes	no data	no data	no data	no data	no data
Total pool producers	1,524	548	113	540	133
Bacterioplankton	138	44	1	22	2
Zooplankton	70	24	1	11	2
Benthic bacteria	613	526	122	498	85
Benthic herbivores	205	72	5	43	9
Benthic filter feeders	87	30	2	19	3
Benthic detrivores	498	222	39	155	41
Benthic carnivores	85	35	2	23	2
Benthic feeding fish	189	85	4	85	27
Zooplankton feeding fish	71	43	4	33	6
Piscivorous fish	23	12	1	12	3
Birds	no,data	no data	no data	no data	no data
Seals	no data	no data	no data	no data	no data
Total pool consumers	1,980	1,092	180	899	179
Top 10 cm regolith pool	33,718	19,864	3,613	11,960	754
Particulate pool	290	263	345	10	118
Dissolved pool	58	53	40	2	29

The fluxes to and from the basins are clearly dominated by advective flux in the three basins 116, 121 and 126 (see Table 6-8). The model also indicates a net outflux of carbon in these basins. NPP is the largest flux in Basin 134, and NPP is of the same order of magnitude as the advective flux in Basin 120. There is also a small advective influx of carbon in these basins. Runoff makes a very small carbon contribution to all basins except for Basin 120, where it contributes about 80% of the net influx of carbon. Burial is small relative to other fluxes. It is negligible in Basins 116, 121, and 126, but a bit larger in Basins 121, 120 and 134, approximately 10% of the outflux from biota (i.e. respiration). Considering all fluxes in and out, according to mass balance calculations (runoff, deposition, advection, diffusion, NPP, respiration and burial), there is a total net influx of carbon in 2 of the 5 basins (Basins 134 and 120). In the others there is a net outflux of carbon.

Nitrogen

The nitrogen pools in the fives basins are dominated by sediment, as in the whole marine basin. Sediment comprises between 56 and 88% of the nitrogen pools in the five basins, and similar results are found in all other basins (see Table 6-9 Appendix 9). In most basins the dissolved pool is larger than the particulate pool. In Basin 134 they are of the same magnitude. The largest biotic pool is macrophytes (2–20%), benthic detrivores and meiofauna (1–4%), microphytes (1–4%) and benthic bacteria (1–4%). All other pools contain less than 1% of the total nitrogen inventory in the five basins.

In four of the basins the total pool of producers is larger than the total pool of consumers, although in Basin 126 the consumer pool is slightly larger, Table 6-9.

The fluxes to and from the basins are clearly dominated by advective flux in three of the basins (see Table 6-9) and the model indicates a large net advective influx of nitrogen to all but one basin (Basin 116). Runoff makes the largest nitrogen contribution in Basin 120, while in Basin 134 it is incorporation of nitrogen during photosynthesis, see Figure 6-64 and Table 6-9. Considering all fluxes in the mass balance calculations, there is a positive net influx of carbon in all basins, but Basin 116.

Phosphorus

The phosphorus pools in the fives basins are dominated by sediment. Sediment comprises between 84 and 90% of the phosphorus pools in the five basins, and similar results are found in all other basins (see Table 6-10 and Appendix 9). The sediment pool is followed by the particulate pool in Basins 134 and 120 (8–10%), but for the rest of the basins the abiotic pools contain around or less than 1% of the total phosphorus inventory. The biotic pools are quite large for phosphorus, and the total consumer pool is larger than the producers in all basins, Table 6-10.

The fluxes to and from the basins are clearly dominated by advective flux in the three Basins 116, 121 and 126 (see Table 6-10). In Basins 116 and 121 there is also a net outflux of phosphorus. NPP is the largest flux in Basin 134. There is a small influx of phosphorus in Basins 121 and 126. Runoff makes a very small phosphorus contribution to all basins. Burial is small relative to other fluxes, but in Basins 120 and 134 it is larger in comparison with other fluxes. Considering all fluxes, there is a net outflux of phosphorus in 3 out of 5 basins (116, 134 and 120).

Actinides and Iodine

The fluxes considered are advective flow and burial. The other fluxes were not included due to a lack of data. For some functional groups (benthic bacteria, bacterioplankton, benthic filter feeders, benthic carnivores, birds and seals) no concentration data were available and they are not included in the mass balances, which entails an underestimation of the consumer pool. Some analyses of biota were below the detection limit, and estimated means based on half the detection limit were used to give a rough estimate (estimated mean). The biotic pools for which estimated means of concentrations were used are marked in Table 6-11 to Table 6-13.

Thorium

In four of the five basins, the thorium pools are dominated by sediment (~ 90%). Except in Basin 120, the sediment and the dissolved phase are of the same order of magnitude (50% and 43%, respectively). The particulate pool varies from 0.5 to 3% of the total thorium inventory in the basins. Except for microphytobenthos (2–4%), the biotic pools do not exceed 1% of the total thorium inventory in the basins, see Table 6-11.

In Basins 134 and 121 there is an according to the model net outflux of thorium, considering all fluxes, while in the rest of the basins there is a net influx. Burial is a small flux, but in Basin 134 it is larger than the advective flux and in Basin 120 it is about 25% of the advective flux, see Table 6-11 and Figure 6-66.

Table 6-11. Pools and fluxes of Thorium (in kg) for five basins in the Forsmark marine model area. Pool marked with * denotes reported concentrations below the detection limit, were half of the reported value have been used in the calculations.

	Kg Th basin^{-1}y^{-1} Basin 116	Basin 126	Basin 134	Basin 121	Basin 120
Fluxes					
Advective influx	4,091	1,824	0.1	620	3
In by deposition	0.07	0.03	0.003	0.02	0.004
Advective outflux	4,012	1,710	0.1	821	2
Accumulation by burial	0.1	0.05	0.3	1	0.4
Pools					
Phytoplankton	0.01	0.004	0.0001	0.002	0.0003
Microphytes	3	1	0.2	1	0.2
Macrophytes	0.2	0.05	0.01	0.1	0.02
Emerg macrophytes	No data	No data	No data	No data	No data
Total pool producers	**4**	**1**	**0**	**1**	**0**
Bacterioplankton	No data	No data	No data	No data	No data
Zooplankton	0.001	0.0002	0.00001	0.0001	0.00001
Benthic bacteria	No data	No data	No data	No data	No data
Benthic herbivores	0.02	0.006	0.0005	0.004	0.001
Benthic filter feeders	No data	No data	No data	No data	No data
Benthic detrivores	0.1	0.03	0.004	0.02	0.005
Benthic carnivores	No data	No data	No data	No data	No data
Benthic feeding fish*	0.00003	0.00001	0.000001	0.00001	0.000004
Zooplankton feeding fish*	0.00001	0.00001	0.000001	0.000005	0.000001
Piscivorous fish	0.000006	0.000003	0.0000001	0.000003	0.000001
Birds	No data	No data	No data	No data	No data
Seals	No data	No data	No data	No data	No data
Total pool consumers	**0.08**	**0.03**	**0.005**	**0.02**	**0.01**
Top 10 cm regolith pool	109	64	12	39	2
Particulate pool	3	1	0.1	1	0.1
Dissolved pool	2	2	1	0.1	2

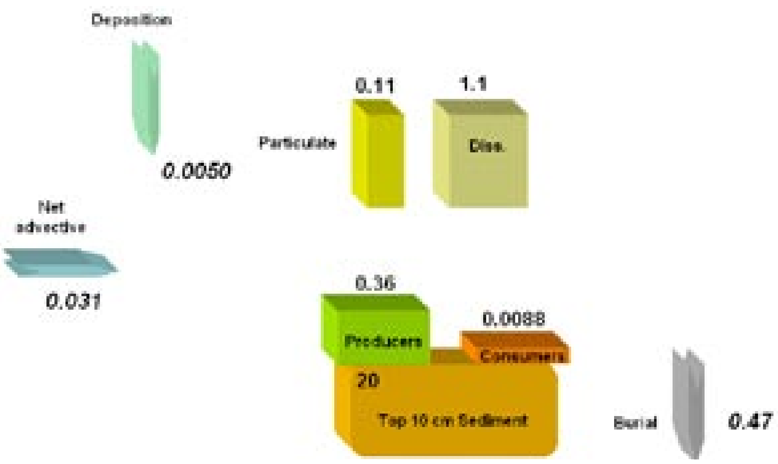


***Figure 6-66.** Schematic overview of pools and fluxes, in mg per m^2, of thorium in Basin 134.*

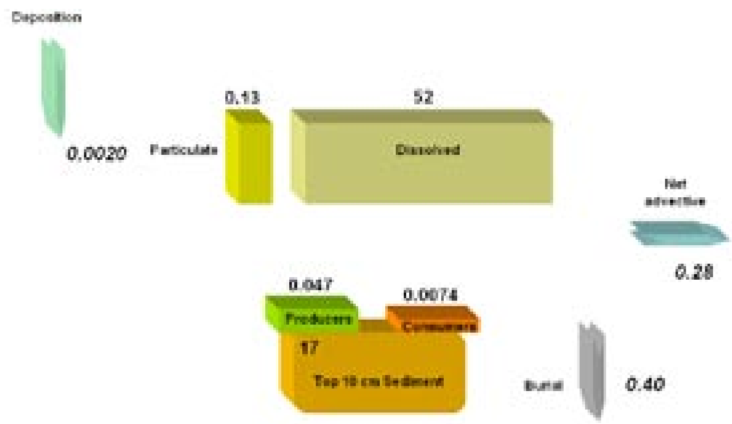


Figure 6-67. *Schematic overview of pools and fluxes of, in mg per m², of uranium in Basin 134.*

Uranium

The uranium pools in three of the five basins (116, 126 and 120) are dominated by sediment (66–96%). In Basins 134 and 120, sediment constitutes 25% and 13%, respectively. In all the basins, the major part of the remaining uranium is distributed in the dissolved pool. The biotic pools are very small even for the primary producers, see Table 6-12. Data for the bitic pools are from Laxemar-Simpevarp, due to lack of data for these groups in Forsmark.

According to the model there is a net outflux of uranium in all but one basin (Basin 121). Burial is a small flux, but in Basin 134 it is of the same order of magnitude as the advective fluxes, see Figure 6-67 and Table 6-12.

Iodine

In four of the five basins, the iodine pools are dominated by the dissolved phase (43–94%), but in Basin 121 the dissolved phase constitutes only 8% and sediment is the major pool (54%). The four other basins have sediment pools varying from 2 to 30%. The particulate pool varies from 1 to 14% of total iodine inventory in the basins. The producer pool is a much larger pool for iodine than the consumer pool. The total pool of consumers constitutes less than 1%, while the total producer pool constitutes 2–23%, see Table 6-13.

According to the model there is a net advective influx of iodine in three of five basins (116, 126 and 120), while for the others there is a net outflux of iodine. Burial is a small flux in all basins, including Basin 134 (see Figure 6-66).

Metalloids

Si and Se are included in the chemical group metalloids, together with As. They have properties of both metals and non-metals. They are generally not distributed similar to each other in the pools of an ecosystem and are therefore presented separately. These metalloids are regarded as recycled elements, i.e. elements that are incorporated into soft tissues or into skeletal material and will be more or less depleted in surface waters and enriched in the deep ocean. Si is also classified as biolimiting together with P and N, while the others can be considered as biointermediate /Bearman 2005/.

Table 6-12. Pools and fluxes of uranium (in kg) for five basins in the Forsmark marine model area. Functional groups marked with an * denotes reported analyses below detection limit, were half the reported concentration was used in the calculations.

	Kg uranium basin^{-1}y^{-1} Basin 116	Basin 126	Basin 134	Basin 121	Basin 120
Fluxes Area (km^2):	**14**	**5.4**	**0. 6**	**3.7**	**0.7**
Advective inflow	51,555	20,866	0.6	8,153	17
In by precipitation	0.03	0.01	0.001	0.01	0.001
Advective outflow	52,755	22,479	0.7	5,432	26
Accumulation by burial	0.05	0.04	0.2	1	0.3
Pools					
Phytoplankton	0.003	0.001	0.00003	0.00044	0.0001
Microphytes	0.06	0.03	0.004	0.02	0.003
Macrophytes	0.3	0.08	0.02	0.1	0.03
Emerg macrophytes	No data	No data	No data	No data	No data
Total pool producers	0.3	0.1	0.03	0.1	0.03
Bacterioplankton	No data	No data	No data	No data	No data
Zooplankton	0.000	0.0002	0.00001	0.0001	0.00001
Benthic bacteria	No data	No data	No data	No data	No data
Benthic herbivores	0.02	0.005	0.0004	0.003	0.001
Benthic filter feeders	No data	No data	No data	No data	No data
Benthic detrivores	0.05	0.02	0.003	0.01	0.004
Benthic carnivores	No data	No data	No data	No data	No data
Benthic feeding fish	0.000005	0.000002	0.0000001	0.000002	0.000001
Zooplankton feeding fish	0.000002	0.000001	0.0000001	0.000001	0.0000002
Piscivorous fish*	0.000002	0.000001	0.00000004	0.000001	0.0000002
Birds	No data	No data	No data	No data	No data
Seals	No data	No data	No data	No data	No data
Total pool consumers	0.06	0.03	0.004	0.02	0.004
Top 10 cm regolith pool	93	55	10	33	2
Particulate pool	1	1	0.03	0.3	0.1
Dissolved pool	30	27	30	0.9	14

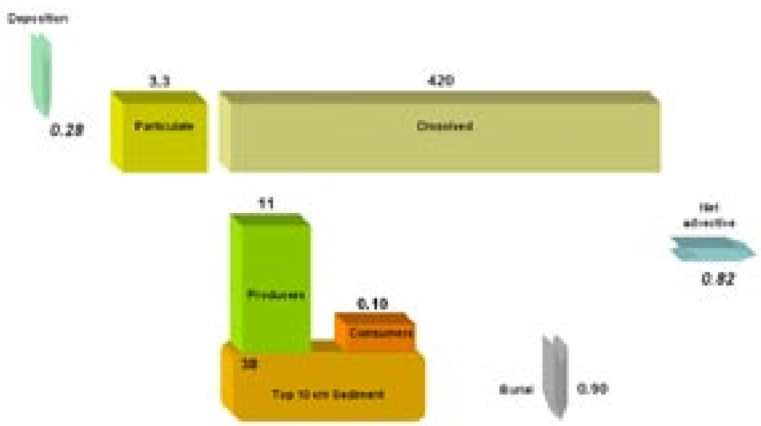


Figure 6-68. *Schematic overview of pools and fluxes, in mg per m^2, of iodine in Basin 134.*

Table 6-13. Pools and fluxes of iodine (in kg) for five basins in Forsmark marine model area.

	Kg I basin^{-1}y^{-1} Basin 116	Basin 126	Basin 134	Basin 121	Basin 120
Fluxes					
Advective inflow	511,199	220,598	9	78,658	262
In by precipitation	4	2	0.2	1	0.2
Advective outflow	508,943	216,860	10	85,637	255
Accumulation by burial	0.1	0.1	1	1	1
Pools					
Phytoplankton	0.1	0.05	0.002	0.02	0.003
Microphytes	62	27	4	21	4
Macrophytes	30	9	3	11	3
Emerg macrophytes	No data	No data	No data	No data	No data
Total pool producers	92	36	6	32	7
Bacterioplankton	No data	No data	No data	No data	No data
Zooplankton	0.09	0.03	0.001	0.01	0.002
Benthic bacteria	No data	No data	No data	No data	No data
Benthic herbivores	0.9	0.3	0.02	0.2	0.04
Benthic filter feeders	No data	No data	No data	No data	No data
Benthic detrivores	0.5	0.2	0.04	0.1	0.04
Benthic carnivores	No data	No data	No data	No data	No data
Benthic feeding fish	0.01	0.003	0.0001	0.003	0.001
Zooplankton feeding fish	0.002	0.001	0.0001	0.001	0.0002
Piscivorous fish	0.003	0.002	0.0001	0.002	0.0004
Birds	No data	No data	No data	No data	No data
Seals	No data	No data	No data	No data	No data
Total pool consumers	1	1	0.1	0.3	0.1
Top 10 cm regolith pool	206	121	22	73	5
Particulate pool	92	38	2	20	4
Dissolved pool	286	259	248	11	221

Si is the most abundant element of the analyzed metalloids and is also the metalloid with the largest biotic pools (1–2%). Sediment is the major pool for Si (78–97%), followed by the particulate pool (2–18%). The dissolved pool dominates (52–93%) for As, followed by the sediment pool (6–44%). Se is least distributed in the biotic pools of the metalloids, with less than 1% in all but one basin. Se is more evenly distributed in the three abiotic pools, see Table 6-14.

The net advective flux of all metalloids in all basins is almost +/– 0. Burial is a small flux for Se and As but important for Si. Since Si and Se are widely used among organisms they are specifically presented in Table 6-14.

Table 6-14. Pools and fluxes of Si and Se, in Basin 116, 126, 134, 121 and 120 in Forsmark.

kg Si basin⁻¹y⁻¹	Basin 116	Basin 126	Basin 134	Basin 121	Basin 120
Fluxes					
Runoff	991	2,370	9,686	56,692	791,902
Advective inflow	39,062	16,646	1	6,044	19
In by precipitation	113	46	5	31	6
Advective outflow	39,107	16,663	1	6,055	20
Accumulation by burial	1,600	1,372	8,058	21,234	10,615
Pools					
Total pool producers	**24,819**	**9,947**	**1,570**	**8,301**	**1,667**
Total pool consumers	**1,201**	**479**	**59**	**309**	**71**
Top 10 cm regolith pool	3 160,554	1,862,014	338,709	1,121,119	70,680
Particulate pool	400,483	164,077	8,351	87,916	16,011
Dissolved pool	95,518	30,264	785	15,141	1,353
kg Se basin^{-1}y^{-1}	**Basin 116**	**Basin 126**	**Basin 134**	**Basin 121**	**Basin 120**
Fluxes					
Runoff	No data	No data	No data	No data	No data
Advective inflow	3	1	0.00005	0.4	0.001
In by precipitation	No data	No data	No data	No data	No data
Advective outflow	3	1	0.0001	0.4	0.001
Accumulation by burial	0.01	0.005	0.03	0.08	0.04
Pools					
Total pool producers	**0.2**	**0.08**	**0.01**	**0.1**	**0.01**
Total pool consumers	**0.2**	**0.09**	**0.01**	**0.06**	**0.02**
Top 10 cm regolith pool	11	7	1	4	0.3
Particulate pool	9	4	0.2	2	0.4
Dissolved pool	7	2	0.1	1	0.1

Metals

Mg, Na, Ca, K, Li and Mo are metals that are concentrated into the dissolved pool Zn and Ba is concentrated in is the particulate pool and for the rest of the metals the sediment pool dominates.

For all metals except Ca, the dominant biotic pool is producers. To exemplify metal pools and fluxes, Fe, Mg and Ca are presented in Table 6-15 because they represent various distributions within the chemical group of metals.

Ca and Mg, which are major constituents of marine water, are distributed to a very large extent in the dissolved water pool (around 99% for Mg and between 74 and 94% for Ca). Fe is mainly distributed in the sediment pool (90–98%). Fe is the only metal (of these three) with a biotic pool of over 1%, see Table 6-12.

The net advective flux of Fe, Mg and Ca is around +/– 0 in all basins. Burial is an important flux for iron in several basins, but for the other elements it is small compared with the advective flux, see Table 6-15.

Table 6-15. Pools and fluxes of Fe, Mg and Ca, in Basin 116, 126, 134, 121 and 120 in Forsmark, in kg basin^{-1} year^{-1}.

kg Fe basin^{-1}y^{-1}	Basin 116	Basin 126	Basin 134	Basin 121	Basin 120
Fluxes					
Runoff	No data	No data	No data	No data	No data
Advective inflow	4,062	1,731	0.1	629	2
In by precipitation	244	98	11	67	13
Advective outflow	4,067	1,733	0.1	630	2
Out to air, respiration	No data	No data	No data	No data	No data
Accumulation by burial					
Pools					
Total pool producers	**9,731**	**4,159**	**594**	**3,275**	**577**
Total pool consumers	**310**	**132**	**20**	**90**	**23**
Top 10 cm regolith pool	371,022	218,584	39,761	131,610	8,297
Particulate pool	2,476	1,014	52	543	99
Dissolved pool	9,995	3,167	82	1,584	142

kg Mg basin^{-1}y^{-1}	Basin 116	Basin 126	Basin 134	Basin 121	Basin 120
Fluxes					
Runoff	1,209	2,893	11,825	69,214	966,813
Advective inflow	8,475,084	3,611,597	140	1,311,356	4,017
In by precipitation	620	249	27	169	33
Advective outflow	8,484,866	3,615,386	166	1,313,838	4,251
Accumulation by burial	53	46	268	706	353
Pools					
Total pool producers	**6,176**	**2,186**	**465**	**2,201**	**555**
Total pool consumers	**456**	**181**	**18**	**118**	**24**
Top 10 cm regolith pool	4	2	0,4	1	0
Particulate pool	8,210	3,364	171	1,802	328
Dissolved pool	20,853,772	6,607,319	171,286	3,305,593	295,420

Kg Ca basin^{-1}y^{-1}	Basin 116	Basin 126	Basin 134	Basin 121	Basin 120
Fluxes					
Runoff	1,209	2,893	11,825	69,214	966,813
Advective inflow	3,706,803	1,579,628	61	573,556	1,757
In by precipitation	2,270	912	98	619	122
Advective outflow	3,711,081	1,581,285	72	574,642	1,859
Accumulation by burial	61	52	305	803	402
Pools					
Total pool producers	**12,181**	**4,494**	**887**	**4,308**	**1,025**
Total pool consumers	**133,224**	**54,331**	**7,408**	**36,494**	**8,773**
Top 10 cm regolith pool	119,551	70,433	12,812	42,408	2,674
Particulate pool	280,717	115,009	5,854	61,625	11,223
Dissolved pool	9,120,945	2,889,884	74,917	1,445,788	129,210

Lanthanides

Lanthanides are regarded as trace elements in the marine ecosystem. The lanthanides seem to be distributed the same way in the marine ecosystem. Like many of the other elements the lanthanides (Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Tm, Yb, Lu) are most abundant in the sediments. Ce, Tb and Er have been selected to illustrate the distribution of lanthanides, see Table 6-16.

Lanthanide distribution is fairly similar within the pools. However, Tb seems to have a slightly smaller sediment pool and a larger dissolved pool. All of them have very small biotic pools, see Table 6-16.

The net advective fluxes of Ce, Er and Mg are +/– 0 in all basins, see Table 6-16.

6.5.2 Basins – Laxemar-Simpevarp

The selected marine basins in Laxemar-Simpevarp are marked in Figure 6-69.

The basic physical characteristics of Basins 521, 504, 502, 506 and 508 are presented in Table 6-17. Physical data for the rest of the basins are presented in Appendix 7.

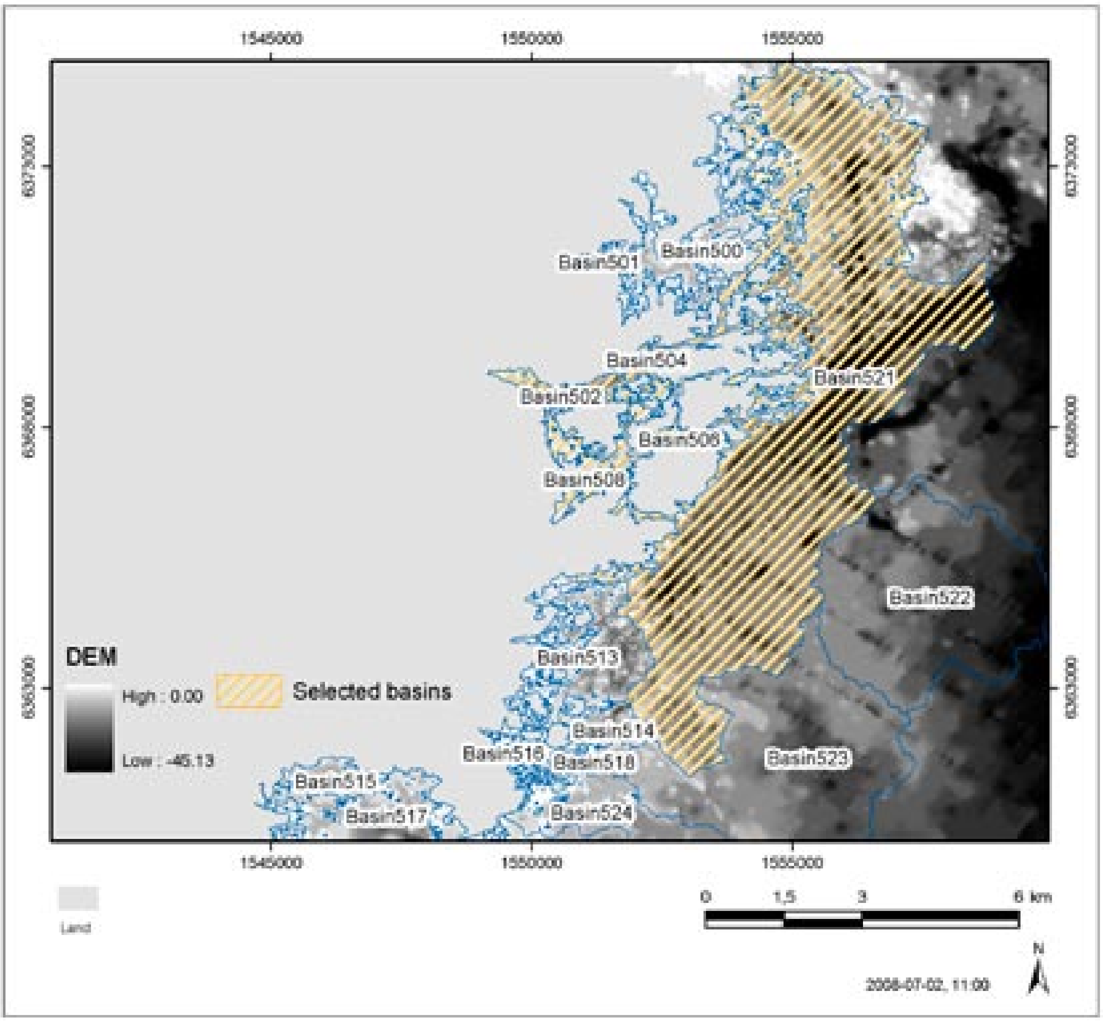


Figure 6-69. *Basins 502, 504, 506, 508 and 521 and their catchment areas are presented in this chapter.*

Table 6-16. Pools and fluxes of Ce, Er and Tb, in Basin 116, 126, 134, 121 and 120 in Forsmark.

kg Ce basin^{-1}y^{-1}	Basin 116	Basin 126	Basin 134	Basin 121	Basin 120
Fluxes					
Runoff	No data	No data	No data	No data	No data
Advective inflow	12	5	0.0002	2	0.01
Net Primary Production	No data	No data	No data	No data	No data
In by precipitation	No data	No data	No data	No data	No data
Advective outflow	13	5	0.0002	2	0.01
Out to air, respiration	No data	No data	No data	No data	No data
Accumulation by burial	0.4	0.3	2	5	3
Pools					
Total pool producers	0.1	0.05	0.01	0.04	0.01
Total pool consumers	0.1	0.05	0.01	0.04	0.01
Top 10 cm regolith pool	783	461	84	278	18
Particulate pool	27	11	1	6	1
Dissolved pool	31	10	0.3	5	0.4

kg Er basin^{-1}y^{-1}	Basin 116	Basin 126	Basin 134	Basin 121	Basin 120
Fluxes					
Runoff	No data	No data	No data	No data	No data
Advective inflow	1	0.4	0.00002	0.2	0.0005
Net Primary Production	No data	No data	No data	No data	No data
In by precipitation	No data	No data	No data	No data	No data
Advective outflow	1	0.4	0.00002	0.2	0.001
Out to air, respiration	No data	No data	No data	No data	No data
Accumulation by burial	0.01	0.01	0.1	0.2	0.1
Pools					
Total pool producers	0.1	0.002	0.0003	0.001	0.0003
Total pool consumers	0.1	0.002	0.0002	0.001	0.0003
Top 10 cm regolith pool	461	17	3.0	10	1
Particulate pool	11	2	0.1	1	0.2
Dissolved pool	10	1	0.02	0.4	0.04

kg Tb basin^{-1}y^{-1}	Basin 116	Basin 126	Basin 134	Basin 121	Basin 120
Fluxes					
Runoff	No data	No data	No data	No data	No data
Advective inflow	3	1	0.00004	0.4	0.001
Net Primary Production	No data	No data	No data	No data	No data
In by precipitation	No data	No data	No data	No data	No data
Advective outflow	3	1	0.0001	0.4	0.001
Out to air, respiration	No data	No data	No data	No data	No data
Accumulation by burial	0.004	0.004	0.02	0.06	0.03
Pools					
Total pool producers	0.001	0.001	0.0001	0.0005	0.0001
Total pool consumers	0.001	0.001	0.0001	0.0004	0.0001
Top 10 cm regolith pool	9	5	1	3	0.2
Particulate pool	0.2	0.1	0.003	0.04	0.01
Dissolved pool	6	2	0.1	1	0.1

Table 6-17. Basic characteristics of five basins in the Laxemar-Simpevarp marine model area.

	Basin 521	Basin 504	Basin 502	Basin 506	Basin 508
Marine basin area (m^2)	38,044,800	608,000	1,126,800	334,400	1,374,800
Mean depth (m)	11.1	3.6	4.8	3.3	1.7
Max depth (m)	45.1	16.1	18.1	12.1	8.1
Volume (m^3)	425,691,909	2,187,558	5,461,854	1,105,921	2,387,159
Total drainage area to basin (m^2)	1,538,000	1,948,000	34,675,000	951,000	46,517,000
Runoff (m^3 $year^{-1}$)	338,360	428,560	7,628,500	209,220	10,233,880
Advective outflow (m^3)	226,170,479,016	228,477,024	89,939,160	309,264,480	60,906,168
Advective inflow (m^3)	355,090,217,688	229,423,752	90,254,736	302,637,384	55,225,800

Basic specific food webs – carbon, nitrogen and phosphorus

Food webs illustrating the sizes of C, N, P pools and fluxes in the ecosystem are presented in Figure 6-70, 6-71 and 6-72, data for pools and fluxes of C, N and P in Appendix 9.

The largest pool in the 5 basins is the sediment (from 66–76% of the total carbon pool), followed by the DIC and DOC pools. Basin 521 looks more like the average in whole marine area in Laxemar-Simpevarp with DIC as the largest pool. Filter feeders constitute a major part of the carbon biomass in the whole marine area. This is also true of Basin 521, but in the other four basins filter feeders constitute around 1% of the total carbon pool. In these basins the macrophyte pool is larger instead. The fluxes in Basin 508 are similar to the fluxes in the whole marine basin on average, although consumption by the filter feeders is smaller and consumption by birds is larger. Consumption by filter feeders is the largest biotic flux of carbon, see Figure 6-70.

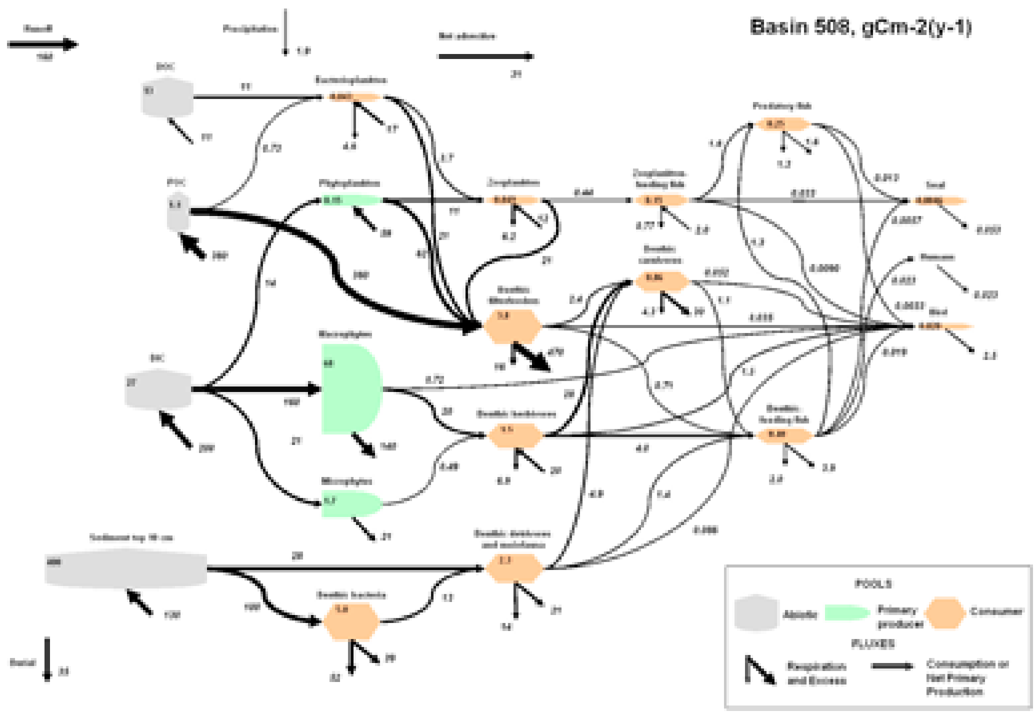


Figure 6-70. *Pools and fluxes of carbon in basin 508. Boxes and arrows denote relative size of pools and fluxes. Fish and benthic fauna are summarized in one pool.*

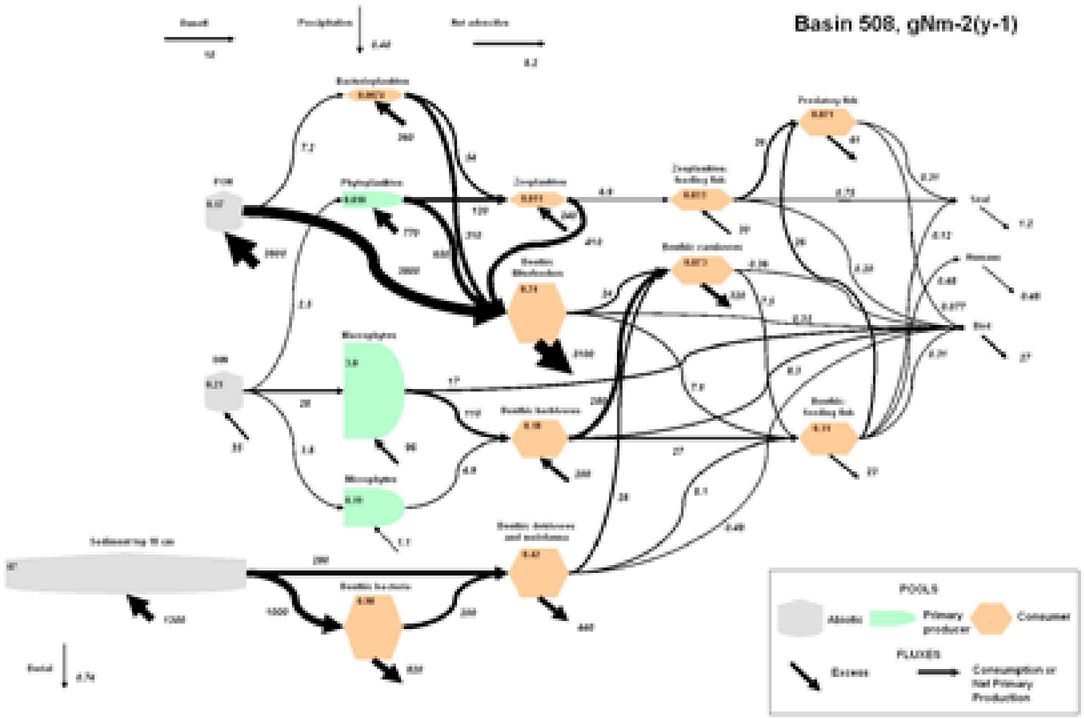


Figure 6-71. *Pools and fluxes of nitrogen in basin 508. Boxes and arrows denote relative size of pools and fluxes. Fish and benthic fauna are summarized in one pool.*

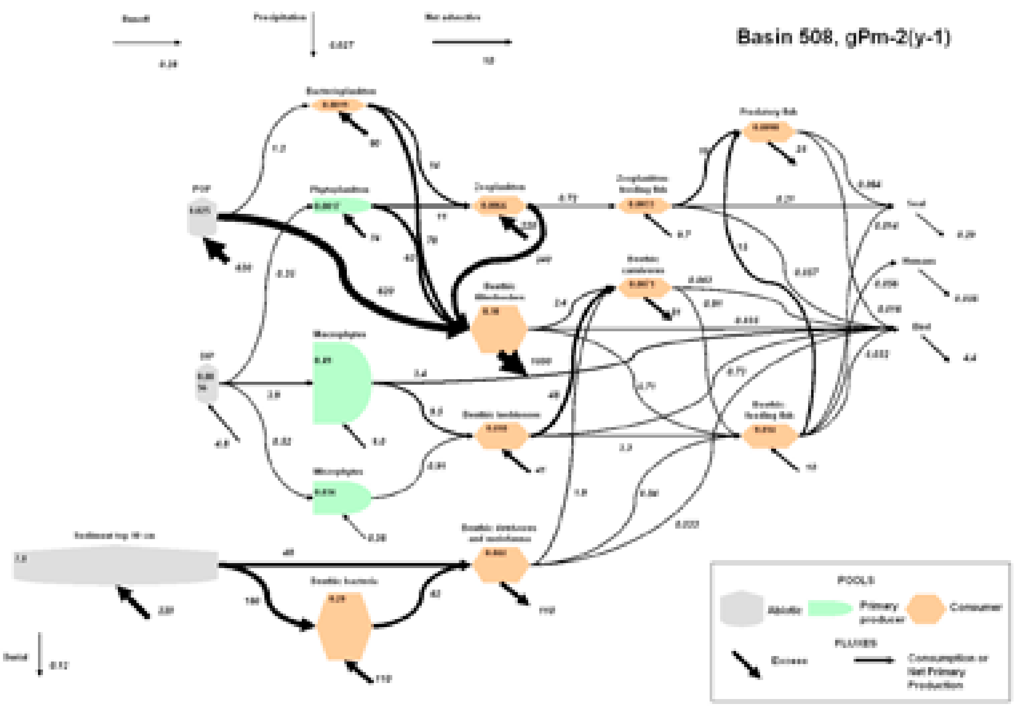


Figure 6-72. *Pools and fluxes of phosphorus in basin 508. Boxes and arrows denote relative size of pools and fluxes. Fish and benthic fauna are summarized in one pool.*

Even more than for carbon, the sediment in the 5 basins constitutes the largest nitrogen pool followed by the biotic pools of benthic filter feeders and macrophytes. The fluxes in Basin 508 are similar to the fluxes in the whole marine basin on average, although consumption by filter feeders is smaller and consumption by birds is larger, as is burial. Consumption by filter feeders is the largest biotic flux of nitrogen, see Figure 6-71.

As in the case of carbon and nitrogen, the sediment in the 5 basins constitutes the largest phosphorus pool, followed by the biotic pools of benthic filter feeders and macrophytes. The fluxes in Basin 508 are similar to the fluxes in the whole marine basin on average, although consumption by filter feeders is smaller and consumption by birds is larger, as is burial. Consumption by filter feeders is the largest biotic flux of phosphorus, see Figure 6-72.

Basin-specific mass balances – carbon, nitrogen and phosphorus

Overviews of pools and fluxes of carbon, nitrogen and phosphorous in Basin 508 are given in Figures 6-73, 6-74 and 6-75 and Tables 6-18, 6-19 and 6-20.

Carbon

Considering all fluxes in the mass balance calculations (see Table 6-18 and Appendix 9), there is a net outflux of carbon in 3 of the five basins (521, 504 and 506). The fluxes to and from the basins are dominated by advective flux in all basins. Carbon burial is very small in all basins except for 521, where it constitutes about 50% of the net outflux of carbon. Runoff is small relative to other fluxes, but in Basin 508 it is approximately 50% of the advective influx of carbon.

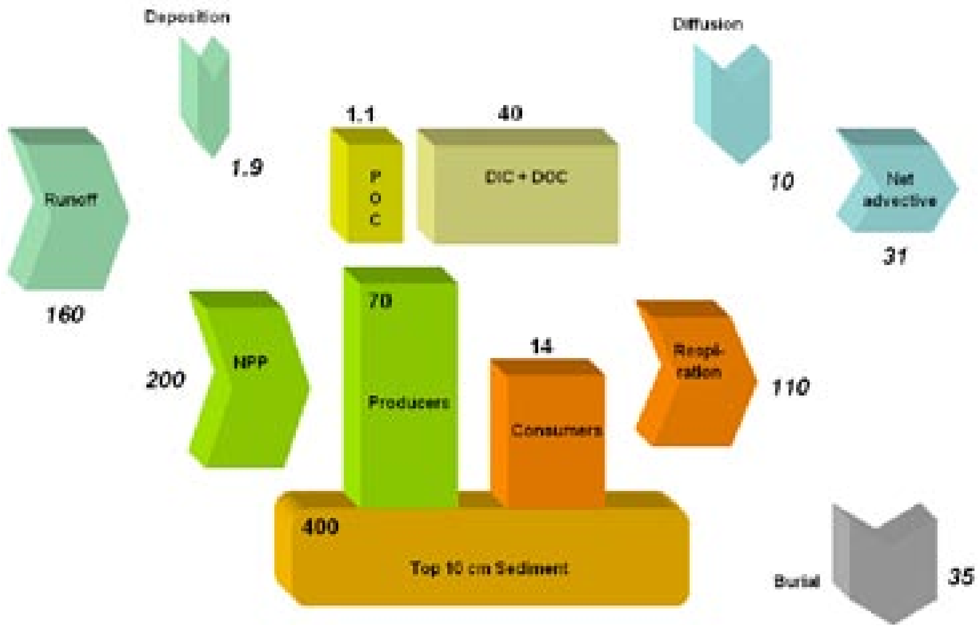


Figure 6-73. *Schematic overview of pools and fluxes of carbon in gC m^{-2} year^{-1} in Basin 508 in Laxemar-Simpevarp.*

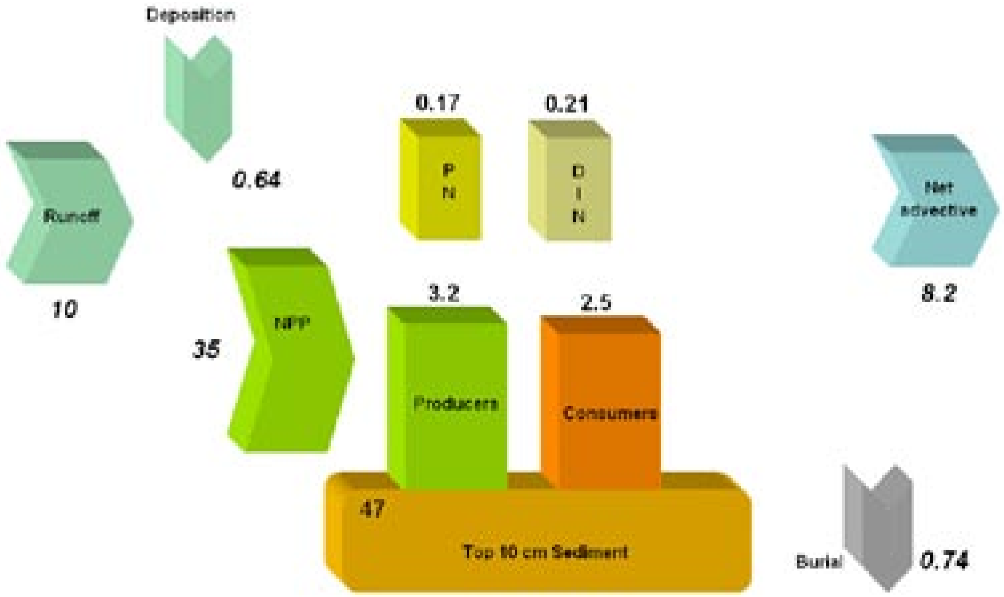


Figure 6-74. *Schematic overview of pools and fluxes of nitrogen in gN m^{-2} year^{-2} in Basin 508 in Laxemar-Simpevarp.*

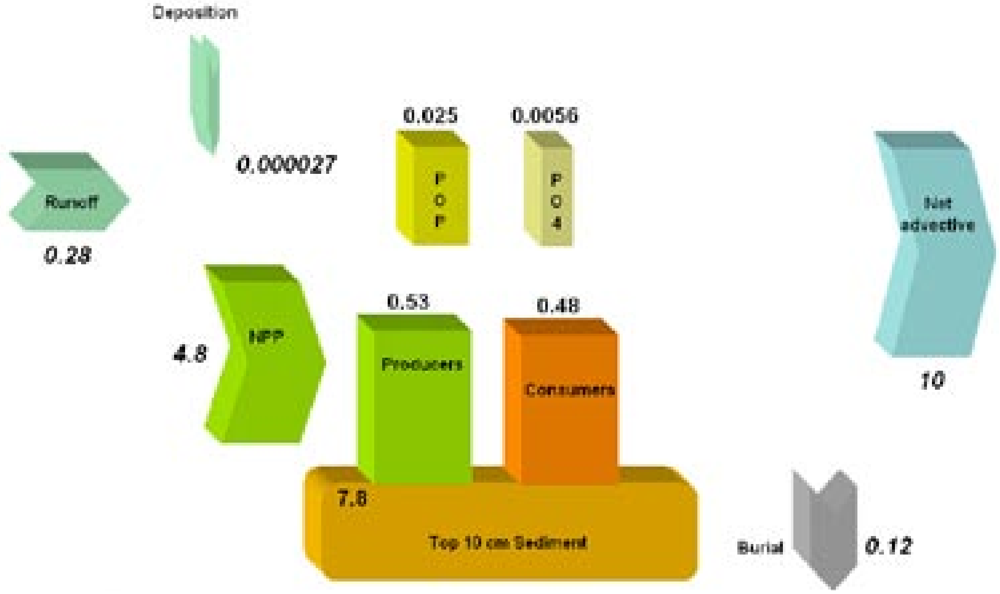


Figure 6-75. *Schematic overview of pools and fluxes of phosphorus in P m^{-2} year^{-1} in Basin 508.*

Table 6-18. Pools and fluxes of carbon (in tonnes basin^{-1} year^{-1}) for five basins in Laxemar-Simpevarp marine model area.

	tonnes C basin^{-1}y^{-1} Basin 521	Basin 504	Basin 502	Basin 506	Basin 508
Fluxes					
Runoff	6	8	162	4	213
Advective influx	897,247	1,179	689	1,393	411
Net Primary Production	5,824	96	112	29	265
In by deposition	72	1	2	1	3
Advective outflux	923,369	1,757	657	2,326	454
Out to air, respiration	12,655	60	130	36	145
Accumulation by burial	25	15	51	2	48
Pools					
Phytoplankton	10	0.1	0.3	0.1	0.2
Microphytes	51	1	1	0.4	2
Macrophytes	1,023	23	33	11	94
Emerg macrophytes	no data	no data	no data	no data	no data
Total pool producers	**1,084**	**24**	**34**	**12**	**96**
Bacterioplankton	10	0.1	0.1	0.03	0.1
Zooplankton	3	0.04	0.1	0.02	0.1
Benthic bacteria	43	3	6	2	7
Benthic herbivores	139	1	2	1	2
Benthic filter feeders	1,714	2	4	2	5
Benthic detrivores	296	1	3	1	3
Benthic carnivores	10	0.4	1	0.2	1
Benthic feeding fish	8	0.2	0.4	0.1	1
Zooplanktonfeeding fish	15	0.1	0.2	0.05	0.2
Piscivorous fish	1	0.2	0.3	0.1	0.3
Birds	0.1	0.01	0.01	0.005	0.03
Seals	0.2	0.003	0.01	0.002	0.01
Total pool consumers	**2,240**	**8**	**17**	**5**	**20**
Top 10 cm regolith pool	3,465	178	560	84	545
Particulate pool	70	1	3	1	1
Dissolved pool	1,718	16	39	8	17

Table 6-19. Pools and fluxes of nitrogen (in kg year^{-1}) for five basins in Laxemar-Simpevarp marine model area.

	Kg N basin^{-1}y^{-1} Basin 521	Basin 504	Basin 502	Basin 506	Basin 508
Fluxes					
Runoff	240	366	10,285	207	14,027
Advective influx	84,093,648	82,845	47,214	99,925	27,962
Net Primary Production	1,025,626	16,865	19,659	5,099	46,669
In by precipitation	24,349	389	721	214	880
Advective outflux	62,719,560	111,268	48,407	150,612	39,194
Accumulation by burial	2,910	1,723	6,098	294	5,664
Pools					
Phytoplankton	1,217	13	32	7	24
Microphytes	5,955	111	126	45	266
Macrophytes	44,323	981	1,419	485	4,069
Emerg macrophytes	No data	No data	No data	No data	No data
Total pool producers	**51,495**	**1,106**	**1,577**	**536**	**4,359**
Bacterioplankton	1,703	9	23	5	10
Zooplankton	762	8	20	4	15
Benthic bacteria	7,826	468	1,163	278	1,231
Benthic herbivores	16,106	119	195	66	245
Benthic filter feeders	332,820	429	850	320	1,018
Benthic detrivores	54,071	256	500	133	576
Benthic carnivores	833	37	67	20	101
Benthic feeding fish	2,321	57	104	35	153
Zooplankton feeding fish	3,372	20	37	11	45
Piscivorous fish	385	43	80	24	98
Birds	No data	No data	No data	No data	No data
Seals	No data	No data	No data	No data	No data
Total pool consumers	**420,199**	**1,446**	**3,039**	**895**	**3,491**
Top 10 cm regolith pool	410,404	21,044	66,285	9,983	64,489
Particulate pool	7,819	138	378	70	238
Dissolved pool	9,034	172	562	87	283

Table 6-20. Pools and fluxes of phosphorus (in kg year^{-1}) for five basins in the Laxemar-Simpevarp marine model area.

	Kg P basin-1y-1 Basin 521	Basin 504	Basin 502	Basin 506	Basin 508
Fluxes					
Runoff	6	9	295	6	391
Advective influx	6,559,145	6,266	7,454	17,070	1,669
Net Primary Production	141,939	2,334	2,721	706	6,459
In by deposition	1,027	16	30	9	37
Advective outflux	5,664,998	6,626	2,900	8,969	15,909
Accumulation by burial	482	286	1 011	49	939
Pools					
Phytoplankton	118	1	3	1	2
Microphytes	1,098	20	23	8	49
Macrophytes	7,307	162	234	80	671
Emerg macrophytes	no data	no data	no data	no data	no data
Total pool producers	**8,523**	**184**	**260**	**89**	**722**
Bacterioplankton	431	2	6	1	3
Zooplankton	450	5	12	2	9
Benthic bacteria	2,413	144	359	86	380
Benthic herbivores	1,605	12	19	7	24
Benthic filter feeders	46,147	60	118	44	141
Benthic detrivores	5,652	27	52	14	60
Benthic carnivores	81	4	7	2	10
Benthic feeding fish	295	7	13	4	19
Zooplankton feeding fish	335	2	4	1	4
Piscivorous fish	49	5	10	3	12
Birds	no data	no data	no data	no data	no data
Seals	no data	no data	no data	no data	no data
Total pool consumers	**57,458**	**268**	**600**	**165**	**663**
Top 10 cm regolith pool	68,023	3,488	10,986	1,655	10,689
Particulate pool	1,418	28	107	14	35
Dissolved pool	6,970	20	43	10	8

Nitrogen

Sediment, primary producers and benthic filter feeders constitute the major pools. The rest of the pools constitute less than 1% of the total nitrogen inventory in the marine basin. Basin 521 has an almost even distribution between the sediment pool and consumers (46 and 47%, respectively), followed by producers (5%), and the dissolved pool (1%), see Table 6-19.

The fluxes to and from the basins are dominated by advective flux, followed by primary production followed by precipitation (deposition) or burial. Deposition of nitrogen is quite an important flux, especially in Basin 521. Considering all fluxes (see Table 19), all basins of the five considered here but one (Basin 506) show a net influx of nitrogen, especially Basin 521, mainly due to high accumulation during NPP.

Phosphorus

In Basin 508, sediment dominates the phosphorus pool. All other pools are considerably smaller, see Figure 6-75.

The fluxes to and from the basins are dominated by advective flux, although NPP is quite an important flux (see Table 6-20), followed by deposition and burial. Considering all fluxes of phosphorus the model indicates that there is a net influx in all but one basin, Basin 508, which has a small net outflux.

Actinides and iodine

The fluxes considered are advective flux, precipitation and burial. The other fluxes were not included due to lack of data. For some functional groups (benthic bacteria, bacterioplankton, benthic filter feeders, benthic carnivores, birds and seals), no analysis data were available and they are not included in the mass balances, which suggests an underestimation of the consumer pool. Data on uranium concentrations in some of the biotic functional groups were not available for Laxemar-Simpevarp, so data from Forsmark were used to give a rough estimate of these pools relative to other pools. Since salinity in particular but also other chemical characteristics will affect the uranium distribution, these estimates of uranium concentrations are to be regarded as very rough. Some analyses of biota were below the detection limit, and estimated means based on half the detection limit were used to give a rough estimate (estimated mean). For the biotic pools half the detection limit was used as where estimated means of concentrations they are marked in the tables.

Th has the smallest pools in water compared with sediments and I the largest, see Figures 6-76 , 6-77 and 6-78 and Tables 6-21, 6-22 and 6-23.

Thorium

The major pool for thorium is sediment in all basins. Sediment comprises 91–98% of the pool in the whole basin, followed by the particulate pool (1–4%), and producers (1–3%). All other pools constitute less than 1% of the total thorium inventory in the marine model area in Laxemar-Simpevarp (see also Appendix 9).

The major flux of thorium is the advective flux. Burial is a small flux in comparison with advection in all basins except Basin 508, but larger than deposition. Considering all fluxes there is according to the model a total net outflux of thorium in all but one basin, Basin 521, see Figure 6-76 and Table 6-21.

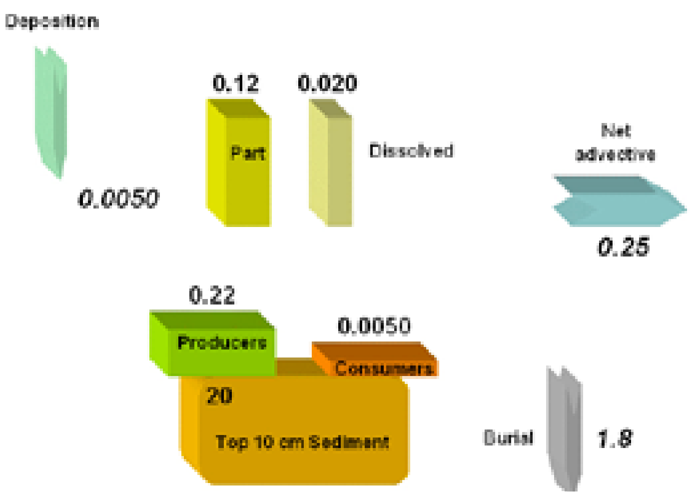


Figure 6-76. *Schematic overview of pools and fluxes of Thorium in mgTh m^{-2} year^{-}, in Basin 508.*

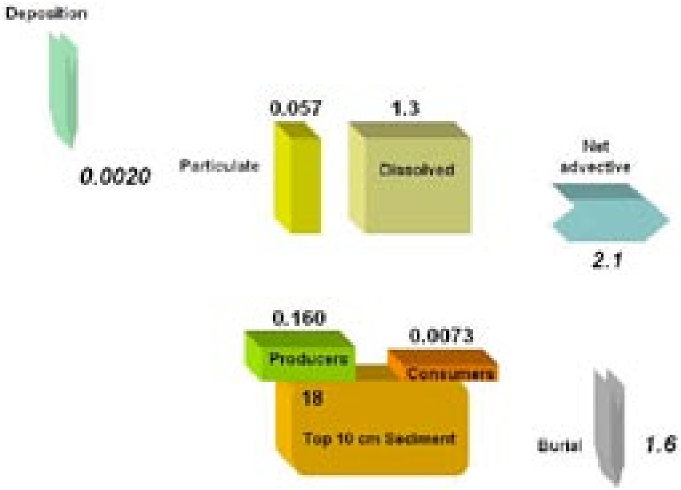


Figure 6-77. *Schematic overview of pools and fluxes of Uranium in mgU m^{-2} year^{-1} in Basin 508 in Laxemar-Simpevarp.*

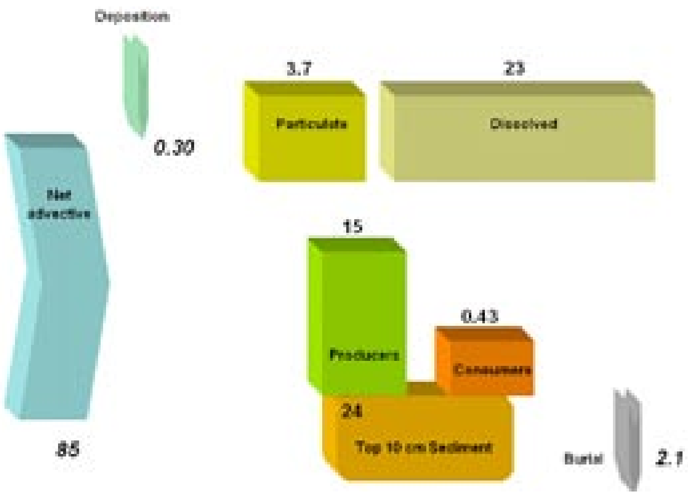


Figure 6-78. *Schematic overview of pools and fluxes of Iodine in Basin 508 in mg I m^{-2} year^{-1} in Laxemar-Simpevarp.*

Table 6-21. Pools and fluxes of Thorium (in kg and kg year⁻¹ respectively) for Basin 521, 504, 502, 506 and 508 in Laxemar-Simpevarp.

	Kg Th basin^{-1}y^{-1} Basin 521	Basin 504	Basin 502	Basin 506	Basin 508
Fluxes					
Runoff	No data	No data	No data	No data	No data
Advective influx	689	1	1	1	0.4
In by deposition	0.2	0.003	0.006	0.002	0.007
Advective outflux	622	2	1	2	1
Accumulation by burial	1	0.7	3	0.1	2
Pools					
Phytoplankton	0.1	0.001	0.002	0.0004	0.002
Microphytes	5.3	0.1	0.1	0.04	0.2
Macrophytes	0.7	0.02	0.02	0.01	0.1
Emerg macrophytes	No data	No data	No data	No data	No data
Total pool producers	**5**	**0.1**	**0.1**	**0.04**	**0.2**
Bacterioplankton	No data	No data	No data	No data	No data
Zooplankton	0.004	0.00005	0.0001	0.00002	0.00008
Benthic bacteria	No data	No data	No data	No data	No data
Benthic herbivores	0.1	0.001	0.002	0.0006	0.002
Benthic filter feeders	0.1	0.0001	0.0003	0.0001	0.0004
Benthic detrivores	0.2	0.001	0.002	0.0005	0.002
Benthic carnivores	0.02	0.001	0.002	0.0004	0.002
Benthic feeding fish	0.0002	0.000005	0.00001	0.000003	0.00001
Zooplankton feeding fish	0.0001	0.0000005	0.000001	0.0000003	0.000001
Piscivorous fish	0.00003	0.000004	0.000007	0.000002	0.00001
Birds	No data	No data	No data	No data	No data
Seals	No data	No data	No data	No data	No data
Total pool consumers	**0.5**	**0.003**	**0.01**	**0.002**	**0.01**
Top 10 cm regolith pool	178	9	29	4	28
Particulate pool	8	0.2	0.4	0.1	0.2
Dissolved pool	1	0.02	0.03	0.01	0.03

Table 6-22. Pools and fluxes of uranium (in kg and kg year^{-1} respectively) for five basins in Basin 521, 504, 502, 506 and 508 in Laxemar-Simpevarp.

	Kg uranium basin^{-1}y^{-1}				
	Basin 521	**Basin 504**	**Basin 502**	**Basin 506**	**Basin 508**
Fluxes Area (km^2):	**14**	**5.4**	**0. 6**	**3.7**	**0.7**
Runoff	No data	No data	No data	No data	No data
Advective influx	173,495	177	68	232	42
In by deposition	0.08	0.001	0.002	0.001	0.003
Advective outflux	174,604	174	69	235	45
Accumulation by burial	1	0.7	2	0.1	2
Pools					
Phytoplankton	0.02	0.0002	0.001	0.0001	0.0005
Microphytes	0.1	0.002	0.002	0.001	0.01
Macrophytes	2	0.05	0.07	0.03	0.2
Emerg macrophytes	No data	No data	No data	No data	No data
Total pool producers	**0.1**	**0.002**	**0.003**	**0.001**	**0.006**
Bacterioplankton	No data	No data	No data	No data	No data
Zooplankton	No data	No data	No data	No data	No data
Benthic bacteria	No data	No data	No data	No data	No data
Benthic herbivores	0.1	0.001	0.001	0.0005	0.002
Benthic filter feeders	1	0.002	0.004	0.001	0.005
Benthic detrivores	0.3	0.001	0.002	0.0006	0.003
Benthic carnivores	0.01	0.000	0.001	0.0002	0.001
Benthic feeding fish	0.000002	0.00000004	0.0000001	0.00000002	0.0000001
Zooplankton feeding fish	0.00002	0.0000001	0.0000002	0.0000001	0.0000002
Piscivorous fish	0.0000003	0.00000003	0.0000001	0.00000002	0.0000001
Birds	No data	No data	No data	No data	No data
Seals	No data	No data	No data	No data	No data
Total pool consumers	**2**	**0.004**	**0.01**	**0.003**	**0.01**
Top 10 cm regolith pool	156	8	25	4	24
Particulate pool	4	0.1	0.2	0.04	0.1
Dissolved pool	329	2	4	0.8	2

Table 6-23. Pools and fluxes of iodine (in kg and kg year^{-1} respectively) for Basin 521, 504, 502, 506 and 508 in Laxemar-Simpevarp.

Kg I basin^{-1}y^{-1}	Basin 521	Basin 504	Basin 502	Basin 506	Basin 508
Fluxes					
Advective influx	2,751,206	3,132	1,336	3,519	917
In by deposition	11	0.2	0.3	0.1	0.4
Advective outflux	2,555,726	3,495	1,689	4,731	800
Accumulation by burial	1.5	0.9	3	0.2	3
Pools					
Phytoplankton	0.9	0.01	0.02	0.005	0.02
Microphytes	99	2	2	1	4
Macrophytes	180	4	6	2	17
Emerg macrophytes	No data	No data	No data	No data	No data
Total pool producers	**280**	**6**	**8**	**3**	**21**
Bacterioplankton	No data	No data	No data	No data	No data
Zooplankton	0.6	0.01	0.01	0.003	0.01
Benthic bacteria	No data	No data	No data	No data	No data
Benthic herbivores	7	0.1	0.08	0.03	0.1
Benthic filter feeders	No data	No data	No data	No data	No data
Benthic detrivores	15	0.07	0.1	0.04	0.16
Benthic carnivores	0.5	0.02	0.04	0.01	0.06
Benthic feeding fish	0.02	0.0004	0.0008	0.0003	0.0011
Zooplankton feeding fish	0.01	0.00004	0.0001	0.00002	0.0001
Piscivorous fish	0.003	0.0003	0.0006	0.0002	0.0007
Birds	No data	No data	No data	No data	No data
Seals	No data	No data	No data	No data	No data
Total pool consumers	**23**	**0**	**0.3**	**0.1**	**0.3**
Top 10 cm regolith pool	213	11	34	5	33
Particulate pool	240	5	11	2	5
Dissolved pool	4,810	33	103	17	31

Uranium

For uranium, the sediment pool is the dominant pool for four of the basins, followed by the dissolved pool. However, in Basin 521 the dissolved pool is largest (66%), followed by sediment (32%). All other pools constitute less than 1% of the total thorium inventory in the marine model area in Laxemar-Simpevarp. This is also true in Basin 508, see Figure 6-77 and Table 6-22.

The major flux of uranium is the advective flux. Considering all fluxes, all basins except Basin 504 have a net outflux of uranium according to the model. In most basins it is quite small, except for Basin 521, were the net outflux is quite large. Burial is very small in comparison with the advective fluxes, see Figure 6-77 and Table 6-22.

Iodine

For iodine the dissolved pool in water is the dominant pool for of the basins (521, 502 and 506). In Basin 521 the domination iodine pool is producers (78%), while in Basin 508 the majority of the iodine is distributed in the sediment (36%), followed by the dissolved pool (34%) and the producer pool (23%). The particulate pool varies between 2 and 9% in the basins, while all other pools, including all consumers, contain less than 1% of the total iodine inventory, Table 6-23.

The major flux of iodine is the advective flux. In three of five basins there is a net outflux of iodine, according to the model. In Basin 521 there is a large net influx of iodine on an annual basis. Burial is very small in comparison with the advective fluxes, see Figure 6-78.

Metalloids

Si and Se are included in the chemical group metalloids, together with As. They have properties of both metals and non-metals. They are generally not distributed similar to each other in the pools of an ecosystem and are therefore presented separately. These metalloids are regarded as recycled elements, i.e. elements that are incorporated into soft tissues or into skeletal material and will be more or less depleted in surface waters and enriched in the deep ocean. Si is also classified as biolimiting together with P and N, while the other metalloids can be considered as biointermediate.

The Si in the fives basins is mainly distributed in the sediment pool (75–96%), followed by the particulate pool (3–16%), see Table 6-24. The rest of the pools contain around 1% or less of the total inventory of Si in the basins.

Table 6-24. Pools and fluxes of Si and Se, in Basin 521, 504, 502, 506 and 508 in Laxemar-Simpevarp.

kg Si basin^{-1}y^{-1}	Basin 521	Basin 504	Basin 502	Basin 506	Basin 508
Fluxes					
Runoff	1,910	2,419	43,065	1,181	57,772
Advective inflow	365,743	236	93	312	57
In by deposition	1,240	20	37	11	45
Advective outflow	232,956	235	93	319	63
Accumulation by burial	34,903	20,573	73,070	3,519	67,820
Pools					
Total pool producers	**66,956**	**1,291**	**1,779**	**587**	**4,189**
Total pool consumers	**10,678**	**60**	**114**	**32**	**132**
Top 10 cm regolith pool	4,916,632	252,107	794,087	119,602	772,574
Particulate pool	1,044,009	20,721	49,622	10,281	21,946
Dissolved pool	438,401	2,253	5,625	1,139	2,458
kg Se basin^{-1}y^{-1}	**Basin 521**	**Basin 504**	**Basin 502**	**Basin 506**	**Basin 508**
Fluxes					
Runoff	No data	No data	No data	No data	No data
Advective inflow	No data	No data	No data	No data	No data
In by precipitation	No data	No data	No data	No data	No data
Advective outflow	No data	No data	No data	No data	No data
Accumulation by burial	0.2	0.1	0.4	0.02	0.3
Pools					
Total pool producers	**1**	**0.03**	**0.04**	**0.01**	**0.1**
Total pool consumers	**13**	**0.02**	**0.04**	**0.02**	**0.1**
Top 10 cm regolith pool	25	1	4	1	4
Particulate pool	24	0.5	1	0.2	1
Dissolved pool	No data	No data	No data	No data	No data

Se and As are, in comparison to Si, slightly less abundant in the sediment pool (40–85% for Se and 29–86% for As) and more abundant in the particulate and dissolved pools (11–38% for Se and 29–86% for As). In Basin 521, Se is quite abundant in the consumer pool (20%), but much less so in the other biotic pools. For As, the producer pool constitutes the largest biotic pool (93%).

According to the model there is a net outflux of the metalloids Si and As (no site specific data for Se is available) in all basins, except for Basin 521 where there is a large influx. Burial is quit important (for both Si and As) and is the largest flux in all basins but Basin 521. Since Si and Se are of widely used among organisms they are specifically presented in Table 6-24.

Metals

For Mg, Na, Ca, K, Li and Mo for the dissolved pool dominates. For Zn and Ba it is the particulate pool, and for the rest of the metals the sediment pool dominates (Appendix 9).

For all metals except Ca, the dominant biotic pool is producers. To exemplify metal pools and fluxes, Fe, Mg and Ca are presented in Table 6-25 because they represent various distributions of elements in the metals chemical group.

Ca and Mg, which are major constituents of marine water, are distributed to a high degree in the dissolred water pool (around 99% for Mg and between 77 and 96% for Ca). Fe is mainly distributed in the sediment pool (88–98%), and Fe is the only metal (of these three) with a biotic pool of over 1%, see Table 6-25.

According to the model there is a net outflux of Fe, Mg and Ca in all basins but Basin 521. In Basin 521 there is a large net influx of Fe, Mg and Ca. Burial is a important flux for iron in several basins, but for the others it is very small compared with the advective flux, see Table 6-25.

Lanthanides

Lanthanides are regarded as trace elements in the marine ecosystem. The lanthanides seem to be distributed similarly in the marine ecosystem (see section 6.2). Like many of the other elements, the lanthanides (Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Tm, Yb, Lu) are most abundant in the sediments (Appendix 9). Ce, Tb and Er have been selected to illustrate the distribution of lanthanides, see Table 6-26.

Ce and Er are distributed with their major pool in the sediment (except in Basin 521, who has a huge dissolved pool), while Tb seems to have a slightly smaller sediment pool and a larger dissolved pool. All of them have very small biotic pools, see Table 6-26.

According to the model there is a net influx of Ce, Tb and Er in Basin 521. In the other basins there is a net outflux due to the large burial term. Burial is quite an important flux for Ce and Tb, but the advective flux is still of major importance, see Table 6-26.

Table 6-25. Pools (kg) and fluxes (kg year^{-1}) of Fe, Mg and Ca, in Basin Basin 521, 504, 502, 506 and 508 in Laxemar-Simpevarp.

kg Fe basin^{-1}y^{-1}	Basin 521	Basin 504	Basin 502	Basin 506	Basin 508
Fluxes					
Advective influx	35,509	23	9	30	6
In by deposition	1,432	23	42	13	52
Advective outflux	22,617	23	9	31	6
Accumulation by burial	4,653	2,743	9,741	469	9,041
Pools					
Total pool producers	**20,220**	**394**	**486**	**169**	**1,143**
Total pool consumers	**1,324**	**6**	**10**	**3**	**12**
Top 10 cm regolith pool	655,447	33,609	105,862	15,944	102,994
Particulate pool	6,453	128	307	64	136
Dissolved pool	58,502	301	751	152	328
kg Mg basin^{-1}y^{-1}	**Basin 521**	**Basin 504**	**Basin 502**	**Basin 506**	**Basin 508**
Fluxes					
Runoff	437	554	9,859	270	13,226
Advective influx	75,694,582	48,906	19,240	64,513	11,772
In by deposition	4,946	79	146	43	179
Advective outflux	48,212,761	48,704	19,172	65,926	12,983
Accumulation by burial	1,588	936	3,324	160	3,085
Pools					
Total pool producers	**41,477**	**900**	**1,282**	**437**	**3,587**
Total pool consumers	**30,417**	**72**	**140**	**44**	**165**
Top 10 cm regolith pool	17	1	2.8	0.4	3
Particulate pool	21,402	425	1,017	211	450
Dissolved pool	90,744,796	466,322	1,164,304	235,749	508,871
Kg Ca basin^{-1} y^{-1}	**Basin 521**	**Basin 504**	**Basin 502**	**Basin 506**	**Basin 508**
Fluxes					
Runoff	2,231	2,825	50,292	1,379	67,467
Advective influx	31,027,783	20,047	7,886	26,444	4,826
In by deposition	15,941	255	472	140	576
Advective outflux	19,762,776	19,964	7,859	27,024	5,322
Accumulation by burial	1,171	690	2,452	118	2,276
Pools					
Total pool producers	**180,841**	**3,967**	**5,678**	**1,942**	**16,108**
Total pool consumers	**282,873**	**2,023**	**3,670**	**1,108**	**4,875**
Top 10 cm regolith pool	165,009	8,461	26,651	4,014	25,929
Particulate pool	731,795	14,524	34,783	7,207	15,383
Dissolved pool	37,199,011	191,159	477,283	96,641	208,601

Table 6-26. Pools (kg) and fluxes (kg year^{-1}) of Ce, Er and Tb, in Basin 521, 504, 502, 506 and 508 in Laxemar-Simpevarp.

kg Ce basin^{-1}y^{-1}	Basin 521	Basin 504	Basin 502	Basin 506	Basin 508
Fluxes					
Runoff	No data	No data	No data	No data	No data
Advective inflow	71	0.05	0.02	0.1	0.01
In by precipitation	No data	No data	No data	No data	No data
Advective outflow	45	0.05	0.02	0.1	0.01
Accumulation by burial	24	14	50	2	46
Pools					
Total pool producers	23	0.50	0.7	0.3	2
Total pool consumers	1.3	0.003	0.01	0.002	0.01
Top 10 cm regolith pool	3,361	172	543	82	528
Particulate pool	71	1	3	1	1
Dissolved pool	88	0.5	1.1	0.2	0.5
kg Er basin^{-1}y^{-1}	**Basin 521**	**Basin 504**	**Basin 502**	**Basin 506**	**Basin 508**
Fluxes					
Runoff	No data	No data	No data	No data	No data
Advective inflow	21,589	14	5	18	3
In by precipitation	No data	No data	No data	No data	No data
Advective outflow	13,751	14	5	19	4
Accumulation by burial	0.75	0.44	1.6	0.1	1.5
Pools					
Total pool producers	0.7	0.02	0.02	0.008	0.06
Total pool consumers	0.1	0.0001	0.0002	0.0001	0.1
Top 10 cm regolith pool	106	5	17	3	17
Particulate pool	14	0.3	0.6	0.1	0.3
Dissolved pool	25,886	133	332	67	145
kg Tb basin^{-1}y^{-1}	**Basin 521**	**Basin 504**	**Basin 502**	**Basin 506**	**Basin 508**
Fluxes					
Runoff	No data	No data	No data	No data	No data
Advective inflow	36	0.02	0.01	0.03	0.01
In by precipitation	No data	No data	No data	No data	No data
Advective outflow	23	0.02	0.01	0.03	0.01
Accumulation by burial	0.2	0.1	0.5	0.02	0.5
Pools					
Total pool producers	0.2	0.004	0.0062	0.0021	0.0178
Total pool consumers	0.02	0.00003	0.0001	0.00002	0.0001
Top 10 cm regolith pool	33	2	5	1	5
Particulate pool	0.4	0.01	0.020	0.004	0.01
Dissolved pool	26	0.1	0.3	0.1	0.1

6.6 Confidence and uncertainties

The biomass distribution of the various functional groups in the marine ecosystems at the two sites are based on data from extensive site investigations and can be considered reliable for most groups. The annual cycle of some organism may not have been covered and it is possible that for example the yearly maximum densities of phyto- and zooplankton have been missed. However, since the data is site specific it has quite good reliance regarding magnitude.

The calculations of primary production in various macrophyte communities were based on extensive site specific measurements and have god confidence. The calculated values for primary production in the various macrophyte communities were in good agreement with other studies /Binzer and Sand-Jensen 2006/ (see also discussion in section 4.6.1), and with measurements of primary production at the sites.

Respiration was calculated from biomass and average annual temperature, using conversion factors (from T days to respiration) /Kautsky 1995b/ and consumption was estimated from respiration using reported conversions factors /Kumblad et al. 2003, 2005/. Human consumption was estimated from fishery catch. Since these calculations is based on extensive data from site investigations regarding temperature and biomass and reliable conversion factors the confidence is fairly good. Small differents in the conversion factors used will greatly influence the size of the biotic fluxes, for most elemensts the biotic fluxes are small compared to advective flux and the altered conversion factor will not greatly influence the massbalance.

In the food webs the various organisms is supposed to eat of each possible food item, as much as is available, i.e. if there is as much benthic detrivores, herbivores and benthic carnivores the benthic feeding fish will eat just as much of them all. In reality it is more likely that they have a certain food preference and feed more of the preys easiest to find or with the highest food quality. However, this assumption gives a rough estimate of the flow of matter in the food web, but with some uncertainty.

The estimations of pools and fluxes of different elements in the marine ecosystems at the two investigated sites are based on data from extensive site investigations. Site-specific water chemistry data for most elements are available for the period November 2002–July 2007 (Forsmark) and Okctober 2002–April 2007 (Laxemar-Simpevarp), giving these estimates a relatively good resolution both in time and space. The estimated pools of various elements in the marine basins have, when possible, been calculated with data from a sample site within the basin. When no sample site where located in a basin a mean value for the whole marine area were used.

The pool 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 considered as reliable estimates with good resolution in time and space. The estimated pools of other elements in particulate matter and sediment are, on the other hand, based on a single sampling performed in spring 2008 and on a limited amount of sediment samples. The use of the results from this sampling to estimate the mean annual pool of different elements in particulate matter and sediment implies of course a relative high uncertainty in the estimates. However, as data are site-specific it gives a high confidence in the magnitude of the pools of element in the particulate component.

Sediment pool estimates depend on the spatial distribution mapping of the various sediment types and their stratigraphy, an assumption of bioactive layer depth, and on the chemical element analyses and their representativity. Given that the spatial distribution rests on e.g. seismic sonar, the certainty regarding sediment distribution must be considered relatively good. The active layer depth could probably be better justified locally and possibly sediment type specific. Element and water content analyses could have been better distributed spatially and across sediment types. Thus, and in any case since also further bioavailability of the various elements (e.g. labile or refractory nutrients) is probably less certain than the pool estimates, derived results need to be considered as being within at least half an order of magnitude.

The largest uncertainty in pools of element in the biotic component is the lack of data on chemical composition of bacteria for all elements except phosphorus, nitrogen, sulfur and carbon. This of course leads to uncertainties in the distribution of elements within the biotic component. For other organisms, the elemental composition data for biotic pools are reliable estimate since it is mainly site specific. There are relatively few replicates, which induce some uncertainties, but the available replicates show small deviations from each other. When estimating the pools of different elements, biomass data are used together with the chemical composition. Although small, uncertainties are of course also connected with the biomass data.

Mass balances for a large number of elements have been constructed for five of the marine basins in Forsmark and Laxemar-Simpevarp. The mass balance calculations for the basins are in general not well balanced, due to several reasons, but probably mainly due to that not all fluxes which may occur is included. For example is the exchange between sea surface and atmosphere only included for carbon and only with a general value for exchange in the Baltic. This process can according to /Baes et al. 1985/ be much larger depending on how much is needed to reach equilibrium. The large advective fluxes in the sea do also convey large uncertainties. The fluxes of elements, calculated with water chemistry data and oceanographic estimates of water fluxes, can be considered as relative reliable (see section 5.6 for discussion of uncertainties in advective flux). However, since the volumes of water moved in the advective fluxes are so large, it has a huge impact on the results in the mass balance. Even if the concentration of respective element in the water is reliable, just a minor concentration difference will largely affect the advective flux of the element. Thus the advective fluxes of elements have a bring amount of uncertainty into the mass balance calculations.

The estimates of burial rely on a mapping of bottoms of accumulation, both spatial and vertical, and on the estimation (and applicability) of the relationship between gross accumulation and net burial. The former depends on both a fairly crude sediment classification, however relatively well mapped spatially, and locally also on thickness modeling. The latter relationship draws upon on few core dating and analyses only. The outcome can probably be considered rough order-of-magnitude estimates.

The site specific data on atmospheric deposition includes only a few elements. Thereby this flux is missing for many elements. For most elements (except phosphorus) this flux is small and probably does not alter the mass balance in any significant way. However, for the lanthanides atmospheric deposition has not been estimated for a single element. Although, less likely, we cannot exclude the possibility that the atmospheric deposition is high for this

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.

7 Long-term development of the marine ecosystem

In this chapter, the long-term development of the Forsmark and Laxemar-Simpevarp landscape is described /Söderbäck 2008/. The historical description is mainly based on the elevation model, the shoreline displacement equation /cf. Påsse 1997/, old cadastral maps and site-specific information on Quaternary deposits. Prediction of the future evolution is associated with more uncertainties than the historical description. The future evolution of the area may be different than expected due to e.g. greenhouse gas-induced warming inducing a climate change which cannot be predicted today. Such changes are expected to influence important characteristics of the biosphere, such as the hydrological cycle and the sea level and salinity of the Baltic Sea.

It should be noted that the descriptions of the future evolution in the following text are based on existing knowledge of the past, known processes (e.g. shoreline displacement) and knowledge about the current situation e.g. existing ecosystems, climate, geometry and geology of the seafloor etc. All these descriptions have their uncertainties. Thus, the descriptions presented here are a sketch of the future which is logically coherent, but the exact dates and spatial extent of the various domains are uncertain because of limitations in the underlying data and conceptual models.

The text in the sections describing periods with permafrost and glaciation is not site-specific and describes only in broad terms what the biosphere looks like under such conditions. Thus, the descriptions only concern processes that may be important for the distribution of radionuclides.

Land uplift and the resulting shoreline displacement have strongly influenced biosphere conditions in the past and will continue to do so also in the future, e.g. succession on newly exposed land and sediment redistribution (sedimentation and resuspension/erosion). The estimated rate of shoreline displacement is shown in Figs. 7-1 and 7-8 for Forsmark and Laxemar-Simpevarp, respectively. In the future ecosystems, today's early successional stages of vegetation and associated fauna are assumed to gradually move in the landscape, following shoreline displacement.

7.1 Interglacial period – Forsmark

The last deglaciation in Forsmark took place during the Preboreal climatic stage, c. 10,800 years ago /Strömberg 1989, Persson 1992, Fredén 2002/. The closest shore/land area at that time was situated c. 80 km to the west of Forsmark. The Forsmark area was initially covered with approximately 150 m of Yoldia Sea water. Since most of the Forsmark area has been situated below the Baltic Sea until the last 2,000 years or so, the post-glacial development of the area is mainly described by shoreline displacement and the evolution of the Baltic basin.

The past salinity of the Baltic Sea since the onset of the Littorina period has been reviewed by /Westman et al. 1999/ and /Gustafsson 2004a/ with an updated chronology from /Fredén 2002/. From proxy data, they estimated a range within which the salinity of the Baltic Proper (the Baltic Sea south of Åland) can be described over time. They also presented a model that makes use of knowledge of the sills in the southern Baltic Sea together with river runoff to estimate past and future salinity changes. The model can also be used to evaluate differences in salinity between the different basins of the Baltic Sea /Gustafsson 2004a,b/, cf. Table 7-1 and Figure 7-1.

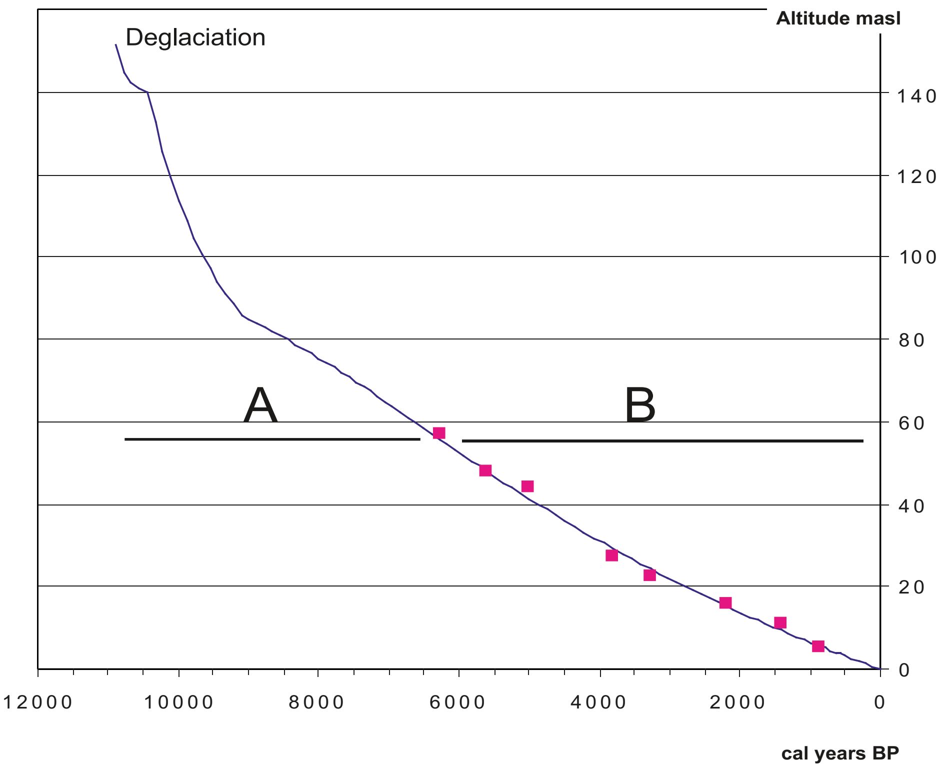


***Figure 7-1.** Shoreline displacement curve for Forsmark. The purple squares are ages and altitude of dated isolation basins /Hedenström and Risberg 2003, Risberg et al. 2005/. The solid black line is the mathematically modelled shoreline displacement /Påsse 1997/. The older part of the curve, marked A, has a greater uncertainty than the younger part, marked B.*

Table 7-1. Summary of the stages of the Baltic Sea /Fredén 2002, Westman et al. 1999/. Note that the altitudes and ages are approximate values, based on regional extrapolations and interpolations. BP = Before Present.

Baltic Stage	Calendar year	Salinity	Environment in Forsmark	Environment in Laxemar-Simpevarp
Baltic Ice Lake not applicable in Forsmark	15,000–11,550 BP (13050–9600 BC) not applicable in Forsmark	Glacio-lacustrine not applicable in Forsmark	Covered by inland ice	Regressive shoreline from 40 m.a.s.l. to 20 m.a.s.l.
Yoldia Sea	11,500–10,800 BP (9550–8850 BC)	Lacustrine/Brackish/Lacustrine	Deglaciation, regressive shoreline from c. 150 m.a.s.l. Minor (or no) influence of brackish water.	Deglaciation. Regressive shoreline from c. 100 m.a.s.l. to 40 m.a.s.l.
Ancylus Lake	10,800–9,500 BP (8850–7550 BC)	Lacustrine	Regressive shoreline from c. 140–75 m.a.s.l.	This period started with a transgressive shoreline reaching 30 m.a.s.l. and was followed by a regression to 20 m.a.s.l.
Littorina Sea sensu lato	9,500–present (7550–present BC)	Brackish	Regressive shoreline from 75–0 m.a.s.l. Most saline period 6,500–5,000 calendar years BP. Present Baltic Sea during approximately the last 2,000 years.	Regressive shoreline interrupted by transgression

The model by /Gustafsson 2004ab/, together with proxy records of salinity in the Baltic Proper, has been used to make a rough estimate of the probable range of past salinity in the Bothnian Sea, i.e. the basin where the Forsmark area is situated (Figure 7-2). The difference in estimated salinity between the Baltic Proper and the Bothnian Sea back in time is generally low (< 1 ppt), due to the low sill in the Åland Sea. Shoreline displacement in northern Uppland during the last 10,000 years has been studied using stratigraphical methods by /Robertsson and Persson 1989, Hedenström and Risberg 2003, Risberg et al. 2005/. Påsse made a mathematical model of shoreline displacement /Påsse 1997, 2001/, and his curve is similar to the curve presented by /Hedenström and Risberg 2003/, based partly on site-specific data. However, Påsse's mathematical model continues back to the deglaciation, whereas the stratigraphical investigations only cover the last 6,500 years. The curve in Figure 7-1 shows that the shoreline in Forsmark has been continuously regressive since the deglaciation. During the first c. 2,000 years after the deglaciation, the regression rate in Forsmark was fast, on the order of 3.5 m/100 years. During the subsequent c. 9,000 years the regression rate has been slower, on the order of 0.9 m/100 years (Figure 7-1). The present land uplift rate in Forsmark is c. 6 mm y^{-1} /Ekman 1996/.

Preliminary results from a sediment core collected from the seafloor east of Forsmark, indicate only a minor influence of brackish water during the deglaciation /Kaislahti et al. 2006/. Thus, the transition to the next Baltic stage, the Ancylus Lake, was characterized by continuous freshwater conditions and a regressive shore line. Global eustatic sea level rise, in combination with a reducing isostatic rebound in the southern Baltic basin, enabled marine water to enter the Baltic basin through the Danish straits, marking the onset of the Littorina Sea sensu lato. This stage includes an initial phase when the salinity was stable and low, the Mastogloia Sea, which lasted for approximately 1,000 years in Southern Uppland before the onset of the brackish water Littorina sensu stricto /Hedenström and Risberg 2003/. Preliminary results from the site show that the most saline period was between 7,000 and 4,500 years ago /Kaislahti et al. 2006/.

7.1.1 1000–0 BC

The major part of the Forsmark regional model area was still covered by water until c. 2,500 years ago. The first islands started to form at c. 500 BC (Figure 7-3). A few scattered islands, situated close to the present location of the church of Forsmark, were the first land areas to emerge from the brackish water of the Bothnian Sea. The surface of the first islands was covered by sandy till and exposed bedrock, i.e. 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/.

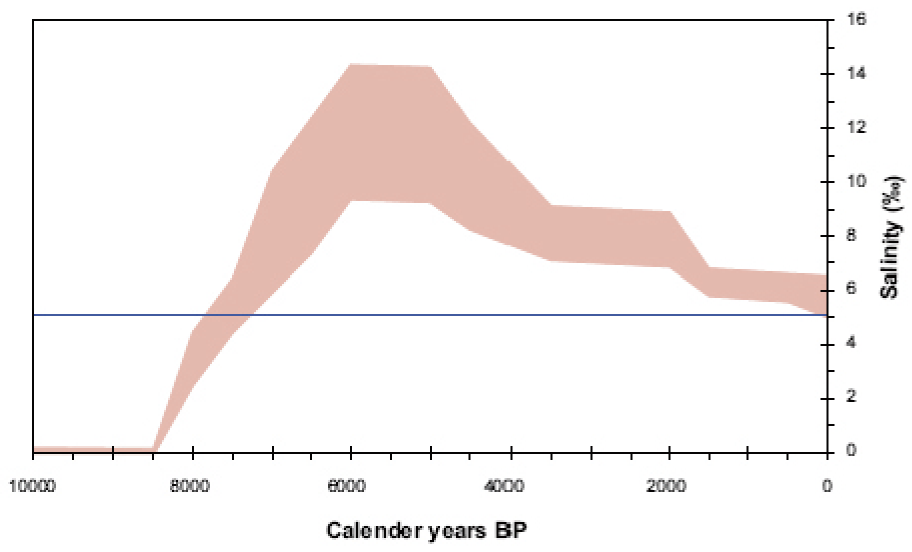


Figure 7-2. Estimated range of the salinity of Baltic Sea water in the Forsmark area from the onset of the Littorina period until today. Maximum and minimum estimates are derived from /Westman et al.1999, Gustafsson 2004ab/. The present salinity in the area is shown as a horizontal reference line.

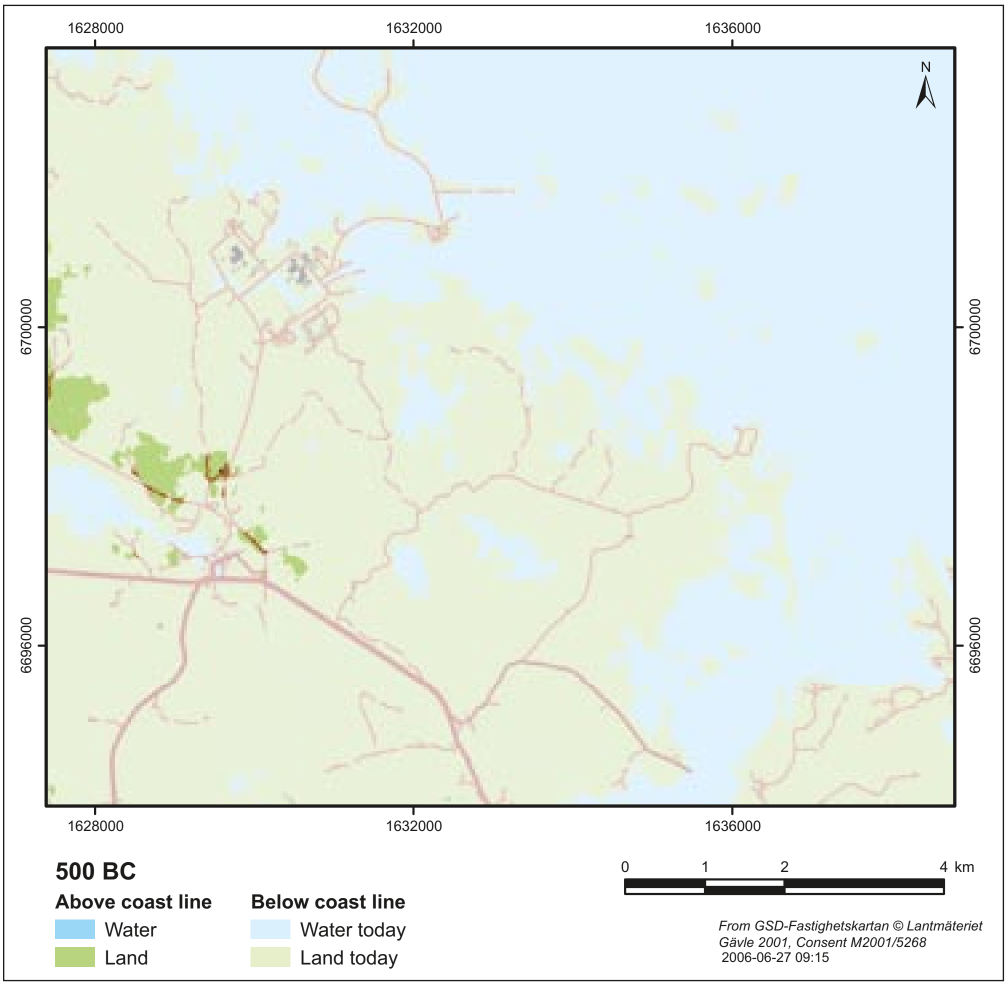


Figure 7-3. *The distribution of land and sea in the Forsmark area at c. 500 BC.*

7.1.2 0 BC–950 AD

At 0 BC, the Bothnian Sea still covered the Forsmark candidate area (Figure 7-4), whereas the islands in the area close to Forsmark church had expanded in size. Land areas presently covered by peat had emerged and, at that time, these basins were newly isolated from the Bothnian Sea, and most probably a number of small and shallow freshwater lakes/ponds existed in the archipelago. At the same time, the isolation process of the first larger lake, Lake Bruksdammen, had started in the western part of the area.

7.1.3 950–1,450 AD

At c. 950 AD, the mainland had expanded further in the south-western part of the area (Figure 7-5). The isolation process of the Lake Eckarfjärden basin had been initiated, but the bay still had an open connection to the Baltic through the threshold area in the north /cf. Hedenström and Risberg 2003/. The area presently occupied by the Stenrösmossen mire had emerged and a short lake phase was succeeded by infilling of reed /cf. Fredriksson 2004/. The Börstilåsen esker and the most elevated areas at Storskäret constituted some small islands in the east, exposed to waves and erosion.

7.1.4 1,450 AD until present

At 1,450 AD, the candidate area comprised shallow, restricted waters and an exposed archipelago, see Fig. 9-6. A shallow strait covered the area that today is Lake Fiskarfjärden and Lake Bolundsfjärden. A considerable part of the overall study area had emerged and several freshwater lakes were isolated from the Baltic, e.g. Eckarfjärden and Gällsboträsket. The area covered by clayey till at Storskäret formed a large island, partly protected from wave exposure by the Börstilåsen esker.

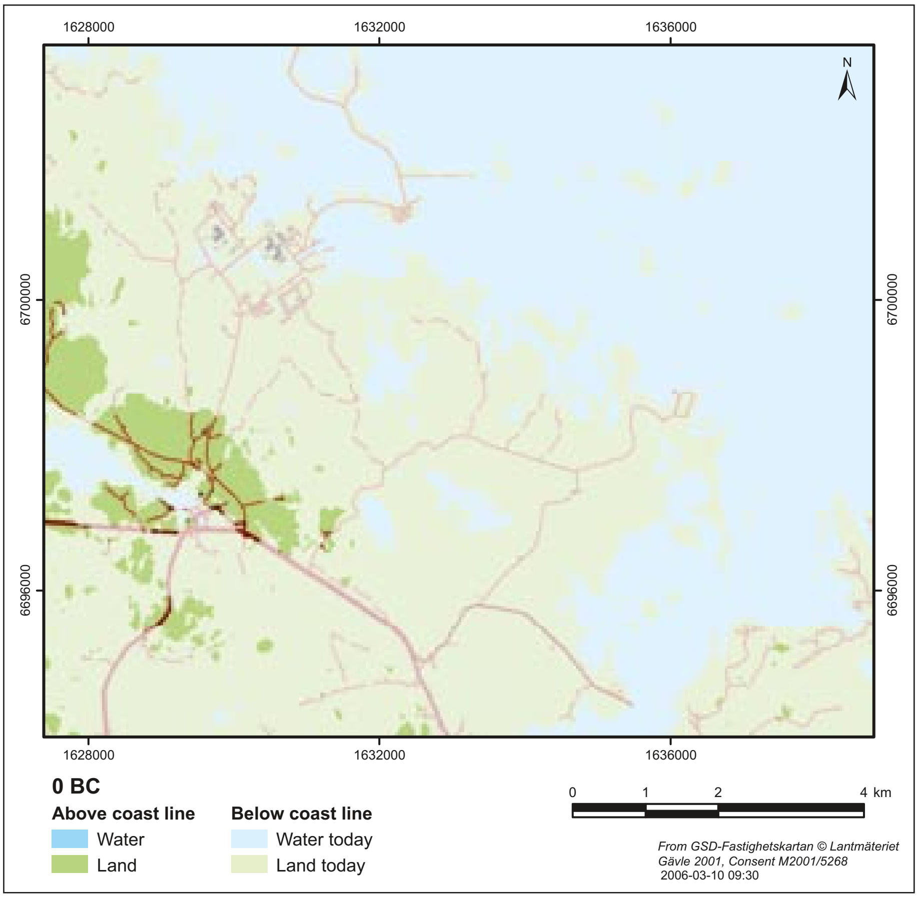


***Figure 7-4.** The distribution of land and sea in the Forsmark area at c. 0 AD.*

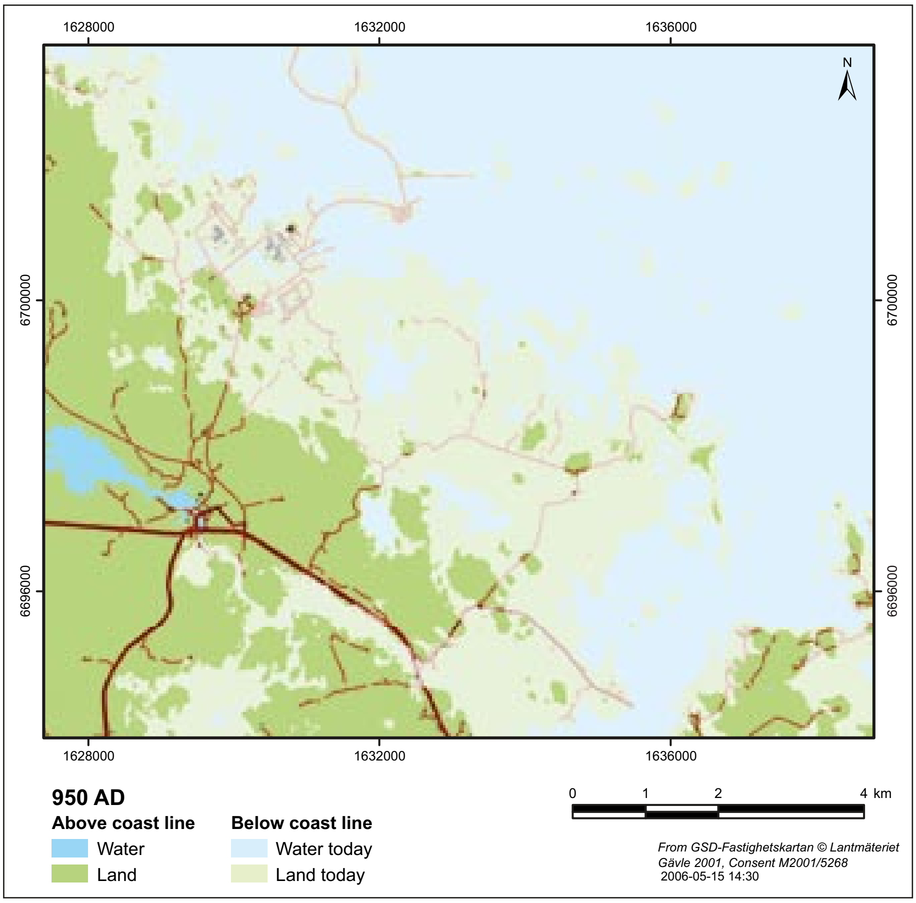


***Figure 7-5.** The distribution of land and sea in the Forsmark area at c. 950 AD.*

At 1,550 AD the strait mentioned above had been cut off and Fiskarfjärden and Bolundsfjärden were separate bays with different conditions. In contrast to the exposed situation of Bolundsfjärden, the conditions in Fiskarfjärden were favourable for sediment accumulation. The small lake Stocksjön had been isolated and was at that time considerably larger than the present lake.

At 1,650 AD the major part of the candidate area was situated above sea level. Lake Bolundsfjärden was in contact with the Baltic through the exposed strait at Puttan. The land area north of Lake Fiskarfjärden had emerged and this transformed the previously exposed lake basin into a sheltered position, favouring sedimentation. In the western part of the area, clay and peat areas were used for cultivation and pasture. Cultivation was predominant on clay areas, whereas pasture dominated on peat, sand and till areas. The increase in land areas continued, and by 1,735 AD the shores of the shallowest bays at the eastern side of Bolundsfjärden were utilized as pastures. The clayey till at Storskäret was used partly for cultivation and partly for pasture. At 1,850 AD the Börstilåsen esker had established contact with the main land (Storskäret). The small lake Fräkengropen was isolated. Cultivation and pasture continued on clay and peat areas. The cultivated areas at Storskäret had expanded and included areas formerly used for pasture (Figure 7-7).

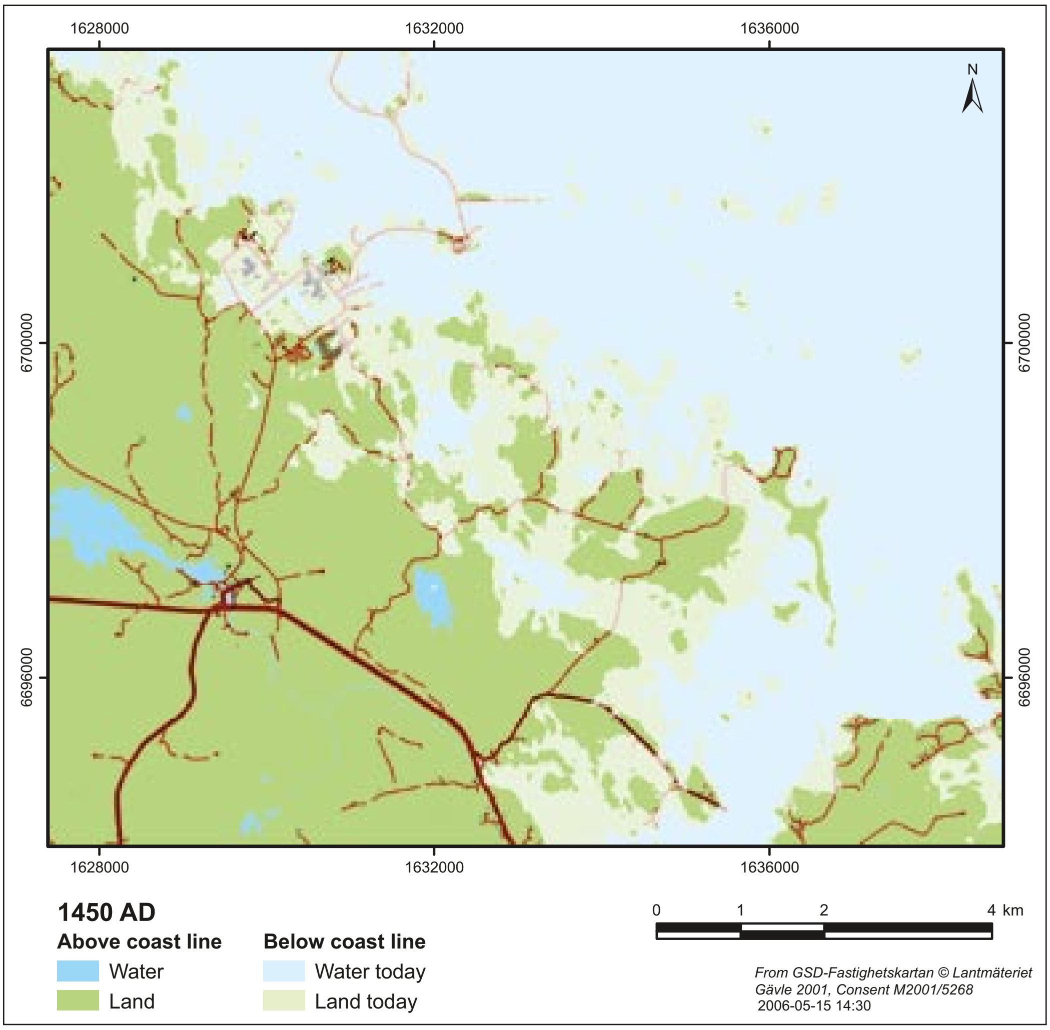


***Figure 7-6.** The distribution of land and sea in the Forsmark area at c. 1,450 AD.*

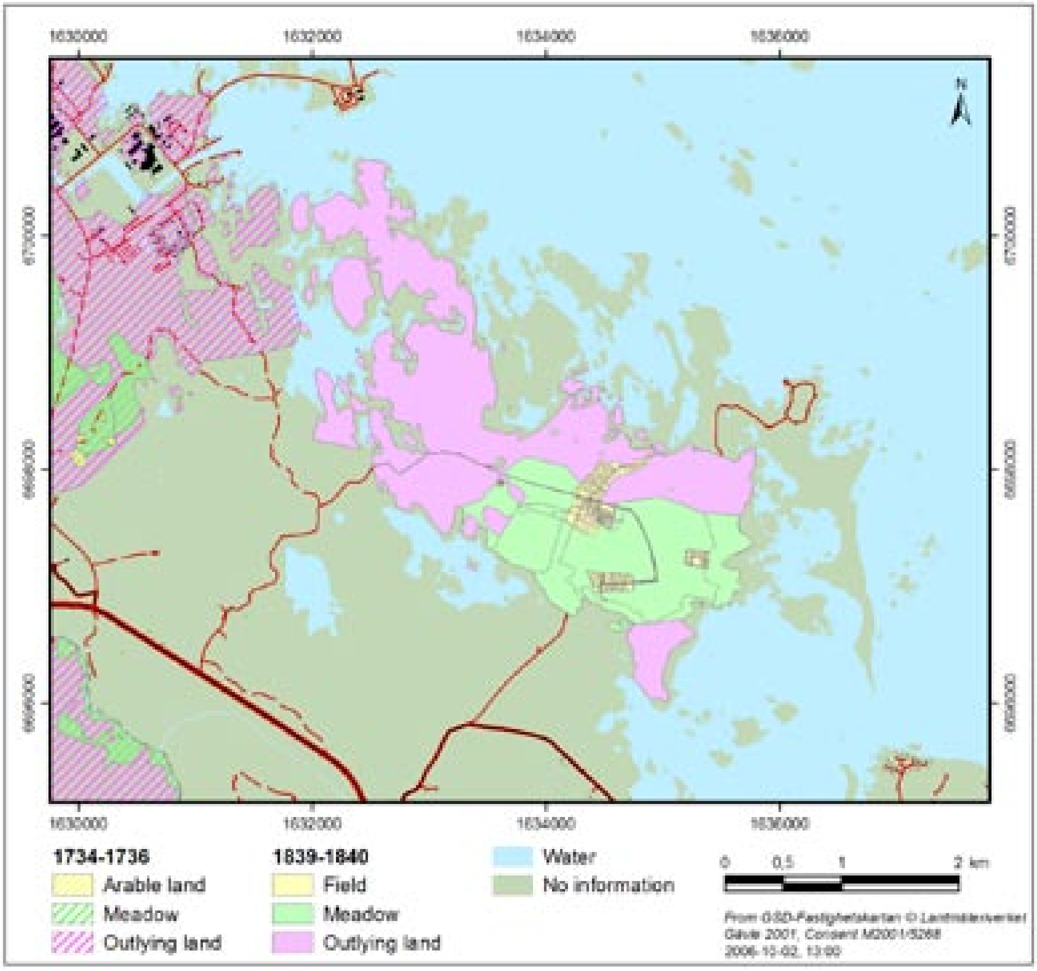


Figure 7-7. Distribution of agricultural land based on historical maps, c. 1,735 and 1,840 AD. The map is a combination of two non-overlapping maps for the different stages. Thus, the eastern part of the map provides no information on land use during the earlier stage, and the western part of the map provides no information on the latter stage.

7.1.5 Present to 2,500 AD

A number of lakes in the area, e.g. Bolundsfjärden, Norra Bassängen, Puttan, Fiskarfjärden and Lillfjärden, are currently isolated from the Baltic Sea. The human impact in the area today is dominated by the construction of the nuclear power plants and the circulation of their cooling water. For example, a very deep channel has been created and the water circulation has been considerably changed by construction of new islands and the Biotest Basin. Most of the area is forested and includes a fairly high frequency of younger and older clear-cuts /Lindborg 2005/. Active cultivation and pasturage occur at Storskäret only.

During the next 500 years, the shallowing process will continue and new land areas will be created, predominantly in the northern part of the area (Figure 7-8). At 2,400 AD, Tixelfjärden will be isolated. The inner parts of Kallrigafjärden will also become land. At 2,500 AD, the channel for cooling water will become isolated into a deep freshwater lake. Lake Stocksjön will be totally filled with sediment and transformed into a mire, Table 7-2. The land areas will expand around the sea bay west of Biotest basin, but the basin will still be a part of the Baltic Sea.

The ongoing change in the distribution of land and sea will continue with the emergence of new land areas, forming new and larger islands. The distribution of minerogenic Quaternary deposits will be affected by soil-forming processes at the surface, but no major redistribution will take place after the area has been isolated from the Baltic. The most notable change will be observed in the distribution of organic soils, for example the sedimentation of gyttja in the lakes and the formation of peat in the wetlands (cf. the lake sedimentation model /Brydsten and Strömgren 2004/).

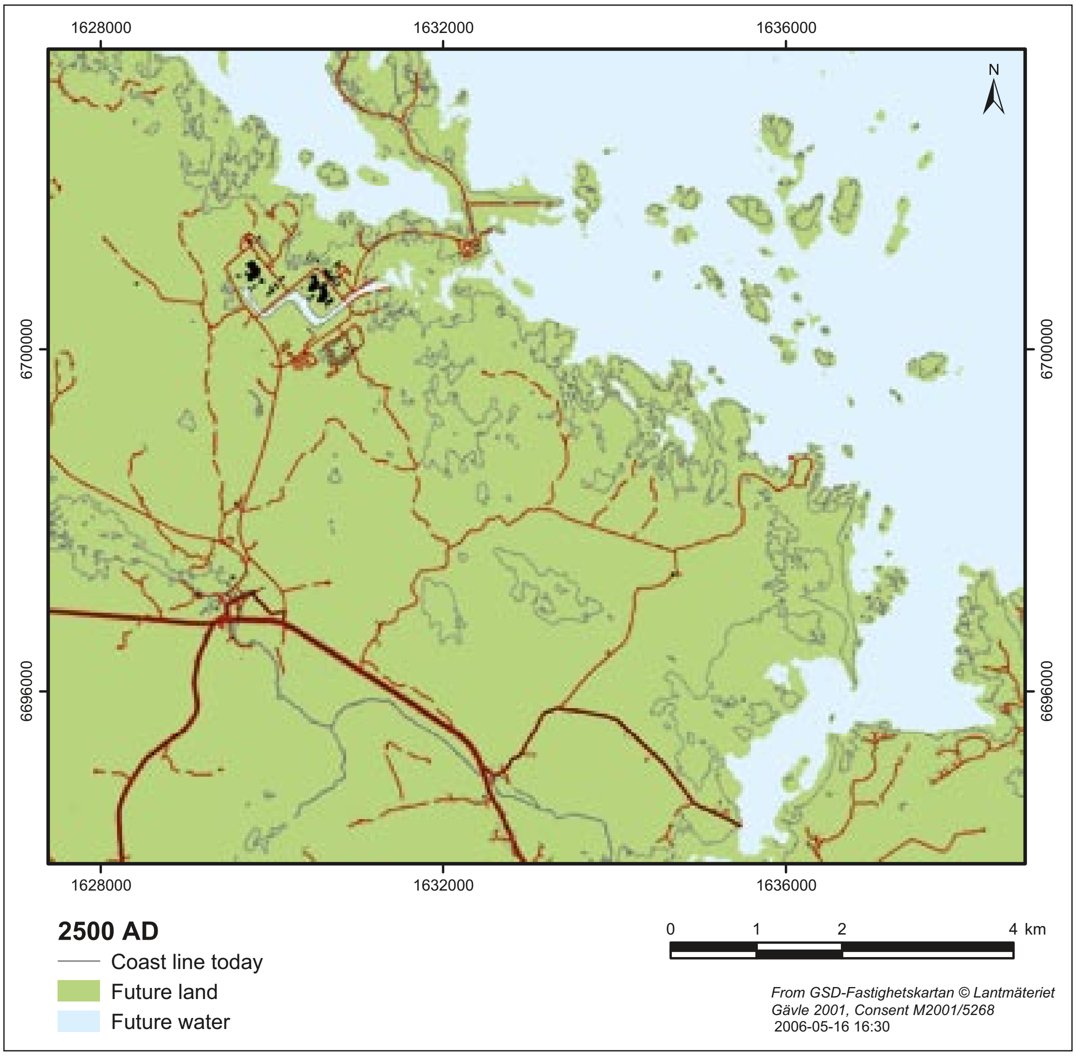


Figure 7-8. *The distribution of land and sea in the Forsmark area at 2,500 AD.*

7.1.6 2,500 AD until permafrost

The coastal period, during which the candidate area will be situated at the coast, will continue until about 4,000 to 5,000 AD. A semi-enclosed archipelago northeast of the area is expected to exist from approximately 3,000 to 5,000 AD. At 5,000 AD most straits in this archipelago are expected to become closed and the lakes so formed will become isolated from the sea. The transformation of the landscape from 5,000 AD is dominated by a general regression of the sea, and the current lakes in Forsmark will all be filled in and transformed into mires by 5,600 AD, see Table 7-2. These mires are later assumed to be transformed into forests or, if they are managed as such by humans, into agricultural land. In the landscape model, a cautious approach is adopted in which a transformation to agricultural land is assumed, unless factors such as boulder density suggest that this would be very difficult. During the period up to 7,000 AD, the coast extends along the island of Gräsö, the coastline is about 7 km from the central Forsmark area and the bay gradually shrinks to form two large and 20–30 m deep lakes. Most of the new lakes are expected to be transformed into mires rather rapidly. Only a few deeper lakes are projected to exist for more than 1,000 years. However, the large lakes near Gräsö are expected to last for a period of around 10,000 years. The salinity of the sea is expected to decrease to 3–4 ppt at 6,000 AD due to the shallower sills between Ålands hav and the Baltic Proper /Gustafsson 2004b/. This means that an ecosystem similar to the Northern Quark, with a low abundance of marine species, will develop. Around 10,000 AD, freshwater is predicted for the entire Bothnian Sea. Öregrundsgrepen will consist of freshwater anyway due to shoreline displacement. The terrestrial period of the Forsmark area is assumed to end at 10,000 AD, when a permafrost period will begin (see below).

Table 7-2. Dates when current lakes in the Forsmark area will have been completely transformed into mire (based on the sedimentation model in /Brydsten and Strömgren 2004/). The location of the larger lakes is shown on the detailed map in Figure 7-11, whereas the smaller lakes (denoted by an asterisk in the table) are situated within the regional model area, but are not shown on the map.

Lake	Year (AD) of complete transformstion
Simpviken	2,200
Kungsträsket	2,200
Gunnarsbo-Lillfjärden, north part	2,300
Märrbadet	2,300
Stocksjön	2,400
Gällboträsket	2,500
Graven	2,500
Tallsundet	2,600
Gunnarsbo-Lillfjärden, south part	2,900
Gunnarsboträsket	2,900
Vambörsfjärden	3,000
Puttan	3,200
Norra bassängen	3,400
Lillfjärden	3,700
Labboträsket	3,700
Bredviken	3,900
Fiskarfjärden	4,700
Eckatfjärden	5,400
Bolundsfjärden	5,600

7.2 Interglacial period – Laxemar-Simpevarp

The last deglaciation in the Laxemar-Simpevarp area took place before or during the relatively cold Older Dryas chronozone, c. 14,000 years ago /Lundqvist and Wohlfarth 2001/. Results from studies of clay-varves along the coast of Småland indicate that the ice margin retreated more or less continuously at a rate of c. 125–300 m·y–1 /Kristiansson 1986/. There are, however, indications of an ice marginal oscillation in the Vimmerby area, 40 km north-west of the regional model area /Agrell 1976/. This presumed oscillation may have taken place during or after the Older Dryas chronozone (c. 14,000 years ago).

7.2.1 Vegetation

The relatively cold Older Dryas chronozone was characterized by tundra vegetation dominated by herbs and bushes and a low coverage of trees. During the following Alleröd chronozone (Figure 7-9), a sparse *Pinus* and *Betula* forest dominated the vegetation.

The following cold Younger Dryas chronozone was characterized by tundra vegetation, reflected by a high proportion of Artemisia pollen. At the beginning of the Holocene c. 11,500 years ago, the temperature increased and south-eastern Sweden was first covered by forests dominated by Betula (birch) and later by forests dominated by Pinus (pine) and Corylus (hazel).

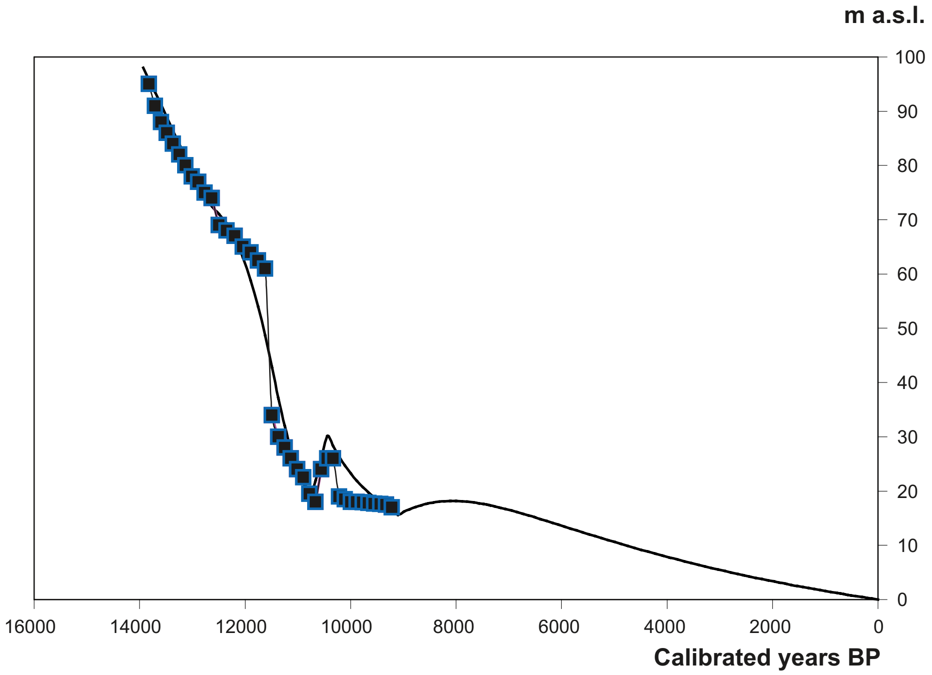


Figure 7-9. *Shoreline displacement curve for the Oskarshamn area after the last glaciation. The blue symbols show a curve established by /Svensson 1989/ after a study of lake sediments in the region. The curve without symbols was calculated by means of a mathematical model /Påsse 2001/.*

9,000–6,000 years ago a forest dominated by Tilia (lime), Quercus (oak) and Ulmus (elm) covered south-eastern Sweden. Picea (spruce) reached the Simpevarp area c. 2,000 years ago.

A pollen investigation, covering the last c. 1,500 years, was carried out on sediments from two lakes situated 20 and 25 km west of Fårbo (M. Aronsson and T. Persson, Dept. of Quaternary Geology, Lund University, unpublished data). The results show an increase of Juniperus (juniper) and Cerealea (corn) c. 1,200 years ago, indicating that areas used as arable land and pasture increased at that time.

7.2.2 Shoreline displacement

A major crustal phenomenon that has affected and continues to affect northern Europe following melting of the last ice sheet is the interplay between isostatic recovery on the one hand and eustatic sea level variations on the other. Isostatic recovery is an ongoing process, caused by the removal of the load of the Weichselian ice sheet. The rate of recovery has decreased significantly since the deglaciation, and has during the last 100 years has been c. 1 mm per year /Ekman 1996/.

The highest shoreline in the Oskarshamn region is located c. 100 m above the present sea level /Agrell 1976/. Thus, the whole Simpevarp regional model area is situated below the highest shoreline. According to e.g. /Svensson 1989, Björck 1995/, the shoreline dropped instantaneously c. 25 m due to drainage of the Baltic Ice Lake 11,500 years ago. The Yoldia Sea stage was characterized by a regressive shoreline displacement. The onset of the following Ancylus Lake stage was characterized by a transgression with an amplitude of c. 11 m. There are no studies from the Oskarshamn area dealing with shoreline displacement during the Littorina Sea stage. Results from a study c. 100 km north of Simpevarp /Robertsson 1997/ suggest a regressive shoreline displacement during the Littorina era. However, more detailed stratigraphical studies of sediments from areas north (Södermanland) and south (Blekinge) of the Simpevarp area have shown that three transgressions occurred in Södermanland during that period and six in Blekinge /Risberg et al. 1991, Berglund 1971/. It is therefore likely that several transgressions occurred in the model area during the Littorina era. Figure 7-11 shows the former shoreline in the Simpevarp regional model area on three different occasions during Holocene. A large part of the Simpevarp regional model area was free of water already at the end of the Baltic Ice Lake 9,700 years ago (cf. Fig. 7-11A).

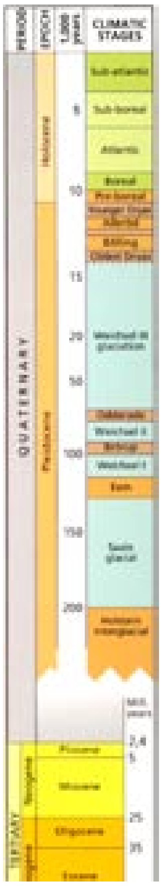


Figure 7-10. *Geological timescale showing the subdivision of the late Quaternary period with climatic stages from /Fredén 2002/. The ages are approximate and given in calendar years before present.*
From: Swedish National Atlas, www.sna.se.

7.2.3 Salinity changes in the Baltic Sea

The evolution of the Baltic Sea since the last deglaciation is characterized by changes in salinity, caused by variations in the relative sea level. This history has therefore been divided into four main stages /Björck 1995, Fredén 2002/, summarized in Table 7-1. The Baltic Ice Lake stage was characterized by freshwater conditions. Weak brackish conditions prevailed 11,300–11,100 years ago during the Yoldia Sea stage /e.g. Andrén et al. 2000/. The salinity was between 10‰ and 15‰ in the central Yoldia Sea /Schoning et al. 2001/. The Baltic Sea was thereafter characterized by freshwater conditions until the onset of the Littorina Sea around.

9,500 years ago /Fredén 2002, Berglund et al. 2005/. The salinity of the Baltic Proper since the onset of the Littorina period has been reviewed by /Westman et al. 1999, Gustafsson 2004a/ with an updated chronology from /Fredén 2002/. Freshwater conditions prevailed during most of the deglaciation of Sweden. Salinity was probably low during the first c. 1,000 years of the Littorina Sea stage but started to increase 8,500 years ago. Salinity variations since the onset of the Littorina Sea are shown in Figure 9-1. The most saline period occurred 6,000–5,000 years ago when the surface water salinity in the Baltic proper (south of Åland) was 10–15‰ compared with approximately 7‰ today /Westman et al. 1999/. Variations in salinity during the Littorina Sea stage have mainly been caused by variations of freshwater input and changes of the cross-sectional areas in the Danish Straits /cf. Westman et al. 1999/. Since the Simpevarp area has been situated close to the coast during most of the Littorina stage, it can be assumed that salinity has been generally lower than is shown in Figure 9-1.

7.2.4 Quaternary deposits

The distribution of fine-grained water-laid QD is mainly related to the local bedrock morphology. These sediments are mostly restricted to the long and narrow valleys which are characteristic of the investigated area. The highest areas have been subjected to erosion by waves and streams. Periods with erosion have also occurred in the valleys, but it is evident that long periods with deposition of fine-grained material have also occurred in these areas.

The oldest fine-grained deposit, glacial clay, was deposited during the last deglaciation when the water was relatively deep. As the water depth decreased, streams and waves started to erode the uppermost clay and deposited a layer of sand/gravel on top of the clay. The lowest areas became sheltered bays as the water depth decreased, and post-glacial clay containing organic material started to deposit. The maps in Fig. 9-11 clearly show that the present areas covered with gyttja clay coincide with areas that were once sheltered bays. The areas that are used as arable land today were long and narrow bays during the Littorina Sea period (cf. Figure 7-11B and C). The processes of erosion and deposition are still active at the seafloor and along the present coast. The floors of many of the valleys are former or present wetlands where layers of peat have formed. The areas consisting of wetlands have, however, decreased significantly due to artificial draining.

Results from three radiocarbon dates of sediments from Borholmsfjärden show that theclay gyttja at that site started to accumulate in the Littorina Sea c. 3,000 years ago. The accumulation rate calculated from the 14C analyses is c. 1.2 $mm \cdot y^{-1}$. /Lidman 2005/ used 210-Pb dates to calculate the peat growth rate in wetlands. The accumulation rate in the peat bog Klarebäcksmossen is 1.45 ± 0.06 $mm \cdot y^{-1}$ according to these dates. That corresponds to an annual accumulation of material of 51.0 ± 0.8 $g \cdot m^{-2} \cdot y^{-1}$.

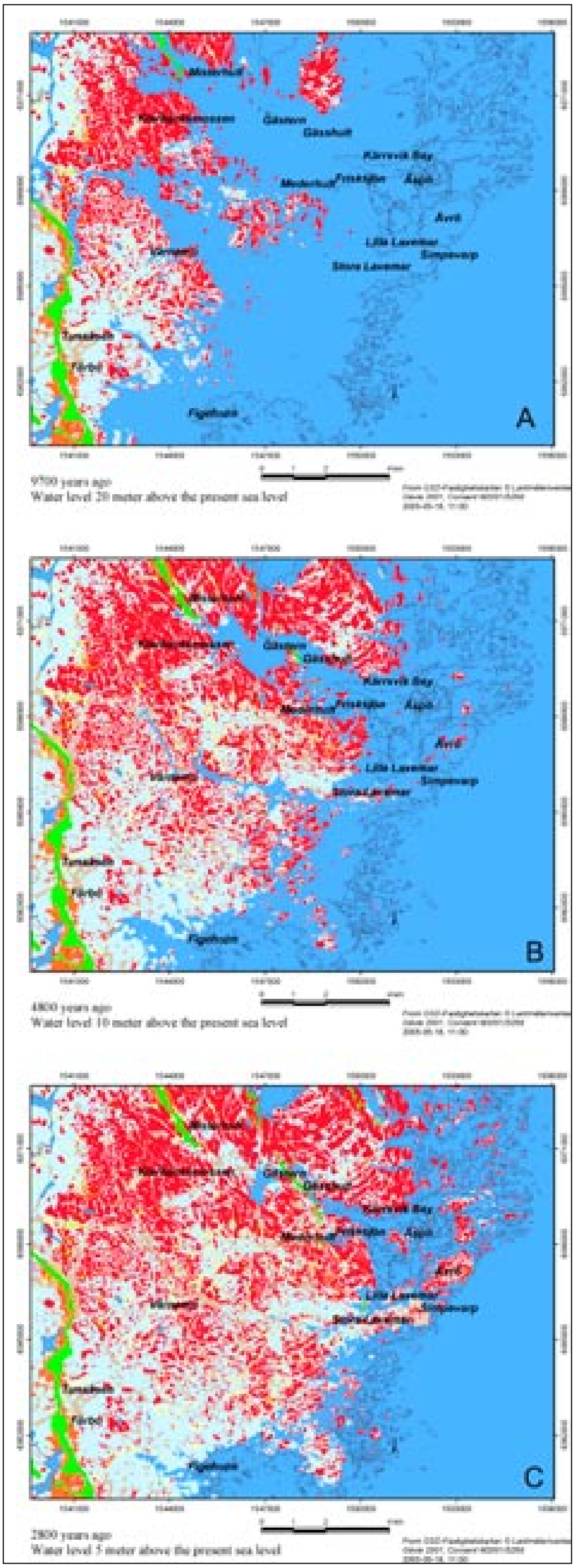


Figure 7-11. The distribution of land and sea on three different occasions during Holocene, A) 9,700 years ago, B) 4,800 years ago, C) 2,800 years ago.

7.2.5 Evolution from the present situation 500 years ahead in time

The relatively low rate of land uplift in the Laxemar-Simpevarp area today, in combination with the generally relatively deep areas near today's coastline, means that no major changes in the landscape due to the shoreline displacement are to be expected during the next 500 years.

7.2.6 Evolution from 2,500 AD until the next period with permafrost

The Laxemar-Simpevarp area will probably continue to be situated at, or at least near, the coast for the whole period until the next period with permafrost. The most important change in the future landscape will be the isolation of the inner coastal basins from the Baltic Sea, which means that a number of new lakes will be formed. Lake Frisksjön will become filled with sediments and vegetation and is projected to become a mire at 3,000 AD.

At 4,000 AD, the bays north and south of Äspö are expected to become isolated from the sea and form large lakes. A terrestrial landscape will subsequently dominate the surroundings of the repository, and it is assumed that most of the area close to the repository will be agricultural land. The remaining lakes will be gradually infilled, a process which will take c. 2,000 years for the shallow Borholmsfjärden. However, the deeper Granholmsfjärden with its relatively steep shores will remain a lake even after 10,000 AD. The coastline on the seaward side of the Simpevarp peninsula will also change only slightly.

The surface ecosystems around the proposed repository location will stabilize quite early in the period as potential agricultural land, which will persist for the rest of the interglacial period. It is assumed that the terrestrial period of the Laxemar-Simpevarp-Simpevarp area will end at 10,000 AD, when a permafrost period will begin (see below).

8 Couplings to the interaction matrix

8.1 Introduction

The overall objective of this report is to provide a thorough description of the marine ecosystem that may be further used in the Safety Assessment. By the aid of an interaction matrix this chapter illustrates how important processes for the safety assessment are considered in the report. The general principles of an interaction matrix are illustrated in Figure 8-1. 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 8-1. 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.

8.2 Elements in the interaction matrix

From previous studies, 15 diagonal elements of the interaction matrix have been identified and the interaction matrix for the marine ecosystem is presented in Figure 8-2. The diagonal components of the marine ecosystem are further described in Table 8-1. The number of elements is a compromise between the need to keep the matrix to a manageable size and the requirement to be

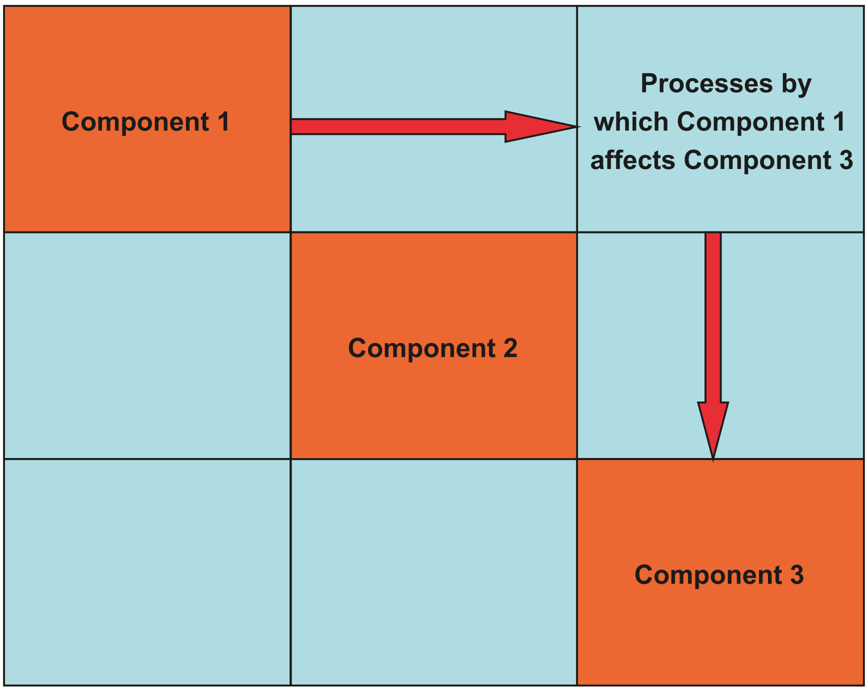


Figure 8-1. *Illustrative interaction matrix.*

Figure 8-2. *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. Most processes are considered in the report and only processes shaded in the figure are not considered.*

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 8-1.

Table 8-1. Components of the marine 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	Autotrophic organism, able to utilize inorganic sources of carbon as starting material for biosynthesis, using sunlight as energy source.
Decomposers	Organisms 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	Bipedal primates of the species *Homo sapiens* in the family Hominidae. Tend to be omnivores, although some individuals are strict herbivores or even frugivores.
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. The Earth's **atmosphere** is a layer of gases surrounding the planet Earth that is retained by the Earth's gravity.
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 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 extaernal conditions is the environment outside the marine ecosystem.

8.3 Processes in the interaction matrix

All processes in the marine 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 marine ecosystems in this report. The processes in the interaction matrix (Table 8-2 and Figure 8-2) are ranked according to importance for the safety assessment: 0 = irrelevant, 1 = insignificant, 2 = unknown 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 8-2, 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 8-2. In total, 57 grouped processes were identified and how these are considered in the report is described in the section below.

8.3.1 Biological processes

Important and indefinable processes (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 burrowing, construction and flushing by establishing root structures. Bioturbation is included in the descriptive chapters of this book (Chapter 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.

Table 8-2. Processes in the interaction matrix for the marine system. The processes are ranked according to importance for the safety assessment as follows: 0 = not relevant, 1 = insignificant, 2 = unknown influence, 3 = important.

Processes	Ranking	Considered
Biological processes		
Bioturbation	3	yes
Consumption, Feeding	3	yes
Decomposition, Degradation	3	yes
Food supply	3	yes
Human activitis, Resurc,Filtein,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
Geometric extension	3	yes
Land uplift	3	yes
Resuspesio,Deposition RemoalSpray/ 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

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 Chapters 3 and 4.

Settlement is the active choice by organisms of a place for living. Settlement in the seas 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 sea, and settlement is thereby 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 the sea. 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 sea are often thick and it is unlikely that roots from marine 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 (immigration) or leave the area (emigration) 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 marine ecosystems. Migration is therefore considered to be irrelevant.

Intrusion is when organisms enter the geosphere by locomotion or growth (e.g. roots). However, considering the great depths of the marine sediments and anoxic conditions in deeper layers of sediment, this is most probably an insignificant process in the sea and is considered irrelevant.

Movement is the influence of animal movement on surface waters. Considering the small size and biomass of the animals in the sea, this process is considered to be insignificant and irrelevant.

Pollution, Anthropogenic effects and **Fertilizing** are different examples of how humans may affect the marine ecosystems. The marine ecosystems in the Forsmark area and the Laxemar-Simpevarp area are generally affected by agriculture and forestry realeases and in Forsmark, earlier iron industry and mining. However, current human impact on the marine ecosystems in Forsmark and Laxemar is small, so this process is considered to be irrelevant for the safety assessment. Nevertheless, human impact is accounted for in the descriptive chapters 3.

Stimulation/Inhibition. 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 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 overall ecosystem productivity. The process is assumed to be already included in the input data for the descriptive chapters (Chapters 3 and 4), e.g. as biomass and occurrence of different species.

8.3.2 Chemical processes

Important and indefinable processes (rank 3-2)

Mixing pertains to water, the solvent and main carrier of the elements in the ecosystem. The magnitude, direction and distribution of the water flow in the sea will affect the mixing of water from different sources, and thereby also the composition of the water. In addition, temperature influences diffusion. Water chemistry and temperature measurements are available for both the surface and bottom water in both Forsmark and Laxemar-Simpevarp. Thus, this process is considered in the report.

Reactions include chemical reactions, exothermic/endothermic 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 concentration of oxidants such as 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 the temperature and chemical composition of water, is measured at the sites, so this process is to a great 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 composition of the water, 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 inasmuch as both temperature and period of ice cover are 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.

8.3.3 External processes

Important and indefinable processes (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 (Chapters 3, 4, 5, and 7).

8.3.4 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 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 marine 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 to be 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.

8.3.5 Hydrological and meteorological processes

Important and indefinable processes (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 advection: the hydraulic conductivity and storage capacity (porosity) of Quaternary deposits, topography, atmospheric pressure, the pressure of existing gas, temperature and temperature changes, air intrusion and infiltration of water in sediments by human activities, bottom topography and fetch (the distance where the blowing wind is not disturbed). Water flow and CO_2 gas exchange have been estimated in calculations of the mass balances, so advection is considered in the report (Chapter 4 and 6).

Precipitation/dissolution. The amount of precipitation such as rainfall, snow fall and hail will influence the amount of surface waters and of ice and snow on surfaces, as well as the amount of different substances transported to the sea. This has been considered in the mass balances, where precipitation of different elements, as well as transport of different elements to the sea, has been calculated (Chapter 6).

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, landslides, earth tides, weather and climatic changes. This has been addressed in the historical description as evolution of the area (Chapter 8). Future evolution of the marine area 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.

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 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 not been considered for the marine areas in the calculations.

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 amount of surface waters and of snow/ice on surfaces. Wind has been considered in the calculations of advective water flux and in the mass (Chapter 5 and 4).

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 sea surface 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 for Forsmark, so water content is considered although changes are not (Chapters 3).

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 atmospheric humidity. The surface area of primary producers influences the amount of water from precipitation and irrigation that is retained in the primary producers, and thereby influences the amount of surface water as the droplets on primary producers are included in the definition of surface water. In the marine 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 the sea) to "free" water. Potentially, this process affects the water content of the Quaternary deposits. However, the water content in sea sediments is high and this process is considered irrelevant.

Light absorption, light attenuation, insolation. Light absorption and light attenuation determine the settlement of primary producers and insolation determines primary production. This has been considered in the models (Chapter 4).

Light reflection, scattering and radiation in surface water influence the adsorption and distribution of light and thereby the type and productivity of primary producers. Light reflection itself is not measured at the sites, but the resulting productivity of primary producers and the 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, manmade 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 wind velocities and directions. Wind speed is included in the oceanographic calculations of advective flow (Chapter 5).

8.3.6 Mechanical processes

Important and indefinable processes (rank 3-2)

Deposition, sedimentation, surface deposition/uptake are important for the mass balances of the marine ecosystems. These processes have been included in the report in the description, in the ecosystem carbon models, as well as in the mass balances (Chapter, 3, 4, and 6).

Land uplift is the recovery of the earth crust from the compression caused by the load of the last glacial ice cover. Interglacial conditions prevail today and land uplift influences the topography. Isostatic land uplift in combination with eustatic sea level changes result in shoreline displacement, which is accounted for in the description of long-term evolution of the marine areas (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 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 4 and 6), and although resuspension is not measured, sediment accumulation (net effect of sedimentation and resuspension) is included.

Consolidation is the transformation of sediments to solid rock. 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 the marine area that is traditionally used for these kinds 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 since most calculations are performed with GIS grids based on the DEM for the areas (Chapter 4, 5, 6).

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 organisms dependent on gravitation and other forces e.g. wind. Movement of solid matter can also be caused by disturbances, 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. Relocation is accounted for in the report as the extent of accumulation bottoms used in the calculation of mass balances (Chapter 7), i.e. from which all other bottom relocation occurs. Disturbance is considered to be small and is not further treated.

Weathering, Erosion are the processes whereby solid matter disintegrates into smaller pieces. This is considered irrelevant for the marine 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 composition of the water. However, the difference in density is too small to have any significant impact on water composition, and the process is considered irrelevant. The result of the process is considered in the report 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 exerts on the underlying regolith or rock. Changes in the 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 marine 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), 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 marine ecosystem and is not included in the report.

8.3.7 Radiological processes

Important and indefinable processes (rank 3-2)

Decay, Formation of stabile isotopes. The decay of radionuclides to stable isotopes affects the water composition in the different components of the biosphere (surface water, groundwater, water in regolith). The decay is not considered in this version of the report.

External exposure. The concentration, location and types of radionuclides in surface waters, Quaternary deposits and in the atmosphere, i.e. in all parts of the biosphere system, affect the external exposure of 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 the long-term behaviour of the radionuclides that may originate from nuclear waste. The concentrations of radionuclides and stable isotopes in water, Quaternary deposits and biota are considered in the mass balances (Chapter 4 and 6).

Internal exposure: The concentration, location and types of radionuclides and other toxicants incorporated into organisms will affect the exposure of and the radiological and toxic effects on the organism. This is considered as concentrations of radionuclides and stable isotopes in biota (Chapter 3 and 6).

Insignificant and irrelevant processes (rank 0-1)

Irradiation, Radiolysis. Irradiation of the materials in Quaternary deposits by radionuclides may affect the mineralogical structure of the materials in Quaternary deposits. Radiolysis is radiation from decaying radionuclides that causes radiolytic decomposition of the water, which thereby affects the water composition in the different components of the biosphere system. Both irradiation and radiolysis are considered to be of minor importance for the marine ecosystem and are not treated in the report.

8.3.8 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 marine ecosystem and are thus not treated in the report.

9 Synthesis

The aims of this report have been to give a coherent description of the marine ecosystems of the sites in the Forsmark and Laxemar-Simpevarp area and to present descriptions of food webs, pools and fluxes of organic matter, water and a number of other elements. The descriptions serve to underpin a thorough understanding of ecosystem patterns and processes at the two sites and to identify the major pools and fluxes of carbon and other elements. The following text is intended to summarize the general description of the marine ecosystem at the two sites, describe general food webs, the major pools and fluxes of carbon and other elements, estimate the human impact in the marine area and provide a brief description of the historical long-term evolution of the sites.

9.1 General description – both sites

In comparison with the Gulf of Bothnia and the Baltic Proper, salinity is somewhat lower in Forsmark and Laxemar-Simpevarp, respectively, probably due the influence of freshwater from land. Mean light penetration depth and water temperature are also lower at both sites than in the national monitoring programme, probably due to their location near the coast, with higher loads of organic material. The oxygen levels in Laxemar-Simpevarp are relatively high compared with the levels found in the national monitoring programme.

The nitrogen and phosphorus levels are low to moderately high at the two sites compared with the environmental monitoring data for the corresponding areas in the Baltic Sea. In Forsmark, nitrogen seems to be the limiting nutrient during the summer months. In Laxemar-Simpevarp, nitrogen seems to be the limiting nutrient in the outer areas and phosphorus in the inner bays. This coincides with general conditions in the Bothnian Sea (Forsmark) and the Baltic Proper (Laxemar-Simpevarp).

The major and minor constituents in water at the two sites agree with the data from the national monitoring programme. Only Mn is clearly higher than the reference at both sites. Concentrations of trace metals in the Baltic Sea are generally high. Some of the analyzed trace metals at the sites are even higher than the Baltic in general, e.g. Cd, Pb and Cu in Forsmark and Pb and Zn in Laxemar-Simpevarp, which may be due to the strong anthropogenic influence in the area but may also be an effect of different detection limits in different studies.

Forsmark is situated in an area with somewhat higher precipitation than Laxemar-Simpevarp. The annual mean water temperature is slightly above the mean for the Baltic Sea in Forsmark and slightly lower in Laxemar-Simpevarp-Simpevarp. Runoff in the Forsmark area is higher (0.6 m^3 m^{-2} $year^{-1}$) than in Laxemar-Simpevarp (0.2 m^3 m^{-2} $year^{-1}$). Global irradiation is relatively evenly distributed throughout Sweden and the sites have similar daily values. Laxemar-Simpevarp has a slightly higher mean value than Forsmark.

The sea level has fluctuated since 2003 between 0.6 below and 1.3 m above the mean in Forsmark and between-0.5 and 0.7 m in Laxemar-Simpevarp. Because the coastline in Forsmark has a gentler slope, the sea level fluctuation has a more marked effect on the landscape there, than in Laxemar-Simpevarp which have a steeper slope.

Both areas, showing low surface relief (< 25 m) associated with the subcambrian peneplains, have undergone bathymetric surveys further compiled using kriging into detailed digital elevation models. The overall bedrock surface slope is slightly gentler in Forsmark (1:500) than in Laxemar-Simpevarp (1:400). Lineaments include bedrock fissures and in the Forsmark area, faultlines related to the Gräsö trough forming the deeper part of Öregrundsgrepen. Forsmark has a narrow shallow archipelago while Laxemar-Simpevarp is more clearly divided into the inner sheltered bays and the outer exposed coast.

Sediment conditions have been mapped in both areas using extensive seismic investigations, side-scan sonar, coring and probing. The sediment shows the characteristic sequence till, glacifluvial sediments along eskers, glacial and postglacial clay (redistributed by coastal processes during isostatic uplift). It is thickest along the lineaments, up to 10–20 m in both areas.

Both areas have also been relatively well exposed to coastal processes. Bedrock and till are typically exposed nearshore, while glacial clay, usually covered with a thin sand layer, is exposed offshore. Postglacial clays and mud deposits (accumulation bottoms, or A-bottoms) are found only in either sheltered inshore settings, lagoonal areas (flads and gloes) in the Forsmark area and inner bays in Laxemar-Simpevarp, or in the deeper troughs.

The historic development of A-bottoms areas has been studied through wave-ray modelling and the present organic carbon burial rates have been quantified as they constitute a potential sink of redistributed elements. Organic carbon burial rates are higher in the Laxemar-Simpevarp A-bottom locations (74–95 gC $m^{-2}yr^{-1}$) than in Forsmark (~ 14 gC $m^{-2}yr^{-1}$). Although, in Laxemar-Simpevarp the general burial takes place in the bays, in the more exposed outer areas the burial is very small.

The mean depth in the marine areas is somewhat higher in Forsmark than in Laxemar-Simpevarp and the extension of exposed hard bottoms is higher in Laxemar-Simpevarp. The burial is more rapid in the secluded bays in Laxemar-Simpevarp than in Forsmark although, the burial occurs over larger areas in Forsmark.

In Forsmark the macrophyte vegetation in the photic zone is dominated by red algae (e.g. *Polysiphonia nigrescens*) and brown filamentous algae (e.g. *Spacelaria arctica*) and the larger *Fucus vesiculosus*. In the sublittoral zone, green algae, e.g. *Cladophora glomerata*, are present as well as the moss *Fontinalis dalecarlica*. In secluded bays, soft bottom-dwelling phanerogams (e.g. *Potamogeton pectinatus* and *Charophyceae* (e.g. *Chara tomentosa*) dominate the macrophytes. In deeper areas in Tixelfjärden and Kallrigafjärden, the *Xanthophyceae* algae *Vaucheria dichotoma* is found in high densities.

In Laxemar-Simpevarp, the red algae community covers the largest area followed by the *Potamogeton pectinatus* community, *Chara sp* and *Fucus vesiculosus.* The inner soft bottom parts of the archipelago north of Laxemar-Simpevarp (around the island of Äspö) are dominated by *Chara sp*. West of Ävrö, a large area is covered by *Xanthophyceae*. On inner soft bottoms in the southern area, the vegetation is dominated by vascular plant communities, mostly *P. pectinatus* and *Zostera marina*. Further out towards more exposed areas, *P. pectinatus* and *Z. marina* occur together in a patchy distribution. On hard substrates in shallow areas, the vegetation is dominated by *Fucus vesiculosus*, while in deeper areas red algae covers the hard substrate.

At both sites as generally in marine areas, the photic zone on the seabed is covered to a large extent with a layer of microalgae (microphytes), mainly diatoms.

Generally in the Baltic, the spring bloom as well as the autumn maxima is dominated by the diatoms. After the spring bloom of the diatoms, dinoflagellates and other smaller flagellates become more important, later to be followed by maximum densities of the consumers cyanobacteria and zooplankton. This is not entirely true for Forsmark and Laxemar-Simpevarp, where Forsmark has a dominance of diatoms only during the late winter growth period, while the autotrophic red-tide ciliate *Mesodinium rubrum* is the main constituent during the rest of the blooming period, and Laxemar-Simpevarp has a spring bloom dominated by the diatoms and later on in July by dinophytes and cyanobacteria. In comparison with data from the national environmental monitoring programme, the chlorophyll values in Forsmark are considered quite low, which is quite the opposite of Laxemar-Simpevarp where they are considered high.

Benthic bacteria, i.e., all heterotrophic bacteria on the sea floor and in the sea bed, in Forsmark and Laxemar-Simpevarp show a higher abundance and biomass than generally found in Kattegat and the Baltic Sea. The species and abundances of the benthic fauna in the Baltic and Bothnian Sea are clearly dependent on salinity, and the salinity levels in Forsmark, are considered to harbour the fewest species. The site investigations at Laxemar-Simpevarp and Forsmark confirm these conclusions, where both taxa and mean biomass are much higher in Laxemar-Simpevarp than in Forsmark.

The abundance and distribution of benthic fauna in Forsmark are similar to those in the geographical region. Since the start of the monitoring (1970), increases have been seen in benthic biomass and species diversity. The increase in total biomass can also be seen elsewhere in the Baltic, probably due to the increased nutrient load. The biomass at the soft bottom sampling sites has been dominated by the Baltic mussel (*Macoma baltica*), and in deeper areas another important species has been *Monoporeia affinis*. On hard bottoms the blue mussel (*Mytilus edulis*) also contributes to the benthic fauna. The highest biomass values in the Forsmark area are found in vegetation-associated soft bottom fauna.

In soft bottoms in Laxemar-Simpevarp, the filter-feeding bivalve *M. baltica* clearly made the largest contribution to the total biomass in all areas. The most frequent taxa in the samples from the archipelago north of Simpevarp were *Chironomidae* and *M. baltica*. *Chironomidae* was also the leading contributor to the total abundance. The sessile macrofauna attached to hard substrates (hard bottom fauna) is completely dominated by *M. edulis* in terms of both biomass and abundance. Exposed hard bottoms in the area covered with *M. edulis* have the highest biomasses of benthic fauna in the area.

The zooplanktion species in Forsmark and Laxemar-Simpevarp are generally the same species as in the rest of the Baltic. Winter and spring are dominated by copepods at both sites. However, in Laxemar-Simpevarp, a more diverse structure is found in the summer with cladocerans, rotifers and larvae of some benthic macroinvertebrates.

Bacterioplankton, i.e. free living bacteria in the pelagic habitat, in Forsmark and Laxemar-Simpevarp, show similar mean abundances as in the Gulf of Finland, the Baltic Sea and other temperate areas in the North Sea.

Test fishing in Forsmark and Laxemar-Simpevarp show similar development as in other nearby coastal areas and herring and sprat are the dominant species in offshore areas at both sites. The fish biomass was higher in Forsmark than in a reference area. In the inner bays at the sites, perch and pike are the most frequent species.

Both sites harbour common bird species (as well as rarer ones), which feed in the marine habitat as piscivores or herbivores. Three species of seal live in the Baltic: grey seal, ringed seal and harbour seal. Grey seal live in the archipelago at the two sites, although not in high densities.

The biotic samples from the two marine ecosystems Forsmark and Laxemar-Simpevarp were analyzed for various elements. The average carbon content in the functional groups at the two sites varied between 140 gC/kg dw and 530 gC/kg dw, and was generally highest in zooplankton and fish. This distribution was also valid for N and P, although in lower concentrations.

The impact of industry and forestry was historically more direct in the Forsmark area, through iron ore mining, than in Laxemar-Simpevarp where emissions of heavy metals have been important mainly in a larger-scale regional context. The Forsmark area is influenced regionally also by pulp bleach industries along the Gulf of Bothnia coast to the north. Agricultural nutrient emissions are also either local via rivers and streams, or part of the larger-scale eutrophication of the Baltic Sea.

An impact more specific to the Forsmark region is that of dredging and use of toxic repellents with the location of boat jetties in or near sensitive flad and gloe habitats.

The main impact of the nuclear reactors in both areas is that of the warm-water plume created by the emission of heated cooling water, resulting locally in stratification and changed oxygen conditions. Its current impact in surface and bottom waters, and the slightly higher impact of planned elevated emissions, has been simulated using numeric hydrographic modelling. The area of elevated temperature is approximately 30 km^2 in the Forsmark area and 17–20 km^2 in Laxemar-Simpevarp.

Fishery represents mainly a larger-scale impact in both areas. This impact has been characterised by overfishing of Baltic herring, in particular by catches due to trawling, however ameliorated with recent legislation, and by hydropower regulation affecting migrating fish. The overall status of the Forsmark area is not markedly below average among Baltic Sea coastal areas. This is true also for the Laxemar-Simpevarp area, which shows better status than already the adjacent Västervik-Misterhult archipelago to the north.

The oceanographic models that quantify water exchange in the coastal area at the two sites indicate a more rapid water exchange in Forsmark than in Laxemar-Simpevarp. In Forsmark the mean residence time in the various basins varies between 0.06 to 4.5 days, while in Laxemar-Simpevarp the mean residence time for the basins varies between 0.3 and 29 days.

9.2 Marine ecossystem model and mass balances

The massbalance calculations for the various elements are not all in balance, i.e. there is a net outflux or a net influx. This indicates uncertainties in the calculations.

9.2.1 Forsmark

The total biomass varies from just over 5 gC m^{-2} to 160 gC m^{-2} in the whole area and is distributed unevenly, focused mainly along the coast and in shallow areas. The mean biomass is 18 g C m^{-2} in the whole area resulting in an estimated total of 4,400 tonnes of carbon fixed in biota in all basins. The biomass in most basins is dominated by macrophytes, 4 to 87% of the biomass in separate basins. Macrophytes are especially dominant in basins along the western coastline. Primary producers (due to the dominance of the macrophytes) are the most abundant group in most of the basins, especially in the coastal zone. Benthic fauna tend to dominate in offshore basins. Pelagic fauna is the smallest group in all basins. A total of between 70 and 100% (on average 91%) of the total biomass in all basins consists of benthic organisms.

Like biomass, net primary production (NPP) is concentrated to the shoreline, where the highest values are found. The mean annual NPP in the whole marine area in Forsmark is 100 gC m^{-2}. In separate basins, the mean NPP ranges from 43 to 287 gC m^{-2}. The results show that although most of the studied area is heterotrophic, the mean for the whole area is autotrophic, i.e. more carbon is fixed in biomass by primary producers than is released by all organisms. The mean NEP in the whole model area is 24 gC m^{-2} $year^{-1}$, while the annual mean in separate basins range between –33 and 224 gC m^{-2} $year^{-1}$. The coastal shallow basins generally tend to be autotrophic while the offshore areas are heterotrophic.

On average in the marine area, 20% of the carbon fixed by the primary producers is transferred to the next trophic level in the food web. The other pathway for carbon flux in the food web is via consumption of POC or in surface sediment. The average size of primary consumption by heterotrophs in this pathway is four times higher than primary consumption by herbivorous. Of the total initially consumed carbon in the whole food web, around 4% is transferred all the way up to the top predators (piscivorous fish, seals, birds and humans).

The largest pools of carbon in all basins in the marine area in Forsmark are the abiotic pools – sediment, DIC and DOC – followed by the largest biotic pool, macrophytes. The sediment content of carbon is around 20 times higher than in the other pools. Sediment comprises around 76% of the total carbon in the whole basin, followed by the dissolved pool (15%), macrophytes (3%), benthic detrivores and meiofauna (1.5%) and the particulate pool (1%). All other pools constitute less than 1% of the total carbon inventory in the whole marine model area in Forsmark. The advective flow of carbon is the overall dominant flux, and advective flux is several orders of magnitude greater than any other carbon flux, such as NPP, runoff and burial. Transport from land, lakes and streams makes only a minor contribution of organic matter to the marine ecosystem. The largest biotic carbon flux is fixation of carbon by primary producers, while the second largest is consumption of DOC by bacterioplankton. But the biotic fluxes are still small in comparison with the advective flux of carbon.

According to the model the total flux of carbon in the whole marine area (runoff, advection, deposition, diffusion and net primary production, advection, respiration and burial), is negative, i.e. there is a net outflux of carbon from the whole marine area of about 36,000 tonnes per year. This is equivalent to around 50 gC m^{-2} $year^{-1}$. But not all of the basins show a net outflux.

For nitrogen, phosphorus and thorium the major pool in the ecosystem is sediment, while for uranium the sediment pool and the dissolved pool are almost equally large, and for iodine the dominant pool is the dissolved phase. Mass balance calculations for the elements nitrogen, phosphorus, iodine, thorium and uranium also show a net outflux, except for phosphorus, which has a small net influx in the whole marine area, although burial for phosphorus is still very small.

9.2.2 Laxemar-Simpevarp – Simpevarp

The total biomass varies from just below 2 gC m^{-2} to over 450 gC m^{-2} in the area. The mean biomass is 91 g C m^{-2} in the whole area, resulting in an estimated total of 10,430 tonnes of carbon fixed in biota in all basins in Laxemar-Simpevarp marine model area. The highest average biomass in the area is found among the filter feeders, which, when the substrate is suitable, form very dense colonies with high biomasses. The biomass in 8 out of 19 basins is dominated by macrophytes, and they are all secluded bays. The average macrophyte fraction of the biomass in all separate basins varies between 26 and 80%. In some of the more exposed basins, filter feeders constitutes a large portion (50–60%) of the total biomass, but for the whole marine area the filter feeders only constitute on average 28% of the total biomass. Other organisms contribute less than 10% of the total biomass on average. Net primary production (NPP) is concentrated to the shoreline, where the highest values are found, but also to the offshore areas, where depth and enhanced water transparency permit high phytoplankton production. The average NPP for the whole marine area in Laxemar-Simpevarp is 170 gC m^{-2}. Average values for separate basins range from 99 to 707 gC m^{-2}. This agrees well with other reported average values of primary production in the Baltic. The marine area as a whole is heterotrophic, i.e. more carbon is released than is fixed in biomass. Nine out of 19 basins are autotrophic, all of them coastal basins with macrophyte biomass constituting more than 50% of the total biomass. Thus, bays in the area tend to be autotrophic, while the more offshore basins are heterotrophic. The annual average NEP in the Laxemar-Simpevarp model area is –161 gC m^{-2} $year^{-1}$. The annual mean range in separate basins is between –282 and 651 gC m^{-2} $year^{-1}$.

In the separate basins (the inner bays) the sediment pool can be the major carbon pool but in an average for the whole marine area, the dominant carbon pool is the dissolved phase. DIC and DOC, constitute in total 54% of the whole carbon pool in the area, followed by the sediment pool (21%), the consumer pool (16%, dominated by the filter feeders) and the producer pool (8.5%). Among the producers it is the macrophytes that constitute the main pool, while the other producers contribute less than 1% to the producer pool.

According to the model there is a net influx of carbon to the whole marine area in Laxemar-Simpevarp equivalent to around 9 gC m^{-2} $year^{-1}$. But not all basins show this net influx; some have a net outflux of carbon instead. The major flux of carbon is the advective flux. All other fluxes including burial are very small in comparison with the advective flux, and since there is less uncertainty in the burial term than in the advective term, the large net influx does not indicate that the area is a sink for carbon.

Of the total inventory of nitrogen in the whole marine area in Laxemar-Simpevarp, consumers constitute the largest pool (49%), followed by sediment (40%) and macrophytes (6%). The consumer pool is totally dominated by filter feeders. Phosphorus is quite evenly distributed between the sediment and consumer pools, which are of the same order of magnitude (43% and 44%, respectively). The third largest pool, although much smaller than the former ones, is primary producers (7%). For thorium and uranium, sediment is the dominant pool in most basins, while for iodine it is generally the dissolved phase, although the producer pool is often quite large.

Mass balance calculations for other elements (nitrogen, phosphorus, iodine, thorium and uranium) show a net outflux for nitrogen, thorium, and iodine. For uranium and phosphorus there is a net influx on average in the whole marine area. Burial is small for these elements.

Comparison marine ecosystem models and mass balances

In general biomasses of all functional groups and the primary production are higher in Laxemar-Simpevarp. The high abundances and thereby high consumption by the blue mussels in Laxemar-Simpevarp greatly affects the ecosystem and the resulting negative NEP in the area. The major carbon pool in Forsmark is the sediments and in Laxemar-Simpevarp it is the DIC-pool. Less carbon is transferred to the top predators in the food web of Laxemar-Simpevarp than in Forsmark. In Forsmark there is according to the model a net outflux of carbon in average in the whole marine area, in contrast to Laxemar-Simpevarp where there in average is a net in flux of carbon. Although at both sites the burial is generally small in comparison to other fluxes.

9.3 Abundance and distribution of carbon and other elements

The most abundant elements are the major constituents such as Cl, Na, Mg, S. They are distributed to a large extent in the dissolved phase, and will therefore be very abundant due to the large water volume. Cl is the most abundant element in the marine ecosystem in both Forsmark and Laxemar-Simpevarp. On average, the total Cl content in all pools at the two sites is 31 kg m^{-2} and 32 kg m^{-2}, respectively, followed by Na and Mg and in a slightly different order at the two sites Ca, K, S, Si and C. The rest of the elements are minor constituents contributing less than 1% of the total (by weight).

In Forsmark, the elements Mn, P, N, C, I, Co, Ni, Th, Cu, Fe and Ca have biotic pools larger than 1% (by weight), while 99% of all other elements is present in the abiotic pools considered (sediment, particulate matter and dissolved matter). In Laxemar-Simpevarp, more elements are heavily distributed in the biotic pool, generally due to the higher biomass in the area. The major portion of all lanthanides and the majority of the metals are in the sediments. But nitrogen, phosphorus, carbon and selenium in particular have biotic pools of substantial magnitude, from 25 to 50%.

9.4 Long-term evolution of the marine ecosystem

The evolution of the Baltic Sea following the last deglaciation has been characterized by progressive shoreline displacement. The interaction between isostatic recovery and eustatic sea level variations has caused varying depth in the straits connecting the Baltic Sea with the Atlantic Ocean in the west, which has in turn caused varying salinity throughout the Holocene. At 4500–3000 BC, during the middle of the Littorina Sea stage, the salinity of the Baltic Basin was almost twice as high as it is today in Laxemar-Simpevarp and Forsmark. It is suggested that all known loose deposits in both of the model areas were deposited during the last phase of the last glaciation and after the following deglaciation. In Forsmark, a till unit consisting of overconsolidated silty-clayey till was deposited during an earlier phase of the last glaciation. However, the possibility of the occurrence of older deposits cannot be excluded and there are indications of older deposits in neighbouring areas.

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Appendices

1. **Map over Forsmark**
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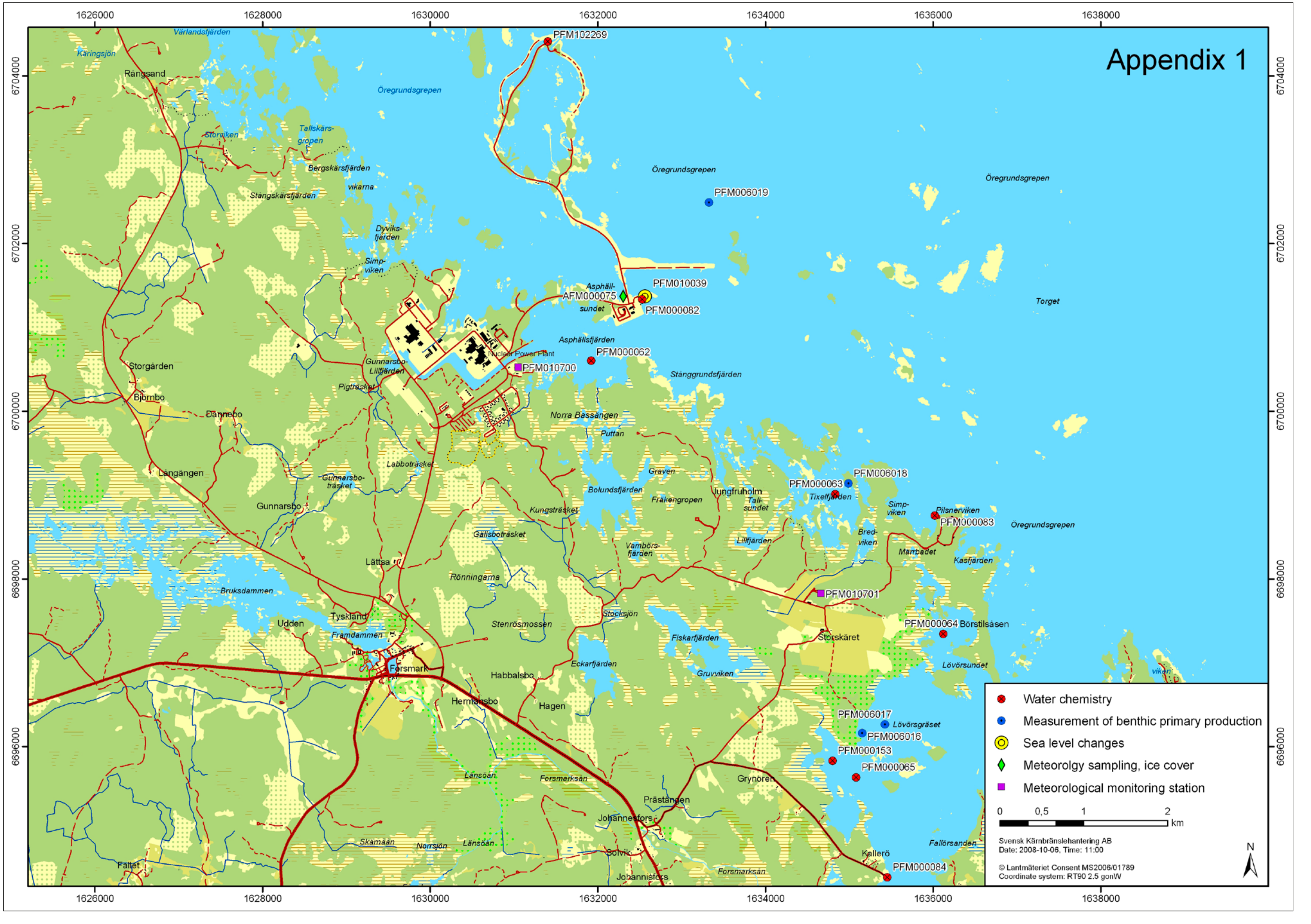
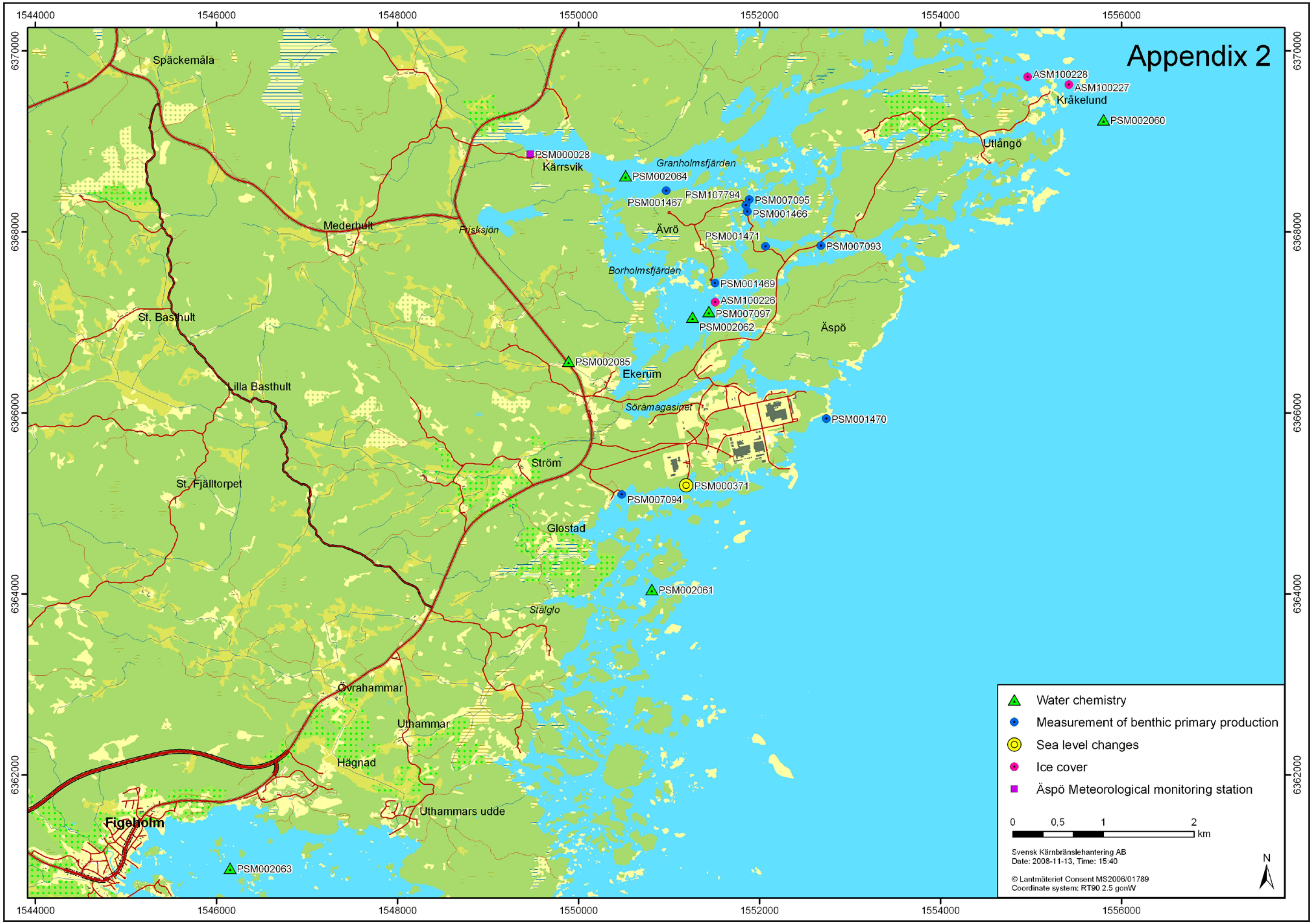
Map over Forsmark



Map over Laxemar-Simpevarp



Appendix 3

Site specific input data table

In this table, SKB-reports used in the description and modelling of the marine ecosystems are listed. In addition, site data from the database SICADA and marine data in literature have been used in some of the models in Chapter 4, 5 and 6. For these references, see descriptions in the chapters.

Available data	Reference	Usage in the report	Section
Human population and activities	SKB R-04-10	Description	3
Human population and activities	SKB R-04-11	Description	3
Meteorological monitoring at	SKB P-06-322		3
Meteorological, hydrological and hydrogeological monitoring data	SKB R-08-73		3
Identification of catchments	SKB P-04-25	Description and modelling	3
Sensitivity analysis	SKB TR-00-01	Description and modelling	5
Coastal oceanographic models	SKB TR-08-01	Description and modelling	5
Biomass of benthic and planktonic bacteria	SKB P-06-232	Description and modelling	3 and 4
Benthic macro invertebrates	SKB P-04-252	Description and modelling	3 and 4
Soft-bottom macrozoobenthos community	SKB P-04-17	Description and modelling	3 and 4
Marine fauna attached to hard substrates	SKB P-05-45	Description and modelling	3 and 4
Bird monitoring	SKB P-05-73	Description	3 and 4
Bird monitoring	SKB P-06-46	Description	3 and 4
Test fishing	SKB P-05-116	Description and modelling	3 and 4
Fish community biomass	SKB P-06-10	Description and modelling	3 and 4
Pelagic fish	SKB P-05-57	Description and modelling	3 and 4
The coastal fish community	SKB P-05-148	Description and modelling	3 and 4
Snow depth, frost in ground and ice cove	SKB P-03-117	Description	3 and 4
Snow depth, snow water content and ice cover during	SKB P-04-137	Description	3 and 4
Snow depth, snow water content and ice cover during	SKB P-05-134	Description	3 and 4
Snow depth, snow water content and ice cover during	SKB P-06-97,.	Description	3 and 4
Snow depth, snow water content and ice cover during	SKB P-07-81	Description	3 and 4
Meteorological, hydrological and hydrogeological monitoring data	SKB R-08-10	Description and modelling	3 and 4
Meteorological and oceanographic information and data	SKB TR-02-02	Description and modelling	3 and 4
Meteorological and oceanographic information and data	SKB TR-02-03	Description and modelling	3 and 4
Late Holocene distribution of lake sediment and peat	SKB R-01-12	Description	3 and 4
Surface sediment	SKB P-04-05	Description and modelling	3 and 4
Investigation of marine and lacustrine sediment	SKB P-03-24	Description and modelling	3 and 4
Investigation of marine and lacustrine sediment	SKB P-04-86	Description and modelling	3 and 4
Description of the regolith	SKB R-08-04	Description and modelling	3 and 4
Depth and stratigraphies of regolith	SKB R-08-07	Description and modelling	3 and 4
Bathymetric and geophysical	SKB P-04-254	Description and modelling	3 and 4
Mapping of Quaternary deposits	SKB P-06-88	Description and modelling	3 and 4
Vegetation mapping	SKB P-03-83	Description	3 and 4
Benthic vegetation, plant associated macrofauna	SKB P-05-135	Description and modelling	3 and 4
Phytobenthic production	SKB P-06-252	Description and modelling	3 and 4
Element composition of biota,	SKB TR-08-09	Description and modelling	3 and 4
Modelling of marine organisms	SKB R-07-50	Description and modelling	3 and 4
Phytobentic plant and animal communities	SKB P-04-82	Description and modelling	3 and 4
Sampling and analyses of surface waters	SKB P-07-95	Description and modelling	3 and 4

Surface hydrology and near-surface hydrogeology	SKB R-08-08	Description and modelling	3 and 4
Salinity change in the Baltic Sea during the last 8,500 years	SKB TR 99-38		8
Digital elevation models	SKB R-05-38	Description and modelling	4, 5 and 6
Digital elevation models	SKB R-04-70	Description and modelling	4, 5 and 6
Geological survey of the sea bottom	SKB P-03-101	Description and modelling	4, 5 and 6
Geological survey of the sea bottom	SKB P-05-35	Description and modelling	4, 5 and 6
Isostatci land up-lift	SKB R-01-41	modelling	4,5 and 6
Shore displacement	SKB TR-03-17	Description and modelling	4, 5 and 6
Mathematical model of past, present and future shore level displacement in	SKB TR 9 -28	Understanding and modelling	4, 5 and 6
Change in coastal sedimentation conditions	SKB TR-99-37	Description and modelling	3, 4 and 6
Shoreline displacement, sediment dynamics,	SKB TR-06-40	Description and modelling	3, 4 and 6
Chemical composition of suspended material, sediment	SKB P-08-81	Description and modelling	3, 4 and 6
Holocene sedimentary environmental changes at sites	SKB P-06-250	Description and modelling	3, 4 and 6
Investigation of sediments, peat lands and wetlands	SKB P-04-273	Description and modelling	3, 4 and 6
Depth and stratigraphy of regolith	SKB R-08-06	Description and modelling	3, 4 and 6
Depth and stratigraphy of Quaternary deposits	SKB R-05-54	Description and modelling	3, 4 and 6
Holocene sediment accumulation	SKB R-02-47	Understanding and modelling	3, 4 and 6
Bio- and lithostratigraphy	SKB P-05-139	Understanding and modelling	3, 4 and 6
Quaternary deposits	SKB P-05-49	Description and modelling	3, 4 and 6
Geological evolution, palaeoclimate	SKB R-08-19	Description	3, 4 and 6
Soils, Quaternary deposits and bedrock	SKB P-06-120	Description and modelling	3, 4 and 6
Description of regolith	SKB R-08-05	Description and modelling	3, 4 and 6
Quaternary deposits	SKB R-04-39	Description and modelling	3, 4 and 6
Dating of sediments and peat	SKB P-06-301	Description and modelling	3, 4 and 6
Chemical characterisation of deposits and biota	SKB P-06-320	Description and modelling	3, 4 and 6
Analysis of radioisotopes	SKB P-07-32	Description and modelling	3, 4 and 6
Chemical characterisation of deposits and biota	SKB P-06-320	Description and modelling	3, 4 and 6
Macrophyte communities	SKB R-05-47	Description and modelling	3, 4 and 6
Macrophyte communities	SKB P-05-47	Description and modelling	3, 4 and 6
Macrophyte communities	SKB P-03-69	Description and modelling	3, 4 and 6
Sampling of phyto- and zooplankton	SKB P-05-72	Description and modelling	3, 4 and 6
Distribution of aquatic plant and animal communities in the Forsmark area	SKB R-99-69	Description and modelling	3, 4 and 6
Phytoplankton and zooplankton.	SKB P-04-253	Description and modelling	3, 4 and 6
Vegetation communities	SKB P-03-68	Description and modelling	3, 4 and 6
Chemical characteristics of surface systems in the Simpevarp area	SKB R-06-18		3, 4 and 6
Chemical characteristics of surface systems in the Forsmark area.	SKB R-06-19		3, 4 and 6
Primary production and respiration in shallow phyto-benthic communities.	SKB P-06-303		3, 4 and 6
Surface water sampling	SKB P-04-13	Description and modelling	3, 4 and 6
Surface water sampling	SKB P-04-75	Description and modelling	3, 4 and 6
Surface water sampling	SKB P-05-118	Description and modelling	3, 4 and 6
Surface water sampling	SKB P-06-155	Description and modelling	3, 4 and 6
Monitoring of brook levels, water	SKB P-07-135	Description and modelling	3, 4 and 6
Sampling and analyses of surface waters.	SKB P-03-27	Description and modelling	3, 4 and 6
Sampling and analyses of surface waters	SKB P-04-146	Description and modelling	3, 4 and 6
Sampling and analyses of surface waters.	SKB P-05-274	Description and modelling	3, 4 and 6
Sampling and analyses of surface waters.	SKB P-07-95	Description and modelling	3, 4 and 6

Appendix 4

List of species mentioned in the report

In the following table, species mentioned in the rport in Forsmark (Fm) and Laxemar-Simpevarp (Lx) is listed. Data are gathered from SKB-reports.

Latin name	English name	Swedish name	Functional group
Mammals			
Halichoerus grypus	Grey seal	Grå säl	Mammal
Phoca vitulina	Harbour seal	Knubbsäl	Mammal
Pusa hispida	Ringed seal	Vikare	Mammal
Birds			
Alcidae sp.	Auks	Alkor	Bird
Aythya fuligula	Tufted duck	Vitkindad gås	Bird
Aythya marila	Scaup	Bergand	Bird
Cepphus grylle	Black guillemont	Tobisgrissla	Bird
Cygnus olor	Mute swan	Knölsvan	Bird
Gavia arctica	Black-throathed diver	Storlom	Bird
Haliaeetus albicilla	White tailed eagle	Havsörn	Bird
Laridae sp.	Gulls	Måsar	Bird
Mergus albellus	Smew	Salskrake	Bird
Mergus merganser	Goosander	Storskrake	Bird
Pandion haliaetus	Osprey	Fiskgjuse	Bird
Phalacrocorax carbo	Cormorants	Storskarv	Bird
Polysticta stelleri	Stellers Eider	Alförrädare	Bird
Somateria mollissima	Eider duck	Ejder	Bird
Sterna caspia	Caspian tern	Skräntärna	Bird
Sterna hirundo	Common tern	Fisktärna	Bird
Macrophytes			
Chara sp.	Stonewort	Sträfse	Macrophytes/ Kransalger
Chara tomentosa	Coral stonewort	Rödsträfse	Macrophytes/ Kransalger
Cladophora glomerata	Blanket weed	Grönslick	Macrophytes/ Green algae
Cladophora rupestris	’’	Bergsborsting	Macrophytes/ Green algae
Cladophora sp.	’’	(Grönslick)	Macrophytes/ Green algae
Dictyosiphon foeniculaceus	filamentous brown alga/ golden sea hair	Smalskägg	Macrophytes/ Brown alga
Enteromorpha sp.	Hollow green weed	Tarmtång	Macrophytes/ Brown algae
Fontanilis dalecarlica	Fontinalis moss	Smal snäckmossa	Macrophytes/ Moss
Fucus vesiculosus	Bladderrack	Blåstång	Macrophytes/ Brown algae
Myriophyllum spicatum	Water milfoil	Axslinga	Macrophytes/ Green algae
Najas marina	Holly-leafed najad	Havsnajas	Macrophytes/ Phanerogam
Phragmites australis	Reed	Bladvass	Macrophytes/ Phanerogam
Phyllophora sp.		Rödblad	Macrophytes/ Red algae
Pilayella littoralis	Sea felt	Brunslick	Macrophytes/ Brown algae
Polysiphonia fibrillosa		Violettslick	Macrophytes/ Red algae
Polysiphonia fucoides		Fjäderslick	Macrophytes/ Red algae
Polysiphonia nigrescens		Fjäderslick	Macrophytes/ Red algae
Potamogeton pectinatus	Sago pondweed	Borstnate	Macrophytes/ Phanerogam
Potamogeton perfoliatus	Clasping leaf pondweed	Ålnate	Macrophytes/ Phanerogam
Sphacelaria arctica		ishavstofs	Macrophytes/ Brown algae
Ulothrix sp.	Hair alage	Armbandsalger	Macrophytes/Green algae
vaucheria dichotoma	Water felt	Sjalgräs	Macrophytes/Yellow/green algae
Vaucheria sp.	Water felt	’’	Macrophytes/Yellow/green algae
Zanichellia sp.	Horned pondweed	Särv	Macrophytes/Phanerogam
Zostera marina	Eelgrass	Ålgräs/Bandtång	Macrophytes/ Phanerogam
Phytoplankton			

Mesodinium rubrum	Red-tide ciliate	Röd ciliat	Phytoplankton
	Diatoms	Diatomeer (Kise-lalger)	Phytoplankton
Zooplankton			
Acarttia bifilosa	Copepod	Hoppkräfta	Zooplankton
Bosmina coregoni	Water flea	Hinnkräfta	Zooplankton
Benthic fauna			
Hydrobia sp.	Laver spire shell	Tusensnäcka	Benthic herbivore
Idotea baltica	Isopod	Havsvatten-gråsugga	Benthic herbivore
Idotea chelipes	Isopod	Tånggråsugga	Benthic herbivore
Macoma baltica	Baltic clam	Östersjömussla	Benthic filter feeder
Marenzelleria viridis	Spionid polychaeta	Havsborstmask	Benthic carnivore
Monoporeia affinis	Amphipod	Vitmärla	
Mya arenaria	Soft shell clam	Sandmussla	Benthic filter feeder
Mysis sp.	Shrimp	Räka	
Mytilus edulis	Blue/Common mussel	Blåmussla	Benthic filter feeder
Nereis diversicolor	Ragworm	Rovborstmask	Benthic carnivore
Oligochaeta sp		Glattmaskar/Dagg-maskar	Benthic detrivore
Prostoma obscurum		Småmaskar	Benthic detrivore
Pygospio elegans		Havsborstmask	Benthic detrivore
Saduria (Mesidothea) entomon		Skorv	Benthic carnivore/ Benthic detrivore
Sphaeroma hookeri		Vattengråsugga	Benthic detrivore
Theodoxus fluviatilis		Båtsnäcka/ Schackmönstrad båtsnäcka	Benthic herbivore
Fish			
Abramis brama	Common bream	Braxen	Benthivorous fish
Abramis vimba	Vimba	Vimma	Benthivorous fish
Acerina cernua	Ruffe	Gers	Benthivorous fish
Anguilla anguilla	Eel	Ål	Benthivorous fish/ Piscivorous fish
Blicca bjoerkna	White silver bream	Björkna	Benthivorous fish
Clupea harengus	Herring	Strömming	Zooplanktivorous fish
Coregonus albula	Bleak	Siklöja	Zooplanktivorous fish
Coregonus sp.	Baltic white fish	Sik	Zooplanktivorous fish
Cottus gobio	Bullhead	Stensimpa	Benthivorous fish
Cottus quadricornis	Fourhorned sculpin	Hornsimpa	Benthivorous fish
Cuprinidae	Carps	Karp	Benthivorous fish
Esox lucius	Pike	Gädda	Piscivorous fish
Gadus morhua	Cod	Torsk	Piscivorous fish
Gasterosteus aculeatus	Stickleback	Storspigg	
Leuciscus erytrophthalmus	Rudd	Sarv	Benthivorous fish
Leuciscus idus	Ide	Id	Piscivorous fish
Limanda limanda	Dab	Sandskädda	Benthivorous fish
Lota lota	Burbot	Lake	Piscivorous fish
Lucioperca sandra	European pike-perch	Gös	Piscivorous fish
Myoxocephalus scorpius	Bull routs	Rötsimpa	
Osmerus eperlanus	Smelt	Nors	Zooplanktivorous fish
Perca fluviatilis	Perch	Aborre	Piscivorous fish
Peuronectes flesus		Flundra, Skrubb-skädda	Benthivorous fish
Pungitius pungitius	Nine-spined stickleback	Småspigg	Benthivorous fish
Rutilus rutilus	Roach	Mört	Benthivorous fish
Sprattus sprattus	sprat	Skarpsill	Zooplanktivorous fish
Syngnathus typhle	Deep snouted pipefish	Tångsnälla	Benthivorous fish
Tinca vulgaris	Tench	Sutare	Benthivorous fish/ Piscivorous fish
Zoarces viviparus	Eelpout	Tånglake	Benthivorous fish

Chemical analyzes of biota and sediment – Forsmark

A large number of elements have been analyzed in samples from most of the biotic pools and in the sediment. Concentrations of elements in water used in the model calculations are from the database SICADA and is not presented here. Values marked with an * were reported below detection limit and has therefore been divedid by two (best estimate).

mg/kg ts Element	N=3 Phyto-plankton	std dev	N=2 Micrphyto-benthos	std dev	N=9 Macro- phytes	std dev
C	1.74E+05	4.51E+03	1.44E+05	2.97E+04	3.40E+05	4.32E+04
N	2.11E+04	1.21E+03	1.67E+04	2.97E+03	2.18E+04	3.48E+03
P	1.31E+03	1.62E+02	2.66E+03	4.03E+02	2.18E+03	8.10E+02
Al	5.19E+00	1.19E+00	2.71E+01	4.17E+00	2.55E+00	2.10E+00
As	1.26E+01	3.16E+00	5.48E+01	3.76E+01	1.91E+01	1.28E+01
Ba	4.15E–02	7.16E–03	4.86E–01	1.85E–01	1.23E+02	9.21E+01
Br	1.31E+03	1.27E+02	1.04E+03	2.26E+02	2.71E+02	6.34E+01
Ca	3.40E+00	1.99E–01	2.92E+01	9.69E+00	1.63E+04	8.38E+03
Cd	2.50E–01	4.94E–02	2.81E+00	1.70E+00	2.05E+00	2.27E+00
Ce	9.54E–03	2.58E–03	4.83E–01	3.11E–02	6.83E–02	4.28E–02
Cl	6.35E+04	2.12E+03	4.15E+04	9.19E+03	2.57E+04	1.89E+04
Co	1.67E+00	3.86E–01	3.75E+01	2.30E+01	1.75E+00	9.11E–01
Cr	6.31E+00	1.21E+00	2.50E+01	1.13E+00	2.90E+00	2.39E+00
Cs	5.14E–01	1.26E–01	2.46E+00	1.41E–01	3.13E–01	2.66E–01
Cu	2.26E+01	5.46E+00	4.51E+01	1.58E+01	5.57E+00	1.98E+00
Dy	5.27E–04	1.59E–04	2.85E–02	9.90E–04	5.54E–03	4.16E–03
Er	2.97E–04	9.45E–05	1.60E–02	2.69E–03	3.31E–03	2.60E–03
Eu	2.00E–04*	0.00E+00	5.35E–03	8.34E–04	9.26E–04	6.33E–04
F	9.65E+02	4.95E+01	1.10E+02*	9.83E+01	3.14E+02*	4.12E+02
Fe	3.87E+03	9.25E+02	4.26E+04	1.42E+04	2.05E+03	1.63E+03
Gd	6.63E–04	2.02E–04	3.87E–02	1.63E–03	6.90E–03	5.18E–03
Hg	5.60E–02	6.67E–03	1.18E–01	1.41E–02	2.56E–02	6.60E–03
Ho	2.00E–04*	0.00E+00	5.47E–03	6.51E–04	1.14E–03	8.91E–04
I	1.52E+01	3.68E+00	3.05E+02	1.60E+02	7.38E+01	3.70E+01
K	9.02E+03	8.52E+02	1.30E+04	1.63E+03	2.01E+04	3.82E+03
Li	8.68E+00	2.16E+00	1.94E+01	2.19E+00	3.89E+00	2.29E+00
Lu	2.00E–04*	0.00E+00	2.20E–03	3.96E–04	5.22E–04*	3.85E–04
Mg	7.40E+03	2.25E+02	1.13E+04	1.06E+03	8.25E+03	1.46E+03
Mn	4.50E+02	6.15E+01	1.51E+04	9.24E+03	4.93E+02	2.76E+02
Mo	3.36E–01	2.55E–02	6.91E+00	5.37E+00	6.40E–01	5.36E–01
Na	4.80E+04	1.85E+03	3.16E+04	3.82E+03	2.06E+04	5.53E+03
Nd	4.05E–03	1.20E–03	2.27E–01	1.27E–02	3.65E–02	2.51E–02
Ni	6.10E+00	1.99E+00	1.34E+02	9.20E+01	9.96E+00	6.22E+00
Pb	1.13E+01	2.00E+00	8.92E+01	7.61E+01	2.87E+00	2.00E+00
Pr	1.09E–03	3.21E–04	6.17E–02	4.03E–03	9.77E–03	6.73E–03
Rb	1.28E+01	2.49E+00	5.63E+01	2.40E+00	1.35E+01	5.36E+00
S	7.20E+03	2.07E+02	9.34E+03	1.36E+03	1.65E+04	1.11E+04
Se	4.98E–01	5.78E–02	6.65E–01	9.90E–03	2.64E–01*	2.16E–01
Si	1.39E+05	1.39E+04	8.29E+04	2.33E+03	3.66E+04	2.73E+04
Sm	7.50E–04	2.25E–04	4.36E–02	4.17E–03	6.82E–03	4.72E–03
Tb	2.00E–04*	0.00E+00	5.33E–03	2.12E–05	9.82E–04	7.32E–04
Th	1.40E+00	2.45E–01	1.67E+01	6.01E+00	8.05E–01	6.69E–01
Ti	1.83E+02	3.89E+01	8.70E+02	8.77E+01	9.18E+01	7.67E+01
Tm	2.00E–04*	0.00E+00	2.25E–03	3.82E–04	4.90E–04*	3.38E–04
V	7.04E+00	1.55E+00	5.60E+01	1.56E+01	4.38E+00	3.39E+00
Yb	2.77E–04	8.39E–05	1.41E–02	2.26E–03	3.04E–03	2.45E–03
Zn	3.91E+02	1.49E+02	5.08E+02	2.18E+02	1.24E+02	8.84E+01
Zr	1.50E+01	1.42E+00	1.29E+02	1.27E+01	9.49E+00	6.97E+00

mg/kg ts N Element	N=1 Zoo- plankton	std dev	N=4 Benthic herbivores	std dev	N=2 Benthic filterfeeders	std dev
C	4.27E+05		2.63E+05	1.14E+05	1.54E+05	7.07E+02
N	9.71E+04		4.06E+04	3.06E+04	1.01E+04	7.78E+02
P	9.48E+03		4.48E+03	3.88E+03	1.06E+03	5.66E+01
Al	2.88E+03		7.13E–01	3.49E–02	2.72E–01	8.77E–02
As	2.34E+01		4.39E+00	2.73E+00	6.72E–01	5.59E–02
Ba	4.98E+01		4.69E+01	3.97E+01	3.11E+01	2.12E+00
Br	1.32E+04		1.13E+02	2.98E+01		
Ca	8.91E+04		2.23E+05	1.17E+05	3.16E+05	2.19E+04
Cd	3.57E+00		1.29E+00	6.71E–01	1.65E–01	2.76E–02
Ce	4.89E+00		1.16E–01	9.01E–02	1.38E–01	2.12E–03
Cl			2.90E+03	2.83E+02		
Co	1.68E+00		5.28E–01	2.81E–01	1.06E–01	1.37E–02
Cr	1.01E+01		6.94E–01	4.36E–01	2.58E–01	1.00E–01
Cs	3.24E–01		6.67E–02	3.38E–02	2.48E–02	1.27E–02
Cu	2.01E+02		3.41E+01	2.66E+01	1.73E+00	2.97E–01
Dy	2.76E–01		7.25E–03	5.44E–03	9.87E–03	6.15E–04
Er	1.56E–01		3.55E–03	2.49E–03	5.56E–03	2.33E–04
Eu	4.80E–02		1.37E–03	1.10E–03	2.15E–03	1.34E–04
F			2.05E+01*	7.07E–01		
Fe	2.09E+03		4.20E+02	1.93E+02	2.40E+02	1.05E+02
Gd	2.88E–01		9.59E–03	7.36E–03	1.52E–02	7.07E–05
Hg	6.01E–01		2.86E–02	4.80E–03	1.26E–02	2.62E–03
Ho	6.01E–02		1.34E–03	9.80E–04	2.01E–03	5.66E–05
I	7.09E+01		8.12E+00	3.25E–01		
K	6.45E+04		3.81E+03	3.14E+03	7.60E+02	1.44E+02
Li	9.99E+00		9.76E–01	6.23E–01	3.91E–01	1.08E–01
Lu	2.40E–02		4.93E–04*	3.27E–04	6.95E–04*	2.12E–05
Mg	2.69E+04		4.06E+03	3.81E+03	3.54E+02	4.81E+01
Mn	1.72E+02		1.23E+02	4.43E+01	2.29E+01	8.84E+00
Mo	2.58E+00		2.03E–01	5.31E–02	5.79E–02	5.37E–03
Na	1.93E+05		9.37E+03	5.22E+03	4.65E+03	5.23E+02
Nd	1.86E+00		5.34E–02	3.96E–02	7.46E–02	4.45E–03
Ni	1.23E+01		1.52E+00	6.09E–01	3.21E+00	4.24E–02
Pb	1.81E+01		6.65E–01	2.82E–01	2.38E–01	1.34E–02
Pr	4.80E–01		1.50E–02	1.14E–02	1.98E–02	8.49E–04
Rb	3.96E+01		2.55E+00	1.24E+00	9.25E–01	3.19E–01
S	4.72E+04		5.26E+03	4.45E+03	5.81E+02	4.10E+01
Se	1.04E+01		6.05E–01	4.23E–02	2.45E–01	8.56E–02
Si	9.80E+04		4.42E+03	1.50E+03	9.85E+02	1.48E+02
Sm	3.72E–01		1.02E–02	7.97E–03	1.40E–02	1.06E–03
Tb	4.80E–02		1.29E–03	9.63E–04	1.95E–03	1.84E–04
Th	5.41E–01		2.80E–01	5.52E–02	8.19E–02	3.41E–02
Ti	1.10E+02		2.04E+01	7.62E+00	8.13E+00	3.36E+00
Tm	2.40E–02		5.03E–04*	3.40E–04	7.20E–04*	4.24E–05
V	3.82E+00		9.35E–01	3.71E–01	3.86E–01	1.01E–01
Yb	1.44E–01		3.11E–03	2.18E–03	4.61E–03	7.07E–05
Zn	1.04E+03		3.69E+01	2.40E+01	7.32E+00	8.20E–01
Zr	4.90E+00		2.42E+00	3.29E–01	1.31E+00	1.13E+00

mg/kg ts N Element	N=3 Benthic detrivores and meiofauna	std dev	N=3 Benthi-vorous fish	std dev	N=3 Zooplankt-ivorous fish	std dev
C	1.71E+05	1.20E+04	4.28E+05	1.33E+04	4.82E+05	1.04E+04
N	1.36E+04	1.76E+03	1.15E+05	2.08E+03	1.16E+05	3.21E+03
P	1.52E+03	2.87E+02	2.96E+04	3.67E+03	1.98E+04	1.65E+03
Al	6.04E–01	6.70E–02	3.28E–03	3.73E–03	7.71E–04	6.34E–04
As	2.02E+00	4.54E–01	6.97E–01*	1.18E–01	7.76E–01*	5.58E–01
Ba	2.97E+01	4.24E+00	2.10E+00	1.33E+00	2.12E+00	7.85E–01
Br	3.18E+01	8.41E+00	1.90E+01	9.19E–01	1.50E+01	1.20E+00
Ca	2.68E+05	4.86E+04	5.80E+04	2.71E+04	3.42E+04	8.22E+03
Cd	1.63E–01	7.42E–02	1.00E–02	3.22E–03	3.53E–02	1.44E–02
Ce	3.20E–01	1.24E–02	2.90E–04	1.31E–04	2.00E–04	0.00E+00
Cl	1.85E+03	2.12E+02	1.55E+03	2.12E+02	9.30E+02	1.41E+01
Co	2.95E–01	6.72E–02	2.27E–02	8.70E–03	3.14E–02	4.23E–03
Cr	5.21E–01	4.35E–02	2.03E–02	5.20E–04	1.33E–02	5.77E–03
Cs	5.54E–02	3.08E–03	3.72E–02	7.72E–03	2.11E–02*	5.86E–04
Cu	2.28E+01	6.92E+00	1.75E+00	5.01E–01	1.94E+00	1.36E–01
Dy	1.83E–02	1.86E–03	2.00E–04*	0.00E+00	2.00E–04*	0.00E+00
Er	9.49E–03	1.13E–03	2.00E–04*	0.00E+00	2.00E–04*	0.00E+00
Eu	4.43E–03	4.92E–04	2.00E–04*	0.00E+00	2.00E–04*	0.00E+00
F	2.15E+01*	2.12E+00	2.00E+01	0.00E+00	2.00E+01	0.00E+00
Fe	8.06E+02	9.70E+01	2.24E+01	4.70E+00	3.84E+01	2.03E+01
Gd	2.92E–02	2.75E–03	2.00E–04*	0.00E+00	2.00E–04*	0.00E+00
Hg	3.78E–02	7.35E–03	2.99E–01	7.04E–02	3.05E–01	1.50E–01
Ho	3.49E–03	3.01E–04	2.00E–04	0.00E+00	2.00E–04	0.00E+00
I	1.62E+00	3.54E–01	1.04E+00	2.26E–01	8.00E–01	0.00E+00
K	1.23E+03	1.29E+02	1.40E+04	9.54E+02	1.35E+04	1.15E+03
Li	4.77E–01	4.39E–02	3.80E–01	6.34E–02	2.81E–01	7.86E–02
Lu	1.26E–03*	7.51E–05	2.00E–04*	0.00E+00	2.00E–04*	0.00E+00
Mg	4.43E+02	3.80E+01	1.73E+03	2.57E+02	1.62E+03	1.88E+02
Mn	2.47E+01	5.29E+00	4.79E+00	2.43E+00	7.94E+00	5.45E+00
Mo	1.87E–01	3.35E–02	2.53E–02	8.96E–03	3.76E–02	1.03E–02
Na	4.17E+03	5.27E+02	4.29E+03	4.72E+02	2.89E+03	4.37E+02
Nd	1.60E–01	5.03E–03	2.00E–04	0.00E+00	2.00E–04	0.00E+00
Ni	5.23E–01	1.18E–01	9.71E–02	4.59E–02	8.66E–02	2.99E–02
Pb	9.47E–01	3.81E–01	7.77E–02	1.91E–02	8.49E–02	3.64E–02
Pr	4.31E–02	1.68E–03	2.00E–04	0.00E+00	2.00E–04*	0.00E+00
Rb	1.70E+00	1.01E–01	8.00E+00	5.42E–01	5.94E+00	7.49E–01
S	1.27E+03	4.37E+02	9.86E+03	5.30E+02	9.41E+03	4.62E+02
Se	4.12E–01	1.13E–01	1.91E+00	2.91E–01	1.50E+00	8.96E–02
Si	1.97E+03	4.36E+02	3.73E+02	4.98E+02	7.05E+01	2.32E+01
Sm	2.96E–02	2.16E–03	2.00E–04*	0.00E+00	2.00E–04*	0.00E+00
Tb	3.65E–03	2.90E–04	2.00E–04*	0.00E+00	2.00E–04*	0.00E+00
Th	1.90E–01	3.58E–02	5.23E–03*	2.14E–03	3.67E–03*	1.15E–03
Ti	1.81E+01	2.91E+00	1.32E+00	7.19E–01	6.85E–01	3.25E–01
Tm	1.24E–03*	1.16E–04	2.00E–04*	0.00E+00	2.00E–04*	0.00E+00
V	7.94E–01	1.32E–01	2.34E–01	2.20E–01	2.26E–02	7.60E–03
Yb	7.83E–03	6.91E–04	2.00E–04*	0.00E+00	2.00E–04*	0.00E+00
Zn	3.94E+01	1.25E+01	6.42E+01	4.71E+00	1.62E+02	5.52E+01
Zr	2.78E+00	9.40E–01	1.32E–01	6.89E–02	2.05E–02	1.96E–03

mg/kg ts N Element	N=3 Pisci- vorous fish	std dev	N=1 Sediment	std dev
C	4.12E+05	1.14E+04	7.00E+04	
N	1.08E+05	4.51E+03	8.28E+03	
P	3.44E+04	2.73E+03	1.10E+03	
Al	7.88E–04	9.75E–05	5.20E+04	
As	2.43E+00*	4.17E–01	2.50E–02	
Ba	4.65E–01	1.61E–01	3.70E+02	
Br	2.48E+01	7.07E+00	1.70E+02	
Ca	1.30E+04	6.07E+03	7.40E+03	
Cd	1.09E–02	5.06E–03	3.10E+00	
Ce	1.67E–04	5.77E–05	8.10E+01	
Cl	1.50E+03	0.00E+00	6.78E+03	
Co	1.31E–02	6.93E–04	1.10E+01	
Cr	1.00E–02	0.00E+00	7.20E+01	
Cs	5.77E–02	2.65E–03	6.00E+00	
Cu	1.56E+00	3.99E–01	5.50E+01	
Dy	1.67E–04*	5.77E–05	4.40E+00	
Er	1.67E–04*	5.77E–05	2.80E+00	
Eu	1.67E–04*	5.77E–05	1.00E+00	
F	2.00E+01	0.00E+00	3.50E+01*	
Fe	1.57E+01	5.06E+00	3.70E+04	
Gd	1.67E–04*	5.77E–05	6.50E+00	
Hg	2.61E–01	6.95E–02	4.00E–01*	
Ho	1.67E–04*	5.77E–05	9.50E–01	
I	1.96E+00	6.36E–02	1.70E+01*	
K	1.68E+04	2.10E+03	2.20E+04	
Li	2.97E–01	2.81E–02	3.90E+01	
Lu	1.67E–04*	5.77E–05	4.00E–01*	
Mg	1.25E+03	1.65E+02	1.10E+04	
Mn	6.20E+00	8.34E–01	3.80E+02	
Mo	1.62E–02	4.99E–03	2.40E+00	
Na	3.47E+03	3.42E+02	1.40E+04	
Nd	1.67E–04	5.77E–05	3.40E+01	
Ni	8.52E–02	6.86E–03	3.30E+01	
Pb	5.87E–02	1.26E–02	6.30E+01	
Pr	1.67E–04	5.77E–05	9.30E+00	
Rb	5.77E+00	8.96E–01	1.20E+02	
S	8.07E+03	1.33E+02	1.60E+04	
Se	1.56E+00	6.08E–02	8.30E–01	
Si	2.11E+02	2.64E+02	2.50E+05	
Sm	1.67E–04*	5.77E–05	6.70E+00	
Tb	1.67E–04	5.77E–05	8.80E–01	
Th	3.33E–03	5.77E–04	1.10E+01	
Ti	2.95E–01	1.90E–01	2.90E+03	
Tm	1.67E–04*	5.77E–05	3.90E–01	
V	2.94E–02	9.51E–03	7.00E+01	
Yb	1.67E–04*	5.77E–05	2.50E+00	
Zn	6.85E+01	1.28E+01	2.90E+02	
Zr	2.65E–02	3.82E–03	2.30E+02	

Appendix 5b

Chemical analyzes of sediment and biota – Laxemar-Simpevarp

A large number of elements have been analyzed in samples from most of the biotic pools and in the sediment. Concentrations of elements in water used in the model calculations are from the database SICADA and is not presented here. Values marked with an * were reported below detection limit and has therefore been divided by two (best estiment).

mg/kg ts Element	N=12 Macro-phytes	std dev	N=2 Filter-feeders	std dev	N=3 Piscivorous fish	std dev
C	3.14E+05	4.69E+04	3.65E+05	7.07E+03	4.25E+05	4.25E+05
N (tot)	1.36E+04	6.71E+03	7.09E+04	2.11E+04	1.19E+05	1.19E+05
P	2.24E+03	8.40E+02	9.83E+03	3.89E+02	1.52E+04	1.52E+04
Ag	1.16E–02*	3.70E–03	2.70E–02	4.24E–03	8.33E–03*	8.33E–03
Al	1.10E+03	1.21E+03	4.32E+01	6.51E+00	2.80E–01	2.80E–01
As	4.58E+00	5.18E+00	6.26E+00	8.84E–01	2.47E+00	2.47E+00
B	2.47E+02	2.10E+02	1.80E+01	3.89E+00	9.20E–01	9.20E–01
Ba	6.41E+01	6.36E+01	3.20E+00	4.24E–01	0.00E+00	0.00E+00
Be	1.33E–01*	1.18E–01	3.75E–02*	3.54E–03	3.83E–02*	3.83E–02
Br	1.75E+02	5.67E+01	3.25E+02	4.24E+00	9.81E+00	9.81E+00
Ca	5.23E+04	6.72E+04	1.78E+04	2.97E+03	6.81E+02	6.81E+02
Cd	5.77E–01	5.45E–01	2.77E+00	2.40E–01	1.83E–03*	1.83E–03
Ce	6.92E+00	7.91E+00	2.50E–01	7.07E–02	0.00E+00	0.00E+00
Cl	3.58E+04	1.37E+04	7.81E+04	4.09E+04	1.44E+03	1.44E+03
Co	1.69E+00	1.86E+00	3.30E–01	7.78E–03	6.70E–03	6.70E–03
Cr	8.09E–01	7.50E–01	5.09E–01*	2.19E–02	1.00E–02*	1.00E–02
Cs	5.57E–02	3.85E–02	1.02E–02*	4.95E–04	8.56E–02	8.56E–02
Cu	3.80E+00	2.27E+00	1.10E+01	1.98E+00	5.03E–01	5.03E–01
Dy	3.56E–01	3.78E–01	1.79E–02	8.49E–04	1.50E–04*	1.50E–04
Er	2.13E–01	2.24E–01	1.07E–02	7.78E–04	1.50E–04*	1.50E–04
Eu	9.79E–02	9.77E–02	4.95E–03	2.12E–04	1.50E–04*	1.50E–04
Fe	1.60E+03	2.25E+03	1.27E+02	4.95E+00	1.00E+01*	1.00E+01
Ga	1.43E–01*	1.38E–01	1.05E–02*	6.36E–04	3.00E–03*	3.00E–03
Gd	4.12E–01	4.33E–01	2.38E–02	2.12E–04	1.50E–04*	1.50E–04
Hf	3.34E–02	2.63E–02	2.50E–03	1.41E–04	1.93E–03	1.93E–03
Hg	7.17E–03*	1.09E–02	8.00E–02*	1.13E–02	4.07E–01	4.07E–01
Ho	7.20E–02	7.66E–02	3.85E–03	2.12E–04	1.50E–04*	1.50E–04
I	5.53E+01	3.39E+01	1.97E+01	4.88E+00	8.77E–01	8.77E–01
K	2.63E+04	2.00E+04	9.28E+03	9.55E+02	2.19E+04	2.19E+04
La	3.85E+00	4.01E+00	2.45E–01	4.88E–02	3.67E–04	3.67E–04
Li	1.22E+00	9.52E–01	4.95E–01	1.20E–01	1.83E–02*	1.83E–02
Lu	3.03E–02	3.18E–02	1.40E–03	1.41E–04	1.50E–04*	1.50E–04
Mg	1.14E+04	4.58E+03	4.91E+03	7.00E+02	1.84E+03	1.84E+03
Mn	2.39E+02	1.93E+02	3.22E+01	1.09E+01	6.30E–01	6.30E–01
Mo	4.71E–01	4.79E–01	5.90E–01	9.90E–02	1.00E–02	1.00E–02
Na	2.25E+04	5.26E+03	3.39E+04	6.79E+03	1.99E+03	1.99E+03
Nb	1.13E–01	1.03E–01	8.95E–03	1.77E–03	1.50E–04*	1.50E–04
Nd	3.41E+00	3.58E+00	1.70E–01	2.47E–02	2.67E–04*	2.67E–04
Ni	5.45E+00	4.15E+00	2.69E+00	1.48E–01	1.50E–02*	1.50E–02
Pb	1.03E+00	7.05E–01	8.26E–01	4.16E–01	1.50E–02*	1.50E–02
Pr	8.98E–01	9.42E–01	4.24E–02	7.64E–03	1.50E–04*	1.50E–04
Rb	7.75E+00	4.38E+00	3.90E+00	4.24E–01	1.07E+01	1.07E+01
S	2.20E+04	1.32E+04	9.82E+03	5.44E+02	1.45E+04	1.45E+04

mg/kg ts Element	N=12 Macro-phytes	std dev	N=2 Filter-feeders	std dev	N=3 Piscivorous fish	std dev
Sb	2.90E–02	1.20E–02	2.80E–02	0.00E+00	1.50E–03*	1.50E–03
Sc	1.83E–01	1.85E–01	4.45E–02	2.62E–03	7.33E–04	7.33E–04
Se	3.37E–01	8.66E–02	2.48E+00*	2.33E–01	9.76E–01	9.76E–01
Si	9.08E+03	7.45E+03	5.64E+02	1.80E+02	1.70E+02	1.70E+02
Sm	5.58E–01	5.88E–01	2.93E–02	4.10E–03	1.50E–04*	1.50E–04
Sn	8.08E–02	5.57E–02	3.50E–02*	7.07E–03	3.00E–02	3.00E–02
Sr	9.26E+02	9.24E+02	8.00E+01	7.57E+00	4.33E–01	4.33E–01
Ta	8.92E–03	6.02E–03	2.50E–03*	7.07E–04	1.17E–03*	1.17E–03
Tb	5.91E–02	6.39E–02	3.25E–03	7.07E–05	1.50E–04*	1.50E–04
Th	2.18E–01*	2.34E–01	2.47E–02*	1.23E–02	1.00E–02	1.00E–02
Ti	1.98E+01	1.92E+01	1.56E+00	1.41E–02	6.00E–02	6.00E–02
Tl	3.04E–02*	2.30E–02	7.50E–03*	3.54E–03	8.33E–03*	8.33E–03
Tm	3.02E–02	3.22E–02	1.25E–03	7.07E–05	1.50E–04*	1.50E–04
U	7.13E–01	7.63E+00	3.16E–01	2.83E–01	8.33E–05*	2.28E+01
V	1.77E+00	4.23E–01	2.02E–01	3.04E–02	8.33E–03*	8.33E–05
W	4.51E–02	1.93E+00	3.30E–02*	2.12E–02	8.00E–04	8.33E–03
Y	2.83E+00	3.20E–02	1.57E–01	8.49E–03	1.50E–04*	8.00E–04
Yb	1.99E–01	3.01E+00	8.45E–03	2.33E–02	1.50E–04*	1.50E–04
Zn	3.29E+01	2.12E–01	8.88E+01	1.06E–03	1.79E+01	1.50E–04
Zr	1.53E+00	2.18E+01	1.40E–01	2.83E–01	1.70E–01	1.79E+01

mg/kg ts Element	N=3 Zooplankti-vorous fish	std dev	N=3 Benthi-vorous fish	std dev	N=6 Sediment	std dev
C	5.31E-05	2.02E+05	4.24E+05	1.19E+04	1.38E+05	1.07E+04
N (tot)	1.18E+05	1.65E+04	1.31E+05	1.61E+04	1.64E+04	1.34E+03
P	1.17E+04	3.06E+02	1.20E+04	7.57E+02	1.63E+03	2.84E+02
Ag	6.67E–03*	2.89E–03	5.00E–03*	0.00E+00	1.42E–02*	3.00E–03
Al	1.40E–01	6.08E–02	6.57E–01	3.61E–01	2.56E+04	1.61E+03
As	1.12E+00	1.96E–01	7.43E+00	1.94E+00	6.43E+00	1.00E+00
B	1.05E+00	8.02E–02	5.00E–01*	0.00E+00	7.50E–01*	3.00E–01
Ba	0.00E+00	0.00E+00	3.33E–02	5.77E–02	1.08E+02	2.10E+01
Be	3.67E–02*	2.89E–03	3.33E–02*	2.89E–03	2.52E+00	4.00E–01
Br	9.60E+00	4.22E–01	1.05E+01	9.35E–01	1.41E+02	2.50E+01
Ca	1.26E+03	4.59E+02	5.83E+02	2.91E+02	6.59E+03	7.00E+02
Cd	2.50E–03*	1.32E–03	4.00E–03*	2.00E–03	1.94E+00	1.00E+00
Ce	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.34E+02	8.00E+00
Cl	2.84E+03	1.01E+02	4.23E+03	1.03E+03	4.21E+04	1.03E+04
Co	1.40E–02	2.88E–03	7.83E–03	2.36E–03	1.01E+01	3.00E+00
Cr	1.00E–02*	0.00E+00	1.00E–02*	0.00E+00	2.77E+01	4.00E+00
Cs	2.91E–02	3.06E–03	7.59E–02	1.27E–03	1.93E+00	2.00E–01
Cu	1.51E+00	2.92E–01	7.77E–01	3.51E–02	5.93E+01	8.00E+00
Dy	1.50E–04*	0.00E+00	1.33E–04*	2.89E–05	7.40E+00	3.00E–01
Er	1.50E–04*	0.00E+00	1.33E–04*	2.89E–05	4.24E+00	3.00E–01
Eu	1.50E–04*	0.00E+00	1.33E–04*	2.89E–05	1.83E+00	2.00E–01
Fe	6.67E+00*	2.89E+00	5.00E+00*	0.00E+00	2.62E+04	4.28E+03
Ga	2.67E–03*	2.89E–04	2.83E–03*	2.89E–04	5.00E–01*	0.00E+00
Gd	1.50E–04*	0.00E+00	1.33E–04*	2.89E–05	9.18E+00	1.00E+00
Hf	1.50E–04*	0.00E+00	1.33E–04*	2.89E–05	7.19E–01	3.00E–01
Hg	1.59E–01	4.59E–02	3.88E–01	1.11E–01	6.52E–02*	0.00E+00
Ho	1.50E–04*	0.00E+00	1.33E–04*	2.89E–05	1.41E+00	1.00E–01
I	2.50E–01*	0.00E+00	2.50E–01*	0.00E+00	8.49E+00	1.00E+00
K	2.12E+04	1.62E+03	2.07E+04	1.47E+03	8.11E+03	1.02E+03
La	2.00E–04*	8.66E–05	4.00E–04	1.00E–04	7.04E+01	4.00E+00
Li	1.67E–02*	2.89E–03	1.83E–02*	2.89E–03	3.00E+01	7.00E+00
Lu	1.50E–04*	0.00E+00	1.33E–04*	2.89E–05	6.95E–01	1.00E–01
Mg	1.56E+03	1.27E+02	1.48E+03	1.00E+02	8.93E+03	1.84E+02
Mn	1.33E+00	3.11E–01	4.87E–01	1.03E–01	1.73E+02	1.10E+01
Mo	1.00E–02	0.00E+00	2.00E–02	0.00E+00	1.38E–01*	2.00E+00
Na	2.41E+03	5.00E+01	3.30E+03	3.37E+02	2.33E+04	3.10E+03
Nb	1.50E–04*	0.00E+00	3.00E–04	0.00E+00	3.00E+00*	0.00E+00
Nd	1.50E–04*	0.00E+00	2.67E–04*	2.02E–04	7.24E+01	2.00E+00
Ni	1.50E–02*	0.00E+00	7.37E–02*	1.02E–01	3.32E+01	4.00E+00
Pb	1.50E–02*	0.00E+00	2.50E–02*	1.73E–02	2.43E+01	3.00E+00
Pr	1.50E–04*	0.00E+00	8.83E–05*	6.83E–05	1.70E+01	1.00E+00
Rb	3.67E+00	2.52E–01	8.03E+00	6.03E–01	3.27E+01	9.00E+00

mg/kg ts Element	N=3 Zooplankti-vorous fish	std dev	N=3 Benthi-vorous fish	std dev	N=6 Sediment	std dev
S	9.35E+03	3.41E+02	1.09E+04	6.24E+02	3.08E+04	3.53E+03
Sb	1.50E–03*	2.66E–19	3.33E–03*	3.18E–03	5.24E–01	1.00E–01
Sc	4.00E–04	1.00E–04	6.67E–04	2.08E–04	5.51E+00	1.00E+00
Se	9.60E–01	4.98E–02	9.04E–01	1.18E–01	1.00E+00*	0.00E+00*
Si	1.46E+02	5.70E+01	1.42E+02	1.19E+01	1.96E+05	8.81E+03
Sm	1.50E–04*	0.00E+00	1.33E–04*	2.89E–05	1.08E+01	1.00E+00
Sn	2.00E–02	0.00E+00	1.50E–02*	0.00E+00	1.00E+01*	0.00E+00
Sr	1.40E+00	5.29E–01	1.33E+00	9.24E–01	1.03E+02	9.00E+00
Ta	3.33E–03	1.53E–03	1.17E–03	7.64E–04	2.27E–01	1.00E–01
Tb	1.50E–04*	0.00E+00	1.33E–04*	2.89E–05	1.32E+00	1.00E–01
Th	2.83E–03*	2.89E–04	2.83E–03*	2.89E–04	7.11E+00	1.00E+00
Ti	5.27E–01	8.43E–01	1.40E–01	1.56E–01	9.49E+02	1.67E+02
Tl	6.67E–03*	2.89E–03	5.00E–03*	0.00E+00	4.59E–01	1.00E–01
Tm	1.50E–04*	0.00E+00	1.33E–04*	2.89E–05	6.43E–01	1.00E–01
U	5.67E–04	1.22E+00	6.67E–04	2.65E–01	6.21E+00	1.00E+00
V	6.67E–03*	5.77E–05	1.03E–02*	3.79E–04	3.41E+01	2.00E+00
W	4.33E–04	2.89E–03	1.30E–03	9.24E–03	3.00E+01*	0.00E+00
Y	2.00E–04*	1.15E–04	3.50E–04	2.00E–04	5.46E+01	4.00E+00
Yb	1.50E–04*	8.66E–05	1.33E–04*	1.80E–04	4.48E+00	4.00E–01
Zn	3.00E+01	0.00E+00	1.95E+01	2.89E–05	1.65E+02	5.00E+01
Zr	3.67E–03*	6.30E+00	4.93E–03*	1.42E+00	4.89E+01	1.00E+01

Appendix 6a

C:X ratios for the pools of the mass balances – Forsmark

Ratios between carbon (C) and a large number of elements (X) in various pools of the marine ecosystem in Forsmark. The ratios are based on analyzes in the same sample. For some elements the concentration have been bellow the detection limit, for these elements an estimated mean have been used. These values are marked in italic in the table.

	N=3 Particulate matter	N=3 Dissolved matter	N=4 Benthic herbivores (mean two species)	N=3×3 Macrophytes (mean 3 species)	N=3 Phytoplankton
Al	0.3	11,036	364	309	35
As	*5,791*	*2,163*	66,500	41,224	14,335
Ba	0.3	871	8,670	4,898	4,287
Br	*145*	*1*	1,496	1,274	132
C	1	1	1	1	1
Ca	0.1	0.2	2	26	51
Cd	687	810,971	210,867	588,926	714,619
Ce	986	1,463,333	5,205,619	7,781,578	19,398,659
Cl	26	0.01	57	23	3
Co	25,768	1,258,824	520,297	240,063	108,821
Cr	120	23,253	429,164	240,715	28,396
Cs	5,165	243,889	4,088,215	2,343,442	355,391
Cu	1,082	18,814	10,362	67,971	7,994
Dy	27,540	1,463,333	78,975,524	110,761,649	356,631,731
Er	5,103	1,463,333	145,218,002	192,986,048	640,290,530
Eu	*10,961*	*1,463,333*	480,379,871	578,838,117	868,333,333
F	380	49	8,038	5,292	178
Fe	11	5,938	633	345	47
Gd	25,367	1,463,333	61,465,184	86,305,801	284,565,693
Hg	*57,909*	*7,316,667*	9,028,090	14,032,549	3,134,448
Ho	139,547	1,463,333	412,965,207	558,569,061	*868,333,333*
I	290	624	20,249	5,074	11,594
K	0.4	0.2	99	18	19
Li	772	534	307,770	138,470	20,816
Lu	309,187	1,463,333	966,984,207	*945,827,455*	*868,333,333*
Mg	3	0.08	130	42	24
Mn	221	7,195	2,679	907	391
Mo	539	8,677	1,258,119	865,212	519,584
N	9	67	9	16	8
Na	0.1	0.01	30	18	4
Nd	3,594	1,186,633	10,449,433	15,352,101	46,358,557
Ni	2,752	15,581	172,419	46,114	30,693
P	53	2,867	86	183	85
P	59	2,663	92	185	134
Pb	185	13,023	394,299	229,095	15,791
Pr	13,749	1,463,333	38,947,386	57,771,175	172,108,404
Rb	110	787	105,266	29,160	14,024
S	7	0.11	78	29	24

Se	*2,895*	*572,662*	435,602	*4,371,999*	352,295
Si	0	38	58	29	1
Sm	16,085	1,463,333	57,299,866	82,437,961	251,050,982
Tb	166,314	146,333	443,213,976	609,664,715	868,333,333
Th	8,656	365,833	1,007,991	992,109	127,079
Ti	79	287,233	12,731	8,058	988
Tm	309,187	1,463,333	964,968,615	*970,135,158*	*868,333,333*
U					
V	4,621	115,638	278,074	136,517	25,710
Yb	50,003	1,463,333	166,145,571	216,988,878	681,586,700
Zn	0	10,425	8,175	4,133	488
Zr	213	243,889	107,033	60,662	11,665

	N=2 microphyto-benthos	N=3 Benthic detrtivore	N=2 Filter feeder	N=3 benthivorous fish	N=3 piscivorous fish
Al	5	287	595	263,811	617,609
As	3,194	87,313	229,342	*602,399*	*201,511*
Ba	307	5,824	4,946	262,128	1,123,817
Br	139	5,570		21,918	20,445
C	1	1	1	1	1
Ca	5	1	0.49	8	43
Cd	59,011	1,167,413	946,064	43,942,179	50,526,532
Ce	300,741	534,651	1,116,536	1,597,608,696	3,201,666,667
Cl	3	94		271	323
Co	4,437	598,361	1,455,719	20,126,142	36,893,707
Cr	5,793	329,409	643,133	20,294,976	48,200,000
Cs	58,286	3,091,981	7,126,639	11,382,999	8,355,692
Cu	3,282	7,988	90,020	247,306	320,692
Dy	5,037,573	9,468,751	15,592,614	*2,060,000,000*	*3,201,666,667*
Er	8,970,641	18,266,385	27,659,840	*2,060,000,000*	*3,201,666,667*
Eu	26,809,057	39,028,173	71,692,073	*2,060,000,000*	*3,201,666,667*
F	*1,998*	*8,041*		*20,725*	*24,225*
Fe	3	214	709	18,893	32,696
Gd	3,745,226	5,906,983	10,132,015	2,060,000,000	3,201,666,667
Hg	1,213,976	4,614,950	12,496,755	1,434,921	1,921,717
Ho	26,187,759	49,380,465	76,403,368	2,060,000,000	3,201,666,667
I	518	110,447		406,629	248,069
K	11	141	206	30	29
Li	7,402	359,489	408,513	1,109,409	1,632,349
Lu	65,297,379	136,589,744	220,950,704	*2,060,000,000*	*3,201,666,667*
Mg	13	387	438	241	392
Mn	11	7,126	7,267	99,315	78,752
Mo	27,485	925,772	2,662,022	17,789,454	31,571,337
N	9	13	15	4	4
Na	5	41	33	97	140
Nd	639,034	1,074,392	2,062,987	2,060,000,000	3,201,666,667
Ni	1,307	334,413	47,825	5,147,513	5,688,628
P	47	104	229	14	36
P	54	115	145	12	24
Pb	2,314	196,413	647,436	5,528,756	8,506,021
Pr	2,356,550	3,972,507	7,760,417	*2,060,000,000*	*3,201,666,667*
Rb	2,549	101,180	176,399	51,703	85,210
S	15	146	265	42	60
Se	216,233	432,516	668,220	218,995	309,203
Si	2	90	158	3,406	5,885
Sm	3,354,600	5,817,950	11,037,415	*2,060,000,000*	*3,201,666,667*
Tb	27,053,577	47,184,318	79,086,538	*2,060,000,000*	*3,201,666,667*
Th	9,596	917,907	2,049,945	85,981,602	146,944,444
Ti	168	9,553	20,638	425,392	2,062,049
Tm	63,798,701	138,703,042	213,594,203	*2,060,000,000*	*3,201,666,667*
U					
V	2,598	218,313	412,121	2,889,979	18,056,238
Yb	10,174,777	22,005,659	33,299,921	*2,060,000,000*	*3,201,666,667*
Zn	299	4,656	21,108	6,443	7,215
Zr	1,110	65,906	185,037	3,618,224	18,408,550

	N=3 zooplnkativorous fish	N=1 Zooplankton	N=3×3 Sediment (top 10mean)
Al	2,169,376	148	1
As	791,269	18,230	1,727
Ba	225,158	8,566	29
Br	28,905	32	193
C	1	1	1
Ca	13	5	2
Cd	14,330,926	87,342	18,734
Ce	2,141,666,667	119,691	4,634
Cl	463	0	4
Co	13,876,028	253,916	1,286
Cr	35,883,333	42,370	298
Cs	20,288,112	1,316,604	2,550
Cu	221,183	2,129	605
Dy	*2,141,666,667*	1,545,578	41,100
Er	*2,141,666,667*	2,734,484	104,972
Eu	*2,141,666,667*	8,887,074	215,280
F	21,500	0	5,250
Fe	13,438	204	0
Gd	*2,141,666,667*	1,481,179	34,102
Hg	1,662,309	710,966	35,209
Ho	*2,141,666,667*	7,109,659	212,836
I	537,500	6,025	879
K	32	7	3
Li	1,603,936	42,726	415
Lu	*2,141,666,667*	17,774,147	549,994
Mg	268	16	2
Mn	79,103	2,486	23
Mo	11,953,200	165,341	16,902
N	4	4	9
Na	151	2	4
Nd	*2,141,666,667*	229,344	6,207
Ni	5,380,836	34,851	619
P	18	7	11
P	15	45	11
Pb	5,839,340	23,542	160
Pr	*2,141,666,667*	888,707	22,023
Rb	72,767	10,772	65
S	46	9	8
Se	286,909	41,192	73,197
Si	6,580	4	32
Sm	*2,141,666,667*	1,146,719	32,547
Tb	*2,141,666,667*	8,887,074	234,513
Th	*124,244,444*	789,962	5,508
Ti	710,311	3,872	6
Tm	*2,141,666,667*	17,774,147	592,246
U			71,333
V	20,448,179	111,787	194
Yb	*2,141,666,667*	2,962,358	91,171
Zn	2,945	410	90
Zr	21,098,521	87,128	23

Appendix 6b

C:X ratios for the pools of the mass balances – Laxemar-Simpevarp

Ratios between carbon (C) and a large number of elements (X) in the analyzed pools of the marine ecosystem in Laxemar-Simpevarp. The ratios are based on analyzes in the same sample. For some elements the concentration have been bellow the detection limit, for these elements an estimated mean have been used. These values are marked in italic in the table.

	N=12 Macrophytes	N=3 Filter feeders (Mytilus edulis)	N=3 Benthivorous fish (Flounder)	N=3 Piscivorous fish (Perch)
Ag	27,085,612	*13,518,519*	*84,700,000*	*51,028,000*
Al	286	8,449	644,924	1,518,690
As	68,440	58,353	56,999	172,392
B	1,271	20,334	847,000	462,043
Ba	4,893	114,063	12,705,000	
Be	2,367,862	*9,733,333*	*12,705,000*	*11,093,043*
Br	1,796	1,123	40,423	43,332
C	1	1	1	1
Ca	6	21	726	625
Cd	543,746	131,769	105,875,000	231,945,455
Ce	45,360	1,460,000		
Cl	9	5	100	296
Co	185,802	1,107,739	54,063,830	63,467,662
Cr	387,734	*717,797*	*42,350,000*	*42,523,333*
Cs	5,634,391	*35,960,591*	5,582,162	4,969,614
Cu	82,545	33,182	545,279	844,834
Dy	880,472	20,391,061	*3,176,250,000*	*2,834,888,889*
Er	1,471,124	34,272,300	*3,176,250,000*	*2,834,888,889*
Eu	3,204,716	73,737,374	*3,176,250,000*	*2,834,888,889*
F				
Fe	196	2,885	84,700	42,523
Ga	2,200,666	34,928,230	*149,470,588*	*141,744,444*
Gd	761,309	15,368,421	*3,176,250,000*	*2,834,888,889*
Hf	9,381,759	146,000,000	3,176,250,000	219,948,276
Hg	43,777,907	4,562,500	1,090,558	1,045,656
Ho	4,357,523	94,805,195	*3,176,250,000*	*2,834,888,889*
I	5,673	18,575	*1,694,000*	*484,688*
K	12	39	20	19
La	81,571	1,492,843	1,058,750,000	1,159,727,273
Li	258,047	737,374	*23,100,000*	*23,194,545*
Lu	10,371,625	260,714,286	*3,176,250,000*	*2,834,888,889*
Mg	28	74	286	231
Mn	1,313	11,335	870,205	674,974
Mo	666,354	618,644	21,175,000	42,523,333
N	23	5	3	4
Na	14	11	128	214
Nb	2,786,544	40,782,123	*1,411,666,667*	*2,834,888,889*
Nd	92,112	2,153,392	1,588,125,000	1,594,625,000
Ni	57,567	135,940	5,748,869	28,348,889
P	140	37	35	28
Pb	305,394	441,889	16,940,000	28,348,889
Pr	349,553	8,608,491	*4,794,339,623*	*2,834,888,889*
Rb	40,483	93,590	52,718	39,618
S	14	37	39	29
Sb	10,818,678	13,035,714	*127,050,000*	*283,488,889*

	Macrophytes	Filter feeders (Mytilus edulis)	Benthivorous fish (Flounder)	Piscivorous fish (Perch)
Sc	1,718,662	8,211,474	635,250,000	579,863,636
Se	*929,835*	147,475	468,301	435,839
Si	35	648	2,989	2,506
Sm	562,144	12,457,338	3,176,250,000	2,834,888,889
Sn	3,881,340	10,428,571	28,233,333	14,174,444
Sr	339	4,565	317,625	981,308
Ta	35,185,981	146,000,000	363,000,000	364,485,714
Tb	5,307,161	112,307,692	3,176,250,000	2,834,888,889
Th	1,439,347	14,777,328	149,470,588	42,523,333
Ti	15,816	233,974	3,025,000	7,087,222
Tl	10,314,795	48,666,667	84,700,000	51,028,000
Tm	10,385,931	292,000,000	3,176,250,000	2,834,888,889
U	440,283	1,156,894	635,250,000	5,102,800,000
V	176,955	1,806,931	40,983,871	51,028,000
W	6,960,436	11,060,606	325,769,231	531,541,667
Y	110,980	2,332,268	1,210,000,000	2,834,888,889
Yb	1,579,435	43,195,266	3,176,250,000	2,834,888,889
Zn	9,543	4,110	21,681	23,800
Zr	205,004	2,607,143	85,844,595	2,499,412

	N=3 Zooplanktivorous fish (Roach)	N=2 Sediment (top 10 cm)
Ag	*79,600,000*	9,764,706
Al	3,790,476	5
As	474,940	21,514
B	504,916	184,444
Ba		1,283
Be	*14,472,727*	54,894
Br	55,259	983
C	1	1
Ca	422	21
Cd	212,266,667	71,392
Ce		1,031
Cl	187	3
Co	37,904,762	13,724
Cr	53,066,667	5,003
Cs	18,235,968	71,613
Cu	352,212	2,333
Dy	*3,537,777,778*	18,706
Er	*3,537,777,778*	32,664
Eu	*3,537,777,778*	75,523
F		
Fe	*79,600*	5
Ga	*199,000,000*	276,667
Gd	*3,537,777,778*	15,066
Hf	*3,537,777,778*	192,308
Hg	3,337,526	2,122,762
Ho	*3,537,777,778*	98,341
I	*2,122,667*	16,287
K	25	17
La	2,653,333,333	1,965
Li	*31,840,000*	4,606
Lu	*3,537,777,778*	199,184
Mg	341	15
Mn	400,000	801
Mo	53,066,667	1,000,000
N	4	8
Na	220	6
Nb	3,537,777,778	46,111
Nd	3,537,777,778	1,911
Ni	*35,377,778*	4,173
P	45	85
Pb	*35,377,778*	5,704
Pr	*3,537,777,778*	8,137
Rb	144,727	4,230
S	57	4
Sb	353,777,778	264,079
Sc	1,326,666,667	25,121
Se	552,970	138,333
Si	3,646	1

	N=3 Zooplanktivorous,fish, (Roach)	N=2 Sediment, (top,10,cm)
Sm	*3,537,777,778*	12,862
Sn	*26,533,333*	13,833
Sr	379,048	1,346
Ta	*159,200,000*	608,504
Tb	*3,537,777,778*	104,666
Th	*187,294,118*	19,461
Ti	1,007,595	146
Tl	*79,600,000*	301,708
Tm	*3,537,777,778*	215,305
U	936,470,588	22,270
V	*79,600,000*	4,055
W	1,224,615,385	4,611
Y	*2,653,333,333*	2,533
Yb	3,537,777,778	30,855
Zn	17,689	836
Zr	*144,727,273*	2,832

Physical charactenstivs of the basins – Forsmark.

Physical characteristics of the marine basins in the marine Forsmark area.

IDKOD	Marine basin area (m²)	Mean depth (m)	Max depth (m)	Volume (m³)	Total drainage area to basin (m²)	Runoff (m³ year⁻¹)	Advective outflow (m³)	Avdective inflow (m³)	AvA days	Net advective flow (m3)
Basin 102	34,173,600	10.9	24.9	370,872,411	65,213,200	55,630,862	146,331,158,485	146,180,202,705	0.676	–150,955,780
Basin 100	18,455,600	19.4	55.9	357,667,682	22,922,000	53,650,152	274,020,917,607	273,937,775,954	0.345	–83,141,653
Basin 101	21,798,800	16.1	27.2	351,911,108	21,800,000	52,786,666	199,998,839,854	199,899,086,280	0.391	–99,753,574
Basin 105	22,664,000	18.2	58.8	412,799,830	27,716,000	61,919,974	235,063,186,637	234,961,476,492	0.487	–101,710,145
Basin 103	5,693,600	5.5	14.8	31,342,357	6,317,200	4,701,354	31,451,639,046	31,426,402,434	0.127	–25,236,613
Basin 104	2,698,000	7.6	11.3	20,631,606	2,746,400	3,094,741	23,632,530,445	23,620,181,956	0.067	–12,348,489
Basin 108	7,193,600	10.6	20.1	76,441,352	7,590,000	11,466,203	60,258,899,534	60,228,111,939	0.189	–30,787,595
Basin 106	1,385,600	4.5	9	6,227,718	1,434,000	934,158	8,657,076,489	8,650,805,994	0.137	–6,270,495
Basin 111	6,736,800	3.3	9.3	22,247,608	18,810,000	3,337,141	3,374,817,080	3,349,321,695	0.994	–25,495,385
Basin 107	4,627,600	7.0	13.2	32,359,557	4,840,000	4,853,934	21,819,748,293	21,798,822,449	0.217	–20,925,845
Basin 110	7,072,400	12.4	23.7	87,928,320	7,169,200	13,189,248	87,612,923,074	87,581,081,455	0.124	–31,841,618
Basin 114	14,030,800	19.4	45.2	272,614,235	18,974,800	40,892,135	154,336,567,378	154,273,543,695	0.444	–63,023,683
Basin 109	1,521,200	19.3	27.3	29,331,322	1,525,200	4,399,698	44,854,811,320	44,847,742,418	0.045	–7,068,902
Basin 116	**13,534,000**	**9.5**	**18.9**	**128,153,311**	**14,101,600**	**19,222,997**	**52,142,360,552**	**52,082,246,480**	**0.74**	**–60,114,072**
Basin 113	1,596,800	12.5	20.1	19,990,020	1,598,000	2,998,503	43,629,729,510	43,622,322,941	0.031	–7,406,569
Basin 117	5,762,800	3.7	10	21,379,066	16,125,200	3,206,860	1,769,974,267	1,746,034,672	1.411	–23,939,595
Basin 112	696,400	10.9	13.4	7,587,139	693,200	1,138,071	13,108,992,327	13,105,975,420	0.023	–3,016,907
Basin 115	4,211,200	16.1	25.9	67,701,357	4,214,800	10,155,204	74,020,809,137	74,002,038,677	0.119	–18,770,460
Basin 151	41,924,400	13.2	43.5	553,750,053	91,454,000	83,062,508	73,081,613,936	72,912,922,785	4.52	–168,691,151
Basin 118	1,446,400	3.1	8	4,429,817	2,001,200	664,473	227,782,757	221,954,068	0.666	–5,828,689
Basin 123	7,284,400	13.6	23.1	98,880,631	7,717,200	14,832,095	83,375,277,029	83,342,343,517	0.125	–32,933,511
Basin 152	2,134,800	1.4	4.7	3,066,448	1,277,480,000	459,967	402,539,278	84,448,138	0.524	–318,091,141
Basin 150	5,856,800	3.6	14.2	21,083,192	15,624,800	3,162,479	3,347,210,492	3,324,384,880	0.686	–22,825,612
Basin 146	3,404,000	7.7	16.2	26,299,440	3,823,200	3,944,916	23,179,435,891	23,164,029,471	0.091	–15,406,420
Basin 126	5,440,400	7.5	16.4	40,604,153	7,232,000	6,090,623	22,217,768,523	22,194,479,015	0.245	–23,289,509
Basin 134	586,400	1.8	5.8	1,052,611	1,957,600	157,892	1,017,417	862,217	0.024	–155,200
Basin 121	3,692,400	5.5	12.8	20,313,960	13,983,600	3,047,094	8,073,976,047	8,058,725,774	0.27	–15,250,273
Basin 120	729,200	2.5	12.3	1,815,453	10,336,400	272,318	26,125,590	24,685,617	0.329	–1,439,973
Allbasins	246,352,000	12.6	58.8	3,088,481,756	1,675,400,800	463,272,263	1,690,017,727,996	**1,688,642,009,137**		–1,375,718,859

Physical charactenstivs of the basins – Laxenar-Simpevarp.

Physical characteristics of the marine basins in the marine Laxemar-Simpevarp area.

IDKOD	Marine basin area (m²)	Mean depth (m)	Max depth (m)	Volume (m³)	Total drain-age area to basin (m²)	Runoff (m³ year⁻¹)	Advective outflow (m³)	Avdective inflow (m³)	AvA days	Net advective flow (m3)
Basin 524	14,680,400	11.6	27.7	170,467,920	138,000	30,360	465,695,503,200	843,092,841,600	0.14	377,397,338,400
Basin 525	15,211,200	6.9	24.7	105,559,158	0	0	55,819,082,880	46,610,575,200	0.31	–9,208,507,680
Basin 522	13,567,200	15.9	35.8	216,473,156	0	0	267,987,139,200	469,577,088,000	0.19	201,589,948,800
Basin 523	13,933,600	11.5	25.8	160,983,466	0	0	201,933,926,640	337,281,317,280	0.27	135,347,390,640
Basin 521	**38,044,800**	**11.1**	**45.1**	**425,691,909**	**1,538,000**	**338,360**	**226,170,479,016**	**355,090,217,688**	**0.81**	**128,919,738,672**
Basin 501	334,800	3.2	10.4	1,066,472	12,214,000	2,698,112	27,770,688	27,770,688	15.8	0
Basin 500	2,906,000	2.0	9.1	5,757,570	13,300,000	2,938,013	0	911,067,912	4.26	911,067,912
Basin 504	**608,000**	**3.6**	**16.1**	**2,187,558**	**1,948,000**	**428,560**	**228,477,024**	**229,423,752**	**5.88**	**946,728**
Basin 502	**1,126,800**	**4.8**	**18.1**	**5,461,854**	**34,675,000**	**7,628,500**	**89,939,160**	**90,254,736**	**24.4**	**315,576**
Basin 506	**334,400**	**3.3**	**12.1**	**1,105,921**	**951,000**	**209,220**	**309,264,480**	**302,637,384**	**2.78**	**–6,627,096**
Basin 508	**1,374,800**	**1.7**	**8.1**	**2,387,159**	**46,517,000**	**10,233,880**	**60,906,168**	**55,225,800**	**10.3**	**–5,680,368**
Basin 513	4,062,800	4.3	16.1	17,556,328	7,356,000	1,618,320	8,429,034,960	8,410,100,400	0.29	–18,934,560
Basin 514	952,000	4.5	17.1	4,298,745	0	0	8,488,994,400	8,498,461,680	0.31	9,467,280
Basin 516	482,000	0.1	0.87	73,975	2,732,000	601,040	2,556,165,600	2,556,165,600	9.25	0
Basin 518	758,800	3.7	16.6	2,863,972	0	0	11,329,178,400	11,322,866,880	0.40	–6,311,520
Basin 515	869,600	3.3	8.2	2,872,032	11,552,000	2,541,440	716,041,944	716,041,944	6.86	0
Basin 517	6,686,000	3.5	18.4	23,713,485	22,719,000	4,998,180	6,065,370,720	6,060,952,656	1.03	–4,418,064
Basin 520	2,269,200	2.4	11.3	5,560,975	12,200,000	2,695,019	1,084,319,136	1,082,425,680	0.40	–1,893,456
Basin 519	590,400	0.2	2.7	138,681	139,057,000	30,718,136	12,307,464	12,307,464	7.98	0
Allbasins	**118,792,800**	**9.9**	**45.1**	**1,154,220,339**	**306,897,000**	**67,677,140**	**1,257,003,901,080**	**2,091,927,742,344**		**834,923,841,264**

Results generated in GIS-models for marine ecosystems, in gC m^{-2} $year^{-2}$, for functional groups, abiotic pools and fluxes – Forsmark.

Physical parameters in the marine Forsmark area, depths and areas in m and m^2 respectively.

IDKOD	AREA (m2)	secchi	Depth	Medel PAR	Burial (gC m^{-2} $year^{-1}$)
Basin 102	34173600	10.84	10.85	0.91	0.34
Basin 100	18455600	10.18	19.38	0.44	0.42
Basin 101	21798800	11.10	16.14	0.29	0.00
Basin 105	22664000	10.15	18.21	0.37	0.85
Basin 103	5693600	10.57	5.50	1.72	0.40
Basin 104	2698000	11.05	7.65	1.13	0.01
Basin 108	7193600	9.90	10.63	0.70	0.72
Basin 106	1385600	11.00	4.49	1.77	0.01
Basin 111	6736800	8.21	3.30	1.99	2.84
Basin 107	4627600	11.01	6.99	1.20	0.02
Basin 110	7072400	10.97	12.43	0.56	0.04
Basin 114	14030800	9.55	19.43	0.35	3.51
Basin 109	1521200	10.91	19.28	0.15	1.97
Basin 116	**13534000**	**10.71**	**9.47**	**0.88**	**0.06**
Basin 113	1596800	10.87	12.52	0.55	0.29
Basin 117	5762800	7.53	3.71	1.74	3.14
Basin 112	696400	11.09	10.89	0.60	0.00
Basin 115	4211200	10.75	16.08	0.34	3.72
Basin 151	41924400	7.20	13.21	0.51	0.74
Basin 118	1446400	4.46	3.06	1.31	11.51
Basin 123	7284400	10.24	13.57	0.50	0.25
Basin 152	2134800	2.88	1.44	1.58	24.37
Basin 150	5856800	4.34	3.60	1.14	9.35
Basin 146	3404000	9.18	7.73	0.99	0.32
Basin 126	**5440400**	**8.61**	**7.46**	**0.93**	**0.14**
Basin 134	**586400**	**3.35**	**1.80**	**1.35**	**7.47**
Basin 121	**3692400**	**7.48**	**5.50**	**1.09**	**3.13**
Basin 120	**729200**	**2.59**	**2.49**	**0.95**	**7.91**

Biomasses and masses in the marine Forsmark area, in g m^{-1} $year^{-1}$.

IDKOD	Phyto-plank-ton	Micro-phytes	Macro-phytes	Bacterio-plankton	Zoo-plank-ton	Benthic bacteria	Benthic herbiv-ores	Benthic filterfeed-ers	Benthic detri-vores	Benthic carni-vores	Benth-vorus fish	Zooplank-tivorus fish	Pisciv-orus fish	Bird	Seal	DIC	DOC	POC	Sediment (top 10cm)
Basin 102	0.16	2.24	5.81	0.27	0.05	0.58	1.10	1.04	4.62	0.26	0.07	0.07	0.01	0.01	0.014	68.84	30.39	1.92	55.54
Basin 100	0.36	1.08	5.29	0.37	0.12	0.88	0.87	0.84	3.24	0.35	0.05	0.20	0.02	0.00	0.014	92.46	57.69	3.94	122.39
Basin 101	0.29	0.86	0.43	0.39	0.10	0.75	0.65	0.69	2.84	0.39	0.03	0.10	0.00	0.00	0.014	104.46	45.16	2.91	167.98
Basin 105	0.36	0.96	3.27	0.38	0.12	1.36	0.59	0.62	3.24	0.45	0.05	0.18	0.01	0.00	0.014	101.39	55.29	3.90	219.48
Basin 103	0.04	3.77	15.87	0.14	0.01	0.35	1.68	1.44	6.10	0.13	0.16	0.06	0.04	0.01	0.014	41.11	15.97	1.03	0.00
Basin 104	0.05	3.06	4.45	0.19	0.02	0.68	1.01	1.03	5.13	0.32	0.17	0.06	0.04	0.01	0.014	64.80	21.46	1.38	531.98
Basin 108	0.15	1.85	4.82	0.27	0.05	0.59	1.03	1.06	4.45	0.28	0.10	0.07	0.02	0.01	0.014	86.58	31.27	2.09	143.20
Basin 106	0.02	4.62	8.75	0.11	0.01	0.62	1.71	1.39	7.23	0.11	0.30	0.10	0.10	0.02	0.014	41.40	12.99	0.86	276.12
Basin 111	0.03	4.43	28.93	0.08	0.01	0.89	1.90	1.86	5.70	0.20	0.47	0.19	0.17	0.02	0.014	35.79	11.39	0.87	46.87
Basin 107	0.05	3.26	5.61	0.17	0.02	0.58	1.41	1.37	5.68	0.19	0.22	0.08	0.07	0.01	0.014	63.12	20.03	1.31	278.60
Basin 110	0.19	1.60	5.92	0.31	0.06	0.68	1.07	1.20	3.29	0.35	0.09	0.08	0.02	0.00	0.014	98.67	36.15	2.45	72.11
Basin 114	0.43	0.90	2.13	0.40	0.14	1.81	0.37	0.44	3.31	0.53	0.05	0.21	0.02	0.00	0.014	123.10	62.18	4.64	425.20
Basin 109	0.45	0.45	0.33	0.45	0.15	1.42	0.37	0.42	2.76	0.51	0.01	0.14	0.00	0.00	0.014	123.77	57.62	4.05	350.43
Basin 116	**0.12**	**2.37**	**11.07**	**0.24**	**0.04**	**0.82**	**1.31**	**1.47**	**3.85**	**0.33**	**0.19**	**0.10**	**0.06**	**0.01**	**0.014**	**83.73**	**28.35**	**1.97**	**126.91**
Basin 113	0.21	1.60	8.60	0.31	0.07	0.86	1.14	1.35	2.80	0.39	0.06	0.08	0.01	0.00	0.014	96.11	37.46	2.64	114.44
Basin 117	0.04	3.83	22.60	0.09	0.01	0.85	1.67	1.59	5.55	0.20	0.65	0.24	0.24	0.02	0.014	44.02	13.57	1.08	78.39
Basin 112	0.12	1.76	2.60	0.27	0.04	0.79	0.92	1.03	3.50	0.34	0.15	0.08	0.05	0.00	0.014	95.39	31.79	2.17	95.04
Basin 115	0.36	0.99	3.81	0.39	0.12	1.32	0.65	0.79	2.99	0.47	0.04	0.12	0.01	0.00	0.014	115.49	48.50	3.44	260.84
Basin 151	0.32	1.17	5.71	0.31	0.11	1.72	0.75	0.87	3.71	0.44	0.07	0.17	0.02	0.01	0.014	105.39	49.26	4.00	300.36
Basin 118	0.05	2.65	33.23	0.08	0.02	1.66	1.17	1.27	5.26	0.18	0.64	0.23	0.22	0.02	0.014	39.17	15.58	1.37	47.01
Basin 123	0.27	1.33	6.00	0.34	0.09	1.63	0.63	0.89	3.07	0.51	0.08	0.11	0.02	0.00	0.014	105.79	42.04	3.05	300.52
Basin 152	0.15	2.35	92.72	0.04	0.05	2.66	0.54	0.57	5.53	0.17	0.83	0.28	0.29	0.03	0.014	20.46	8.47	0.75	285.98
Basin 150	0.18	2.52	24.28	0.09	0.06	4.36	1.12	1.23	5.17	0.21	0.39	0.16	0.12	0.02	0.014	40.52	16.89	1.45	350.40
Basin 146	0.10	2.68	10.65	0.19	0.03	1.63	1.19	1.37	3.91	0.37	0.23	0.14	0.08	0.01	0.014	69.57	25.32	1.92	188.60
Basin 126	**0.10**	**2.56**	**8.21**	**0.19**	**0.03**	**1.74**	**1.14**	**1.27**	**4.26**	**0.34**	**0.21**	**0.15**	**0.08**	**0.01**	**0.014**	**68.23**	**25.71**	**2.01**	**186.01**
Basin 134	**0.03**	**3.28**	**22.28**	**0.05**	**0.01**	**3.74**	**0.81**	**0.72**	**6.89**	**0.15**	**0.09**	**0.11**	**0.03**	**0.02**	**0.014**	**19.33**	**11.04**	**0.95**	**313.91**
Basin 121	**0.06**	**2.91**	**15.21**	**0.14**	**0.02**	**2.43**	**1.00**	**1.17**	**4.38**	**0.33**	**0.31**	**0.16**	**0.11**	**0.01**	**0.014**	**55.31**	**20.05**	**1.59**	**165.01**
Basin 120	**0.05**	**2.50**	**23.48**	**0.06**	**0.02**	**2.09**	**1.08**	**1.04**	**5.93**	**0.17**	**0.49**	**0.14**	**0.13**	**0.02**	**0.014**	**31.92**	**17.24**	**1.46**	**52.68**

Net Primary production(NPP) and Net Ecosystem Production (NEP) in the marine Forsmark area, in g m^{-1} $year^{-1}$.

IDKOD	Benthic NPP	Macrophyte NPP	Microphyte NNP	Pelagic NPP	Total NPP	Total NEP	Benthic NEP	Pelagic NEP
Basin 102	96.85	68.02	28.83	16.63	113.48	45.84	65.66	–19.82
Basin 100	49.34	35.38	13.97	36.27	85.62	5.11	23.84	–18.74
Basin 101	13.60	2.60	11.01	29.67	43.28	–33.61	–9.29	–24.32
Basin 105	36.10	23.70	12.40	36.59	72.69	–10.92	7.89	–18.80
Basin 103	248.72	200.25	48.48	4.37	253.09	195.42	209.44	–14.02
Basin 104	93.78	54.37	39.41	5.48	99.26	38.84	57.67	–18.83
Basin 108	52.09	28.20	23.89	15.19	67.28	–0.68	19.83	–20.51
Basin 106	186.45	126.81	59.64	2.30	188.75	125.37	138.36	–12.99
Basin 111	284.76	227.58	57.18	2.88	287.64	224.47	235.31	–10.84
Basin 107	101.21	59.14	42.08	4.85	106.06	43.10	61.05	–17.95
Basin 110	40.29	19.69	20.60	19.62	59.91	–11.11	11.28	–22.39
Basin 114	34.13	22.47	11.65	43.03	77.16	–13.49	2.79	–16.28
Basin 109	7.00	1.17	5.83	46.11	53.11	–37.88	–17.98	–19.90
Basin 116	**83.32**	**52.77**	**30.54**	**11.72**	**95.04**	**27.95**	**48.12**	**–20.17**
Basin 113	38.41	17.88	20.53	21.31	59.72	–11.52	9.78	–21.30
Basin 117	230.97	181.46	49.51	4.01	234.98	170.21	182.40	–12.19
Basin 112	32.10	9.58	22.52	12.17	44.27	–21.84	1.75	–23.59
Basin 115	25.02	12.27	12.75	35.96	60.98	–23.65	–3.90	–19.75
Basin 151	61.92	46.65	15.27	32.24	94.17	11.17	24.91	–13.74
Basin 118	191.96	157.42	34.54	4.78	196.74	130.24	139.72	–9.48
Basin 123	46.28	29.16	17.12	27.65	73.93	–6.91	13.00	–19.91
Basin 152	207.81	177.18	30.63	14.72	222.53	147.92	147.01	0.91
Basin 150	115.04	82.32	32.72	17.97	133.01	41.28	41.56	–0.28
Basin 146	95.22	60.53	34.70	10.49	105.72	36.52	53.01	–16.49
Basin 126	**80.93**	**47.79**	**33.14**	**9.92**	**90.85**	**20.94**	**37.18**	**–16.23**
Basin 134	**117.64**	**74.73**	**42.91**	**2.95**	**120.59**	**45.33**	**49.80**	**–4.47**
Basin 121	**98.56**	**60.79**	**37.76**	**6.52**	**105.08**	**34.07**	**47.68**	**–13.61**
Basin 120	**92.15**	**59.57**	**32.58**	**4.77**	**96.92**	**28.42**	**34.70**	**–6.28**

Respiration in the marine Forsmark area, in g m^{-1} year^{-1}.

IDKOD	Benthic respiration	Pelagic respiration	Total respiration
Basin 102	31.20	36.45	67.65
Basin 100	25.50	55.01	80.51
Basin 101	22.89	53.99	76.88
Basin 105	28.21	55.39	83.60
Basin 103	39.28	18.39	57.67
Basin 104	36.11	24.32	60.43
Basin 108	32.25	35.71	67.96
Basin 106	48.09	15.29	63.38
Basin 111	49.44	13.73	63.17
Basin 107	40.16	22.80	62.96
Basin 110	29.01	42.01	71.02
Basin 114	31.34	59.31	90.65
Basin 109	24.98	66.01	90.99
Basin 116	**35.19**	**31.89**	**67.08**
Basin 113	28.63	42.61	71.24
Basin 117	48.57	16.20	64.77
Basin 112	30.35	35.76	66.11
Basin 115	28.92	55.71	84.63
Basin 151	37.01	45.98	82.99
Basin 118	52.25	14.26	66.50
Basin 123	33.28	47.56	80.84
Basin 152	60.80	13.81	74.61
Basin 150	73.48	18.25	91.73
Basin 146	42.21	26.98	69.19
Basin 126	**43.75**	**26.15**	**69.91**
Basin 134	**67.84**	**7.42**	**75.26**
Basin 121	**50.88**	**20.13**	**71.00**
Basin 120	**57.44**	**11.05**	**68.49**

Consumption in the marine Forsmark area, in g m⁻¹ year⁻¹.

IDKOD	Cons. of phyto-plankton	Cons. of micro-phytes	Cons. of macro-phytes	Cons. Of bacterio-plankton	Cons. Of zoo-plank-ton	Cons. Of benthic bacteria	Cons. Of benthic herbiv-ores	Cons. of benthic filter feeders	Cons. of benthic detri-vores and meiofauna	Cons. of benthic carni-vores	Cons. of ben-thivorus fish	Cons. of zooplank-tivorous fish	Cons. of pis-civorous fish	Cons. of burial (sedi-ment)	Cons. of DOC	Cons. of POC
Basin 102	5.51	5.44	5.55	8.42	0.55	0.42	0.33	0.43	2.18	0.01	1.63	0.31	0.06	36.74	66.54	13.27
Basin 100	13.67	4.22	4.15	14.16	1.37	0.34	0.41	0.42	2.49	0.01	2.25	0.43	0.05	27.18	91.60	13.18
Basin 101	10.08	4.35	1.73	12.86	0.77	0.07	0.31	0.49	2.77	0.01	0.87	0.27	0.00	26.18	94.74	11.55
Basin 105	13.68	2.74	3.04	14.06	1.21	0.27	0.27	0.42	3.41	0.02	1.45	0.40	0.04	26.30	92.11	11.75
Basin 103	1.20	6.02	11.63	4.17	0.51	1.07	0.56	0.50	1.79	0.02	2.58	0.50	0.18	40.27	35.17	15.76
Basin 104	1.21	5.21	5.45	4.42	0.50	0.41	0.26	0.65	3.55	0.08	1.71	0.38	0.13	38.98	46.34	12.78
Basin 108	4.73	4.78	5.90	8.07	0.66	0.50	0.35	0.56	2.62	0.04	1.66	0.45	0.07	40.01	64.68	13.78
Basin 106	0.61	8.58	10.07	3.17	0.79	0.85	0.61	0.52	2.85	0.03	3.64	0.78	0.30	49.31	27.48	15.54
Basin 111	1.15	4.61	17.02	3.63	1.61	1.35	1.18	1.25	3.67	0.10	5.13	1.39	0.27	33.24	21.81	20.96
Basin 107	1.19	7.56	7.41	4.49	0.70	0.45	0.46	0.61	2.60	0.06	2.11	0.55	0.16	46.03	42.60	15.99
Basin 110	6.39	4.37	6.55	9.87	0.72	0.34	0.49	0.77	2.72	0.04	1.08	0.39	0.05	31.34	74.99	15.88
Basin 114	16.78	1.61	2.12	15.37	1.43	0.29	0.16	0.40	4.35	0.03	3.32	0.42	0.04	25.70	95.47	10.90
Basin 109	17.42	1.99	1.30	17.03	0.99	0.12	0.18	0.35	3.71	0.01	2.50	0.28	0.00	23.12	108.95	10.79
Basin 116	**3.49**	**4.32**	**9.62**	**7.27**	**0.85**	**0.62**	**0.60**	**0.93**	**3.10**	**0.08**	**1.91**	**0.59**	**0.13**	**33.71**	**57.41**	**17.84**
Basin 113	7.13	3.41	7.98	10.46	0.69	0.34	0.52	0.84	2.68	0.02	0.97	0.34	0.04	26.46	75.28	17.31
Basin 117	1.42	5.53	14.20	3.54	1.95	1.39	1.33	1.39	4.78	0.17	6.08	1.71	0.30	37.47	22.88	18.21
Basin 112	3.22	5.29	4.14	7.32	0.72	0.18	0.44	0.77	3.18	0.09	1.15	0.46	0.08	32.79	65.82	13.85
Basin 115	13.36	2.43	4.01	14.19	0.89	0.30	0.27	0.57	3.61	0.02	1.20	0.32	0.02	26.12	93.51	13.47
Basin 151	12.69	1.93	6.29	12.03	1.26	0.75	0.32	0.60	3.84	0.02	3.69	0.53	0.06	30.04	74.37	14.09
Basin 118	1.78	3.39	11.31	2.95	1.86	1.99	1.04	1.17	5.20	0.12	6.35	1.63	0.35	36.77	18.67	15.00
Basin 123	9.79	1.70	4.84	11.75	0.88	0.44	0.25	0.79	4.11	0.05	1.42	0.42	0.05	24.11	81.22	13.81
Basin 152	9.62	0.19	8.25	2.42	2.54	2.91	0.70	0.75	7.30	0.17	8.43	2.14	0.46	31.98	8.77	5.71
Basin 150	10.24	3.49	10.09	4.92	1.63	1.74	0.71	0.87	4.11	0.11	5.47	1.19	0.26	21.64	22.09	12.83
Basin 146	3.31	3.60	9.34	6.20	1.15	0.66	0.60	1.01	3.85	0.11	2.45	0.86	0.16	26.70	46.63	16.52
Basin 126	**3.00**	**4.32**	**8.02**	**5.88**	**1.17**	**0.64**	**0.50**	**0.89**	**3.68**	**0.11**	**2.39**	**0.90**	**0.16**	**31.44**	**45.29**	**15.65**
Basin 134	**1.04**	**1.72**	**8.56**	**1.72**	**0.88**	**2.01**	**0.29**	**0.28**	**2.64**	**0.03**	**8.93**	**1.76**	**0.16**	**30.44**	**11.67**	**8.26**
Basin 121	**1.93**	**2.94**	**8.56**	**4.28**	**1.30**	**1.09**	**0.56**	**0.97**	**4.28**	**0.17**	**3.78**	**1.17**	**0.22**	**26.25**	**33.64**	**14.14**
Basin 120	**1.85**	**1.62**	**12.29**	**2.49**	**1.15**	**2.12**	**0.78**	**0.76**	**4.85**	**0.09**	**5.05**	**0.98**	**0.33**	**43.57**	**15.23**	**12.29**

Results generated in GIS-models for marine ecosystem, in gC m^{-2} $year^{-1}$ for functional groups, abiotic pools and fluxes – Laxemar-Simpevarp.

Physical parameters in the marine Laxemar-Simpevarp area, depths and areas in m and m^2 respectively.

IDKOD	AREA (m2)	secchi	Depth	Medel PAR	Burial (gC m^{-2} $year^{-1}$)
Basin 524	14680400	10 .9	11 .59	0 .810	0 .0
Basin 525	15211200	9 .8	6 .92	1 .413	0 .0
Basin 522	13567200	11 .1	15 .93	0 .382	0 .0
Basin 523	13933600	11 .1	11 .53	0 .697	0 .0
Basin 521	**38044800**	**9 .6**	**11 .15**	**0 .873**	**0 .6**
Basin 501	334800	1 .5	3 .17	0 .837	21 .6
Basin 500	2906000	1 .9	1 .95	1 .692	9 .8
Basin 504	**608000**	**1 .5**	**3 .55**	**1 .019**	**23 .9**
Basin 502	**1126800**	**1 .7**	**4 .83**	**0 .624**	**45 .7**
Basin 506	**334400**	**1 .6**	**3 .28**	**0 .744**	**7 .4**
Basin 508	**1374800**	**1 .6**	**1 .72**	**1 .078**	**34 .8**
Basin 513	4062800	7 .6	4 .28	1 .856	2 .1
Basin 514	952000	9 .2	4 .48	2 .053	0 .0
Basin 516	482000	1 .6	0 .10	3 .362	0 .0
Basin 518	758800	8 .4	3 .72	2 .185	0 .0
Basin 515	869600	2 .9	3 .25	1 .068	24 .0
Basin 517	6686000	4 .4	3 .53	1 .741	12 .1
Basin 520	2269200	4 .4	2 .44	2 .351	0 .0
Basin 519	590400	1 .6	0 .22	3 .383	0 .0

Biomasses and masses in the marine Laxemar-Simpevarp area, in g m^{-1} year^{-1}.

IDKOD	Phyto-plankton	Micro-phytes	Macro-phytes	Bacteri-oplank-ton	Zoo-plank-ton	Benthic bacteria	Benthic herbiv-ores	Benthic filter-feeders	Benthic detri-vores	Benthic carni-vores	Benth-vorus fish	Zoo-plank-tivorus fish	Pisciv-orus fish	Bird	Seal	DIC	DOC	POC	Sediment (top 10cm)
Basin 524	0 .25	1 .25	25 .88	0 .29	0 .083	1 .700	4 .20	52 .16	10 .87	0 .28	0 .22	0 .422	0 .016	0 .002	0 .0046	184 .69	45 .64	1 .76	8 .27
Basin 525	0 .14	2 .18	38 .01	0 .17	0 .045	0 .706	5 .51	69 .13	10 .01	0 .32	0 .24	0 .405	0 .031	0 .006	0 .0046	111 .52	27 .93	1 .12	3 .26
Basin 522	0 .36	0 .59	14 .72	0 .38	0 .121	1 .089	2 .79	36 .73	7 .24	0 .16	0 .20	0 .424	0 .014	0 .000	0 .0046	252 .00	62 .27	2 .40	109 .15
Basin 523	0 .23	1 .08	23 .71	0 .29	0 .076	0 .563	4 .42	60 .54	8 .81	0 .21	0 .21	0 .424	0 .014	0 .001	0 .0046	182 .54	45 .11	1 .74	22 .13
Basin 521	**0 .26**	**1 .35**	**26 .89**	**0 .26**	**0 .088**	**1 .142**	**3 .64**	**45 .06**	**7 .77**	**0 .26**	**0 .22**	**0 .398**	**0 .036**	**0 .004**	**0 .0046**	**179 .19**	**45 .15**	**1 .83**	**91 .08**
Basin 501	0 .14	1 .29	34 .60	0 .08	0 .048	4 .204	1 .72	5 .29	2 .02	0 .70	0 .42	0 .147	0 .253	0 .014	0 .0046	49 .30	23 .01	1 .94	257 .92
Basin 500	0 .09	2 .61	32 .37	0 .05	0 .029	3 .138	2 .08	4 .97	2 .23	0 .68	0 .31	0 .147	0 .253	0 .016	0 .0046	32 .37	15 .11	1 .27	139 .04
Basin 504	**0 .18**	**1 .57**	**37 .26**	**0 .09**	**0 .060**	**4 .271**	**1 .69**	**3 .64**	**2 .30**	**0 .71**	**0 .33**	**0 .147**	**0 .253**	**0 .014**	**0 .0046**	**57 .74**	**26 .95**	**2 .27**	**292 .25**
Basin 502	**0 .23**	**0 .96**	**29 .06**	**0 .12**	**0 .078**	**5 .729**	**1 .49**	**3 .89**	**2 .43**	**0 .70**	**0 .33**	**0 .147**	**0 .253**	**0 .012**	**0 .0046**	**74 .61**	**34 .83**	**2 .93**	**496 .70**
Basin 506	**0 .16**	**1 .15**	**33 .46**	**0 .08**	**0 .054**	**4 .615**	**1 .69**	**4 .94**	**2 .17**	**0 .69**	**0 .37**	**0 .148**	**0 .252**	**0 .015**	**0 .0046**	**52 .17**	**24 .33**	**2 .05**	**252 .08**
Basin 508	**0 .15**	**1 .66**	**68 .31**	**0 .04**	**0 .049**	**4 .970**	**1 .53**	**3 .81**	**2 .29**	**0 .86**	**0 .40**	**0 .147**	**0 .253**	**0 .020**	**0 .0046**	**27 .05**	**12 .62**	**1 .06**	**396 .07**
Basin 513	0 .09	2 .86	59 .58	0 .11	0 .031	1 .266	5 .26	53 .21	8 .25	0 .48	0 .27	0 .339	0 .088	0 .012	0 .0046	72 .01	19 .10	0 .86	72 .42
Basin 514	0 .09	3 .17	76 .68	0 .11	0 .030	0 .874	6 .42	64 .68	9 .78	0 .47	0 .28	0 .405	0 .030	0 .012	0 .0046	74 .80	18 .70	0 .74	47 .44
Basin 516	0 .01	5 .19	55 .29	0 .00	0 .002	0 .650	3 .43	3 .61	1 .75	0 .87	0 .29	0 .147	0 .253	0 .017	0 .0046	2 .72	1 .27	0 .11	0 .00
Basin 518	0 .07	3 .37	64 .27	0 .09	0 .024	1 .068	6 .25	63 .30	10 .46	0 .49	0 .27	0 .384	0 .048	0 .012	0 .0046	62 .63	15 .63	0 .62	59 .84
Basin 515	0 .13	1 .65	17 .05	0 .08	0 .043	4 .219	1 .59	6 .50	2 .72	0 .47	0 .21	0 .147	0 .253	0 .015	0 .0046	49 .86	23 .28	1 .96	279 .39
Basin 517	0 .12	2 .69	27 .94	0 .09	0 .041	2 .436	2 .64	17 .58	3 .39	0 .46	0 .23	0 .201	0 .206	0 .012	0 .0046	56 .92	23 .13	1 .77	176 .47
Basin 520	0 .08	3 .63	37 .17	0 .06	0 .025	0 .459	3 .54	30 .30	3 .84	0 .47	0 .26	0 .271	0 .146	0 .009	0 .0046	44 .65	13 .72	0 .79	0 .00
Basin 519	0 .01	5 .22	45 .54	0 .01	0 .003	0 .650	3 .32	4 .07	1 .84	0 .86	0 .31	0 .147	0 .253	0 .011	0 .0046	3 .93	1 .84	0 .15	0 .00

Net Primary production(NPP) and Net Ecosystem Production (NEP) in the marine Laxemar-Simpevarp area, in g m^{-1} $year^{-1}$.

IDKOD	Benthic NPP	Macrophyte NPP	Microphyte NNP	Pelagic NPP	Total NPP	Total NEP	Benthic NEP	Pelagic NEP
Basin 524	121 .63	106 .06	16 .12	24 .42	146 .2	–206 .28	–123 .65	–18 .33
Basin 525	191 .11	164 .33	28 .12	13 .24	204 .6	–282 .29	–130 .89	–13 .07
Basin 522	63 .49	55 .88	7 .61	35 .64	99 .1	–155 .29	–91 .22	–21 .04
Basin 523	102 .53	88 .68	13 .87	22 .29	124 .8	–274 .99	–151 .43	–19 .46
Basin 521	**126 .87**	**110 .67**	**17 .37**	**25 .91**	**153 .1**	**–179 .56**	**–82 .26**	**–15 .33**
Basin 501	100 .36	88 .11	16 .65	14 .16	115 .1	15 .36	13 .92	–2 .81
Basin 500	233 .26	205 .76	33 .67	8 .46	242 .5	153 .75	153 .36	–2 .79
Basin 504	**138 .72**	**124 .43**	**20 .27**	**17 .71**	**157 .5**	**58 .44**	**56 .61**	**–2 .17**
Basin 502	**75 .39**	**67 .06**	**12 .42**	**23 .00**	**99 .1**	**–16 .29**	**–18 .76**	**–2 .35**
Basin 506	**69 .93**	**60 .37**	**14 .81**	**15 .88**	**86 .6**	**–20 .01**	**–22 .06**	**–2 .42**
Basin 508	**177 .77**	**161 .00**	**21 .46**	**14 .35**	**192 .8**	**87 .11**	**81 .15**	**1 .34**
Basin 513	298 .92	264 .64	36 .94	8 .97	308 .3	–75 .96	22 .95	–9 .16
Basin 514	365 .91	326 .84	40 .85	8 .83	375 .1	–70 .90	34 .54	–9 .60
Basin 516	707 .17	641 .74	66 .91	0 .65	707 .9	651 .92	652 .30	–2 .12
Basin 518	347 .26	306 .12	43 .48	7 .03	354 .7	–80 .02	13 .36	–8 .60
Basin 515	128 .19	109 .82	21 .25	12 .60	141 .1	35 .28	35 .60	–3 .54
Basin 517	239 .01	208 .56	34 .65	12 .08	251 .8	82 .03	114 .93	–4 .83
Basin 520	329 .55	290 .21	46 .79	7 .47	338 .2	72 .38	170 .21	–5 .07
Basin 519	607 .44	543 .04	67 .32	0 .94	608 .5	550 .28	550 .75	–2 .19

Respiration in the marine Laxemar-Simpevarp area, in g m^{-1} $year^{-1}$.

IDKOD	Benthic respiration	Pelagic respiration	Total respiration
Basin 524	309 .58	42 .90	352 .48
Basin 525	460 .33	26 .53	486 .86
Basin 522	197 .74	56 .69	254 .42
Basin 523	358 .06	41 .76	399 .82
Basin 521	**291 .07**	**41 .55**	**332 .63**
Basin 501	82 .19	17 .50	99 .69
Basin 500	76 .72	12 .07	88 .79
Basin 504	**78 .11**	**20 .96**	**99 .07**
Basin 502	**89 .33**	**26 .03**	**115 .36**
Basin 506	**87 .53**	**19 .08**	**106 .60**
Basin 508	**92 .00**	**13 .65**	**105 .65**
Basin 513	365 .72	18 .55	384 .27
Basin 514	427 .21	18 .77	445 .98
Basin 516	53 .13	2 .88	56 .01
Basin 518	418 .69	16 .04	434 .73
Basin 515	89 .37	16 .45	105 .82
Basin 517	152 .15	17 .67	169 .82
Basin 520	252 .11	13 .75	265 .86
Basin 519	54 .96	3 .28	58 .25

Consumption in the marine Laxemar-Simpevarp area, in g m⁻¹ year⁻¹.

IDKOD	Cons. of phyto-plankton	Cons. of micro-phytes	Cons. of macro-phytes	Cons. Of bacterio-plankton	Cons. Of zooplank-ton	Cons. Of benthic bacteria	Cons. Of benthic herbiv-ores	Cons. of benthic filter feeders	Cons. of benthic detrivores and meio-fauna	Cons. of benthic carni-vores	Cons. of ben-thivorus fish	Cons. of zooplank-tivorous fish	Cons. of piscivo-rous fish	Cons. of burial (sediment)	Cons. of DOC	Cons. of POC
Basin 524	701	2 .0	42	1,006	233	120	0 .3	3 .5	0 .9	0 .01	0 .4	0 .2	0 .00	32	70	1 .8
Basin 525	1,036	3 .3	60	1,451	346	124	0 .6	4 .8	1 .0	0 .02	1 .2	0 .4	0 .01	13	44	1 .2
Basin 522	489	1 .0	26	653	160	44	0 .2	2 .1	0 .6	0 .005	0 .1	0 .1	0 .003	47	91	2 .3
Basin 523	763	2 .0	43	1,151	254	88	0 .2	3 .1	0 .5	0 .004	0 .2	0 .2	0 .003	21	70	1 .8
Basin 521	**680**	**1 .9**	**39**	**881**	**225**	**66**	**0 .5**	**3 .5**	**0 .9**	**0 .02**	**0 .9**	**0 .3**	**0 .01**	**43**	**66**	**1 .7**
Basin 501	58	0 .8	22	34	18	13	2 .6	7 .2	3 .1	0 .29	3 .6	0 .8	0 .04	106	20	1 .4
Basin 500	52	2 .0	27	31	16	17	3 .3	6 .0	3 .3	0 .24	4 .4	1 .1	0 .05	87	14	1 .0
Basin 504	**48**	**0 .7**	**22**	**27**	**13**	**16**	**2 .8**	**5 .4**	**4 .0**	**0 .29**	**3 .5**	**1 .0**	**0 .05**	**107**	**24**	**1 .7**
Basin 502	**51**	**0 .4**	**19**	**29**	**13**	**9**	**2 .4**	**5 .4**	**3 .8**	**0 .28**	**3 .1**	**1 .0**	**0 .05**	**142**	**31**	**2 .2**
Basin 506	**61**	**0 .6**	**22**	**37**	**18**	**12**	**2 .6**	**6 .4**	**3 .5**	**0 .30**	**3 .7**	**1 .0**	**0 .05**	**122**	**22**	**1 .6**
Basin 508	**74**	**0 .7**	**21**	**25**	**22**	**13**	**3 .2**	**6 .5**	**5 .3**	**0 .46**	**4 .6**	**1 .0**	**0 .05**	**137**	**11**	**0 .7**
Basin 513	781	3 .1	62	1,116	262	84	1 .4	6 .4	1 .8	0 .07	2 .6	0 .7	0 .02	53	29	0 .8
Basin 514	1,011	3 .4	77	1,426	339	94	1 .0	7 .2	1 .5	0 .03	2 .2	0 .7	0 .01	55	29	0 .8
Basin 516	37	4 .2	45	22	13	27	6 .2	6 .3	3 .3	0 .30	4 .8	1 .2	0 .05	14	1	0 .1
Basin 518	992	4 .1	74	1,414	333	86	1 .4	6 .9	1 .7	0 .05	2 .2	0 .7	0 .01	80	25	0 .6
Basin 515	60	1 .6	20	40	18	13	1 .6	4 .9	2 .6	0 .11	4 .6	1 .3	0 .06	115	20	1 .5
Basin 517	302	2 .7	32	301	99	31	1 .9	5 .1	2 .0	0 .09	3 .6	1 .1	0 .05	66	25	1 .5
Basin 520	726	3 .6	43	697	242	54	2 .4	5 .6	1 .6	0 .11	2 .8	0 .8	0 .03	9	22	0 .8
Basin 519	42	4 .7	43	27	15	28	5 .9	6 .4	3 .3	0 .28	3 .7	1 .0	0 .05	14	3	0 .2

Results for mass balance calculations for carbon, nitrogen, phosphorus, thorium, uranium and iodine in all marine basins – Forsmark.

Pools and fluxes per basin and year for carbon (C) in the marine Forsmark area, in g basin^{-1} year^{-1}.

IDKOD	Runoff (from basin_ drainage_areas)	Advective flow	Net Primary Production	deposition	Advective flow	Respiration	Burial	Producers	Consumers	Regolith_ upper	Particulate	Dissolved
Basin 102	8.23E+07	4.33E+11	3.88E+09	4.30E+07	4.36E+11	2.31E+09	1.15E+07	2.80E+08	2.76E+08	1.90E+09	6.57E+07	1.04E+09
Basin 100	1.17E+07	8.32E+11	1.58E+09	2.32E+07	8.71E+11	1.49E+09	7.82E+06	1.24E+08	1.28E+08	2.26E+09	7.28E+07	1.06E+09
Basin 101	0.00E+00	6.18E+11	9.43E+08	2.74E+07	5.95E+11	1.68E+09	0.00E+00	3.44E+07	1.29E+08	3.66E+09	6.34E+07	9.84E+08
Basin 105	1.33E+07	7.41E+11	1.65E+09	2.85E+07	7.64E+11	1.89E+09	1.93E+07	1.04E+08	1.59E+08	4.97E+09	8.83E+07	1.25E+09
Basin 103	1.66E+06	9.43E+10	1.44E+09	7.16E+06	9.72E+10	3.28E+08	2.26E+06	1.12E+08	5.76E+07	0.00E+00	5.88E+06	9.10E+07
Basin 104	1.23E+05	7.10E+10	2.68E+08	3.39E+06	7.06E+10	1.63E+08	3.99E+04	2.04E+07	2.34E+07	1.44E+09	3.73E+06	5.79E+07
Basin 108	1.06E+06	1.83E+11	4.84E+08	9.05E+06	1.89E+11	4.89E+08	5.17E+06	4.91E+07	5.69E+07	1.03E+09	1.50E+07	2.25E+08
Basin 106	1.17E+05	2.68E+10	2.62E+08	1.74E+06	2.67E+10	8.78E+07	1.00E+04	1.86E+07	1.62E+07	3.83E+08	1.19E+06	1.80E+07
Basin 111	3.20E+07	1.07E+10	1.94E+09	8.47E+06	1.25E+10	4.26E+08	1.92E+07	2.25E+08	7.75E+07	3.16E+08	5.84E+06	7.67E+07
Basin 107	5.57E+05	6.82E+10	4.91E+08	5.82E+06	6.66E+10	2.91E+08	1.10E+05	4.13E+07	4.54E+07	1.29E+09	6.08E+06	9.27E+07
Basin 110	2.63E+05	2.79E+11	4.24E+08	8.90E+06	2.72E+11	5.02E+08	2.72E+05	5.45E+07	5.07E+07	5.10E+08	1.73E+07	2.56E+08
Basin 114	1.32E+07	5.30E+11	1.08E+09	1.76E+07	5.31E+11	1.27E+09	4.93E+07	4.85E+07	1.02E+08	5.97E+09	6.51E+07	8.72E+08
Basin 109	1.38E+04	1.48E+11	8.08E+07	1.91E+06	1.43E+11	1.38E+08	3.00E+06	1.88E+06	9.48E+06	5.33E+08	6.16E+06	8.76E+07
Basin 116	**1.31E+06**	**1.66E+11**	**1.29E+09**	**1.70E+07**	**1.67E+11**	**9.08E+08**	**8.70E+05**	**1.83E+08**	**1.14E+08**	**1.72E+09**	**2.67E+07**	**3.84E+08**
Basin 113	0.00E+00	1.40E+11	9.54E+07	2.01E+06	1.40E+11	1.14E+08	4.68E+05	1.66E+07	1.13E+07	1.83E+08	4.21E+06	5.98E+07
Basin 117	2.75E+07	6.42E+09	1.35E+09	7.25E+06	6.99E+09	3.73E+08	1.81E+07	1.53E+08	6.40E+07	4.52E+08	6.24E+06	7.82E+07
Basin 112	0.00E+00	4.14E+10	3.08E+07	8.76E+05	4.09E+10	4.60E+07	0.00E+00	3.12E+06	5.00E+06	6.62E+07	1.51E+06	2.21E+07
Basin 115	1.27E+04	2.46E+11	2.57E+08	5.30E+06	2.39E+11	3.56E+08	1.57E+07	2.17E+07	2.91E+07	1.10E+09	1.45E+07	2.04E+08
Basin 151	1.31E+08	2.45E+11	3.95E+09	5.27E+07	2.95E+11	3.48E+09	3.12E+07	3.02E+08	3.42E+08	1.26E+10	1.68E+08	2.07E+09
Basin 118	1.46E+06	8.77E+08	2.85E+08	1.82E+06	1.26E+09	9.62E+07	1.66E+07	5.20E+07	1.55E+07	6.80E+07	1.99E+06	2.25E+07
Basin 123	1.16E+06	3.06E+11	5.39E+08	9.16E+06	2.77E+11	5.89E+08	1.84E+06	5.55E+07	5.37E+07	2.19E+09	2.22E+07	3.06E+08
Basin 152	3.38E+09	4.30E+08	4.75E+08	2.69E+06	2.58E+09	1.59E+08	5.20E+07	2.03E+08	2.34E+07	6.11E+08	1.59E+06	1.81E+07
Basin 150	2.97E+07	1.29E+10	7.79E+08	7.37E+06	1.70E+10	5.37E+08	5.48E+07	1.59E+08	7.58E+07	2.05E+09	8.49E+06	9.89E+07
Basin 146	1.00E+06	8.63E+10	3.60E+08	4.28E+06	8.17E+10	2.36E+08	1.07E+06	4.57E+07	3.12E+07	6.42E+08	6.53E+06	8.62E+07
Basin 126	**4.43E+06**	**7.54E+10**	**4.94E+08**	**6.84E+06**	**8.25E+10**	**3.80E+08**	**7.46E+05**	**5.91E+07**	**5.12E+07**	**1.01E+09**	**1.09E+07**	**1.40E+08**
Basin 134	**6.05E+06**	**3.13E+06**	**7.07E+07**	**7.38E+05**	**4.32E+06**	**4.41E+07**	**4.38E+06**	**1.53E+07**	**7.41E+06**	**1.84E+08**	**5.57E+05**	**6.47E+06**
Basin 121	**5.54E+07**	**2.71E+10**	**3.88E+08**	**4.64E+06**	**2.93E+10**	**2.62E+08**	**1.15E+07**	**6.73E+07**	**3.71E+07**	**6.09E+08**	**5.86E+06**	**7.40E+07**
Basin 120	**3.34E+07**	**8.95E+07**	**7.07E+07**	**9.17E+05**	**9.47E+07**	**4.99E+07**	**5.77E+06**	**1.90E+07**	**8.16E+06**	**3.84E+07**	**1.07E+06**	**1.26E+07**
Allbasins	**3.83E+09**	**5.39E+12**	**2.50E+10**	**3.10E+08**	**5.46E+12**	**1.87E+10**	**3.33E+08**	**2.47E+09**	**2.00E+09**	**4.78E+10**	**6.96E+08**	**9.70E+09**

Pools and fluxes per basin and year for nitrogen (N) in the marine Forsmark area, in g basin^{-1} year^{-1}.

IDKOD	Runoff (from basin_drain-age_areas)	Advective flow	Net Primary Production	deposition	Advective flow	Respiration	Burial	Producers	Consumers	Regolith_upper	Particulate	Dissolved
Basin 102	3.44E+06	4.97E+10	6.83E+08	1.23E+07	6.90E+10	4.07E+08	1.32E+06	2.19E+07	2.76E+07	2.18E+08	8.90E+01	1.98E+02
Basin 100	0.00E+00	9.95E+10	2.78E+08	6.64E+06	1.29E+11	2.62E+08	8.97E+05	9.19E+06	1.47E+07	2.59E+08	2.24E+07	4.97E+07
Basin 101	9.80E+06	8.62E+10	1.66E+08	7.85E+06	9.44E+10	2.95E+08	0.00E+00	3.52E+06	1.47E+07	4.20E+08	2.16E+07	4.80E+07
Basin 105	9.49E+05	1.11E+11	2.90E+08	8.16E+06	1.11E+11	3.34E+08	2.22E+06	8.14E+06	1.92E+07	5.71E+08	2.11E+07	4.69E+07
Basin 103	4.13E+05	1.48E+10	2.54E+08	2.05E+06	1.48E+10	5.78E+07	2.59E+05	8.14E+06	5.42E+06	0.00E+00	2.49E+07	5.52E+07
Basin 104	4.16E+06	1.11E+10	4.72E+07	9.71E+05	1.11E+10	2.87E+07	4.58E+03	1.73E+06	2.38E+06	1.65E+08	1.91E+06	4.24E+06
Basin 108	2.15E+05	2.84E+10	8.52E+07	2.59E+06	2.84E+10	8.61E+07	5.93E+05	3.83E+06	5.78E+06	1.18E+08	1.24E+06	2.76E+06
Basin 106	7.27E+05	4.08E+09	4.61E+07	4.99E+05	4.08E+09	1.55E+07	1.15E+03	1.50E+06	1.59E+06	4.39E+07	4.62E+06	1.03E+07
Basin 111	1.14E+06	1.58E+09	3.41E+08	2.43E+06	1.59E+09	7.49E+07	2.20E+06	1.56E+07	8.24E+06	3.62E+07	3.76E+05	8.35E+05
Basin 107	2.29E+05	1.03E+10	8.64E+07	1.67E+06	1.03E+10	5.13E+07	1.26E+04	3.39E+06	4.50E+06	1.48E+08	1.38E+06	3.06E+06
Basin 110	1.08E+06	4.13E+10	7.46E+07	2.55E+06	4.13E+10	8.85E+07	3.12E+04	4.08E+06	5.44E+06	5.85E+07	1.95E+06	4.34E+06
Basin 114	2.83E+06	7.28E+10	1.91E+08	5.05E+06	7.28E+10	2.24E+08	5.66E+06	4.05E+06	1.30E+07	6.85E+08	5.29E+06	1.17E+07
Basin 109	0.00E+00	2.12E+10	1.42E+07	5.48E+05	2.12E+10	2.44E+07	3.44E+05	1.95E+05	1.20E+06	6.12E+07	1.64E+07	3.65E+07
Basin 116	**0.00E+00**	**2.36E+10**	**2.27E+08**	**4.87E+06**	**2.46E+10**	**1.60E+08**	**9.98E+04**	**1.32E+07**	**1.22E+07**	**1.97E+08**	**1.76E+06**	**3.91E+06**
Basin 113	2.85E+06	2.06E+10	1.68E+07	5.75E+05	2.06E+10	2.00E+07	5.37E+04	1.19E+06	1.24E+06	2.10E+07	7.73E+06	1.72E+07
Basin 117	6.33E+05	7.98E+08	2.38E+08	2.07E+06	8.35E+08	6.57E+07	2.08E+06	1.07E+07	7.13E+06	5.18E+07	1.20E+06	2.66E+06
Basin 112	2.12E+06	6.18E+09	5.43E+06	2.51E+05	6.18E+09	8.11E+06	0.00E+00	2.65E+05	5.47E+05	7.60E+06	1.31E+06	2.91E+06
Basin 115	2.42E+06	3.49E+10	4.52E+07	1.52E+06	3.49E+10	6.28E+07	1.80E+06	1.66E+06	3.47E+06	1.26E+08	4.55E+05	1.01E+06
Basin 151	3.01E+05	3.40E+10	6.95E+08	1.51E+07	3.45E+10	6.13E+08	3.58E+06	2.22E+07	4.08E+07	1.45E+09	4.06E+06	9.02E+06
Basin 118	1.55E+06	1.05E+08	5.01E+07	5.21E+05	8.20E+07	1.69E+07	1.91E+06	3.44E+06	1.83E+06	7.80E+06	3.37E+07	7.48E+07
Basin 123	2.10E+06	3.84E+10	9.48E+07	2.62E+06	3.93E+10	1.04E+08	2.12E+05	4.08E+06	6.51E+06	2.51E+08	1.79E+05	3.13E+05
Basin 152	1.16E+06	5.91E+07	8.37E+07	7.69E+05	1.90E+08	2.80E+07	5.97E+06	1.29E+07	3.04E+06	7.01E+07	5.96E+06	1.32E+07
Basin 150	1.09E+06	1.57E+09	1.37E+08	2.11E+06	2.34E+09	9.46E+07	6.28E+06	1.07E+07	9.65E+06	2.36E+08	1.89E+05	4.19E+05
Basin 146	2.94E+05	1.06E+10	6.34E+07	1.23E+06	1.09E+10	4.15E+07	1.23E+05	3.36E+06	3.60E+06	7.37E+07	1.88E+06	4.53E+06
Basin 126	**5.74E+05**	**9.53E+09**	**8.70E+07**	**1.96E+06**	**7.78E+09**	**6.70E+07**	**8.55E+04**	**4.46E+06**	**5.87E+06**	**1.16E+08**	**1.59E+06**	**3.54E+06**
Basin 134	**2.35E+06**	**2.33E+05**	**1.25E+07**	**2.11E+05**	**3.66E+05**	**7.77E+06**	**5.03E+05**	**1.04E+06**	**8.57E+05**	**2.11E+07**	**2.48E+06**	**2.48E+06**
Basin 121	**1.37E+07**	**3.50E+09**	**6.83E+07**	**1.33E+06**	**2.18E+09**	**4.62E+07**	**1.32E+06**	**4.77E+06**	**4.49E+06**	**6.99E+07**	**5.88E+04**	**7.05E+04**
Basin 120	**1.92E+08**	**6.67E+06**	**7.46E+07**	**2.63E+05**	**1.23E+07**	**8.80E+06**	**6.62E+05**	**1.28E+06**	**9.36E+05**	**4.41E+06**	**8.32E+05**	**4.16E+05**
Allbasins	**2.48E+08**	**7.36E+11**	**4.46E+09**	**8.87E+07**	**7.94E+11**	**3.29E+09**	**3.82E+07**	**1.81E+08**	**2.26E+08**	**5.48E+09**	**1.87E+08**	**4.10E+08**

Pools and fluxes per basin and year for phosphorus (P) in the marine Forsmark area, in g basin⁻¹ year⁻¹.

IDKOD	Runoff (from basin_ drainage_areas)	Advective flow	Net Primary Production	deposition	Advective flow	Respiration	Burial	Producers	Consumers	Regolith_upper	Particulate	Dissolved
Basin 102	1.01E+05	1.26E+10	9.45E+07	4.15E+05	2.51E+09	5.63E+07	2.25E+05	2.79E+06	4.32E+06	3.73E+07	1.47E+01	2.95E+00
Basin 100	1.44E+04	2.04E+10	3.85E+07	2.24E+05	4.71E+09	3.62E+07	1.54E+05	1.04E+06	2.73E+06	4.43E+07	3.69E+06	7.41E+05
Basin 101	0.00E+00	7.71E+09	2.30E+07	2.65E+05	3.44E+09	4.08E+07	0.00E+00	5.26E+05	2.71E+06	7.19E+07	3.56E+06	7.15E+05
Basin 105	1.63E+04	4.04E+09	4.01E+07	2.75E+05	4.04E+09	4.62E+07	3.80E+05	9.68E+05	3.87E+06	9.76E+07	3.48E+06	6.99E+05
Basin 103	2.04E+03	5.40E+08	3.51E+07	6.92E+04	5.40E+08	8.00E+06	4.44E+04	9.56E+05	7.39E+05	0.00E+00	4.10E+06	8.23E+05
Basin 104	1.51E+02	4.06E+08	6.53E+06	3.28E+04	4.06E+08	3.97E+06	7.83E+02	2.45E+05	3.70E+05	2.82E+07	3.15E+05	6.33E+04
Basin 108	1.30E+03	1.03E+09	1.18E+07	8.74E+04	1.04E+09	1.19E+07	1.01E+05	4.87E+05	9.13E+05	2.02E+07	2.05E+05	4.11E+04
Basin 106	1.43E+02	1.49E+08	6.37E+06	1.68E+04	1.49E+08	2.14E+06	1.97E+02	2.04E+05	2.33E+05	7.51E+06	7.62E+05	1.53E+05
Basin 111	3.93E+04	5.76E+07	4.72E+07	8.19E+04	5.80E+07	1.04E+07	3.76E+05	1.71E+06	1.30E+06	6.20E+06	6.20E+04	1.24E+04
Basin 107	6.83E+02	3.75E+08	1.20E+07	5.62E+04	3.75E+08	7.10E+06	2.16E+03	4.68E+05	6.73E+05	2.53E+07	2.28E+05	4.56E+04
Basin 110	3.23E+02	1.50E+09	1.03E+07	8.60E+04	1.51E+09	1.22E+07	5.33E+03	4.87E+05	9.04E+05	1.00E+07	3.22E+05	6.47E+04
Basin 114	1.62E+04	2.65E+09	2.64E+07	1.71E+05	2.65E+09	3.10E+07	9.68E+05	5.04E+05	2.81E+06	1.17E+08	8.73E+05	1.75E+05
Basin 109	1.69E+01	7.71E+08	1.97E+06	1.85E+04	7.71E+08	3.37E+06	5.89E+04	2.56E+04	2.57E+05	1.05E+07	2.71E+06	5.44E+05
Basin 116	**6.00E+02**	**8.65E+08**	**3.13E+07**	**1.64E+05**	**8.96E+08**	**2.21E+07**	**1.71E+04**	**1.52E+06**	**1.98E+06**	**3.37E+07**	**2.90E+05**	**5.82E+04**
Basin 113	0.00E+00	7.50E+08	2.32E+06	1.94E+04	7.50E+08	2.77E+06	9.19E+03	1.34E+05	2.12E+05	3.59E+06	1.28E+06	2.56E+05
Basin 117	3.37E+04	2.94E+07	3.30E+07	7.00E+04	3.04E+07	9.10E+06	3.55E+05	1.19E+06	1.17E+06	8.87E+06	1.98E+05	3.97E+04
Basin 112	0.00E+00	2.25E+08	7.51E+05	8.46E+03	2.25E+08	1.12E+06	0.00E+00	3.72E+04	9.28E+04	1.30E+06	2.16E+05	4.34E+04
Basin 115	1.56E+01	1.27E+09	6.26E+06	5.12E+04	1.27E+09	8.69E+06	3.08E+05	1.94E+05	6.91E+05	2.16E+07	7.52E+04	1.51E+04
Basin 151	1.61E+05	1.44E+09	9.62E+07	5.10E+05	1.26E+09	8.48E+07	6.13E+05	2.52E+06	8.16E+06	2.47E+08	6.71E+05	1.35E+05
Basin 118	1.79E+03	3.81E+06	6.94E+06	1.76E+04	3.28E+06	2.34E+06	3.27E+05	3.45E+05	3.42E+05	1.33E+06	5.56E+06	1.11E+06
Basin 123	1.42E+03	1.41E+09	1.31E+07	8.85E+04	1.43E+09	1.44E+07	3.62E+04	4.69E+05	1.31E+06	4.30E+07	2.76E+04	1.59E+04
Basin 152	4.15E+06	1.45E+06	1.16E+07	2.59E+04	6.92E+06	3.88E+06	1.02E+06	1.19E+06	6.52E+05	1.20E+07	9.83E+05	1.97E+05
Basin 150	5.55E+04	5.71E+07	1.90E+07	7.12E+04	7.96E+07	1.31E+07	1.08E+06	1.10E+06	2.15E+06	4.03E+07	3.12E+04	6.25E+03
Basin 146	3.39E+02	3.89E+08	8.77E+06	4.14E+04	3.98E+08	5.74E+06	2.11E+04	3.97E+05	6.64E+05	1.26E+07	3.34E+05	4.29E+04
Basin 126	**3.86E+03**	**3.52E+08**	**1.20E+07**	**6.61E+04**	**3.05E+08**	**9.27E+06**	**1.46E+04**	**5.48E+05**	**1.09E+06**	**1.99E+07**	**2.63E+05**	**5.27E+04**
Basin 134	**5.06E+03**	**9.38E+03**	**1.72E+06**	**7.13E+03**	**1.50E+04**	**1.08E+06**	**8.60E+04**	**1.13E+05**	**1.80E+05**	**3.61E+06**	**3.45E+05**	**3.96E+04**
Basin 121	**4.09E+04**	**1.30E+08**	**9.46E+06**	**4.49E+04**	**8.78E+07**	**6.39E+06**	**2.27E+05**	**5.40E+05**	**8.99E+05**	**1.20E+07**	**9.82E+03**	**2.01E+03**
Basin 120	**2.28E+04**	**2.69E+05**	**1.72E+06**	**8.86E+03**	**4.49E+05**	**1.22E+06**	**1.13E+05**	**1.33E+05**	**1.79E+05**	**7.54E+05**	**1.18E+05**	**2.89E+04**
Allbasins	**4.67E+06**	**5.92E+10**	**6.08E+08**	**2.99E+06**	**2.89E+10**	**4.56E+08**	**6.54E+06**	**2.08E+07**	**4.16E+07**	**9.38E+08**	**3.07E+07**	**6.13E+06**

Pools and fluxes per basin and year for thorium (Th) in the marine Forsmark area, in g basin^{-1} year^{-1}.

IDKOD	Runoff (from basin_ drainage_areas)	Advective flow	Net Primary Production	deposition	Advective flow	Respiration	Burial	Producers	Consumers	Regolith_upper	Particulate	Dissolved
Basin 102	No data	1.12E+07	No data	1.71E+02	1.13E+07	No data	7.25E+02	8.20E+03	2.35E+02	1.20E+05	7.59E+03	1.14E–01
Basin 100	No data	2.11E+07	No data	9.23E+01	2.11E+07	No data	4.94E+02	2.23E+03	9.58E+01	1.43E+05	8.41E+03	2.87E+04
Basin 101	No data	1.54E+07	No data	1.09E+02	1.54E+07	No data	0.00E+00	2.00E+03	9.73E+01	2.31E+05	7.32E+03	2.77E+04
Basin 105	No data	1.81E+07	No data	1.13E+02	1.81E+07	No data	1.22E+03	2.41E+03	1.10E+02	3.14E+05	1.02E+04	2.71E+04
Basin 103	No data	2.42E+06	No data	2.85E+01	2.42E+06	No data	1.43E+02	2.33E+03	5.19E+01	0.00E+00	6.79E+02	3.19E+04
Basin 104	No data	1.82E+06	No data	1.35E+01	1.82E+06	No data	2.52E+00	8.75E+02	1.98E+01	9.07E+04	4.31E+02	2.45E+03
Basin 108	No data	4.63E+06	No data	3.60E+01	4.64E+06	No data	3.27E+02	1.43E+03	4.77E+01	6.51E+04	1.74E+03	1.59E+03
Basin 106	No data	6.66E+05	No data	6.93E+00	6.66E+05	No data	6.33E–01	6.79E+02	1.43E+01	2.42E+04	1.38E+02	5.93E+03
Basin 111	No data	2.58E+05	No data	3.37E+01	2.60E+05	No data	1.21E+03	3.31E+03	6.17E+01	2.00E+04	6.74E+02	4.82E+02
Basin 107	No data	1.68E+06	No data	2.31E+01	1.68E+06	No data	6.96E+00	1.60E+03	3.89E+01	8.15E+04	7.03E+02	1.77E+03
Basin 110	No data	6.74E+06	No data	3.54E+01	6.74E+06	No data	1.72E+01	1.23E+03	3.92E+01	3.22E+04	2.00E+03	2.51E+03
Basin 114	No data	1.19E+07	No data	7.02E+01	1.19E+07	No data	3.12E+03	1.40E+03	6.63E+01	3.77E+05	7.52E+03	6.78E+03
Basin 109	No data	3.45E+06	No data	7.61E+00	3.45E+06	No data	1.90E+02	7.78E+01	6.26E+00	3.37E+04	7.12E+02	2.11E+04
Basin 116	**No data**	**4.09E+06**	**No data**	**6.77E+01**	**4.01E+06**	**No data**	**5.50E+01**	**3.50E+03**	**8.77E+01**	**1.09E+05**	**3.08E+03**	**2.26E+03**
Basin 113	No data	3.36E+06	No data	7.98E+00	3.36E+06	No data	2.96E+01	2.83E+02	8.27E+00	1.15E+04	4.86E+02	9.92E+03
Basin 117	No data	1.34E+05	No data	2.88E+01	1.36E+05	No data	1.14E+03	2.43E+03	4.98E+01	2.85E+04	7.20E+02	1.54E+03
Basin 112	No data	1.01E+06	No data	3.48E+00	1.01E+06	No data	0.00E+00	1.30E+02	3.84E+00	4.18E+03	1.75E+02	1.68E+03
Basin 115	No data	5.69E+06	No data	2.11E+01	5.70E+06	No data	9.91E+02	4.61E+02	2.01E+01	6.94E+04	1.68E+03	5.84E+02
Basin 151	No data	5.61E+06	No data	2.10E+02	5.62E+06	No data	1.97E+03	5.45E+03	2.37E+02	7.96E+05	1.94E+04	5.21E+03
Basin 118	No data	1.71E+04	No data	7.23E+00	1.75E+04	No data	1.05E+03	4.49E+02	1.11E+01	4.30E+03	2.29E+02	4.32E+04
Basin 123	No data	6.41E+06	No data	3.64E+01	6.42E+06	No data	1.17E+02	1.07E+03	3.54E+01	1.38E+05	2.57E+03	1.34E+02
Basin 152	No data	7.18E+03	No data	1.07E+01	3.10E+04	No data	3.29E+03	7.25E+02	1.50E+01	3.86E+04	1.84E+02	7.64E+03
Basin 150	No data	2.56E+05	No data	2.93E+01	2.40E+05	No data	3.46E+03	1.69E+03	4.43E+01	1.30E+05	9.81E+02	2.42E+02
Basin 146	No data	1.76E+06	No data	1.70E+01	1.78E+06	No data	6.79E+01	9.89E+02	2.18E+01	4.06E+04	7.54E+02	1.54E+03
Basin 126	**No data**	**1.82E+06**	**No data**	**2.72E+01**	**1.71E+06**	**No data**	**4.71E+01**	**1.50E+03**	**3.63E+01**	**6.40E+04**	**1.26E+03**	**2.04E+03**
Basin 134	**No data**	**8.77E+01**	**No data**	**2.93E+00**	**6.95E+01**	**No data**	**2.77E+02**	**2.14E+02**	**5.15E+00**	**1.16E+04**	**6.43E+01**	**6.32E+02**
Basin 121	**No data**	**6.20E+05**	**No data**	**1.85E+01**	**8.21E+05**	**No data**	**7.29E+02**	**1.18E+03**	**2.43E+01**	**3.85E+04**	**6.77E+02**	**8.03E+01**
Basin 120	**No data**	**2.51E+03**	**No data**	**3.65E+00**	**2.01E+03**	**No data**	**3.65E+02**	**2.08E+02**	**5.97E+00**	**2.43E+03**	**1.23E+02**	**2.11E+03**
Allbasins	**No data**	**1.30E+08**	**No data**	**1.23E+03**	**1.30E+08**	**No data**	**2.11E+04**	**4.81E+04**	**1.49E+03**	**3.02E+06**	**8.05E+04**	**2.37E+05**

Pools and fluxes per basin and year for uranium (u) in the marine Forsmark area, in g basin^{-1} year^{-1}.

IDKOD	Runoff (from basin_drain-age_areas)	Advective flow	Net Primary Production	deposition	Advective flow	Respiration	Burial	Producers	Consumers	Regolith_upper	Particulate	Dissolved
Basin 102	No data	1.48E+08	No data	6.83E+01	1.48E+08	No data	6.19E+02	5.11E+02	2.09E+02	1.02E+05	3.55E+03	1.50E+00
Basin 100	No data	2.77E+08	No data	3.69E+01	2.77E+08	No data	4.22E+02	2.26E+02	8.65E+01	1.22E+05	3.93E+03	3.78E+05
Basin 101	No data	2.02E+08	No data	4.36E+01	2.02E+08	No data	0.00E+00	6.25E+01	8.79E+01	1.98E+05	3.42E+03	3.64E+05
Basin 105	No data	2.38E+08	No data	4.53E+01	2.38E+08	No data	1.04E+03	1.90E+02	9.84E+01	2.69E+05	4.77E+03	3.56E+05
Basin 103	No data	3.18E+07	No data	1.14E+01	3.18E+07	No data	1.22E+02	2.04E+02	4.61E+01	0.00E+00	3.17E+02	4.19E+05
Basin 104	No data	2.39E+07	No data	5.40E+00	2.39E+07	No data	2.16E+00	3.72E+01	1.75E+01	7.75E+04	2.01E+02	3.22E+04
Basin 108	No data	6.09E+07	No data	1.44E+01	6.10E+07	No data	2.79E+02	8.93E+01	4.26E+01	5.56E+04	8.13E+02	2.09E+04
Basin 106	No data	8.75E+06	No data	2.77E+00	8.76E+06	No data	5.41E–01	3.38E+01	1.25E+01	2.07E+04	6.45E+01	7.79E+04
Basin 111	No data	3.39E+06	No data	1.35E+01	3.41E+06	No data	1.03E+03	4.09E+02	5.63E+01	1.71E+04	3.15E+02	6.34E+03
Basin 107	No data	2.21E+07	No data	9.26E+00	2.21E+07	No data	5.95E+00	7.51E+01	3.47E+01	6.96E+04	3.29E+02	2.33E+04
Basin 110	No data	8.86E+07	No data	1.41E+01	8.86E+07	No data	1.47E+01	9.92E+01	3.65E+01	2.75E+04	9.34E+02	3.29E+04
Basin 114	No data	1.56E+08	No data	2.81E+01	1.56E+08	No data	2.66E+03	8.82E+01	5.81E+01	3.22E+05	3.52E+03	8.92E+04
Basin 109	No data	4.54E+07	No data	3.04E+00	4.54E+07	No data	1.62E+02	3.42E+00	5.54E+00	2.88E+04	3.33E+02	2.77E+05
Basin 116	**No data**	**5.16E+07**	**No data**	**2.71E+01**	**5.28E+07**	**No data**	**4.70E+01**	**3.34E+02**	**8.18E+01**	**9.28E+04**	**1.44E+03**	**2.97E+04**
Basin 113	No data	4.41E+07	No data	3.19E+00	4.41E+07	No data	2.53E+01	3.03E+01	7.91E+00	9.87E+03	2.27E+02	1.30E+05
Basin 117	No data	1.77E+06	No data	1.15E+01	1.79E+06	No data	9.78E+02	2.78E+02	4.50E+01	2.44E+04	3.37E+02	2.02E+04
Basin 112	No data	1.33E+07	No data	1.39E+00	1.33E+07	No data	0.00E+00	5.68E+00	3.51E+00	3.57E+03	8.16E+01	2.21E+04
Basin 115	No data	7.49E+07	No data	8.42E+00	7.49E+07	No data	8.47E+02	3.95E+01	1.83E+01	5.93E+04	7.83E+02	7.68E+03
Basin 151	No data	7.38E+07	No data	8.38E+01	7.39E+07	No data	1.69E+03	5.50E+02	2.13E+02	6.80E+05	9.05E+03	6.85E+04
Basin 118	No data	2.25E+05	No data	2.89E+00	2.30E+05	No data	8.99E+02	9.46E+01	9.87E+00	3.67E+03	1.07E+02	5.68E+05
Basin 123	No data	8.43E+07	No data	1.46E+01	8.44E+07	No data	9.96E+01	1.01E+02	3.27E+01	1.18E+05	1.20E+03	3.70E+03
Basin 152	No data	1.20E+05	No data	4.27E+00	4.07E+05	No data	2.81E+03	3.70E+02	1.26E+01	3.30E+04	8.60E+01	1.01E+05
Basin 150	No data	3.36E+06	No data	1.17E+01	4.27E+06	No data	2.96E+03	2.88E+02	3.94E+01	1.11E+05	4.58E+02	3.18E+03
Basin 146	No data	2.43E+07	No data	6.81E+00	2.35E+07	No data	5.80E+01	8.32E+01	2.02E+01	3.47E+04	3.53E+02	2.74E+04
Basin 126	**No data**	**2.09E+07**	**No data**	**1.09E+01**	**2.25E+07**	**No data**	**4.03E+01**	**1.08E+02**	**3.31E+01**	**5.46E+04**	**5.90E+02**	**2.68E+04**
Basin 134	**No data**	**5.80E+02**	**No data**	**1.17E+00**	**7.42E+02**	**No data**	**2.36E+02**	**2.73E+01**	**4.35E+00**	**9.94E+03**	**3.01E+01**	**3.05E+04**
Basin 121	**No data**	**8.15E+06**	**No data**	**7.38E+00**	**5.43E+06**	**No data**	**6.23E+02**	**1.22E+02**	**2.20E+01**	**3.29E+04**	**3.16E+02**	**8.57E+02**
Basin 120	**No data**	**1.66E+04**	**No data**	**1.46E+00**	**2.64E+04**	**No data**	**3.12E+02**	**3.46E+01**	**5.20E+00**	**2.07E+03**	**5.76E+01**	**1.40E+04**
Allbasins	**No data**	**1.71E+09**	**No data**	**4.93E+02**	**1.71E+09**	**No data**	**1.80E+04**	**4.49E+03**	**1.34E+03**	**2.58E+06**	**3.76E+04**	**3.13E+06**

Pools and fluxes per basin and year for iodine (I) in the marine Forsmark area, in g $basin^{-1}$ $year^{-1}$.

IDKOD	Runoff (from basin_drainage_areas)	Advective flow	Net Primary Production	deposition	Advective flow	Respiration	Burial	Producers	Consumers	Regolith_upper	Particulate	Dissolved
Basin 102	No data	1.43E+09	No data	9.57E+03	1.43E+09	No data	1.38E+03	1.87E+05	3.61E+03	2.28E+05	2.27E+05	1.45E+01
Basin 100	No data	2.67E+09	No data	5.17E+03	2.67E+09	No data	9.39E+02	5.84E+04	1.71E+03	2.71E+05	2.51E+05	3.64E+06
Basin 101	No data	1.95E+09	No data	6.10E+03	1.95E+09	No data	0.00E+00	3.84E+04	1.62E+03	4.39E+05	2.19E+05	3.51E+06
Basin 105	No data	2.29E+09	No data	6.35E+03	2.29E+09	No data	2.32E+03	5.74E+04	1.79E+03	5.97E+05	3.05E+05	3.43E+06
Basin 103	No data	3.07E+08	No data	1.59E+03	3.07E+08	No data	2.71E+02	5.93E+04	8.04E+02	0.00E+00	2.03E+04	4.05E+06
Basin 104	No data	2.31E+08	No data	7.55E+02	2.31E+08	No data	4.79E+00	1.83E+04	2.70E+02	1.72E+05	1.29E+04	3.11E+05
Basin 108	No data	5.88E+08	No data	2.01E+03	5.88E+08	No data	6.20E+02	3.26E+04	7.18E+02	1.24E+05	5.20E+04	2.02E+05
Basin 106	No data	8.44E+07	No data	3.88E+02	8.45E+07	No data	1.20E+00	1.47E+04	2.11E+02	4.59E+04	4.13E+03	7.52E+05
Basin 111	No data	3.27E+07	No data	1.89E+03	3.29E+07	No data	2.30E+03	9.61E+04	1.01E+03	3.79E+04	2.02E+04	6.12E+04
Basin 107	No data	2.13E+08	No data	1.30E+03	2.13E+08	No data	1.32E+01	3.43E+04	5.77E+02	1.55E+05	2.10E+04	2.24E+05
Basin 110	No data	8.55E+08	No data	1.98E+03	8.55E+08	No data	3.26E+01	3.02E+04	6.63E+02	6.12E+04	5.97E+04	3.18E+05
Basin 114	No data	1.51E+09	No data	3.93E+03	1.51E+09	No data	5.92E+03	3.08E+04	1.01E+03	7.16E+05	2.25E+05	8.61E+05
Basin 109	No data	4.38E+08	No data	4.26E+02	4.38E+08	No data	3.60E+02	1.49E+03	1.04E+02	6.40E+04	2.13E+04	2.68E+06
Basin 116	**No data**	**5.11E+08**	**No data**	**3.79E+03**	**5.09E+08**	**No data**	**1.04E+02**	**9.16E+04**	**1.45E+03**	**2.06E+05**	**9.22E+04**	**2.86E+05**
Basin 113	No data	4.26E+08	No data	4.47E+02	4.26E+08	No data	5.62E+01	7.67E+03	1.49E+02	2.19E+04	1.45E+04	1.26E+06
Basin 117	No data	1.70E+07	No data	1.61E+03	1.73E+07	No data	2.17E+03	6.83E+04	7.96E+02	5.42E+04	2.15E+04	1.95E+05
Basin 112	No data	1.28E+08	No data	1.95E+02	1.28E+08	No data	0.00E+00	2.74E+03	5.89E+01	7.94E+03	5.22E+03	2.13E+05
Basin 115	No data	7.22E+08	No data	1.18E+03	7.22E+08	No data	1.88E+03	1.13E+04	3.33E+02	1.32E+05	5.01E+04	7.41E+04
Basin 151	No data	7.12E+08	No data	1.17E+04	7.13E+08	No data	3.75E+03	1.43E+05	3.74E+03	1.51E+06	5.79E+05	6.61E+05
Basin 118	No data	2.17E+06	No data	4.05E+02	2.22E+06	No data	2.00E+03	1.69E+04	1.60E+02	8.16E+03	6.86E+03	5.48E+06
Basin 123	No data	8.13E+08	No data	2.04E+03	8.14E+08	No data	2.21E+02	2.75E+04	5.44E+02	2.63E+05	7.67E+04	3.33E+04
Basin 152	No data	8.07E+05	No data	5.98E+02	3.93E+06	No data	6.24E+03	4.87E+04	1.89E+02	7.33E+04	5.50E+03	9.70E+05
Basin 150	No data	3.24E+07	No data	1.64E+03	3.32E+07	No data	6.57E+03	5.66E+04	6.67E+02	2.46E+05	2.93E+04	3.07E+04
Basin 146	No data	2.27E+08	No data	9.53E+02	2.26E+08	No data	1.29E+02	2.48E+04	3.44E+02	7.70E+04	2.26E+04	2.14E+05
Basin 126	**No data**	**2.21E+08**	**No data**	**1.52E+03**	**2.17E+08**	**No data**	**8.95E+01**	**3.57E+04**	**5.52E+02**	**1.21E+05**	**3.78E+04**	**2.59E+05**
Basin 134	**No data**	**9.15E+03**	**No data**	**1.64E+02**	**9.63E+03**	**No data**	**5.26E+02**	**6.29E+03**	**6.13E+01**	**2.21E+04**	**1.92E+03**	**2.48E+05**
Basin 121	**No data**	**7.87E+07**	**No data**	**1.03E+03**	**8.56E+07**	**No data**	**1.38E+03**	**3.19E+04**	**3.48E+02**	**7.31E+04**	**2.02E+04**	**1.11E+04**
Basin 120	**No data**	**2.62E+05**	**No data**	**2.04E+02**	**2.55E+05**	**No data**	**6.92E+02**	**6.90E+03**	**8.15E+01**	**4.61E+03**	**3.68E+03**	**2.21E+05**
Allbasins	**No data**	**1.65E+10**	**No data**	**6.90E+04**	**1.65E+10**	**No data**	**4.00E+04**	**1.24E+06**	**2.36E+04**	**5.73E+06**	**2.41E+06**	**3.02E+07**

Appendix 9b

Results from massbalance calculations for carbon, nitrogen, phosphorus, thorium, uranium and iodine in all marine basin – Laxemar-Simpevarp.

Pools and fluxes per basin and year for carbon (C) in the marine Laxemar-Simpevarp area, in g basin^{-1} year^{-1}.

IDKOD	Runoff (from basin_drainage_areas)	Advective flow	Net Primary Production	deposition	Advective flow	Respiration	Burial	Producers	Consumers	Regolith_upper	Particulate	Dissolved
Basin 524	5.66E+05	1.83E+12	2.15E+09	2.76E+07	1.85E+12	5.17E+09	0.00E+00	4.02E+08	1.03E+09	1.21E+08	2.59E+07	6.70E+08
Basin 525	0.00E+00	2.01E+11	3.11E+09	2.86E+07	2.27E+11	7.41E+09	0.00E+00	6.13E+08	1.32E+09	4.95E+07	1.70E+07	4.25E+08
Basin 522	0.00E+00	1.06E+12	1.34E+09	2.55E+07	1.06E+12	3.45E+09	0.00E+00	2.13E+08	6.67E+08	1.48E+09	3.26E+07	8.45E+08
Basin 523	0.00E+00	9.46E+11	1.74E+09	2.62E+07	7.96E+11	5.57E+09	0.00E+00	3.49E+08	1.05E+09	3.08E+08	2.43E+07	6.28E+08
Basin 521	**5.53E+06**	**8.97E+11**	**5.82E+09**	**7.15E+07**	**9.23E+11**	**1.27E+10**	**2.46E+07**	**1.08E+09**	**2.24E+09**	**3.47E+09**	**6.96E+07**	**1.72E+09**
Basin 501	5.47E+04	2.18E+08	3.85E+07	6.29E+05	2.04E+08	3.34E+07	7.24E+06	1.21E+07	4.99E+06	8.64E+07	6.49E+05	7.70E+06
Basin 500	5.96E+04	3.81E+09	7.05E+08	5.46E+06	0.00E+00	2.58E+08	2.85E+07	1.02E+08	4.04E+07	4.04E+08	3.70E+06	4.39E+07
Basin 504	**8.18E+06**	**1.18E+09**	**9.58E+07**	**1.14E+06**	**1.76E+09**	**6.02E+07**	**1.45E+07**	**2.37E+07**	**8.21E+06**	**1.78E+08**	**1.38E+06**	**1.64E+07**
Basin 502	**1.62E+08**	**6.89E+08**	**1.12E+08**	**2.12E+06**	**6.57E+08**	**1.30E+08**	**5.15E+07**	**3.41E+07**	**1.71E+07**	**5.60E+08**	**3.31E+06**	**3.92E+07**
Basin 506	**4.40E+06**	**1.39E+09**	**2.90E+07**	**6.29E+05**	**2.33E+09**	**3.56E+07**	**2.48E+06**	**1.16E+07**	**5.03E+06**	**8.43E+07**	**6.85E+05**	**8.14E+06**
Basin 508	**2.13E+08**	**4.11E+08**	**2.65E+08**	**2.58E+06**	**4.54E+08**	**1.45E+08**	**4.78E+07**	**9.64E+07**	**1.98E+07**	**5.45E+08**	**1.46E+06**	**1.74E+07**
Basin 513	3.38E+07	3.46E+10	1.25E+09	7.64E+06	3.80E+10	1.56E+09	8.60E+06	2.54E+08	2.82E+08	2.94E+08	3.51E+06	7.76E+07
Basin 514	0.00E+00	3.58E+10	3.57E+08	1.79E+06	3.57E+10	4.25E+08	0.00E+00	7.61E+07	7.91E+07	4.52E+07	7.07E+05	1.78E+07
Basin 516	1.28E+07	1.08E+10	3.41E+08	9.06E+05	3.14E+10	2.70E+07	0.00E+00	2.92E+07	5.31E+06	0.00E+00	5.15E+04	6.11E+05
Basin 518	0.00E+00	6.69E+10	2.69E+08	1.43E+06	4.80E+10	3.30E+08	0.00E+00	5.14E+07	6.25E+07	4.54E+07	4.69E+05	1.19E+07
Basin 515	5.34E+07	4.75E+09	1.23E+08	1.63E+06	5.19E+09	9.20E+07	2.09E+07	1.64E+07	1.41E+07	2.43E+08	1.71E+06	2.02E+07
Basin 517	1.04E+08	2.71E+10	1.68E+09	1.26E+07	4.02E+10	1.14E+09	8.07E+07	2.06E+08	1.82E+08	1.18E+09	1.19E+07	1.55E+08
Basin 520	5.47E+04	4.56E+09	7.68E+08	4.27E+06	6.15E+09	6.03E+08	0.00E+00	9.27E+07	8.94E+07	0.00E+00	1.79E+06	3.11E+07
Basin 519	6.23E+05	6.98E+07	3.59E+08	1.11E+06	1.02E+08	3.44E+07	0.00E+00	3.00E+07	6.77E+06	0.00E+00	9.13E+04	1.08E+06
Allbasins	**5.98E+08**	**5.12E+12**	**2.06E+10**	**2.23E+08**	**5.06E+12**	**3.91E+10**	**2.87E+08**	**3.70E+09**	**7.13E+09**	**9.09E+09**	**2.01E+08**	**4.73E+09**

Pools and fluxes per basin and year for nitrogen (N) in the marine Laxemar-Simpevarp area, in g $basin^{-1}$ $year^{-1}$.

IDKOD	Runoff (from basin_drainage_areas)	Advective flow	Net Primary Production	deposition	Advective flow	Respiration	Burial	Producers	Consumers	Regolith_upper	Particulate	Dissolved
Basin 524	4.97E+02	1.35E+10	5.23E+07	3.96E+05	1.35E+10	1.26E+08	0.00E+00	3.15E+06	2.64E+07	2.38E+06	2.22E+06	1.58E+06
Basin 525	0.00E+00	1.35E+09	7.58E+07	4.11E+05	1.62E+09	1.80E+08	0.00E+00	4.86E+06	3.33E+07	9.72E+05	1.37E+06	9.78E+05
Basin 522	0.00E+00	7.65E+09	3.28E+07	3.66E+05	7.77E+09	8.41E+07	0.00E+00	1.66E+06	1.72E+07	2.91E+07	2.81E+06	2.01E+06
Basin 523	0.00E+00	6.68E+09	4.24E+07	3.76E+05	5.86E+09	1.36E+08	0.00E+00	2.72E+06	2.68E+07	6.05E+06	2.09E+06	1.49E+06
Basin 521	**5.58E+03**	**6.56E+09**	**1.42E+08**	**1.03E+06**	**5.66E+09**	**3.08E+08**	**4.82E+05**	**8.52E+06**	**5.75E+07**	**6.80E+07**	**1.42E+06**	**6.97E+06**
Basin 501	8.63E+01	8.05E+05	9.39E+05	9.04E+03	8.05E+05	8.13E+05	1.42E+05	9.26E+04	1.60E+05	1.70E+06	1.39E+04	9.88E+03
Basin 500	9.39E+01	2.29E+07	1.72E+07	7.85E+04	0.00E+00	6.29E+06	5.59E+05	8.37E+05	1.19E+06	7.93E+06	7.48E+04	5.34E+04
Basin 504	**9.33E+03**	**6.27E+06**	**2.33E+06**	**1.64E+04**	**6.63E+06**	**1.47E+06**	**2.86E+05**	**1.84E+05**	**2.68E+05**	**3.49E+06**	**2.84E+04**	**2.03E+04**
Basin 502	**2.95E+05**	**7.45E+06**	**2.72E+06**	**3.04E+04**	**2.90E+06**	**3.17E+06**	**1.01E+06**	**2.60E+05**	**6.00E+05**	**1.10E+07**	**1.07E+05**	**4.27E+04**
Basin 506	**5.63E+03**	**1.71E+07**	**7.06E+05**	**9.03E+03**	**8.97E+06**	**8.69E+05**	**4.87E+04**	**8.88E+04**	**1.65E+05**	**1.65E+06**	**1.44E+04**	**1.03E+04**
Basin 508	**3.91E+05**	**1.67E+06**	**6.46E+06**	**3.71E+04**	**1.59E+07**	**3.54E+06**	**9.39E+05**	**7.22E+05**	**6.63E+05**	**1.07E+07**	**3.50E+04**	**7.68E+03**
Basin 513	5.68E+04	2.19E+08	3.05E+07	1.10E+05	2.46E+08	3.80E+07	1.69E+05	1.98E+06	7.13E+06	5.78E+06	8.85E+04	2.77E+05
Basin 514	0.00E+00	2.41E+08	8.70E+06	2.57E+04	2.46E+08	1.03E+07	0.00E+00	5.87E+05	1.98E+06	8.87E+05	5.59E+04	3.98E+04
Basin 516	2.02E+04	7.41E+07	8.32E+06	1.30E+04	7.41E+07	6.58E+05	0.00E+00	2.44E+05	1.14E+05	0.00E+00	9.61E+02	6.86E+02
Basin 518	0.00E+00	3.28E+08	6.56E+06	2.05E+04	3.29E+08	8.04E+06	0.00E+00	4.04E+05	1.57E+06	8.91E+05	3.72E+04	2.65E+04
Basin 515	9.92E+04	2.08E+07	2.99E+06	2.35E+04	2.08E+07	2.24E+06	4.10E+05	1.38E+05	4.46E+05	4.77E+06	3.73E+04	2.66E+04
Basin 517	2.20E+05	1.76E+08	4.10E+07	1.81E+05	1.76E+08	2.77E+07	1.58E+06	1.73E+06	4.93E+06	2.32E+07	3.08E+05	2.20E+05
Basin 520	8.62E+01	3.14E+07	1.87E+07	6.13E+04	3.14E+07	1.47E+07	0.00E+00	7.81E+05	2.24E+06	0.00E+00	7.23E+04	5.15E+04
Basin 519	9.82E+02	3.57E+05	8.76E+06	1.59E+04	3.57E+05	8.38E+05	0.00E+00	2.58E+05	1.48E+05	0.00E+00	1.80E+03	1.29E+03
Allbasins	**1.10E+06**	**3.69E+10**	**5.01E+08**	**3.21E+06**	**3.56E+10**	**9.54E+08**	**5.63E+06**	**2.92E+07**	**1.83E+08**	**1.78E+08**	**1.08E+07**	**1.38E+07**

Pools and fluxes per basin and year for phosphorus (P) in the marine Laxemar-Simpevarp area, in g basin^{-1} year^{-1}.

IDKOD	Runoff (from basin_drainage_areas)	Advective flow	Net Primary Production	deposition	Advective flow	Respiration	Burial	Producers	Consumers	Regolith_upper	Particulate	Dissolved
Basin 524	2.38E+04	1.54E+11	3.78E+08	9.40E+06	2.27E+11	9.11E+08	0.00E+00	1.90E+07	1.93E+08	1.44E+07	1.08E+07	1.34E+07
Basin 525	0.00E+00	2.27E+10	5.48E+08	9.74E+06	2.72E+10	1.30E+09	0.00E+00	2.92E+07	2.47E+08	5.87E+06	6.68E+06	8.30E+06
Basin 522	0.00E+00	8.53E+10	2.37E+08	8.68E+06	1.31E+11	6.08E+08	0.00E+00	1.02E+07	1.25E+08	1.75E+08	1.37E+07	1.70E+07
Basin 523	0.00E+00	8.47E+10	3.06E+08	8.92E+06	9.83E+10	9.81E+08	0.00E+00	1.64E+07	1.98E+08	3.65E+07	1.02E+07	1.27E+07
Basin 521	**2.40E+05**	**8.41E+10**	**1.03E+09**	**2.43E+07**	**6.27E+10**	**2.23E+09**	**2.91E+06**	**5.15E+07**	**4.20E+08**	**4.10E+08**	**7.82E+06**	**9.03E+06**
Basin 501	3.13E+03	1.35E+07	6.78E+06	2.14E+05	1.35E+07	5.88E+06	8.57E+05	5.58E+05	8.91E+05	1.02E+07	6.75E+04	8.39E+04
Basin 500	3.41E+03	2.58E+08	1.24E+08	1.86E+06	0.00E+00	4.54E+07	3.37E+06	4.99E+06	7.10E+06	4.79E+07	3.64E+05	4.53E+05
Basin 504	**3.66E+05**	**8.28E+07**	**1.69E+07**	**3.89E+05**	**1.11E+08**	**1.06E+07**	**1.72E+06**	**1.11E+06**	**1.45E+06**	**2.10E+07**	**1.38E+05**	**1.72E+05**
Basin 502	**1.03E+07**	**4.72E+07**	**1.97E+07**	**7.21E+05**	**4.84E+07**	**2.29E+07**	**6.10E+06**	**1.58E+06**	**3.04E+06**	**6.63E+07**	**3.78E+05**	**5.62E+05**
Basin 506	**2.07E+05**	**9.99E+07**	**5.10E+06**	**2.14E+05**	**1.51E+08**	**6.28E+06**	**2.94E+05**	**5.36E+05**	**8.95E+05**	**9.98E+06**	**7.00E+04**	**8.70E+04**
Basin 508	**1.40E+07**	**2.80E+07**	**4.67E+07**	**8.80E+05**	**3.92E+07**	**2.56E+07**	**5.66E+06**	**4.36E+06**	**3.49E+06**	**6.45E+07**	**2.38E+05**	**2.83E+05**
Basin 513	2.09E+06	2.76E+09	2.21E+08	2.60E+06	2.61E+09	2.75E+08	1.02E+06	1.19E+07	5.25E+07	3.48E+07	5.39E+05	3.52E+05
Basin 514	0.00E+00	3.45E+09	6.29E+07	6.09E+05	4.13E+09	7.48E+07	0.00E+00	3.52E+06	1.47E+07	5.35E+06	2.72E+05	3.38E+05
Basin 516	7.17E+05	1.24E+09	6.01E+07	3.08E+05	1.24E+09	4.75E+06	0.00E+00	1.45E+06	8.66E+05	0.00E+00	4.68E+03	5.82E+03
Basin 518	0.00E+00	5.51E+09	4.74E+07	4.86E+05	5.52E+09	5.81E+07	0.00E+00	2.42E+06	1.17E+07	5.38E+06	1.81E+05	2.25E+05
Basin 515	3.45E+06	3.49E+08	2.16E+07	5.57E+05	3.49E+08	1.62E+07	2.48E+06	8.22E+05	2.55E+06	2.88E+07	1.82E+05	2.26E+05
Basin 517	7.64E+06	2.95E+09	2.97E+08	4.28E+06	2.95E+09	2.00E+08	9.56E+06	1.03E+07	3.35E+07	1.40E+08	1.50E+06	1.87E+06
Basin 520	3.13E+03	5.27E+08	1.35E+08	1.45E+06	5.28E+08	1.06E+08	0.00E+00	4.63E+06	1.66E+07	0.00E+00	3.52E+05	4.37E+05
Basin 519	3.56E+04	5.99E+06	6.33E+07	3.78E+05	5.99E+06	6.06E+06	0.00E+00	1.52E+06	1.12E+06	0.00E+00	8.77E+03	1.09E+04
Allbasins	**3.91E+07**	**4.48E+11**	**3.62E+09**	**7.60E+07**	**5.63E+11**	**6.89E+09**	**3.40E+07**	**1.76E+08**	**1.33E+09**	**1.08E+09**	**5.35E+07**	**6.55E+07**

Pools and fluxes per basin and year for thorium (Th) in the marine Laxemar-Simpevarp area, in g basin^{-1} year^{-1}.

IDKOD	Runoff (from basin_drain-age_areas)	Advective flow	Net Primary Production	deposition	Advective flow	Respiration	Burial	Producers	Consumers	Regolith_upper	Particulate	Dissolved
Basin 524	no data	6.36E+05	no data	7.34E+01	3.35E+06	no data	0.00E+00	6.27E+01	1.06E+04	6.24E+03	2.99E+03	1.23E+03
Basin 525	no data	3.35E+05	no data	7.61E+01	4.01E+05	no data	0.00E+00	8.40E+01	5.45E+03	2.55E+03	1.96E+03	7.59E+02
Basin 522	no data	3.44E+05	no data	6.78E+01	1.93E+06	no data	0.00E+00	3.96E+01	8.15E+04	7.61E+04	3.77E+03	1.56E+03
Basin 523	no data	7.44E+05	no data	6.97E+01	1.45E+06	no data	0.00E+00	6.25E+01	1.99E+04	1.58E+04	2.80E+03	1.16E+03
Basin 521	**no data**	**6.89E+05**	**no data**	**1.90E+02**	**6.22E+05**	**no data**	**1.26E+03**	**1.42E+02**	**1.88E+05**	**1.78E+05**	**8.04E+03**	**1.17E+03**
Basin 501	no data	2.00E+02	no data	1.67E+00	2.00E+02	no data	3.72E+02	5.92E–01	4.52E+03	4.44E+03	7.50E+01	7.67E+00
Basin 500	no data	2.63E+03	no data	1.45E+01	0.00E+00	no data	1.46E+03	6.11E+00	2.12E+04	2.08E+04	4.27E+02	4.14E+01
Basin 504	**no data**	**8.81E+02**	**no data**	**3.04E+00**	**1.64E+03**	**no data**	**7.48E+02**	**1.06E+00**	**9.31E+03**	**9.13E+03**	**1.60E+02**	**1.57E+01**
Basin 502	**no data**	**7.44E+02**	**no data**	**5.63E+00**	**5.40E+02**	**no data**	**2.65E+03**	**1.78E+00**	**2.92E+04**	**2.88E+04**	**3.82E+02**	**3.28E+01**
Basin 506	**no data**	**1.22E+03**	**no data**	**1.67E+00**	**2.22E+03**	**no data**	**1.27E+02**	**5.83E–01**	**4.42E+03**	**4.33E+03**	**7.91E+01**	**7.95E+00**
Basin 508	**no data**	**3.72E+02**	**no data**	**6.87E+00**	**7.16E+02**	**no data**	**2.46E+03**	**2.18E+00**	**2.82E+04**	**2.80E+04**	**1.69E+02**	**2.80E+01**
Basin 513	no data	3.22E+04	no data	2.03E+01	4.64E+04	no data	4.42E+02	2.14E+01	1.57E+04	1.51E+04	4.06E+02	9.66E+01
Basin 514	no data	5.02E+04	no data	4.76E+00	6.10E+04	no data	0.00E+00	6.10E+00	2.44E+03	2.32E+03	8.17E+01	3.09E+01
Basin 516	no data	1.84E+04	no data	2.41E+00	1.84E+04	no data	0.00E+00	1.64E+00	7.97E+00	0.00E+00	5.95E+00	5.32E–01
Basin 518	no data	8.14E+04	no data	3.79E+00	8.15E+04	no data	0.00E+00	4.73E+00	2.42E+03	2.33E+03	5.42E+01	2.06E+01
Basin 515	no data	5.15E+03	no data	4.35E+00	5.15E+03	no data	1.07E+03	1.42E+00	1.27E+04	1.25E+04	1.97E+02	2.07E+01
Basin 517	no data	4.36E+04	no data	3.34E+01	4.36E+04	no data	4.15E+03	1.79E+01	6.22E+04	6.06E+04	1.37E+03	1.71E+02
Basin 520	no data	7.78E+03	no data	1.13E+01	7.80E+03	no data	0.00E+00	8.04E+00	2.60E+02	0.00E+00	2.07E+02	4.00E+01
Basin 519	no data	8.85E+01	no data	2.95E+00	8.85E+01	no data	0.00E+00	1.95E+00	1.34E+01	0.00E+00	1.06E+01	9.97E–01
Allbasins	**no data**	**2.99E+06**	**no data**	**5.94E+02**	**8.02E+06**	**no data**	**1.47E+04**	**4.66E+02**	**4.98E+05**	**4.67E+05**	**2.32E+04**	**6.38E+03**

Pools and fluxes per basin and year for uranium (U) in the marine Laxemar-Simpevarp area, in g basin^{-1} year^{-1}.

IDKOD	Runoff (from basin_drainage_areas)	Advective flow	Net Primary Production	deposition	Advective flow	Respiration	Burial	Producers	Consumers	Regolith_upper	Particulate	Dissolved
Basin 524	no data	3.58E+08	no data	2.94E+01	3.54E+08	no data	0.00E+00	5.33E+01	1.37E+05	5.45E+03	1.40E+03	1.30E+05
Basin 525	no data	3.55E+07	no data	3.04E+01	4.25E+07	no data	0.00E+00	7.25E+01	8.45E+04	2.22E+03	9.16E+02	8.04E+04
Basin 522	no data	2.06E+08	no data	2.71E+01	2.04E+08	no data	0.00E+00	3.27E+01	2.34E+05	6.65E+04	1.76E+03	1.65E+05
Basin 523	no data	1.83E+08	no data	2.79E+01	1.54E+08	no data	0.00E+00	5.33E+01	1.39E+05	1.38E+04	1.31E+03	1.23E+05
Basin 521	**no data**	**1.73E+08**	**no data**	**7.61E+01**	**1.75E+08**	**no data**	**1.10E+03**	**1.20E+02**	**4.90E+05**	**1.56E+05**	**3.76E+03**	**3.29E+05**
Basin 501	no data	2.11E+04	no data	6.70E–01	2.11E+04	no data	3.25E+02	4.98E–01	4.73E+03	3.88E+03	3.51E+01	8.12E+02
Basin 500	no data	7.03E+05	no data	5.81E+00	0.00E+00	no data	1.28E+03	5.23E+00	2.27E+04	1.81E+04	2.00E+02	4.38E+03
Basin 504	**no data**	**1.77E+05**	**no data**	**1.22E+00**	**1.74E+05**	**no data**	**6.53E+02**	**8.86E–01**	**9.72E+03**	**7.98E+03**	**7.46E+01**	**1.67E+03**
Basin 502	**no data**	**6.83E+04**	**no data**	**2.25E+00**	**6.90E+04**	**no data**	**2.31E+03**	**1.45E+00**	**2.95E+04**	**2.51E+04**	**1.79E+02**	**4.19E+03**
Basin 506	**no data**	**2.32E+05**	**no data**	**6.69E–01**	**2.35E+05**	**no data**	**1.11E+02**	**4.88E–01**	**4.67E+03**	**3.79E+03**	**3.70E+01**	**8.42E+02**
Basin 508	**no data**	**4.22E+04**	**no data**	**2.75E+00**	**4.51E+04**	**no data**	**2.15E+03**	**1.82E+00**	**2.63E+04**	**2.45E+04**	**7.90E+01**	**1.77E+03**
Basin 513	no data	6.47E+06	no data	8.13E+00	6.50E+06	no data	3.86E+02	1.85E+01	2.72E+04	1.32E+04	1.90E+02	1.35E+04
Basin 514	no data	6.51E+06	no data	1.90E+00	6.46E+06	no data	0.00E+00	5.29E+00	5.40E+03	2.03E+03	3.82E+01	3.27E+03
Basin 516	no data	1.95E+06	no data	9.64E–01	1.95E+06	no data	0.00E+00	1.43E+00	6.17E+01	0.00E+00	2.78E+00	5.63E+01
Basin 518	no data	8.62E+06	no data	1.52E+00	8.62E+06	no data	0.00E+00	4.10E+00	4.29E+03	2.04E+03	2.53E+01	2.18E+03
Basin 515	no data	5.45E+05	no data	1.74E+00	5.45E+05	no data	9.39E+02	1.19E+00	1.32E+04	1.09E+04	9.21E+01	2.19E+03
Basin 517	no data	4.61E+06	no data	1.34E+01	4.62E+06	no data	3.63E+03	1.53E+01	7.18E+04	5.30E+04	6.40E+02	1.81E+04
Basin 520	no data	8.24E+05	no data	4.54E+00	8.25E+05	no data	0.00E+00	6.95E+00	4.40E+03	0.00E+00	9.69E+01	4.23E+03
Basin 519	no data	9.37E+03	no data	1.18E+00	9.37E+03	no data	0.00E+00	1.69E+00	1.14E+02	0.00E+00	4.93E+00	1.06E+02
Allbasins	**no data**	**9.87E+08**	**no data**	**2.38E+02**	**9.59E+08**	**no data**	**1.29E+04**	**3.96E+02**	**1.31E+06**	**4.08E+05**	**1.08E+04**	**8.83E+05**

Pools and fluxes per basin and year for iodine (I) in the marine Laxemar-Simpevarp area, in g basin^{-1} year^{-1}.

IDKOD	Runoff (from basin_drainage_areas)	Advective flow	Net Primary Production	deposition	Advective flow	Respiration	Burial	Producers	Consumers	Regolith_upper	Particulate	Dissolved
Basin 524	no data	5.12E+09	no data	4.40E+03	7.12E+09	no data	0.00E+00	3.25E+03	2.75E+06	7.46E+03	8.94E+04	2.61E+06
Basin 525	no data	7.13E+08	no data	4.56E+03	8.54E+08	no data	0.00E+00	4.25E+03	1.74E+06	3.04E+03	5.86E+04	1.61E+06
Basin 522	no data	2.91E+09	no data	4.07E+03	4.10E+09	no data	0.00E+00	2.14E+03	3.54E+06	9.09E+04	1.13E+05	3.31E+06
Basin 523	no data	2.89E+09	no data	4.18E+03	3.09E+09	no data	0.00E+00	3.22E+03	2.61E+06	1.89E+04	8.38E+04	2.46E+06
Basin 521	**no data**	**2.75E+09**	**no data**	**1.14E+04**	**2.56E+09**	**no data**	**1.51E+03**	**7.40E+03**	**5.36E+06**	**2.13E+05**	**2.40E+05**	**4.81E+06**
Basin 501	no data	4.25E+05	no data	1.00E+02	4.25E+05	no data	4.44E+02	3.11E+01	2.40E+04	5.30E+03	2.24E+03	1.63E+04
Basin 500	no data	1.04E+07	no data	8.72E+02	0.00E+00	no data	1.75E+03	3.13E+02	1.27E+05	2.48E+04	1.28E+04	8.81E+04
Basin 504	**no data**	**3.13E+06**	**no data**	**1.82E+02**	**3.49E+06**	**no data**	**8.93E+02**	**5.67E+01**	**4.93E+04**	**1.09E+04**	**4.77E+03**	**3.35E+04**
Basin 502	**no data**	**1.34E+06**	**no data**	**3.38E+02**	**1.69E+06**	**no data**	**3.16E+03**	**9.75E+01**	**1.49E+05**	**3.44E+04**	**1.14E+04**	**1.03E+05**
Basin 506	**no data**	**3.52E+06**	**no data**	**1.00E+02**	**4.73E+06**	**no data**	**1.52E+02**	**3.09E+01**	**2.46E+04**	**5.18E+03**	**2.37E+03**	**1.69E+04**
Basin 508	**no data**	**9.17E+05**	**no data**	**4.12E+02**	**8.00E+05**	**no data**	**2.94E+03**	**1.15E+02**	**7.03E+04**	**3.34E+04**	**5.05E+03**	**3.14E+04**
Basin 513	no data	1.03E+08	no data	1.22E+03	9.62E+07	no data	5.28E+02	1.08E+03	2.43E+05	1.81E+04	1.21E+04	2.00E+05
Basin 514	no data	1.16E+08	no data	2.86E+02	1.30E+08	no data	0.00E+00	3.07E+02	7.45E+04	2.77E+03	2.44E+03	6.58E+04
Basin 516	no data	3.91E+07	no data	1.45E+02	3.91E+07	no data	0.00E+00	8.17E+01	1.46E+03	0.00E+00	1.78E+02	1.13E+03
Basin 518	no data	1.73E+08	no data	2.28E+02	1.73E+08	no data	0.00E+00	2.37E+02	5.10E+04	2.79E+03	1.62E+03	4.38E+04
Basin 515	no data	1.10E+07	no data	2.61E+02	1.10E+07	no data	1.28E+03	7.43E+01	6.52E+04	1.49E+04	5.89E+03	4.39E+04
Basin 517	no data	9.27E+07	no data	2.01E+03	9.28E+07	no data	4.96E+03	9.17E+02	4.83E+05	7.24E+04	4.09E+04	3.63E+05
Basin 520	no data	1.66E+07	no data	6.81E+02	1.66E+07	no data	0.00E+00	4.06E+02	9.51E+04	0.00E+00	6.20E+03	8.51E+04
Basin 519	no data	1.88E+05	no data	1.77E+02	1.88E+05	no data	0.00E+00	9.71E+01	2.63E+03	0.00E+00	3.15E+02	2.12E+03
Allbasins	**no data**	**1.50E+10**	**no data**	**3.56E+04**	**1.83E+10**	**no data**	**1.76E+04**	**2.41E+04**	**1.75E+07**	**5.58E+05**	**6.93E+05**	**1.59E+07**